"அன்னையும் பிதாவும் முன்னறி தெய்வம்"

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Welding Technology

For 7th Semester B.E. Mechanical Engineering (Elective) and 4th Semester B.E. Production Engineering

As per the Latest Syllabus of ANNA UNIVERSITY, CHENNAI

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Welding Technology

by Dr. G.K. Vijayaraghavan & Dr. S. Sundaravalli

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PREFACE

We are pleased to bring out our first edition of **"Welding Technology"** book for Engineering and Technology studies. This book is written to serve the needs of under graduate students embarking introductory course in Welding Technology. This book is based on the latest syllabi prescribed by the ***Anna University Chennai, Trichy, Coimbatore & Tirunelveli*** for ***7th Semester Mechanical engineering (Elective)*** and ***4th Semester Production engineering*** students of its affiliated colleges.

This book consists of 5 units.

- ***Unit 1*** deals with fundamental principles, advantages, limitations and applications of various gas and arc welding processes such as Air Acetylene welding, Oxyacetylene welding, Carbon arc welding, Shielded metal arc welding, Submerged arc welding, TIG & MIG welding, Plasma arc welding and Electroslag welding processes.
- ***Unit 2*** describes in detail different types of resistance welding processes such as Spot welding, Seam welding, Projection welding, Resistance Butt welding, Flash Butt welding, Percussion welding and High frequency resistance welding processes with their advantages, limitations and applications.
- ***Unit 3*** has an in depth dealing of various solid state welding processes such as Cold welding, Diffusion bonding, Explosive welding, Ultrasonic welding, Friction welding, Forge welding, Roll welding and Hot pressure welding processes with their advantages, limitations and applications.
- The concept of other important welding processes and topics such as Thermit welding, Atomic hydrogen welding, Electron beam welding, Laser Beam welding, Friction stir welding, Under Water welding, Welding automation in aerospace, nuclear and surface transport vehicles are elaborately discussed in ***Unit 4***.
- ***Unit 5*** deals with design of weld joints, weldability and testing of weldments in which various weld joint designs, weldability of aluminium, copper, and stainless

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steels, various destructive and non-destructive testing of weldments are dealt in detail.

Important solved questions and answers, and two mark questions and answers have been added at the tail end of each unit which will enable the students to score high marks in the University examinations.

With these features, we sincerely hope that this book would serve as a valuable text for the students.

Though efforts have been taken aiming at a '*zero flaw*' content, we do recognize that mistakes may have inadvertently crept in. We welcome constructive criticisms on any specific topics of this book.

Our sincere thanks to **Mrs. Nirmala Durai, Proprietor of "Suchitra Publications"** and **Publishing Advisor Mr. A. DURAI, B.E.** for their involvement to make this publication successful.

- Authors

ANNA UNIVERSITY SYLLABUS - Reg. 2013

ME6008 WELDING TECHNOLOGY

UNIT I GAS AND ARC WELDING PROCESSES

Fundamental principles – Air Acetylene welding, Oxyacetylene welding, Carbon arc welding, Shielded metal arc welding, Submerged arc welding, TIG & MIG welding, Plasma arc welding and Electroslag welding processes - advantages, limitations and applications.

UNIT II RESISTANCE WELDING PROCESSES

Spot welding, Seam welding, Projection welding, Resistance Butt welding, Flash Butt welding, Percussion welding and High frequency resistance welding processes - advantages, limitations and applications.

UNIT III SOLID STATE WELDING PROCESSES

Cold welding, Diffusion bonding, Explosive welding, Ultrasonic welding, Friction welding, Forge welding, Roll welding and Hot pressure welding processes - advantages, limitations and applications.

UNIT IV OTHER WELDING PROCESSES

Thermit welding, Atomic hydrogen welding, Electron beam welding, Laser Beam welding, Friction stir welding, Under Water welding, Welding automation in aerospace, nuclear and surface transport vehicles.

UNIT V DESIGN OF WELD JOINTS, WELDABILITY AND TESTING OF WELDMENTS

Various weld joint designs – Weldability of Aluminium, Copper, and Stainless steels. Destructive and non destructive testing of weldments.

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UNIT 5 DESIGN OF WELD JOINTS, WELDABILITY AND TESTING OF WELDMENTS

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UNIT – 1

GAS AND ARC WELDING PROCESSES

Fundamental principles – Air Acetylene welding, Oxyacetylene welding, Carbon arc welding, Shielded metal arc welding, Submerged arc welding, TIG & MIG welding, Plasma arc welding and Electroslag welding processes - advantages, limitations and applications.

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1

GAS AND ARC WELDING PROCESSES

1.1. INTRODUCTION TO WELDING

The process of joining similar metals by the application of heat is called '*welding*'. It is a fabrication process that joins materials, usually metals or thermoplastics, by causing coalescence. It is often done by melting the workpieces and adding a filler material to form a pool of molten material that cools to become a strong joint.

Welding can be obtained with or without application of pressure and with or without addition of filler metal. During welding, the edges of these metal pieces are either melted or brought to the plastic condition. The welding process is used for making permanent joints which is obtained by homogenous mixture of two materials. The heat may be developed in several ways for welding operation. A good welded joint is as strong as the parent metal.

Nowadays, welding finds wide spread applications in almost all branches of engineering industries. Welding is extensively employed in the fabrication and erection of steel structure in industry and construction e.g. Structural joints of bridges and buildings, pipelines etc. It is also used in various industries such as aircraft frame works, railway wagons, furniture, automobile bodies, ship building etc. depending upon their applications.

1.2. CLASSIFICATION OF WELDING PROCESS BASED ON THE METHOD OF WELDING

In general various welding processes are classified as follows:

1. Gas welding:

(a) Air-acetylene welding

(b) Oxy-acetylene welding

(c) Oxy-hydrogen welding.

2. Arc welding:

(a) Carbon arc welding

(b) Plasma arc welding

(c) Shield metal arc welding

(d) Tungsten Inert Gas (TIG) welding

(e) Metal Inert Gas (MIG) welding

(f) Submerged arc welding

(g) Electro-slag welding.

3. Resistance welding:

(a) Spot welding

(b) Seam welding

(c) Projection welding

(d) Resistance Butt welding

(e) Flash Butt welding

(f) Percussion welding.

4. Solid state welding:

(a) Cold welding

(b) Diffusion welding

(c) Forge welding

(d) Explosive welding

(e) Friction welding

(f) Ultrasonic welding

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(g) Hot pressure welding

(h) Roll welding.

5. Thermo chemical welding:

(a) Thermit welding

(b) Atomic welding.

6. Radiant energy welding:

(a) Electric Beam welding

(b) Laser Beam welding.

There are two main types of welding process which are classified according to the source of energy employed for heating the metals and the state of metal at the place being welded.

1. Fusion welding
2. Pressure or plastic welding.

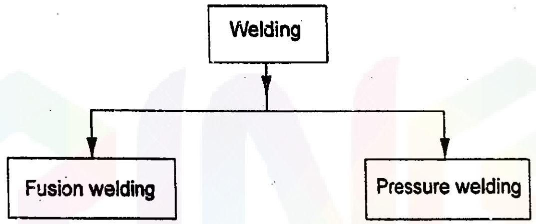

Figure 1.1 Types of welding

1.2.1. Fusion Welding

In fusion welding, the metal at the joint is heated to a molten state and then it is allowed to solidify. When heat alone is used during welding, the process is called *fusion welding*. Pressure is not applied during the welding process and hence, it is also called *non-pressure welding*. Filler material may be required during this type of welding.

Examples: Gas welding, arc welding, electron beam welding.

Fusion welding can be further classified as shown in Figure 1.2:

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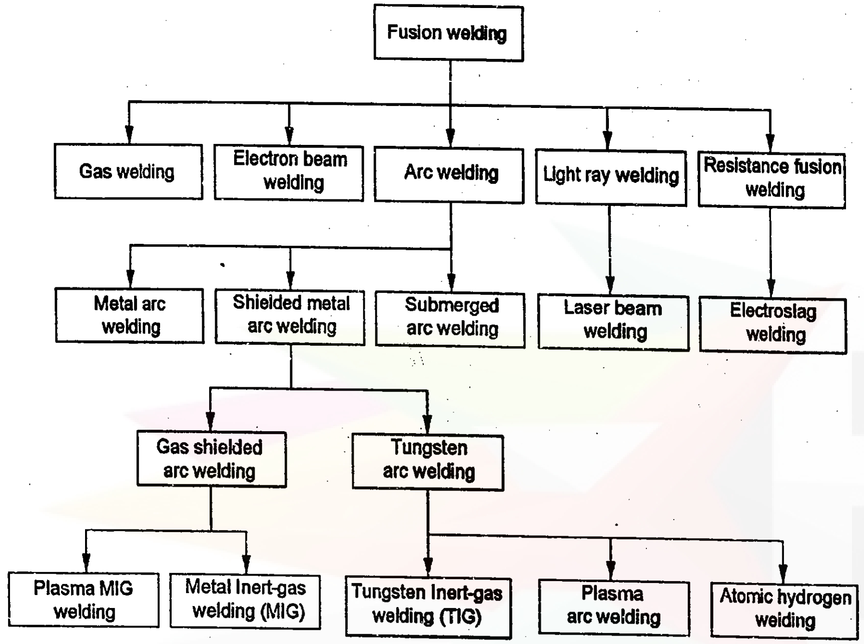

Figure 1.2 Types of fusion welding

1.2.2. Plastic Welding

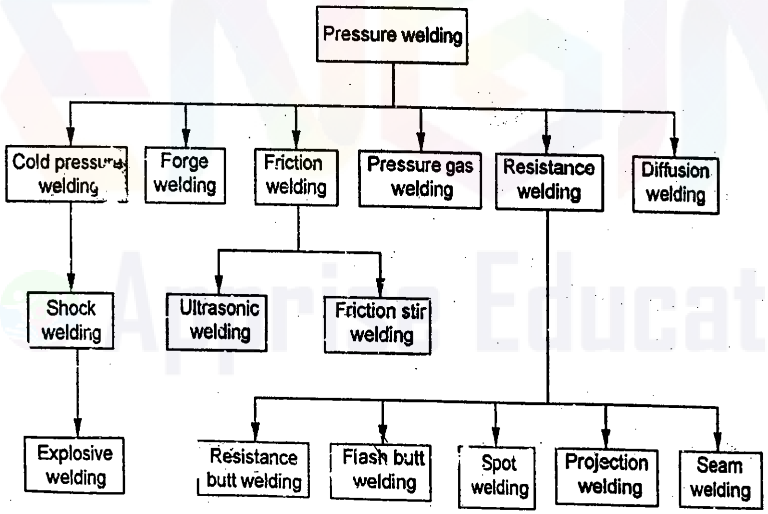

Figure 1.3 Types of pressure welding

In pressure or plastic welding, the metal parts are heated to a plastic state and they are pressed together to make the joint. Hence, it is known as ***pressure welding***. Here, there is no filler materials required.

Examples: Resistance welding, pressure welding and forge welding.

Pressure welding can be further classified as shown in Figure 1.3:

1.3. CLASSIFICATION OF WELDING PROCESS BASED ON THE FILLER METALS

Based on the application of filler metals, the welding process can also be classified as follows:

(a) Autogeneous:

The process is one in which no filler metal is added to the joint interface.

Example: Electric resistance welding.

(b) Homogeneous:

The process is one which the filler metal is added and it is similar to parent metal.

Examples: Arc welding, electron beam welding and diffusion welding.

(c) Heterogeneous:

The process is one which the filler metal is used but it is of different type from the parent metal.

Examples: Brazing and soldering.

1.4. GAS WELDING

Gas welding is one type of welding processes in which the edges of the metals to be welded are melted by using a gas flame. No pressure is applied during welding except pressure gas welding. The flame is produced at the tip of a welding torch. The welding heat is obtained by burning a mixture of oxygen and combustible gas. The gases are mixed at the required proportion in a welding torch which provides a control for the welding flame. The gases commonly employed for gas welding are acetylene, hydrogen, propane and butane. The flame only melts the metal. So, the additional metal required to the weld is supplied by the filler rod. A flux is used during welding to prevent oxidation and remove impurities. Metal having 2 *mm* to 50 *mm* thick are welded by gas welding.

Based on the type and combination of gases used for producing flame, there are three types of gas welding processes used in industries such as

(a) Air-acetylene welding

(b) Oxy-acetylene welding

(c) Oxy-hydrogen welding.

1.4.1. Oxy-Acetylene Welding

The most common form of gas welding is oxy-acetylene welding. It is commonly used to permanently join mild steel. The use of oxygen and acetylene as welding gases dates back to the 1890's. The combination of oxygen and acetylene produces a flame temperature about 3200°C, making it ideal for welding and cutting. When the flame comes in contact with steel, it melts the surface forming a molten pool and allowing welding to take place as shown in Figure 1.4. Oxyacetylene can also be used for brazing, bronze welding, forging / shaping metal and cutting. This type of welding is suitable for the prefabrication of steel sheet, tubes and plates.

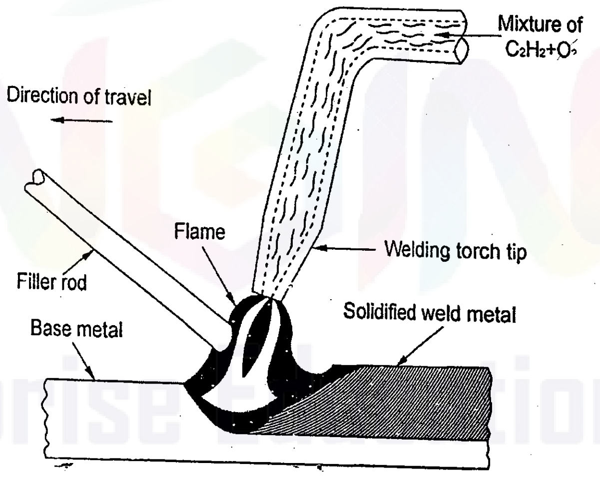

Figure 1.4 Oxy-Acetylene welding

The gases oxygen (O_2) and acetylene (C_2H_2) can be stored at high pressure in separate steel cylinders. But, the acetylene is very harmful if it is not handled carefully. The cost of acetylene is low.

There are two types of oxy- acetylene systems employed depending upon the manner in which acetylene is supplied for welding. They are as follows:

1. High-pressure system, and
2. Low-pressure system.

In high-pressure system, both oxygen and acetylene are supplied from high-pressure cylinders. Oxygen is compressed to 120 *bar* gauge pressure. But, acetylene cannot be compressed more than 1.5 *bar* in the form of "dissolved acetylene". The acetylene is dissolved in acetone under a pressure of 16-22 *bar* gauges. At normal pressure, one liter of acetone is dissolved about 25 liters of acetylene. The maximum recommended pressure of acetylene in the cylinder through a rubber hose is 1 *bar*. In high pressure (H.P) systems, the pressure of acetylene at the welding torch is from 0.66 *bar* to 1 *bar*.

In a low-pressure system, acetylene is produced at the place of welding by the interaction of calcium carbide and water in acetylene generator, the chemical reaction is given by

$$Ca\,C_2 + 2H_2O \Rightarrow Ca\,(OH)_2 + C_2\,H_2 + 127.3\ kJ/mol$$

From above equation, it is obvious that heat generated in this reaction is very high. The pressure of acetylene in the torch is up to 0.06 *bar*. For oxygen, the desired pressure in welding torch is given as follows:

(i) High-pressure System 0.1 to 3.5 *bar*

(ii) Low-pressure System 0.5 to 3.5 *bar*.

1.4.2. Air-Acetylene Welding

This process is similar to oxy-acetylene welding process. Here, air is used instead of oxygen. The air taken from the atmosphere is compressed in a compressor and it is mixed with acetylene to the required proportion in the torch. This type of welding has limited use since the temperature is lower than other gas process. It is successfully used in lead welding and many low melting temperature metals and alloy.

1.4.3. Oxy-Hydrogen Welding

This process is similar to oxy-acetylene welding process. Here, oxygen and hydrogen gases are mixed with the required proportion for producing heat. In this process, a special regulator is used for metering the hydrogen gas. It was once used extensively to weld low temperature metals such as aluminum, lead and magnesium but it is not in use today because more versatile and faster welding process has been developed.

1.4.4. Gas Welding Equipment

The following are the most commonly used equipment (Figure 1.5) for gas welding.

1. Gas cylinders:

For gas welding, a mixture of oxygen and acetylene are used. These two gases are stored in separate cylinders. The standard colour for oxygen cylinder is black. The oxygen is stored in the cylinder at a pressure of 125 to 140 *bar*. Its capacity is 6.23 m^3. The standard colour for acetylene cylinder is maroon. It is stored at a pressure of 16 *bar*. Its capacity is 7.6 m^3. Acetylene cylinder is fitted with a fusible plug to avoid explosion.

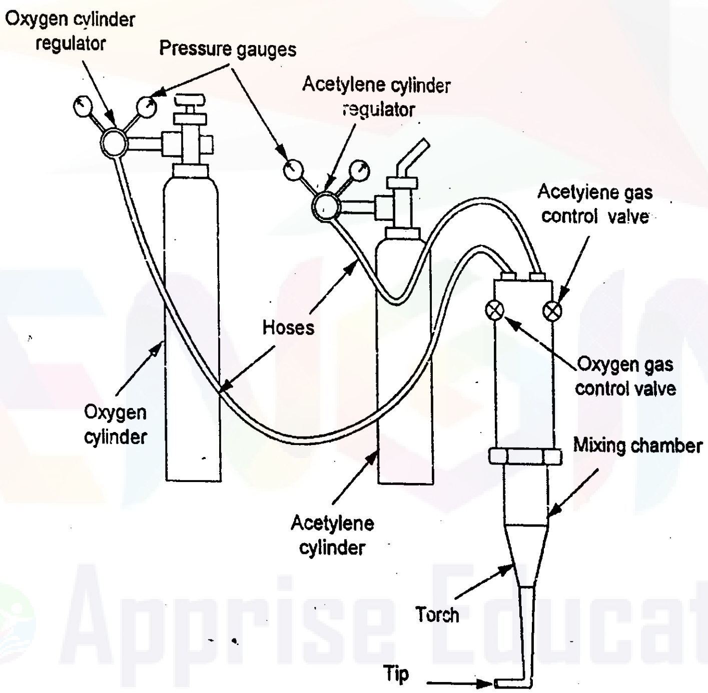

Figure 1.5 Gas welding equipment

2. Pressure regulators:

Each cylinder is fitted with a pressure regulator. These regulators are used to reduce and control the working pressure of the gases. The working pressure of oxygen is between 0.7 *bar* and 2.8 *bar*. The working pressure of acetylene is between 0.07 *bar* and 1.03 *bar* depending upon the thickness of the workpieces to be welded.

3. Pressure gauges:

There are four pressure gauges provided in which two are placed on the oxygen cylinder regulators and two on acetylene cylinder regulators. Among two, one pressure gauge is used to show the cylinder pressure and the other one is used to show the working pressure for welding.

4. Hoses:

The regulator of each cylinder is connected to the torch through two long hoses. It should be flexible, strong, desirable, non-process and light. Oxygen cylinder is connected with black colour hose whereas the acetylene cylinder is connected with red colour hose.

5. Welding torch:

Oxygen and acetylene gases enter the torch through the hose in separate passages as shown in Figure 1.6. Both gases are mixed in the mixing chamber of the torch. When it is ignited, a flame will be produced at the tip of the torch called a *nozzle*. There are two control valves on the welding torch. They are used to control the quantity of oxygen and acetylene to adjust the flame. The nozzles or tips are made of copper or copper alloy. Tips are in different sizes depending upon the type of metal to be welded and its thickness.

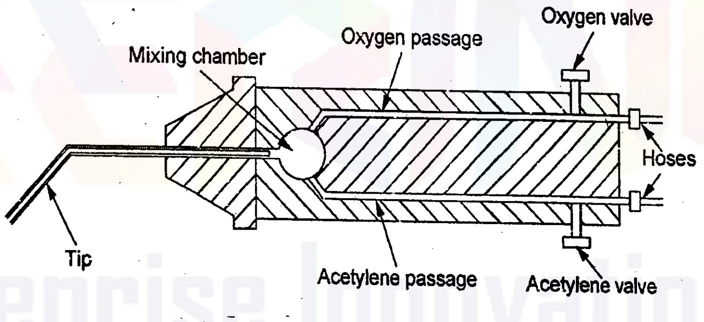

Figure 1.6 Welding torch

There are two types of torches as follows:

(i) Equal pressure type, and

(ii) Injector type.

6. Check valves or control valves:

Check valves are necessary safety devices attached between hoses and regulator outlets. Check valves allow the gases to flow in only one direction to prevent backflow.

7. Flash back arrestors:

Flashback is an explosion occurring at the tip accompanied by gases burning back into hoses and regulator. A flashback can occur if there are no check valves or check valves fail to operate due to improper installation. Once a flashback starts, check valves cannot stop it but a flashback arrestor will. The arrestor connected to the hose at the torch or regulator, same as the check valves. It contains a trap which is spring loaded that cuts off the gas flow in the event of a flashback.

8. Goggles:

The welding goggles are used to protect eyes from the flame heat, and ultraviolet and infrared rays.

9. Welding gloves:

Gloves are used to protect hand from the injury which may be caused by heat and metal splashes.

10. Spark lighter:

It is an igniter to start the burning of oxy acetylene gases.

11. Wire brush:

It is used to clean the weld joint before and after welding.

1.4.5. Flame Characteristics

It is very important to adjust the flame to suit the welding conditions. It is done by regulating the supply of oxygen and acetylene. By varying the ratio of oxygen and acetylene, the following three types of flames can be obtained.

(i) Neutral flame

(ii) Carburising flame and

(iii) Oxidising flame.

(i) Neutral flame:

Neutral flame is obtained by supplying equal quantity of oxygen and acetylene. Neutral flame has two zones i.e. one sharp bright inner cone and one bluish outer cone as shown in Figure 1.7. The reaction of the inner cone for the neutral flame is given by the equation

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$$C_2H_2 + O_2 \Rightarrow 2CO + H_2$$

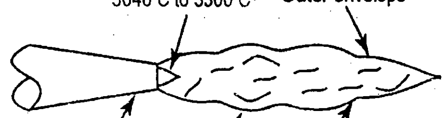

Figure 1.7 Neutral flame

The inner cone develops heat to melt the metal. The maximum temperature of neutral flame is obtained at the inner cone which is about 3200°C. In this type of flame, all acetylene is completely burned and all available heat in the acetylene is released. It is the most desirable flame to be used in oxy-acetylene welding.

The reactions of the outer cone are given by

$$2CO + O_2 \Rightarrow 2CO_2$$

$$H_2 + \tfrac{1}{2} O_2 \Rightarrow H_2O$$

For above reaction, oxygen is supplied from the surrounding air. The outer cone protects the molten metal from oxidation reaction because oxygen in the surrounding air is absorbed by gases from the flame.

Netural flame is used for welding steel, cast-iron, copper, aluminium etc. It has less chemical effect on welded metal.

(ii) Carburising flame:

A carburising flame is also called *reducing flame* which is obtained by supplying more acetylene than oxygen. This flame has three zones as follows:

1. Sharp inner cone
2. White intermediate cone called *feather cone*.
3. Bluish outer cone.

The theoretical mixture of carburising flame is given by

$$O_2 : C_2H_2 = 0.85 \text{ to } 0.95$$

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Length of the intermediate cone is an indication of proportion of excess acetylene in the flame. The temperature of reducing flame is lower. So, it is suitable for applications requiring low heat such as brazing and flame hardening.

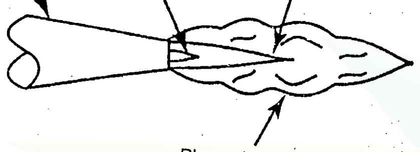

Figure 1.8 Carburising flame

Since unburned carbon goes into the weld pool, the metal is appeared to boil. This excess carbon causes the steel to become extremely hard and brittle. Hence, it is not recommended for general use. It is useful for those materials which are readily oxidized.

Carburising flame is used for welding high carbon steel, High Speed Steels (HSS), cemented carbides, cast irons, monel metal, alloy steels, nonferrous materials etc.

(iii) Oxidising flame:

Oxidising flame is obtained by supplying more oxygen than acetylene. It is similar to neutral flame except the inner white cone is somewhat small, giving rise to higher tip temperatures (3300°C). This flame has two zones such as

1. Smaller inner code and
2. Outer cone.

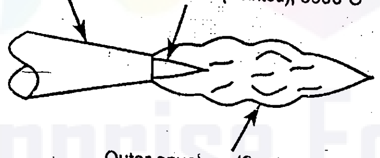

Figure 1.9 Oxidising flame

The theoretical mixture of oxidizing flame is given by

$$O_2 : C_2H_2 = 1.15 \text{ to } 1.5$$

In the case of oxidizing flame, the inner cone is not sharply defined as the neutral or carburising flame. This flame is harmful especially for steels because it oxidizes steel. A thin protective layer of slag forms over the molten metal. Oxidizing flame is desirable for non-ferrous alloys such as copper and zinc base alloys.

1.4.6. Gas Welding Technique

In a gas welding, the speed and quality of the welding can be improved by the proper selection of torch size, filler material, method of moving the torch along the weld and angle at which the torch is held. There are two techniques commonly used depending on the movement of torch along the weld.

1. Leftward or forward welding:

In a left ward welding technique, the torch flame moves from right to the left. The torch is held on the right hand and the welding rod is held on the left hand. The torch is held at an angle 60° to 70 ° to the plane of the weld and the welding rod at 30 ° to 40 °. This method allows preheating of the plate immediately ahead of the molten pool. The torch is given for very slight sideways movement and the weld rod should be moved faster without sideways movement. This technique is suitable for mild steel plates up to 5*mm* thickness and it is also used for welding cast iron and non-ferrous metals.

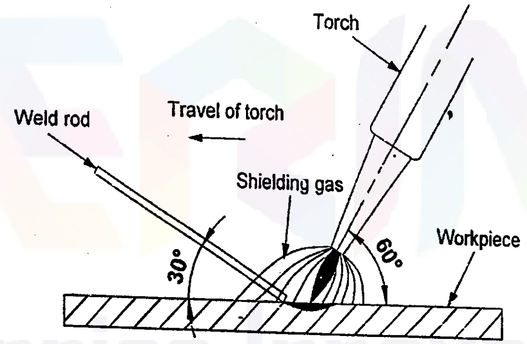

Figure 1.10 Leftward or forward welding

2. Rightward or backward welding:

In a rightward welding technique, the torch flame moves from left to right. There is no sideways movement in this welding. The torch is held at an angle of 40 ° to 50 ° to the plane of the weld and the welding rod is at 30 ° to 40 °. The welding speed is 20 to 25% higher and the fuel consumption is 15 to 25% lower than rightward welding. It provides a better shielding against atmospheric reaction.

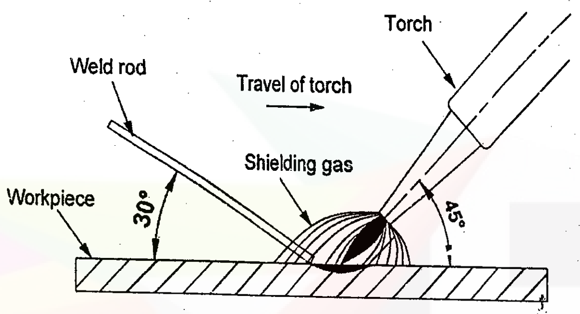

Figure 1.11 Rightward or backward welding

Oxidation of the weld metal slows down its cooling. Hence, this technique is mainly used for welding thick sections (greater than 5*mm* thick).

1.4.7. Filler Rods for Gas Welding

Filler rod or welding rod used in gas welding is to supply additional metal to make the joint. It is a metal rod which is made of the same material as a parent metal. Diameter of the filler rod depends on the thickness of the metal to be weld. The filler rod diameter '*d*' can be approximately determined by the following relationship.

$$d = t/2 + 1$$

where t - thickness of the metal to be welded in *mm*.

Different alloying elements such as chromium and nickel can be added to the filler rod. It will increase the strength of the joint. Filler rods are coated with copper to prevent oxidation of the molten metal.

1.4.8. Advantages, Limitations and Applications of Gas Welding

Advantages:

1. Temperature of flame can be easily controlled.
2. The amount of filler metal deposits can be controlled easily.
3. The flame can be used for welding and cutting.
4. All types of metal can be welded.

5. The cost of equipment is less.
6. It can be used in the factory or in the field.
7. Maintenance cost of gas welding equipment is less.

Limitations:

1. It is not suitable for joining thick plates.
2. It is a slow process.
3. Strength of weld is not so good as arc welding.
4. Handling and storing of gas cylinders need more care.
5. Gas flame takes up a longer time to heat up the metal than an electric arc.

Applications:

1. Oxyacetylene welding is used extensively for joining and cutting of thin steel sheets.
2. It is also used for welding of dissimilar metals, brazing, braze-welding, silver soldering, metal heating (for bending and forming) and oxy-fuel cutting.

1.5. CARBON ARC WELDING

In *arc welding* process, the heat is developed by an electric arc. The arc is produced between an electrode and the work. An *arc* is a sustained electric discharge through the ionized gas column called *plasma* between two electrodes. In order to produce the arc, the potential difference between two electrodes should be sufficient to allow them to move across the air gap. The larger air gap requires, higher will be potential differences. If the air gap becomes too large for the voltage, the arc may be extinguished.

The arc formation is similar for both AC welding or DC welding. In AC, the polarity changes continuously and hence, the temperature across the arc is uniform. In DC, the polarity is fixed and hence, the heat is more concentrated at one of the electrodes. Heat is produced by the electric arc to fusion weld metallic pieces. Electrons liberated from the cathode move towards the anode and they are accelerated in their movement. When they strike the anode at high velocity, large amount of heat is generated. Electrons are moving through the air gap between electrodes also called *arc column*. They collide with the ions in the ionized gas column between electrodes.

Arc welding is the process of joining two metal pieces by melting their edges by an electric arc. In arc welding, the electrical energy is converted into heat energy. The electrode and workpiece are brought near each other with a small air gap of 3 *mm* approximately. Then, the current is passed through workpiece and electrode to produce an electric arc.

Carbon Arc Welding (CAW) is the oldest welding process. CAW is a welding process in which the heat is generated by an electric arc struck between carbon electrode and workpiece as shown in Figure 1.12. The arc heats and melts the workpieces edges by forming a joint. If required, filler rod may be used. The end of the rod is held in the arc zone. The molten rod material is supplied to the weld pool. Shields (neutral gas, flux) may be used for weld pool protection depending on type of welded metal.

The electrodes which are used in carbon arc welding consisting of baked carbon or pure graphite which is placed inside a copper jacket. During welding process, the electrode is not consumed as the weld progresses overtime. However, the electrodes will need to be replaced due to erosion. The average carbon electrode used is typically 150 *mm* long and it can range in diameter from 5 *mm* to 12.5 *mm* in size. The temperature averages between 4000°*C* to 5000°*C* produced using carbon arc welding and they are known for creating an extremely bright light.

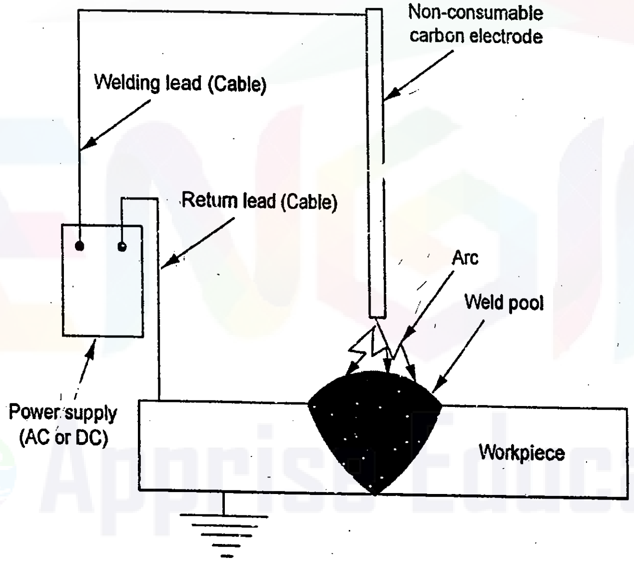

Figure 1.12 Carbon arc welding

The process of carbon arc welding uses low voltage and high amp electricity to heat the metal. DC power supply is generally used. The carbon electrode is connected to negative

terminal and workpiece is connected to positive terminal because the positive terminal is hotter (4000°*C*) than the negative terminal (3000°*C*) when an arc is produced. Hence, carbon from the electrode will not fuse and mix up with the metal weld. If carbon mixes with the weld, the weld will become weak and brittle. To protect the molten metal from the atmosphere, the welding is done with a long arc. In this case, a carbon monoxide gas is produced which surrounds the molten metal and protects it.

The process of carbon arc welding requires the welder to use hand pieces that were designed specifically for the use with this technique. The hand pieces must be able to handle higher temperatures produced by electrodes. The hand pieces used in an industrial setting are water-cooled to help to protect the welder from the significant heat which is produced in this process.

1.5.1. Types of Carbon Arc Welding Techniques

There are two types of carbon arc welding techniques.

(a) Single-carbon electrode arc welding

(b) Twin-carbon electrode arc welding.

In single-carbon electrode arc welding, arc is formed between a carbon electrode and the workpiece being welded. If an arc is formed between two carbon electrodes, the technique is known as *twin-carbon arc welding*. Workpiece is not a part of welding electric circuit in twin carbon electrode arc welding, therefore, the welding torch may be moved from one workpiece to other without extinguishing the arc.

The technique of single-carbon arc welding uses a DC power supply which is connected using a straight polarity i.e. workpiece is connected to positive terminal and electrode to negative terminal. This technique was a favorite one when welders are needed to work with galvanized sheet metal because the heat is produced when welding could be concentrated on one general area and lessen the amount of distortion that the metal is experienced.

1.5.2. Advantages, Limitations and Applications of Carbon Arc Welding

Advantages:

1. Low cost of equipment and welding operation are ensured.
2. High level of operator skill is not required.

3. The process is easily automated.
4. It has less distortion of workpiece.

Limitations:

1. The process is unstable quality of the weld. There may be more porosity in weldment.
2. Carbon of electrode contaminates the weld material with carbides.

Applications:

1. Carbon arc welding is used to weld both ferrous and non-ferrous metals.
2. Sheets of steel, copper alloys, brass and aluminium can be welded in this method.

1.6. SHIELDED METAL OR MANUAL METAL ARC WELDING

Shielded Metal Arc Welding (SMAW) or Manual Metal Arc Welding (MMAW) or Stick welding is the most commonly used arc welding process. 50% of all industrial welding and maintenance welding are currently performed by this process. In this process, metals are melted and joined by heating them with an arc between a consumable coated metal electrode and the workpiece. The stick electrode consists of core metal wire with an outer coating called *flux*. The flux assists in creating and stabilizing the arc and it provides the shielding gas which prevents the reaction of the molten metal with atmospheric air. It also removes the impurities from the molten metal and it forms a *slag*. This slag gets deposited over the weld metal. This slag protects the weld seam from rapid cooling.

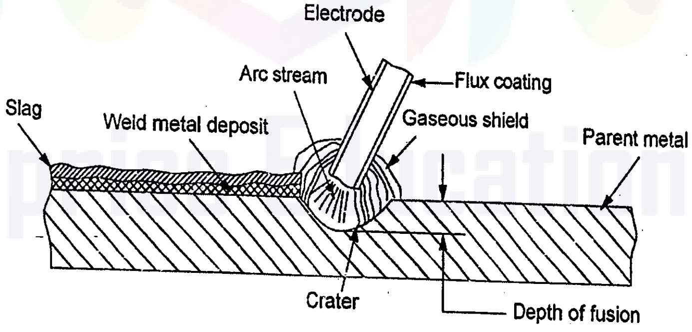

Figure 1.13 Manual metal arc welding process

In this process, the workpieces and electrode are melted by the arc and hence, both workpieces become a single piece without applying any external pressure. The temperature of arc is about 5000°*C* to 6000°*C*. The electrode supplies additional filler metal into the joints and it is deposited along the joint. A transformer or generator is used for supplying the current. The depth to which the metal is melted and deposited is called *depth of fusion*. To obtain a better depth of fusion, the electrode is kept at 70° inclination to the vertical.

The molten metal is forced out of the pool by the electric arc. Hence, a small depression is formed in the parent metal where the molten metal is piled up as shown in Figure 1.13. It is known as "*arc carter*". The distance between the tip of the electrode and bottom of the arc crater is called "*arc length*".

1.6.1. Shielded Metal Arc Welding Equipment

The following are the most commonly used equipment for shielded metal arc welding.

1. Welding power source, i.e. generator (DC) or transformer (AC)
2. Electrode
3. Electrode holder
4. Two cables - one for workpiece and other for electrode
5. Gloves
6. Protective shield
7. Apron
8. Wire brush
9. Chipping hammer
10. Safety goggles.

Figure 1.14 shows the basic equipment used for SMAW. In electric arc welding, both DC and AC are used for producing arc. DC machines and DC generators are driven by an electric motor of an I.C. engine. AC welding machines are transformers which are used for stepping down the main supply voltage because the available supply voltage is at 220/440 *V*. But, the normal welding requires 20 to 90 *V*. In the normal operation of a transformer as amperage is increased, the voltage decreases and vice-versa.

Arc gap is proportional to voltage and heat generated during welding is proportional tc current. DC welding is more expensive than AC welding. But, DC is preferred because of the control of the heat input offered by it. DC welding is generally preferred for difficult tasks.

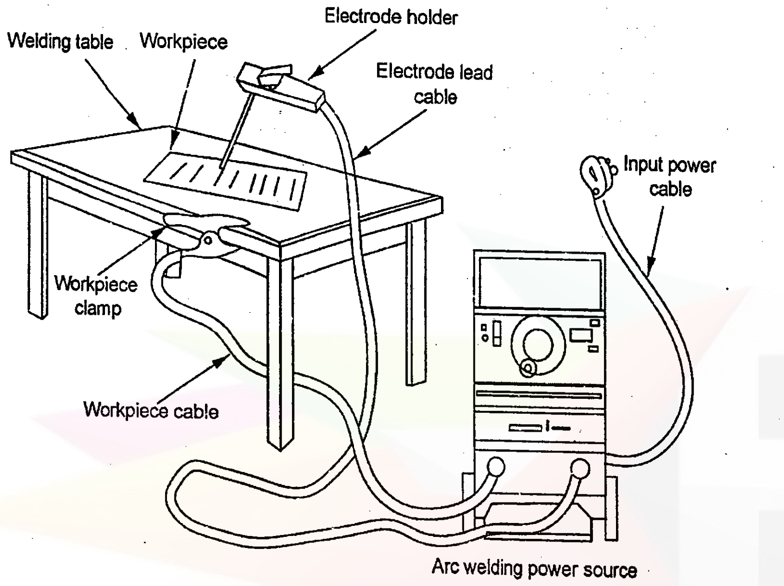

Figure 1.14 Shielded metal arc welding equipment

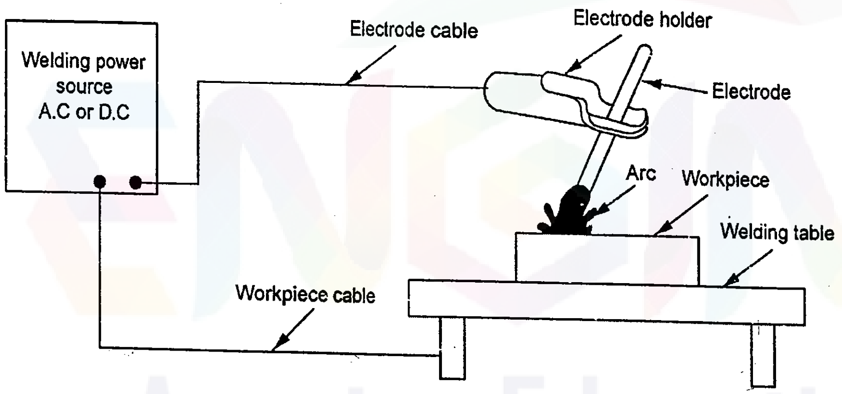

Figure 1.15 Simplified view of SMAW components

The specifications of DC generator and transformer for welding are given below.

Specification for generator:

Generator - Separately or self-excited 3 phase 50 cycles per second

Current range - $50A$ to $500A$ DC machine

Circuit voltage - $30V$ to $80V$

Arc voltage - $20V$ to $40V$

Power factor - 0.7

Efficiency - 60%

Energy consumption - 6 to 10 kWh/kg of metal deposit.

Specification for transformer:

Transformer - Oil cooled, double wound, step down transformer, 3-phase 50 cycles per second

Current - $50A$ to $400A$ AC machine

Circuit - $80V$

Arc Voltage - $40V$

Power factor - 0.4

Efficiency - 85%

Energy consumption - $4kWh/kg$ of metal deposit.

1.6.2. Comparison of AC and DC Welding Machines

S. No.	*AC machine (Transformer)*	*DC machine (Generator)*
	Advantages	*Disadvantages*
1.	Efficiency is more (80 to 85%).	Efficiency is less (30 to 60%).
2.	Power consumption is less.	Power consumption is more.
3.	Cost of equipment is less.	Cost of equipment is more.
4.	Any terminal can be connected to work or electrode.	Positive terminal is connected to work and negative terminal is connected to electrode.
5.	It is noiseless in operation.	It is very noisy in operation.
	Disadvantages	*Advantages*
6.	Voltage is higher. Hence, it is not safe.	Voltage is low. Hence, it provides safe operation.

7.	It is not suitable for welding nonferrous metals.	It is very much suitable for both ferrous and nonferrous metals.
8.	Only coated electrode can be used.	Bare electrodes can be used.
9.	It is not preferred for welding thin sections.	It is preferred for welding thin sections.
10.	Maintenance of equipment is costly and difficult.	Maintenance of equipment is cheaper and simple.
11.	Power factor is low.	Power factor is high.

1.6.3. Power Supply Characteristics

The following are the two different types of power supply characteristics.

1. Constant current, and
2. Constant voltage.

1. Constant current power supply (droop curve machines or droopers):

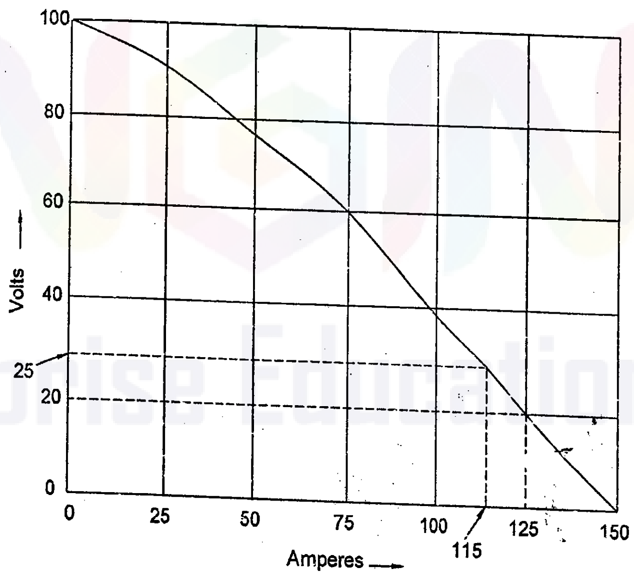

Figure 1.16 Characteristic curves of a constant current arc welding machine

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In constant current power supply, the current (amperage) stays relatively constant when the voltage is changed. For a large change in output voltage, the corresponding change in current is small so that the quality of the weld can be maintained. It is essential for manual metal arc welding processes since the maintenance of constant arc is nearly impossible by a human welder. The machine provides a high Open Circuit Voltage (OCV) for striking the arc. When the arc is struck, the voltage drops to the welding voltage. As the welding proceeds, the current will not vary much as the arc length changes.

Figure 1.16 shows the voltage versus ampere characteristics of constant current power supply. It shows that increasing the voltage from 20 V to 25V (25%) only decreases the amperage from 125 *amp* to 115 *amp* (8%).

2. Constant voltage power supply:

In constant voltage power supply, voltage stays relatively constant when the amperage is changed. These types of machines are used when there is a possibility of maintaining constant arc gap such as automatic welding (self-corrective). When the electrode comes a bit closer to the work, the arc voltage drops raising the output current to a very high value. This current instantly melts the electrode and thus, it maintains the arc gap and vice versa.

Figure 1.17 shows the voltage versus ampere characteristics of constant voltage power supply. It shows that dropping the voltage from 30 V to 25V (16.67%) increases the amperage suddenly from 100 *amp* to 200 *amp* (100%).

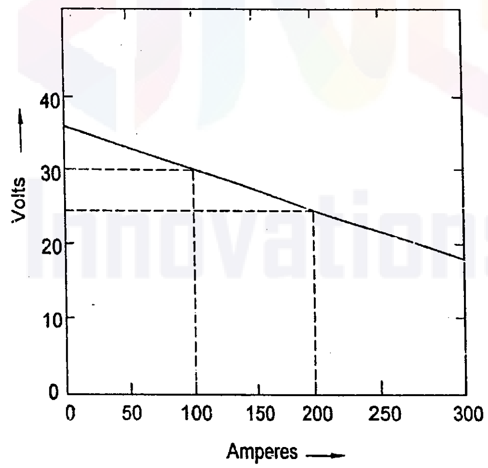

Figure 1.17 Characteristic curves of a constant voltage arc welding machine

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For linear power source characteristics, voltage (V) is given by the following equation

$$V = OCV - \left(\frac{OCV}{SCC}\right)I$$

where OCV = Open circuit voltage

SCC = Short circuit current

For stable arc in constant voltage transformer, $V_{arc} = V_{transformer}$

For stable arc in constant current transformer, $I_{arc} = I_{transformer}$

Power, $P = V \times I$

For maximum power, $dP/dL = 0$

where L= Arc length

The welding voltages range from $20V$ to $30V$ depending upon welding current i.e. higher is the current, higher will be the voltage. Welding current depends on the size of the electrode i.e. core diameter.

The approximate average welding current for structural steel electrodes is $35 \times d$ (where d is electrode diameter in mm) with some variations with the type of coating of electrode.

The output voltage of the power source must be high enough to enable the arc to be started on 'no load' or 'open circuit'. A value of $80V$ is sufficient for most electrodes but certain types may require more or less than this value. A manual welding power source is never loaded continuously because of operations such as electrode changing, slag removal etc. Most SMA welding equipment has a duty cycle of around 40% at maximum welding current.

1.6.4. Types of Electrodes

Commonly, there are two types of electrodes used in arc welding process. They are given below.

1. Consumable electrode and
2. Non-Consumables electrode.

1. Consumable electrode:

The consumable electrode is not only used to produce arc between work and electrode but it also provides filler material during welding. These may be made of various metals

depending upon their purposes and the chemical composition of metals to be welded. Since, it is melting during the welding process, the electrode should move towards the work to maintain constant the arc length.

The consumable electrodes may be classified into following types.

1. Bare electrodes
2. Lightly coated electrode
3. Heavily coated electrode.

Bare electrodes do not have any coating of flux on their surface. They are rarely used to weld wrought iron and mild steel. They must be used only with DC straight polarity i.e. workpiece is connected to positive terminal and electrode is connected to negative terminal and hence, electrons flow from electrode to workpiece. When bare electrodes are used, the molten metal reacts with the atmosphere. It causes defects in the weld. Therefore, it is used in the submerged arc welding and inert gas welding. In these processes, atmospheric reaction is prevented by separately supplying flux or inert gas.

Lightly coated electrodes have a coating layer of several tenths of a millimeter and it is 1% to 5% of the electrode weight. The main purpose of light coating is to increase arc stability called *ionizing coating*. It does not prevent the oxidation of molten metal. The welds due to lack of protection of oxidation reaction have poor mechanical properties and hence, it is used for welding non-essential jobs.

Heavily coated electrodes are covered with high quality covering of $1mm$ to $3mm$ thick. This coating is composed of ionizing, deoxidizing, gas generating, slag-forming alloying and binding materials. The flux coating contains fluorides, carbonates, oxides, metal alloys and cellulose mixed with silicate binders. The weight of such a coating is from 15% to 30% of the electrode rod. The greatest amount of welding is done with heavy coated electrode.

The flux coating is meant for the following purposes:

1. To give stability to the arc.
2. To produce a gas shield around arc and molten metal which prevents atmospheric reaction.
3. To provide the formation of slag so as to protect the welding seam from rapid cooling.

4. To introduce different alloying elements to the weld metals. These alloying elements increase the strength of the weld.
5. To increase deposition efficiency.

2. Non-consumable electrode:

Non-consumable electrodes are made of carbon, graphite or tungsten which do not consume during welding. Tungsten electrodes are used for DC as well as AC welding. Non-consumable electrodes are used in atomic hydrogen welding and TIG welding. Here, arc length remains constant and hence, it is stable.

1.6.5. Specification and Choice of Electrodes

Bare and coated electrodes are specified by the diameter and length. Electrodes are available up to 12*mm* diameters and 450*mm* long. For hand welding, the diameter of electrode will increase with the increase in the thickness of the workpiece. For heavy current, thicker electrodes are used. In semi-automatic welding and automatic welding, electrode wire wound as coil is used.

The metal of the electrode will depend upon the kind of parent metal. The following table represents the electrodes used for welding different metals.

S. No.	Workpiece	Electrode
1.	Wrought iron	Low carbon steel rod.
2.	Cast iron	Cast iron rods.
3.	Mild steel	Mild steel copper coated rod.
4.	Alloy steel	Low alloy steel rod containing 0.25% carbon.
5.	Aluminium	Cast aluminium alloy rod.
6.	Carbon steel	Soft Steel wire containing 0.1 to 0.18% carbon and 0.0025 to 0.04% phosphorus and sulphur.
7.	Copper casting	Copper rod.
8.	Brass	Drawn brass rod.

1.6.6. Filler and Flux Materials Used in SMAW

The electrode rod is made of a material that is compatible with the base material being welded and it is covered with a flux which protects the weld area from oxidation and

contamination by producing CO_2 gas during welding process. The electrode core itself acts as a filler material making separate filler unnecessary. The process is very versatile, requiring little operator training and inexpensive equipment. However, weld times are rather slow since the consumable electrodes must be frequently replaced because slag and residue from the flux must be chipped away after welding. Furthermore, the process is generally limited to welding ferrous materials though specialty electrodes have made possible the welding of cast iron, nickel, aluminium, copper and other metals. The versatility of the method makes it popular in a number of applications including repair work and construction.

1.6.7. Comparison of Shielded Metal Arc Welding and Gas Welding

S. No.	Arc Welding	Gas welding
1.	Heat is produced by electric arc.	Heat is produced by the gas flame.
2.	The arc temperature is about 4000°*C*.	The flame temperature is about 3200°*C*.
3.	Filler rod is used as an electrode.	Filler rod is introduced separately.
4.	It is suitable for welding medium and thick work.	It is suitable for welding thin work.
5.	Arc welded joints have very high strength.	Gas welded joints do not have much strength.
6.	Filler metal should be same as or an alloy of parent metal.	Filler metal need not be same as the parent metal.
7.	Brazing and soldering cannot be done using electric arc.	Brazing and soldering are done using gas.

1.6.8. Advantages, Limitations and Applications of SMAW

Advantages:

1. Equipment is self-contained, portable and relatively inexpensive.
2. Electrode provides its own flux.
3. Most metals and alloys can be welded with SMAW.
4. Useful process for welding in confined spaces.
5. It performs better on unclean surfaces than other welding processes.

6. Most metal thickness can be welded with SMAW.
7. All welding positions are possible with SMAW.
8. It can be used under almost all weather conditions.
9. Arc is continuously visible to the welder.
10. The welder controls the arc.

Limitations:

1. It is not recommended for welding metals less than 1.5 *mm* thick.
2. Excessive spatter is produced during welding.
3. Frequent stop/starts are required to change electrode.
4. The process is discontinuous due to limited length of the electrodes.
5. Slag cleanup is required.
6. High level of skill is needed to produce sound welds.
7. It produces weld beads with rough surfaces.
8. Welds are subjected to porosity.
9. Arc blow must be controlled.
10. It needs more hand eye coordination.
11. Some electrodes become waste (about 10% from discarded stub loss).
12. Potential electric shock occurs from open circuit voltage.
13. It is not as productive as continuous wire processes.
14. Ventilation must be provided when welding in confined spaces. SMAW process produces large amounts of fumes and smoke.

Applications:

1. Because of the versatility of the process, simplicity of its equipment and operation, shielded metal arc welding is one of the world's most popular welding processes.
2. SMAW is often used to weld carbon steel, low and high alloy steel, stainless steel, cast iron and ductile iron.
3. While less popular for nonferrous materials, it can be used for nickel, copper and their alloys.
4. In rare cases, it is used for aluminium.

5. It dominates other welding processes in the maintenance and repair industry.
6. Though flux-cored arc welding is growing in popularity, SMAW continues to be used extensively in the construction of steel structures and in industrial fabrication.

1.7. SUBMERGED ARC WELDING (SAW)

When the flux is required continuously or where the large quantity of flux has to be supplied, on that time the flux is used in the form of wire wound on a rotating drum or reel called *flux core*. It is separately supplied instead of using welding rod along with flux material. Flux is mainly used to avoid oxidation reaction with oxygen present in the atmosphere. If the flux is used along with filler material in the form of coated electrodes, the oxidation reaction may not be completely prevented. In order to avoid oxidation reaction completely, enough quantity of flux should be supplied with a separate control independently with filler material.

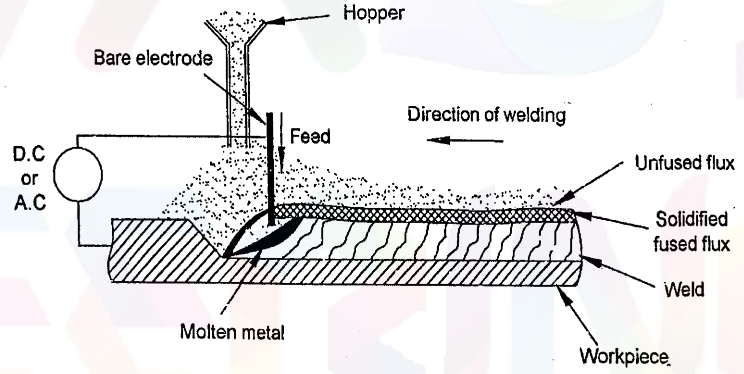

Figure 1.18 Submerged arc welding

Submerged arc welding is also called *sub arc welding or hidden arc welding*. In this welding, the complete welding setup is dipped in the flux powder and hence, it is named as *submerged arc welding*. In this type of welding, an electric arc is produced between consumable bare electrode and workpiece. But, the arc is completely submerged i.e., hidden under the flux powder as shown in Figure 1.18. The arc is not visible outside. The metal electrode is continuously fed from the reel by a moving head. The flux powder is fed in front of the moving head. It is supplied from a hopper. When the arc is produced in the welding zone at the end of the electrode the arc is completely covered by flux powder. So, there will not be any defect in the weld due to atmosphere effects.

The flux powder is made up of silica, metal oxides and other compounds fused together and it is crushed to the proper size. Another group of fluxes is made of similar material bonded and formed into granules. The flux not only protects the weld surface from atmosphere and it also acts as a deoxidiser and scavenger. It may also contain powder metal alloying elements. The flux covers the arc and molten metal. Some of the flux melts and forms the slag on the weld. The unused flux is sucked by a pipe. Voltage used is 25 V to 40V. Current used depends on workpiece thickness. Normally, DC is employed using 600A to 1000A and AC is usually 200A. Since the flux must cover the joint to be welded, this method is restricted to make straight welds in the flat position. Thus, it is suitable for cylinders, steel pipes etc.

Submerged arc welding is used specially for welding carbon steels and alloy steels. It can be used to weld chromium steels and austenitic chromium-nickel steels. Plates of 12 *mm* to 50*mm* can be welded with one pass.

Metals weldable and thickness range:

Submerged arc welding is used to weld low and medium-carbon steels, low-alloy high-strength steels, quenched and tempered steels and many stainless steels.

Experimentally, it has been used to weld certain copper alloys, nickel alloys and even uranium.

Metal thicknesses from 1.6 *mm* to 12.7*mm* can be welded with no edge preparation. With edge preparation, welds can be made with a single pass on material from 6.4*mm* to 25.4*mm*.

When multi-pass technique is used, the maximum thickness is practically unlimited. Horizontal fillet welds can be made up to 9.5*mm* in a single pass and in the flat position, fillet welds can be made up to 25*mm* size.

Welding circuit and current:

Submerged arc welding process uses either direct or alternating current for welding power. Direct current is used for most applications which use a single arc. Both Direct Current Electrode Positive (DCEP) and Direct Current Electrode Negative (DCEN) are used.

The constant voltage type of direct current power is more popular for submerged arc welding with 3.2*mm* and smaller diameter electrode wires.

The constant current power system is normally used for welding with 4*mm* and larger-diameter electrode wires.

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Deposition rate and weld quality:

The deposition rate of the submerged arc welding process is higher than any other arc welding process. There are at least four related factors that control the deposition rate of submerged arc welding: polarity, long stick out, additives in the flux and additional electrodes. The deposition rate is the highest for Direct Current Electrode Negative (DCEN). The deposition rate can be increased by metal additives in the submerged arc flux. Additional electrodes can be used to increase the overall deposition rate.

The quality of the weld metal deposited by the submerged arc welding process is high. The weld metal strength and ductility exceeds the value of mild steel or low-alloy base material when the correct combination of electrode wire and submerged arc flux is used. When submerged arc welds are made by machine or automatically, the human factor inherent to the manual welding processes is eliminated. The weld will be more uniform and free from inconsistencies. In general, the weld bead size per pass is much greater with submerged arc welding than other arc welding processes.

Welding variables for SAW:

The welding variables for submerged arc welding are similar to the other arc welding processes with several exceptions.

In submerged arc welding, the electrode type and flux type are usually based on the mechanical properties required by the weld. The electrode size is related to the weld joint size and current required for the particular joint. It must also be considered in determining the number of passes or beads for a particular joint. Welds for the same joint dimension can be made in many or few passes which depends on the weld metal metallurgy desired. Multiple passes usually deposit higher-quality weld metal. Polarity is established initially and it is based on whether maximum penetration or maximum deposition rate required.

The major variables that affect the weld involve heat input, welding current, arc voltage, and travel speed. Welding current is the most important. For single-pass welds, the current should be sufficient for the desired penetration without burn-through. The higher is the current, the deeper will be the penetration. In multi-pass work, the current should be suitable to produce the size of the weld expected in each pass. The welding current should be selected based on the electrode size. The higher is the welding current, the greater will be the melt-off rate (deposition rate).

The arc voltage is varied within narrower limits than welding current. It has an influence on the bead width and shape. Higher voltage will cause the bead to be wider and flatter.

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Extremely high arc voltage should be avoided since it can cause cracking. It is due to an abnormal amount of flux melting and transferring excess deoxidizers to the weld deposit. Therefore, it lowers its ductility. Higher arc voltage also increases the amount of flux consumed. The low arc voltage produces a stiffer arc that improves penetration, particularly in the bottom of deep grooves. If the voltage is too low, a very narrow bead will result. It will have a high crown and the slag will be difficult to remove.

1.7.1. Advantages, Limitations and Applications of SAW

Advantages:

1. Very high quality welds are produced.
2. It is a very fast method.
3. Deep penetration can be obtained.
4. Shielding accessory for eyes is not needed.
5. Long joints can be easily welded.
6. This welding process has high deposit rate. Almost 45 *kg/h* can be deposited.
7. There is no chance of weld spatter as it is submerged in flux blanket.
8. This process is applicable indoor as well as outdoor.
9. No edge preparation is needed.
10. Very little welding fume is seen.
11. This method ensures high utilization of electrode wire.
12. Easy automation can be obtained for high-operator factor.

Limitations:

1. It is not suitable for welding works which is inclined and vertical.
2. The welding zone is not seen. So, it is difficult to guide the electrode movement.
3. Operation is limited to some specific metals.
4. The application is limited to straight seams and pipes and vessels.
5. The flux handling can be tough.
6. Health issue can be caused because of the flux.
7. Slag removal is needed after welding.

Applications:

1. The submerged arc process is widely used in heavy steel plate fabrication work. It includes the welding of structural shapes, longitudinal seam of larger diameter pipe, manufacture of machine components for all types of heavy industry and manufacture of vessels and tanks for pressure and storage use.
2. It is also used in pressure vessels, boilers, tanks, nuclear reactors, chemical vessels, etc.
3. Another use is in the fabrication of trusses and beams.
4. It is widely used in the shipbuilding industry for splicing and fabricating sub-assemblies and by many other industries where steels are used in medium to heavy thicknesses.
5. It is also used for surfacing and buildup work, maintenance and repair.

1.8. TUNGSTEN INERT GAS (TIG) WELDING

TIG welding is also called *Gas Tungsten Arc Welding* (GTAW). In TIG welding, the electric arc is produced between a non-consumable tungsten electrode and the workpiece as shown in Figure 1.19.

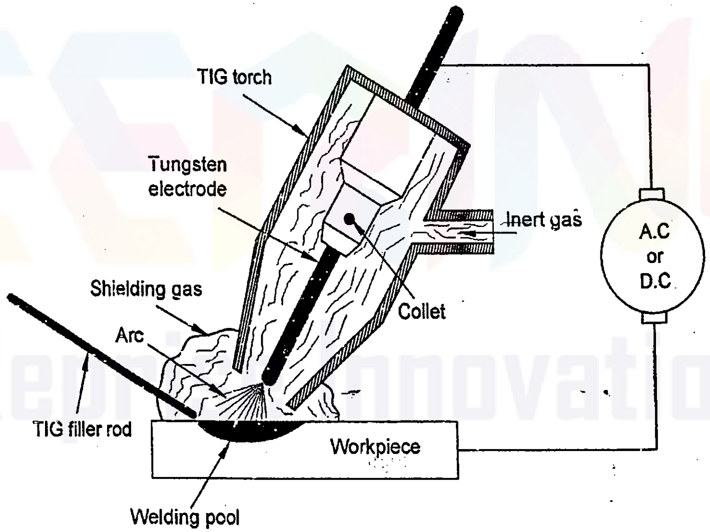

Figure 1.19 TIG welding

There is an electrode holder in which the non-consumable tungsten electrode is fixed when the arc is produced. By supplying the electric power between electrode and workpiece, the inert gas from the cylinder is passed through the nozzle of the welding head around the electrode. The inert gas (Argon, Helium, Nitrogen and CO_2) surrounds the arc and it protects the weld from atmospheric effects and hence, defect free joints are made.

Filler metal may or may not be used. When a filler metal is used, it is usually fed manually into the weld pool. An electrode used in this process is tungsten. It has high melting point (3430°C). Therefore, it will not be melted during welding. Nozzle (shield) size, gas flow rate, filler rod size, electrode diameter and current are chosen depending on position of the weld and metal thickness.

Here energy is supplied by a constant current welding power source. This power supply produces energy which is conducted through a column of ionized gas accompanied by metal vapour known as *plasma*.

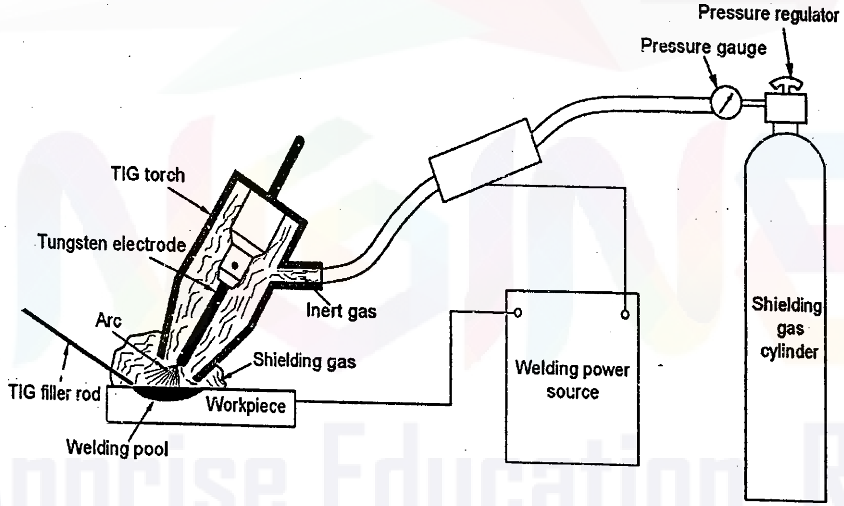

Figure 1.20 TIG welding equipment

Various equipment used in TIG welding (Figure 1.20) are as follows:

1. TIG torch or TIG hand piece
2. Power transformer
3. Shielding gas cylinder

4. Pressure regulator and flow meter
5. Work clamp
6. Coolant system (optional).

An important component of TIG welding equipment is TIG torch. TIG torch is made up of lead, tungsten holder or collet, nozzle and back cap.

Various functions of the TIG torch are as follows:

- It holds the electrode tungsten.
- It delivers welding current to the tungsten via a welding power cable.
- It delivers shielding gas to TIG torch nozzle. The nozzle then directs the shielding gas to cover the weld pool protecting it from contamination from the surrounding air.
- It often will be the way of getting the welder control circuit to the operation, for example: On / Off power supply and / or amperage control.
- TIG torch can be water-cooled. Hoses in TIG lead will supply cooling water to the TIG torch head assembly.
- TIG torch length will allow a distance from TIG power source and workpiece.

This process is used for welding steel, aluminium, cast iron, magnesium, stainless steel, nickel based alloys, copper based alloys and low alloy steel. It is also used for combining the dissimilar metals in hard facing and surfacing of metals. This process is used for metals having thickness less than 6.5*mm*.

This process is difficult in industrial level because the welder has to maintain a short arc length. A great skill and care are needed to conduct the operation without any contact between electrode and workpiece. In TIG welding, the welder has to use both hands. Welder has to supply the filler metal manually and it also maintains the torch.

1.8.1. Advantages, Limitations and Applications of TIG Welding

Advantages:

1. It is applicable to wide range of materials such as aluminum, stainless steel, manganese and copper alloys.
2. It is more suitable for thin sections.
3. It does not create as much spatter and spark.

4. It creates a better work environment with less smoke and fumes.
5. It offers more precision and un-matched control when it comes to thin materials.
6. As in oxy-acetylene welding, the heat source and the addition of filler metal can be separately controlled.
7. TIG welding also has reduced distortion in the weld joint because of the concentrated heat source.
8. It produces welds without contamination.
9. No flux is required.
10. The welding speed is high.
11. It produces high quality weld.
12. No weld cleaning is necessary.

Limitations:

1. It is generally restricted for flat and horizontal welding.
2. Discontinuities in the weld due to contamination of the tungsten electrode by the molten metal.
3. It is slow in operation than consumable electrode gas-metal arc welding.
4. It emits brighter UV rays when compared to other welding processes.
5. Transfer of molten tungsten from the electrode to the weld causes contamination. The resulting tungsten inclusion is hard and brittle.
6. Equipment is more sophisticated. So, it is also more costly.
7. TIG tends to be less forgiving and not as user-friendly as MIG.

Applications:

1. Aluminium, magnesium, copper alloys can be welded easily. Inconel, carbon steels and stainless steels can be welded.
2. Thin parts and sheet metals can be welded easily.
3. Can sealing, instrument diaphragms and transistor cases can be welded very efficiently.
4. Expansion bellows and other delicate parts can be joined.
5. Atomic energy, aircraft, chemical and instrument industries use this welding process.
6. Rocket motor chamber fabrication welding can be done by this process.

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1.9. METAL INERT GAS (MIG) WELDING

MIG welding is also called *Gas Metal Arc Welding (GMAW)*. In this arc welding, the electric arc is produced between a consumable metal wire electrode and the workpiece. During welding, the arc and welding zone are surrounded by an inert gas as shown in Figure 1.21. Argon, helium, CO_2, argon-Oxygen or other gas mixtures are used as the inert gas. The surrounded inert gas protects the weld from atmosphere.

Consumable electrode wire having chemical composition similar to the parent material is continuously fed from a reel to the arc zone through feed unit. The arc heats and melts both workpiece edges and electrode wire. The fused electrode material is supplied to the surfaces of the workpieces, fills the weld pool and forms joint. Due to automatic feeding of the filling wire (electrode), the process is referred to as a semi-automatic. The operator controls only the torch positioning and speed.

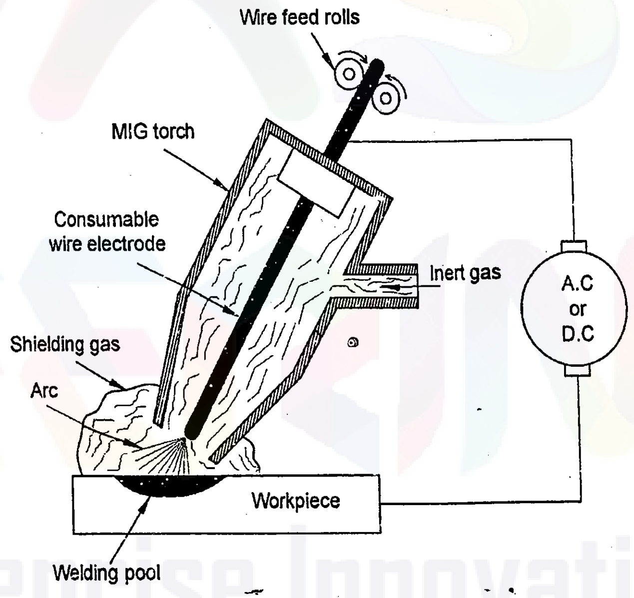

Figure 1.21 MIG Welding process

The welding can be done manually or automatically. Either DC generator or AC transformer is used for MIG welding. A constant voltage DC power source is most commonly used with GMAW but constant current systems as well as AC can be used. The

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current ranges from 100*A* to 400*A* depending upon the diameter of the wire. The welding head may be either air or water-cooled depending upon the current being used.

This process is used for welding thick plates. It is used for welding aluminum, stainless steel, nickel and magnesium without weld defects.

MIG welding equipment:

Gas metal arc welding equipment consists of a welding torch or gun, power supply, shielding gas supply and wire-drive system. The wire drive system pulls the wire electrode from a wire reel and it pushes through a welding gun. Figure 1.22 shows the schematic of MIG welding equipment.

MIG welding gases:

MIG welding uses typically three types of gas for shielding and they are given below.

- Argon
- Carbon dioxide
- Helium.

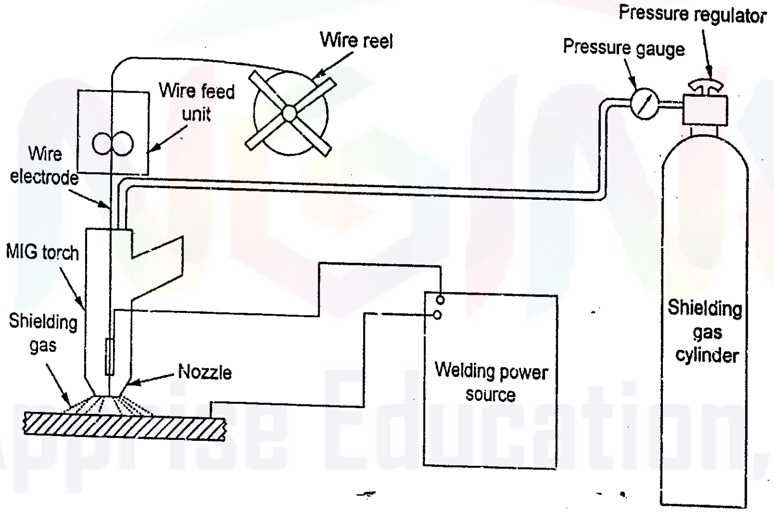

Figure 1.22 MIG Welding equipment

These three gases are typically used as a mixture depending on the metals which are to be welded as given in Table 1.1. The shielding gas needs to be matched to the electrode and base metal. If they are not compatible, then the welds will either not be strong or it will not weld properly.

Table 1.1: Inert Gas mixtures used in MIG welding

S. No.	*Materials*	*Shielding Gas Used*
1.	Non-ferrous metals and alloys	Argon
2.	Steel	Argon + Oxygen
3.	Nickel alloys	Argon +15% helium
4.	Copper	Argon + 50% helium
5.	Steels up to 0.4%C and low alloy steel	CO_2

The type of gas or gas mixture used is based on the following factors:

- How deep the weld penetrates the metal welded
- The characteristics of the welding arc
- The mechanical properties of the weld.

Materials suitable for MIG welding:

MIG welding is a welding process that can weld almost any metal. This process is versatile and can be used with a wide variety of metals and alloys including aluminum, copper, magnesium, nickel, many of their alloys as well as iron and most of its alloys. It may not always be the best choice for weld quality but MIG welding is a fast and cost efficient. This welding produces results that are more than acceptable for most manufacturing and fabrication needs.

The three most common metals welded with a MIG welder are as follows:

- Carbon steel
- Stainless steel
- Aluminum with a special feeder because aluminum wire is very soft.

Electrode deposition in MIG welding:

Filler metal can be transferred from the electrode to the work in two ways:

1. *Short circuiting transfer:* In this type, filler metal is transferred from the electrode to the work when the electrode contacts the molten weld pool thereby establishing a short circuit.

2. *Drop transfer:* In this type, filler metal is transferred from the electrode to the work when discrete drops are moved across the arc gap under the influence of gravity or electromagnetic forces. Drop transfer can be either *globular* or *spray* type.

Shape, size, direction of drops and type of transfer are determined by a number of factors. The factors having the most influence are as follows:

- Magnitude and type of welding current
- Current density
- Electrode composition
- Electrode extension
- Type of shielding gas
- Power supply characteristics.

.9.1. Difference between TIG and MIG Welding

S. No.	*MIG Welding*	*TIG Welding*
1.	It uses consumable electrode.	It uses non-consumable electrode.
2.	It is used for thicker material.	It is used for thinner material.
3.	Feeding of electrode is continuous.	Feeding of electrode is discontinuous.
4.	The process is easier.	It is a difficult process.
5.	It produces low quality weld.	It produces high quality weld.
6.	It needs less skilled welder.	It needs more skilled welder.
7.	Process is fast.	Process is slow.
8.	Automation is easy.	Automation is difficult.
9.	It produces more spark and spatter.	It produces less spark and spatter.
10.	It produces more smoke.	It produces less smoke.

1.9.2. Advantages, Limitations and Applications of MIG Welding

Advantages:

1. It is suitable for welding a variety of ferrous and nonferrous metals.
2. No flux is required and hence, there is no slag to remove.
3. Multiple pass welding does not require any intermediate cleaning of weld pool.
4. Because of the relatively simple nature of the process, training the operators is easy.
5. This process is rapid, versatile and economical.
6. Welding productivity is double as compared to shielded metal arc welding.
7. Easy automation lends readily itself to robotics and FMS.
8. High welding speed is obtained.
9. It provides greater efficiency.
10. It produces high quality weld.
11. The process is cheaper.

Limitations:

1. It cannot be used in the vertical or overhead welding positions due to the high heat input and the fluidity of tne weld puddle.
2. The process is more expensive than any other types of welding.
3. Outdoor welding is not easy because of effect of wind, dispersing the shielding gas.
4. It needs a clean joint.
5. The equipment is complex compared to equipment used for the shielded metal-arc welding process.
6. It needs more maintenance.
7. Contact tips may seize due to weld spatter.
8. Identifying the problem is difficult due to more number of parts.

Applications:

1. Since temperatures are relatively low, it is suitable for thin sheet section (less than 6 *mm*). Examples: Motorcar manufacture, shipbuilding, aircraft engineering, heavy electrical engineering and the manufacture of tanks, pressure vessels, and pipes.
2. It is also used in fabrication and manufacturing industries.

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3. The most common application of MIG welding is automotive repair and such repairs can be carried out on a number of different vehicles whether they are large, small, light or heavy.

4. MIG welding can be used to establish hard facing or it can even be used to reinforce the surface of a worn out railroad track.

1.10. PLASMA ARC WELDING

Conventional methods are not suitable for machining metals such as cast alloy, Waspaloy alloy and carbides having promising applications in various industries also machining these materials in conventional methods causing increased machining cost. So, these types of materials in special welding methods are preferred. It will increase the productivity, reduces number of rejected components and achieves close tolerance.

Principle:

Plasma is high temperature ionized gas. A plasma is the gas region in which there is practically no resultant charge, i.e., where positive ions and electrons are equal in number. The region is an electrical conductor and it is affected by electric and magnetic fields. When this high temperature plasma is passed through the orifice, the proportion of the ionized gas increases and plasma arc welding is formed.

Working:

When the high heat content plasma gas is forced through the torch, an orifice is surrounded by negative tungsten electrode in the form of jet. The plasma cutting force imposes a swirl on the orifice gas flow. The arc is initiated in the beginning by supplying electrical energy between nozzle and tungsten electrode. It will release high energy and heat. This heat is normally between 10,000°*C* to 30,000°*C*. This high amount of heat energy is used to weld the metal. Narrow and deep welds can be made using this process at high welding speeds.

1.10.1. Types of Plasma Arc Welding

There are two types plasma arc welding used practically. They are as follows:

1. Non-transfer type, and
2. Transferred type.

1. Non-transferred type:

In this type, power is directly connected with the electrode and torch of nozzle. The tungsten is connected to the negative pole (cathode) of a DC supply and the nozzle to the positive pole (anode) as shown in Figure 1.23.

Gas is fed into the nozzle and when an arc is struck between tungsten electrode and nozzle. The gas is ionized in its passage through the arc. Due to the restricted shape of the nozzle orifice, ionization is greatly increased and the gas issued from the nozzle orifice as a high-temperature, high-velocity plasma jet, cylindrical in shape and of very narrow diameter realizing temperatures up to 10000°*C*. This type is known as *non-transferred plasma*. The main advantage of this type is that the spot moves inside the wall and heats the incoming gas and outer layer remains cool. This type of plasma has low thermal efficiency.

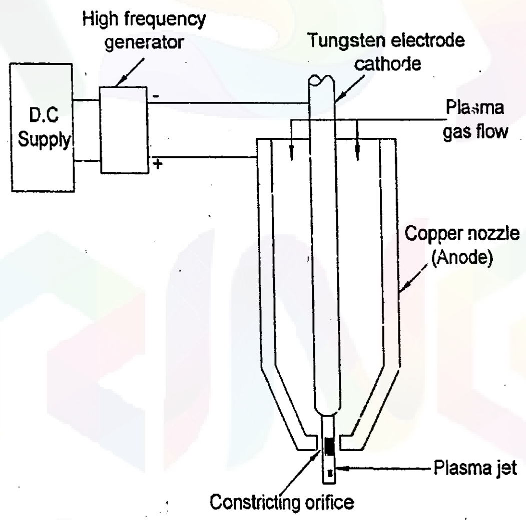

Figure 1.23 Non-transferred type plasma arc welding

The non-transferred plasma arc possesses comparatively less energy density as compared to transferred arc plasma and it is employed for welding and applications involving ceramics or metal plating (spraying). High density metal coatings can be produced by this process. A non-transferred arc is initiated by using a high frequency unit in the circuit.

2. Transferred type:

In the transferred type, the restricting orifice is in an inner water-cooled nozzle within which the tungsten electrode is centrally placed. Both work and nozzle are connected to the anode and the tungsten electrode to the cathode of a DC supply as shown in Figure 1.24.

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Relatively low plasma gas flow (of argon, argon-helium or argon-hydrogen) is necessary to prevent turbulence and disturbance of the weld pool. So, a further supply of argon is fed to the outer shielding nozzle to protect the weld.

It is difficult to initiate the arc first between workpiece and electrode. For this, the pilot arc is struck between nozzle and electrode. A high-frequency generator unit fed from a separate source from the main supply initiates the pilot arc. For initiating a transferred arc, current limiting resistor is put in the circuit which permits a flow of about 50*amp* between nozzle and electrode. A pilot arc is established between electrode and nozzle. As the pilot arc touches the workpiece, main current starts flowing between electrode and job. Thus, it ignites the transferred arc. The arc is transferred from electrode to work via the plasma. The pilot arc initiating unit gets disconnected and pilot arc extinguishes as soon as the arc between electrode and job is started. The temperature of a constricted plasma arc may be in the order of 8000°*C* to 25000°*C*.

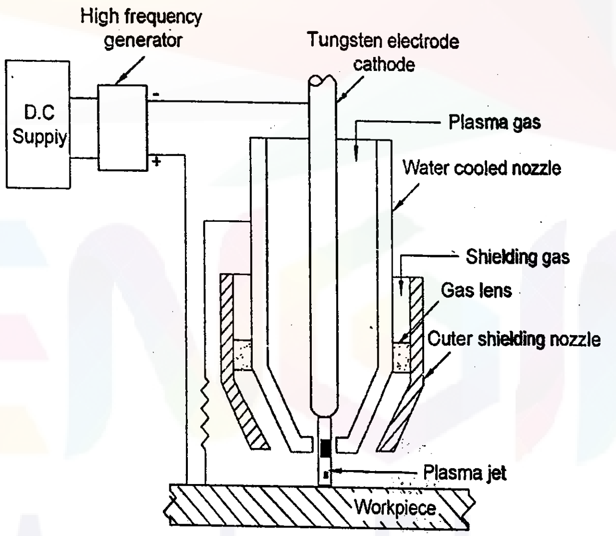

Figure 1.24 Transferred type plasma arc welding

To shape the arc, two auxiliary gas passages on each side of the main orifice may be included in the nozzle design. The flow of cooler gas through these orifices squeezes the circular pattern of the jet into oval form to give a narrower heat affected zone and increased welding speed. Since the tungsten electrode is well inside the nozzle (about 3*mm*) in plasma welding, tungsten contamination by touchdown or by filler rod is avoided to make the welding process easier.

The base metals welded by plasma arc welding are as follows:

1. Stainless steels
2. Titanium alloys
3. Carbon and low alloy steels
4. Copper alloys
5. Aluminium alloys.

The types of joint which are made by plasma arc welding are as follows:

1. Filler welds
2. T-Welds
3. Grooves [Single groove (or) 'V' groove]
4. Square groove.

1.10.2. Plasma Arc Welding Equipment

The equipment needed in plasma arc welding along with their functions are as follows:

(i) Power source:

A constant current drooping characteristic power source occurs with the supplied DC welding current. In the range 5*A*°-200*A*°, a DC rectifier power unit with drooping characteristic and an open circuit voltage of 70 *V* with a duty cycle of 60% can be used for argon and argon-hydrogen mixtures. If more than 5% hydrogen is used, 100*V* or more is required for pilot arc ignition. Rectifiers are generally preferred over DC generators. The power source has a built-in contactor and provisions for remote control current adjustment.

For low-current welding in the range 0.1*A*° -15*A*° referred as micro-plasma welding, the power unit is about 3 *kVA*, 200-250 *V*, 50 *Hz* single-phase input, fan cooled with open circuit voltage of 100 *V* nominal and 150 *V* peak DC for the main arc and output current ranges 0.1-2.0 *A* and 1.0-15 *A*.

(ii) Plasma torch:

The welding torch for plasma arc welding is similar in appearance to a gas tungsten arc torch but it is more complex. All plasma torches are water cooled even the lowest-current range torch because the arc is contained inside a chamber in the torch where it generates considerable heat. If water flow is interrupted briefly, the nozzle may melt. The torch utilizes the 2% thoriated tungsten electrode similar to TIG welding. Since the tungsten electrode is located inside the torch, it is almost impossible to contaminate with base metal.

(iii) Shielding gases:

Very pure argon is used for plasma and shield (or orifice) when welding reactive metals such as titanium and zirconium which have a strong affinity for hydrogen.

A mixture of argon and hydrogen supplies heat energy higher than when only argon is used and thus, it permits keyhole mode welds in nickel base alloys, copper base alloys and stainless steels. Argon+5% hydrogen mixtures are applied for this purpose and argon+8% hydrogen and even up to 15% hydrogen are also used. With these mixtures, the arc voltage is increased, giving higher welding speeds (up to 40% higher).

For copper, nickel and their alloys, argon is used in keyhole welding for thinner sections for both orifice and shielding gas. Argon and helium are used in the melt-in welding of thinner sections and helium for orifice and shielding gas for sections over 3*mm* thick. For cutting purposes, a mixture of argon and hydrogen (10-30%) or nitrogen may be used.

(iv) Control console:

A control console is required for plasma arc welding. The plasma arc torches are designed to connect to the control console rather than power source. The console includes the following.

- A power source for the pilot arc
- A delay timing system for transferring from the pilot arc to the transferred arc
- Water and gas valves
- Separate flow meters for the plasma gas and the shielding gas.

The console is usually connected to the power source and it may operate the contactor. It will also contain a high-frequency arc starting unit, non-transferred pilot arc power supply, torch protection circuit and an ammeter. The high-frequency generator is used to initiate the pilot arc. Torch protective devices include water and plasma gas pressure switches which interlock with the contactor.

1.10.3. Advantages, Limitations and Applications of Plasma Arc Welding

Advantages:

1. Penetration is uniform.

   It has deeper penetration capabilities and produces a narrower weld.

3. Arc stability is good.
4. Fully penetrated keyholes can be obtained.
5. The plasma arc is more stable and it is not as easily deflected to the closest point of base metal. Hence, high accuracy weld can be produced.
6. High speed weld can be obtained.
7. The production rate is high.
8. Greater variation in joint alignment is possible with plasma arc welding.

Limitations:

1. Huge noise occurs during welding.
2. Chances of electric hazards may occur during welding.
3. It is limited to high thickness applications.
4. Frequent orifice replacement is necessary.
5. Cost of the equipment is expensive.
6. Ultraviolet radiations can affect human body.
7. More skilled operator is needed than GTAW process.
8. The torch is more delicate and complex than a TIG torch.
9. Gas consumption is high.

Applications:

1. It is used in aerospace applications.
2. It is used for melting high melting point metals.
3. It is used for welding titanium plates.
4. It is used in welding nickel alloys.
5. It is used for tube mill applications.

1.11. ELECTROSLAG WELDING (ESW)

Electroslag Welding (ESW) is a highly productive, single pass welding process for thick materials in a vertical or close to vertical position.

Principle:

Electroslag welding is a welding process in which the heat is generated by an electric current passing between consumable electrode (filler metal) and workpiece through a molten slag covering the weld surface. In this process, the coalescence is formed by molten slag and the molten metal pool remains shielded by molten slag.

Working:

In this welding process, prior to welding the gap between two workpieces is filled with a welding flux powder. Electroslag welding is initiated by an arc between electrode and workpiece. Heat generated by the arc melts the fluxing powder and it forms molten slag.

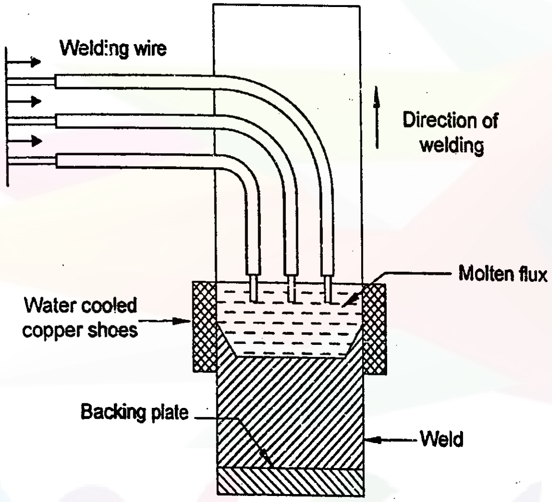

Figure 1.25 Electroslag welding

Additional flux is added until the molten slag reaches the tip of the electrode. The slag having low electric conductivity is maintained in liquid state due to heat produced by the electric current. The slag reaches a temperature of about 1930°*C*. This temperature is sufficient for melting the consumable electrode and workpiece edges. Metal droplets fall to the weld pool and join the workpieces. Thus, the weld is formed.

In this welding process, after the molten slag reaches the tip of the electrode, the arc is extinguished. Heat is continuously produced by the electrical resistance of the molten slag. Because the arc is extinguished, electroslag welding is not strictly an arc-welding process. Single or multiple solid as well as flux-cored electrodes may be used.

To contain the molten puddle, water cooled copper shoes or dams are placed on the sides of the vertical cavity. As the weld joint solidifies, the dams move vertically so as to always remain in contact with the molten puddle.

The electric current passes from the electrode to the workpiece through the slag pool. The welding flux used in electro slag welding should be cleared from impurities and oxidation.

The quality of weld in electroslag welding depends on the following factors:

- The ratio of width of the weld pool and its maximum depth known as *form factor*
- Weld current and voltage
- Slag depth
- Number of electrodes and their spacing etc.

The equipment used in ESW is all automatic and of special design. Electroslag welding is capable of welding plates with thicknesses ranging from 50 *mm* to more than 900 *mm* and welding is done in one pass. The current required is about 600 *A* at 40 *V* to 50 *V* although higher currents are used for thick plates. The travel speed of the weld is in the range from 12*mm*/*min* to 36 *mm*/*min*. Weld quality is high.

1.11.1. Advantages, Limitations and Applications of Electroslag Welding

Advantages:

1. Heavy thickness metals can economically be welded.
2. Stress formation is low.
3. Preparation of joints is easier.
4. Slag consumption is low.
5. High deposition rate of up to 20 *kg/h* is obtained during the weld.
6. Distortion is low.

Limitations:

1. It is difficult to weld cylindrical objects.
2. Hot cracking may occur.
3. Grain size becomes larger.
4. Toughness of the weld is low.
5. Only vertical position is possible.
6. The cost is high as the equipment is fully automatic and it is of special design.

Applications:

1. It is used mainly to join low carbon steel plates and sections are very thick.
2. It is used for welding thick sections of carbon steels alloys steels and nickel alloys.
3. This process is used for large structural-steel sections such as heavy machinery, bridges, ships and nuclear-reactor vessels.
4. Forgings and castings are welded.
5. Heavy plates can be welded.
6. It can also be used on structural steel if certain precautions are observed.

1.12. TWO MARK QUESTIONS AND ANSWERS

1. *Define welding process.*

The process of joining two similar metals by the application of heat with or without application of pressure and with or without addition of filler metal is called *welding*. This is often done by melting the work pieces and adding a filler material to form a pool of molten material that cools to become a strong joint.

2. *What are the advantages of welding?*

1. Permanent joints can be obtained.
2. Strength of the joint is somewhat high when compared to riveted joints.
3. Uniform distribution of same parent metal at the joint can be ensured.
4. Welded parts can be used in heavy duty applications.

3. *State any four applications of welding process.*

1. Fabrication and erection of steel structure in industry.
2. Construction of structural joints.
3. Aircraft frame works, railway wagons and furniture.
4. Automobile bodies and ship building.

4. *State the types of welding.*

1. Fusion welding
2. Pressure or plastic welding.

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5. *Define fusion welding.*

In fusion welding, metals to be welded are heated to a molten state and then it is allowed to solidify. It is also called *non-pressure welding or fusion welding*.

6. *Define plastic welding.*

In pressure or plastic welding, the metal parts are heated to a plastic state and they are pressed together to make the joint. Hence, it is known as *pressure welding*.

7. *Differentiate fission welding from fusion welding.*

In plastic welding, the metals are heated to a plastic state and pressed together to make the joint.

In fusion welding, the metals are heated to a molten state and then it is allowed to solidify (without application of pressure).

8. *Classify the welding process based on the filler metals.*

(a) Autogeneous

(b) Homogeneous

(c) Heterogeneous.

9. *Define Autogeneous.*

The process is one in which no filler metal is added at the joint interface called *autogeneous*.

10. *What is meant by gas welding?*

Gas welding is one type of welding processes in which the edges of the metals to be welded are melted by using a gas flame.

11. *Mention the types of gas welding process.*

(a) Air-acetylene welding

(b) Oxy-acetylene welding

(c) Oxy-hydrogen welding.

12. *What are the various gases commonly used in gas welding?*

1. Acetylente
2. Hydrogen
3. Propane, and
4. Butane.

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13. What is the principle of oxy-acetylene gas welding?

In oxy-acetylene gas welding, the edges of the metals to be welded are melted by using the heat obtained by burning a mixture of oxygen and acetylene gas. The gases are mixed in the required proportion in a welding torch which provides a control for the welding flame. The flame is produced at the tip of a welding torch. No pressure is applied during welding except pressure gas welding.

14. Define high- pressure system of oxy-acetylene welding.

Both oxygen and acetylene are supplied from high-pressure cylinders which are at 120*atm* gauge pressure of oxygen and 1.5*atm* pressure of acetylene.

15. List down the gas welding equipment.

1. Gas cylinders
2. Pressure regulators
3. Pressure gauges
4. Hoses
5. Welding torch
6. Check valves or control valves
7. Flash back arrestors
8. Goggles
9. Welding gloves
10. Spark lighter
11. Wire brush.

16. What is the function of welding torch?

The gases are mixed in the required proportion in a welding torch which provides the control for the welding flame.

17. Name the types of flames used in gas welding process.

(i) Neutral flame,

(ii) Carburising flame, and

(iii) Oxidising flame.

18. What is the function of fluxes in welding?

Fluxes are used in welding to prevent atmospheric reaction and to remove impurities.

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19. How is the acetylene stored in the cylinder?

The acetylene is stored in the form of dissolved acetone under a pressure of 16-to 22*atm* gauges.

20. What is the necessity of providing pressure regulators and pressure gauges?

The pressure regulators are used to reduce and control the working pressure of gases during welding.

It indicates the gauge pressure of gas contained in the cylinder. Each cylinder should have separate pressure gauges.

21. Why do we have to use goggles and gloves?

The welding goggles are used to project eyes from the flame heat, ultraviolet and infrared rays. The gloves protect hand from the injury causing by heat and metal splashes.

22. How can the neutral flame be obtained?

The neutral flame can be obtained by supplying equal quantity of oxygen and acetylene.

23. Write down the chemical reaction equation in neutral flame.

$$C_2H_2 + O_2 \Rightarrow 2CO + H_2$$

where $C_2H_2 \Rightarrow$ Acetylene

$O_2 \Rightarrow$ Oxygen

24. What are the different cones occur in carburising flame?

1. Sharp inner cone
2. White intermediate feather cone
3. Bluish outer cone.

25. What are the applications of carburising flame?

Carburising flame is used for welding:

1. Very few carbon steel
2. Monel alloy
3. Alloy steels and
4. Non-ferrous metals.

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26. How is the oxidizing flame obtained and where it is used?

The oxidizing flame is obtained by supplying excess oxygen than acetylene.

The oxidising flame is mainly used for welding brass and bronze materials.

27. State the applications of air acetylene welding.

1. Lead welding
2. Low melting temperature metals and alloys.

28. State any two applications of oxy-hydrogen welding.

1. Welding of aluminium
2. Welding of lead and magnesium.

29. Name the types of gas welding techniques based on flame movement.

1. Leftward or forward welding
2. Rightward or backward welding.

30. What are the advantages of gas welding?

1. Temperature of flame can be easily controlled.
2. The amount of filler metal deposits can be controlled easily.
3. The flame can be used for welding and cutting.
4. All types of metal can be welded.
5. The cost of equipment is less.
6. It can be used in the factory or in the field.
7. Maintenance cost of gas welding equipment is less.

31. Mention any two limitations of gas welding.

1. It is a slow process.
2. Handling and storing of gas cylinders need more care.

32. State the applications of gas welding.

1. Oxyacetylene welding is used extensively for joining thin steel sheets.
2. It is also used for welding of dissimilar metals, brazing, braze-welding, silver soldering, metal heating (for bending and forming) and oxy-fuel cutting.

33. What is meant by carbon arc welding process?

Carbon arc welding is the process of joining two metal pieces by melting their edges by an electric arc. In arc welding, the electrical energy is converted into heat energy.

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34. Classify carbon arc welding techniques.

(a) Single-carbon electrode arc welding

(b) Twin-carbon electrode arc welding.

35. List out any four arc welding equipment.

1. Welding generator (DC) or transformer (A.C)
2. Electrode
3. Electrode holder
4. Two cables one for work and other for electrode
5. Gloves
6. Protective shield.

36. Note down the purpose of filler rod in welding process.

Filler rod or welding rod used in gas welding is to supply additional metal to make the joint.

37. Why shielding of weld area during welding is required?

Shielding is used to prevent atmospheric reaction between molten metal and atmosphere (prevention of oxidation).

38. Define arc length and arc crater.

The distance between the tip of the electrode and the bottom of the arc crater is known as *arc length*.

The molten metal is forced out of the pool by the electric arc which forms a small depression in the parent metal where the molten metal is piled up known as *arc crater*.

39. State any four advantages of carbon arc welding.

1. Low cost of equipment and welding operation are ensured.
2. High level of operator skill is not required.
3. The process is easily automated.
4. It has less distortion of workpiece.

40. Mention any two limitations and applications of carbon arc welding.

Limitations:

1. The process is unstable quality of the weld. There may be more porosity in weldment.

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2. Carbon of electrode contaminates the weld material with carbides.

Applications:

1. Carbon arc welding is used to weld both ferrous and non-ferrous metals.
2. Sheets of steel, copper alloys, brass and aluminium can be welded in this method.

41. What do you understand by DC straight polarity?

During the welding process, the positive terminal of DC power supply is connected to the workpiece and the negative terminal is connected to the electrode.

42. What are the advantages of AC equipment over DC equipment in arc welding?

S. No.	*AC machine (Transformer)*	*DC machine (Generator)*
1.	Efficiency is more (80 to 85%).	Efficiency is less (30 to 60%).
2.	Power consumption is less.	Power consumption is more.
3.	Cost of equipment is less.	Cost of equipment is more.
4.	Any terminal can be connected to work or electrode.	Positive terminal is connected to work and negative terminal is connected to electrode.
5.	It is noiseless in operation.	It is very noisy in operation.

43. Define the term electrode.

Electrode is a solid rod in arc welding process to produce electric arc by passing the current through it and workpiece for melting the surfaces or edges that are joined without applying external force.

44. Classify electrodes.

(i) Consumable electrodes
 (a) Bare electrodes
 (b) Lightly coated electrodes
 (c) Heavily coated electrodes.

(ii) Non-consumable electrodes.

45. What are the two main differences of consumable electrode and non-consumable electrode?

Consumable electrode	*Non-consumable electrode*
The electrode is with coating of flux.	The electrode is without coating of flux.
The electrode is consumed during welding process.	This type of electrode is used for just producing arc and it will not be consumed.

46. Compare shielded metal arc welding and gas welding.

Arc Welding	*Gas welding*
1. Heat is produced by electric arc.	Heat is produced by the gas flame.
2. The arc temperature is about 4000°*C*.	The flame temperature is about 3200°*C*.
3. Filler rod is used as an electrode.	Filler rod is introduced separately.
4. It is suitable for welding medium and thick work.	It is suitable for welding thin work.
5. Arc welded joints have very high strength.	Gas welded joints do not have much strength.
6. Filler metal should be same as or an alloy of parent metal.	Filler metal need not be same as the parent metal.

47. What are the advantages of SMAW?

1. Equipment is self-contained, portable and relatively inexpensive.
2. Electrode provides its own flux.
3. Most metals and alloys can be welded with SMAW.
4. Useful process for welding in confined spaces.

48. State the limitations of SMAW.

1. It is not recommended for welding metals less than 1.5 *mm* thick.
2. Excessive spatter is produced during welding.

3. Frequent stop/starts are required to change electrode.
4. The process is discontinuous due to limited length of the electrodes.

49. Note down the applications of SMAW.

1. Because of the versatility of the process, simplicity of its equipment and operation, shielded metal arc welding is one of the world's most popular welding processes.
2. SMAW is often used to weld carbon steel, low and high alloy steel, stainless steel, cast iron and ductile iron.
3. While less popular for nonferrous materials, it can be used for nickel, copper and their alloys.
4. In rare cases, it is used for aluminium.

50. Where is the submerged arc welding specially used?

Carbon steels and alloy steels, chromium steels and austenitic chromium-nickel steel.

51. State any two limitations of submerged arc welding.

1. It is not suitable for welding works which is inclined and vertical.
2. The welding zone is not seen. So, it is difficult to guide the electrode movement.
3. Operation is limited to some specific metals.
4. The application is limited to straight seams and pipes and vessels.

52. Name the different areas in which submerged arc welding is used.

1. Construction industry
2. Automotive industry
3. Manufacturing industry
4. Shipping industry.

53. What is the purpose of using inert gas in TIG welding?

The inert gas surrounds the arc and protects the weld from atmospheric effects. Hence, defects free joints are made.

54. Name the various equipment used in TIG welding.

1. TIG torch or TIG hand piece
2. Power transformer

3. Shielding gas cylinder
4. Pressure regulator and flow meter
5. Work clamp
6. Coolant system (optional).

55. Mention the various functions of the TIG torch.

- It holds the electrode tungsten.
- It delivers welding current to the tungsten via a welding power cable.
- It delivers shielding gas to TIG torch nozzle. The nozzle then directs the shielding gas to cover the weld pool protecting it from contamination from the surrounding air.
- It often will be the way of getting the welder control circuit to the operation, for example: On / Off power supply and / or amperage control.
- TIG torch can be water-cooled. Hoses in TIG lead will supply cooling water to the TIG torch head assembly.
- TIG torch length will allow a distance from TIG power source and workpiece.

56. What are the advantages of TIG welding?

1. It is applicable to wide range of materials such as aluminum, stainless steel, manganese and copper alloys.
2. It is more suitable for thin sections.
3. It does not create as much spatter and spark.
4. It creates a better work environment with less smoke and fumes.

57. State any two limitations of TIG welding.

1. It is generally restricted for flat and horizontal welding.
2. Discontinuities in the weld due to contamination of the tungsten electrode by the molten metal.
3. It is slow in operation than consumable electrode gas-metal arc welding.
4. It emits brighter UV rays when compared to other welding processes.

58. Mention the applications of TIG welding.

1. Aluminium, magnesium, copper alloys can be welded easily. Inconel, carbon steels and stainless steels can be welded.

2. Can sealing, instrument diaphragms and transistor cases can be welded very efficiently.
3. Expansion bellows and other delicate parts can be joined.
4. Atomic energy, aircraft, chemical and instrument industries use this welding process.
5. Rocket motor chamber fabrication welding can be done by this process.

59. *What does MIG welding mean?*

Metal inert gas welding is referred as MIG welding. It is also called *Gas Metal Arc Welding (GMAW)*. In this arc welding, the electric arc is produced between a consumable metal wire electrode and the workpiece.

60. *How does MIG welding differ from TIG welding?*

In MIG welding, the consumable electrode without filler material is used whereas in TIG welding non-consumable tungsten electrode is used.

61. *What are the gases commonly used in MIG welding?*

- Argon
- Carbon dioxide
- Helium.

62. *Mention the ways of transferring filler metal to the work in MIG welding.*

1. Short circuiting transfer
2. Drop transfer.

63. *Distinguish MIG welding and TIG welding.*

S. No.	MIG Welding	TIG Welding
1.	It uses consumable electrode.	It uses non-consumable electrode.
2.	It is used for thicker material.	It is used for thinner material.
3.	Feeding of electrode is continuous	Feeding of electrode is discontinuous.
4.	The process is easier.	It is a difficult process.
5.	It produces low quality weld.	It produces high quality weld.
6.	It needs less skilled welder.	It needs more skilled welder.
7.	Process is fast.	Process is slow.
8.	Automation is easy.	Automation is difficult.
9.	It produces more spark and spatter.	It produces less spark and spatter.
10.	It produces more smoke.	It produces less smoke.

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64. *List down the advantages of MIG welding.*

1. It is suitable for welding a variety of ferrous and nonferrous metals
2. No flux is required and hence, there is no slag to remove.
3. Multiple pass welding does not require any intermediate cleaning of weld pool.
4. Because of the relatively simple nature of the process, training the operators is easy.
5. This process is rapid, versatile and economical.

65. *What are the limitations of MIG welding?*

1. It cannot be used in the vertical or overhead welding positions due to the high heat input and the fluidity of the weld puddle.
2. The process is more expensive than any other types of welding.
3. Outdoor welding is not easy because of effect of wind, dispersing the shielding gas.
4. It needs a clean joint.
5. The equipment is complex compared to equipment used for the shielded metal-arc welding process.

66. *State the applications of MIG welding.*

1. Since temperatures are relatively low, it is suitable for thin sheet section (less than 6 *mm*). Examples: Motorcar manufacture, shipbuilding, aircraft engineering, heavy electrical engineering and the manufacture of tanks, pressure vessels, and pipes.
2. It is also used in fabrication and manufacturing industries.
3. The most common application of MIG welding is automotive repair and such repairs can be carried out on a number of different vehicles whether they are large, small, light or heavy.

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4. MIG welding can be used to establish hard facing or it can even be used to reinforce the surface of a worn out railroad track.

67. *Define plasma arc welding.*

It is a temporary state of gas. The passage of electric current will ionize the gas and heat is produced from tungsten alloy electrode and water-cooled nozzle.

68. *What are the two types of plasma arc welding?*

1. Non-transformed arc
2. Transferred arc.

69. *Write short notes on transferred and non-transferred in plasma arc welding.*

1. Transferred type:

In transferred type, the tungsten electrode is connected to negative terminal and the workpiece is connected to positive terminal. An electric arc is maintained between electrode and workpiece which heats a co-axial flowing gas and maintains it in a plasma state. It is difficult to initiate the arc first between workpiece and electrode. For that, the pilot arc is struck between nozzle and electrode.

2. Non-transferred type:

In this type, power is directly connected with the electrode and torch of nozzle. The electrode carries the same current. Thus, the ionizing is at high velocity gas that is strewing towards the workpiece. The main advantage of this type is that the spot moves inside the wall and heat the incoming gas and outer layer remains cool. This type plasma has low thermal efficiency.

70. *Give some metals and alloy melted by plasma Arc welding process.*

Titanium alloys, stainless steels, aluminium alloys, copper alloys.

71. *What are the components of console in plasma arc welding?*

- A power source for the pilot arc.
- A delay timing system for transferring from the pilot arc to the transferred arc.
- Water and gas valves.
- Separate flow meters for the plasma gas and the shielding gas.

72. *What are the advantages of plasma arc welding?*

1. Penetration is uniform.
2. It has deeper penetration capabilities and produces a narrower weld.

3. Arc stability is good.
4. Fully penetrated keyholes can be obtained.

73. *State the limitations of plasma arc welding.*

1. Cost of the equipment is expensive.
2. Ultraviolet radiations can affect human body.
3. More skilled operator is needed than GTAW process.
4. The torch is more delicate and complex than a gas tungsten arc torch.
5. Gas consumption is high.

74. *Mention the applications of plasma arc welding.*

1. It is used in aerospace applications.
2. It is used for melting high melting point metals.
3. It is used for welding titanium plates.
4. It is used in welding nickel alloys.
5. It is used for tube mill applications.

75. *State the principle involved in Electroslag welding.*

In this welding process, the heat is generated by an electric current passing between consumable electrode (filler metal) and workpiece through a molten slag covering the weld surface. In this process, the coalescence is formed by molten slag and the molten metal pool remains shielded by molten slag.

76. *List down the factors involved in deciding the quality of weld in electroslag.*

- The ratio of width of the weld pool and its maximum depth known as *form factor*
- Weld current and voltage
- Slag depth
- Number of electrodes and their spacing etc.

77. *Mention any four advantages of electroslag welding.*

1. The chief advantage of electric slag welding is that it can weld materials of thickness up to 400 *mm*.
2. Heavy thickness metals can economically be welded.
3. Stress formation is low.

4. Preparation of joints is easier.
5. Slag consumption is low.

78. What are the limitations of electroslag welding?

1. It is difficult to weld cylindrical objects.
2. Hot cracking may occur.
3. Grain size becomes larger.
4. Toughness of the weld is low.
5. Only vertical position is possible.
6. The cost is high as the equipment is fully automatic and it is of special design.

79. State the applications of electroslag welding.

1. It is used mainly to join low carbon steel plates and sections are very thick.
2. It is used for welding thick sections of alloys steels and nickel alloys.
3. This process is used for large structural-steel sections such as heavy machinery, bridges, ships and nuclear-reactor vessels.
4. Forgings and castings are welded.
5. Heavy plates can be welded.
6. It can also be used on structural steel if certain precautions are observed.

1.13. SOLVED QUESTIONS AND ANSWERS

1. Classify welding process based on the methods of welding.

   Refer chapter **1.2** in page **1.2**.

2. Describe with a neat sketch the components of oxyacetylene gas welding equipment.

   Refer chapter **1.4.4** in page **1.8**.

3. Sketch the three types of flames in oxy-acetylene welding and state their characteristics.

   Refer chapter **1.4.5** in page **1.10**.

4. Explain with neat sketches about gas welding techniques.

   Refer chapter **1.4.6** in page **1.13**.

5. Write short notes on filler rods used in gas welding.

   Refer chapter **1.4.7** in page **1.14**.

6. Discuss the principle involved in carbon arc welding with a neat sketch.

   Refer chapter **1.5** in page **1.15**.

7. Elaborate the equipment used in shielded metal arc welding process.

   Refer chapter **1.6.1** in page **1.19**.

8. Compare AC and DC welding machines.

   Refer chapter **1.6.2** in page **1.21**.

9. Write down the observations made in power supply characteristics in arc welding.

   Refer chapter **1.6.3** in page **1.22**.

10. Write short notes on types of electrodes.

    Refer chapter **1.6.4** in page **1.24**.

11. Discuss how electrodes are specified and selected for the particular applications.

    Refer chapter **1.6.5** in page **1.26**.

12. Compare shielded metal arc welding and gas welding.

    Refer chapter **1.6.7** in page **1.27**.

13. Sketch the overall set up of submerged welding process and explain the working principle. Mention its applications.

    Refer chapter **1.7** in page **1.29** for submerged welding process and chapter **1.7.1** in **1.32** for applications.

14. Explain TIG welding system with a neat sketch.

    Refer chapter **1.8** in page **1.33**.

15. Describe MIG welding process with a neat sketch.

    Refer chapter **1.9** in page **1.37**.

16. Compare MIG and TIG welding processes.

    Refer chapter **1.9.1** in page **1.40**.

17. Explain plasma arc welding with neat sketch.

    Refer chapter **1.10** in page **1.42**.

    Explain the types of plasma arc welding with their sketches.

    Refer chapter **1.10.1** in page **1.42**.

19. What are the advantages and limitations of plasma arc welding?

    Refer chapter **1.10.3** in page **1.46.**

20. Describe plasma arc welding and give their applications.

    Refer chapter **1.10.3** in page **1.46.**

21. Describe the process of electroslag welding and identify their major applications.

    Refer chapter **1.11** in page **1.47** for process and **1.11.1** in page **1.49** for applications.

END of Unit 1

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UNIT – 2

RESISTANCE WELDING PROCESSES

Spot welding, Seam welding, Projection welding, Resistance Butt welding, Flash Butt welding, Percussion welding and High frequency resistance welding processes - advantages, limitations and applications.

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2

RESISTANCE WELDING PROCESSES

2.1. FUNDAMENTALS OF RESISTANCE WELDING

In ancient times, metal welding was done in the form of forge welding (metals heated up to melting point are pressed together) and brazing (weld using alloy of low melting point). *Resistance welding* processes are pressure welding processes in which heavy current is passed for short time through the area of interface of metals to be joined with the application of pressure. In other way, it may be defined as "Resistance welding is a thermo-electric process in which heat is generated at the interface of the parts to be joined by passing an electrical current through the parts for a precisely controlled time and under a pressure".

The various types of resistance welding are as follows:

(a) Spot welding
(b) Seam welding
(c) Projection welding
(d) Resistance Butt welding
(e) Flash Butt welding
(f) Percussion welding.

Key advantages of the resistance welding process include:

- Very short process time.
- No consumables such as brazing materials, solder, or welding rods.
- Operator safety because of low voltage.

- Clean and environmentally friendly.
- A reliable electro-mechanical joint is formed.

2.1.1. Features of Resistance Welding

(i) No flux such as solder is necessary. So, welded parts can be easily recycled.

(ii) Easy operation as only pressing buttons facilitates process automation and it does not require trained skills unlike arc welding and gas welding.

(iii) As this welding is performed efficiently in a short period of time, it is suited for a high-volume production of low-cost products.

(iv) Since welding is done in short time duration, it gives less heat-affected area on workpieces by resulting a beautiful appearance with less indentation.

(v) Electric facility is required in some cases due to use of large current. Optimum welding parameters must be figured out before actual welding since those parameters depend on material and thickness of parts to be welded. Welding condition setting must be prepared.

(vi) Visual inspection is difficult because the welded portion cannot be checked from outside.

2.1.2. Principle of Resistance Welding

The name "*resistance*" welding derives from the fact that the resistance of the workpieces and electrodes are used in combination or contrast to generate the heat at their interface. Heat is generated by the passage of electrical current through a resistance circuit. Heat is generated in localized area which is enough to heat the metal to sufficient temperature so that the parts can be joined with the application of pressure. The force applied before, during and after the current flow forces the heated parts together so that coalescence will occur. Pressure is required throughout the entire welding cycle to assure a continuous electrical circuit through the work. Pressure is applied through electrodes. The pressure is applied by mechanical, hydraulic or pneumatic systems.

In resistance welding, the parts to be joined are heated to plastic state by their resistance to the flow of electric current and mechanical pressure is applied to complete the weld. In this process, there are two copper electrodes in a circuit of low resistance as shown in Figure 2.1. When the current is passed through electrodes, the electrical resistance at the

metal joints becomes very high. So, the metals are brought to red-hot plastic condition. Now, the mechanical pressure is applied to complete the weld. The heat developed by the current is proportional to the electric resistance of the weld.

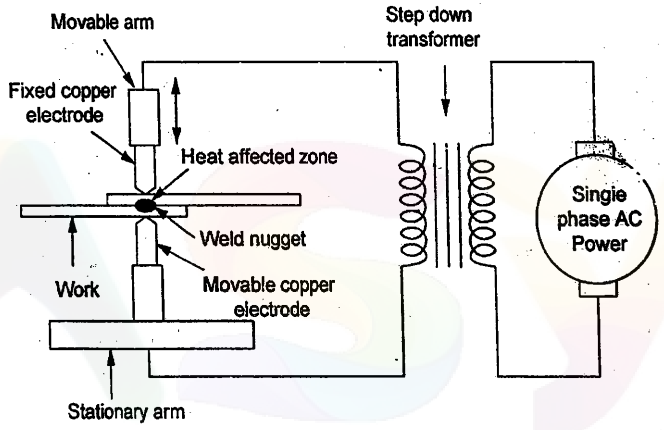

Figure 2.1 Principle of resistance welding

AC with a suitable transformer is used for the power supply. Usually, 4V to 12V is used dependent on the composition, area and thickness of the metal to be welded. The power supply ranges from 6 to 18kW per cm^3 area used.

Resistance welding processes differ from other welding processes in the aspect that no fluxes are used and filler metal rarely used. All resistance welding operations are automatic. Therefore, all process variables are preset and maintained constant. Resistance welding equipment utilizes programmers for controlling current, time cycles, pressure and movement. Welding programs for resistance welding can become quite complex. In view of this, quality welds do not depend on welding operator skill but more on the proper set up and adjustment of the equipment and adherence to weld schedules. Three major factors involved in weld quality are as follows:

- The amount of current that passes through the work
- The pressure that the electrodes transfer to the work
- The time the current flows through the work.

The important characteristics of the resistance welding process is the transfer of heat to two parts being welded for obtaining a proper fusion even if the plates are dissimilar from the stand point of material or thickness.

If the proper heat balance is existed only, the proper fusion can be obtained by providing an electrode with a smaller contact area at the thinner sheet and a thicker electrode at the thicker sheet together with very high current densities for short times. If two dissimilar metals with different electrical conductivities or thermal conductivities are to be joined,

1. Large contact area electrode should be used for the one which has higher electrical conductivity, and
2. Small contact area electrode should be used for the one which has higher thermal conductivity.

2.1.3. Parameters Influencing in Resistance Welding

The principle of resistance welding is the *Joule heating law* where the heat (Q) is generated depending on three basic factors. Therefore, the heat generated in the weld may be expressed by the equation

$$Q = K I^2 R T$$

where $Q \Rightarrow$ Heat

$K \Rightarrow$ Thermal constant

$I \Rightarrow$ Current in amps

$R \Rightarrow$ Resistance of the workpiece assembly

$T \Rightarrow$ Time of current flow.

The weld current (I) and duration of current (T) are controlled by the resistance welding power supply. The resistance of the workpieces (R) is a function of the weld force and the materials used. The thermal constant "K" can be affected by part geometry, fixturing and weld force.

In an actual welding process, numerous parameters influence the results of a resistance welding process. The following are the eight most influential parameters.

1) *Welding current:*

The welding current is the important parameter in resistance welding which determines the heat generation by a power of square as shown in the above equation. The size of the weld nugget increases rapidly with increasing welding current. At the same time, too high current will result expulsions and electrode deteriorations. So, it is a tedious job to the welding engineers to find the optimized welding current and time for each individual welding application.

2) *Welding time:*

The heat generation is directly proportional to the welding time. Due to the heat transfer from the weld zone to base metals, electrodes and free surfaces to the surroundings, a minimum welding current with minimum welding time is required to make a weld. If the welding current is too low, simply increasing the welding time alone will not produce a weld. When the welding current is sufficiently high, the size of the weld nugget increases with increasing welding time until it reaches a size similar to the electrode tip contact area. If the welding time is prolonged, expulsion will occur or in some cases, the electrode may stick to the workpiece.

3) *Welding force:*

The welding force influences the resistance welding process by its effect on the contact resistance at interfaces and on the contact area due to deformation of materials. The workpieces must be compressed with a certain force at the weld zone to enable the passage of the current. If the welding force is too low, expulsion may occur immediately after starting the welding current due to fact that the contact resistance is too high thereby resulting a rapid heat generation. If the welding force is high, the contact area will be large which results a low current density and low contact resistance which will reduce heat generation and the size of weld nugget.

4) *Contact resistance:*

The contact resistance at the weld interface is the main influential parameter related to materials. It has highly dynamic interaction with the process parameters. All metals have rough surfaces in micro scale. When the welding force increases, the contact pressure increases thereby the real contact area at the interface increases due to deformation of the rough surface asperities. Therefore, the contact resistance at the interface decreases which reduces the heat generation and the size of weld nugget. On the metal surfaces, there are also oxides, water vapour, oil, dirt and other contaminants. When the temperature increases, some of the surface contaminants will be burned off in the first couple of cycles and the metals will also be softened at high temperatures. Thus, the contact resistance generally decreases with increasing temperature.

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5) Materials properties:

Almost all material properties change with temperature. The resistivity of material influences the heat generation. The thermal conductivity and the heat capacity influence the heat transfer. In metals such as silver and copper with low resistivity and high thermal conductivity, less heat is generated even with high welding current and also quickly transferred away. They are rather difficult to weld with resistance welding. On the other hand, they can be good materials for electrodes. When dissimilar metals are welded, more heat will be generated in the metal with higher resistivity. Hardness of material also influences the contact resistance. Harder metals will result the higher contact resistance at the same welding force due to the rough surface asperities being more difficult to deform by resulting a smaller real contact area. Electrode materials also influence the heat balance in resistance welding, especially for joining light and non-ferrous metals.

6) Surface coatings:

Most surface coatings are applied for protection of corrosion or as a substrate for further surface treatment. These surface coatings also complicate the welding process. Special process parameter adjustments have to be made according to individual types of the surface coatings. Some surface coatings are provided to facilitate the welding of difficult material combinations. These surface coatings are selected to bring the heat balance to the weld interface. Most of the surface coatings will be squeezed out during welding. Some will remain at the weld interface as a braze metal.

7) Geometry and dimensions:

The geometry and dimensions of the electrodes and workpieces are also important since they influence the current density distribution and also the results of resistance welding. The geometry of electrodes controls the current density and the resulting size of the weld nugget. The diameter of the electrode contact area is a consideration. If the area is too small, it will produce undersized welds with insufficient strength. If the diameter of the electrode is too large, it will cause inconsistent and unstable weld growth characteristics. Different thicknesses of metal sheets need different welding current and other process parameter settings. The design of the local projection geometry of the workpieces is critical in welding which should be considered together with the material properties especially when joining dissimilar metals. Additionally, the embossment or projection should be placed on the material with the lower resistivity in order to get a better heat balance at the weld interface.

8) Welding machine characteristics:

The electrical and mechanical characteristics of the welding machine have a significant influence on resistance welding processes. The electrical characteristics include the dynamic reaction time of welding current and the magnetic / inductive losses due to the size of the welding window and the amount of magnetic materials in the throat. The up-slope time of a welding machine can be very critical in micro resistance welding as the total welding time is often extremely short. The mechanical characteristics include the speed and acceleration of the electrode follow-up as well as the stiffness of the loading frame/arms. If the follow-up of the electrode is too slow, expulsion may easily occur in projection welding.

2.1.4. Weldability in Resistance Welding

Weldability is controlled by the following three factors:

- Resistivity
- Thermal conductivity
- Melting temperature.

Metals with a high resistance to current flow and with a low thermal conductivity and a relatively low melting temperature would be easily weldable. All ferrous metals fall into this category. Metals that have a lower resistivity but a higher thermal conductivity will be slightly more difficult to weld. It includes light metals, aluminum and magnesium. The precious metals comprise the third group. They are difficult to weld because of very high thermal conductivity. The fourth group is the refractory metals which have extremely high melting points and they are more difficult to weld.

These three properties can be combined into a formula which will provide an indication of the ease of welding a metal. It is given by the relation.

$$W = \frac{R}{F \times K_t} \times 100$$

where W = Weldability,

R = Resistivity,

F = Melting temperature of the metal in °C, and

K_t = Relative thermal conductivity with copper equal to 1.00.

If weldability (W) is below 0.25, it is a poor rating. If W is between 0.25 and 0.75, weldability becomes fair. Between 0.75 and 2.0, weldability is good. Above 2.0 weldability is

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excellent. In this equation, mild steel would have a weldability rating of over 10. Aluminum has a weldability factor ranging from 1 to 2 depending on the alloy and they are considered having a good weldability rating. Copper and certain brasses have a low weldability factor and they are known to be very difficult to weld.

2.1.5. Functions of Electrode in Resistance Welding

(i) Electrodes keep the parts aligned and in place.

(ii) They are used to apply the required pressure to develop the correct surface resistance at the interface for containing the molten metal to avoid weld expulsion and to forge the nugget near the end of the cycle.

(iii) They convey the electric welding current to the electrodes.

(iv) They also dissipate excess heat to avoid the surface melting.

2.1.6. Advantages, Limitations and Applications of Resistance Welding

Advantages:

1. Less skill is required to operate the resistance welding machine.
2. This type of welding is well suited for mass production as it gives a high production rate.
3. There is no need of using consumables such as brazing materials, solder or welding rods in this process except for the electrical power and a relatively smaller electrode wear.
4. Heating the workpiece is confined to a very small part which results less distortion.
5. It is possible to weld dissimilar metals as well as metal plates of different thickness.
6. It has a short process time.
7. It offers more safety to operator because of low voltage.
8. It produces clean and environmentally friendly weld.
9. A reliable electro-mechanical joint is formed.
10. The heat is localized, action is rapid and no filler metal is required.
11. The operation can be easily mechanized and automated due to the need of less skill.
12. Both reliability and reproducibility can be obtained with high degree.
13. The welding process is more economical.

Limitations:

1. The resistance welding machine is highly complex with various elements such as a heavy transformer, electrodes and heavy conductors for carrying the high currents, electrode force applying mechanism such as a pneumatic cylinder and its supply, heavy machine structure to support the large forces and an expensive timing arrangement.
2. Certain resistance welding processes are limited only to lap joints.
3. Spot welds have low tensile and fatigue strength.
4. Equipment is not portable as it is heavy.
5. The cost of equipment is high.

Applications:

1. Resistance welding is used in mass production for welding sheet metal, wire and tubes.
2. It is used in welding bars, boxes, cans, rods, pipes and frames metals of medium and high resistance materials such as steel, stainless steel, monei metal and silicon bronze which are easy to weld.
3. It is used in welding aircraft and automobile parts.
4. It is used for making cutting tools.
5. It is used for making fuel tanks of cars, tractors etc.
6. It is used for making wire fabrics, grids, grills, mesh weld, containers etc.

2.2. SPOT WELDING

It is one type of electrical resistance welding processes. Spot welding is used for making lap joints. By using this method, the metal sheets ranging from 0.025 *mm* to 1.25 *mm* thickness can be easily welded. The metal pieces are assembled and placed between two copper electrodes and then current is passed. The parts are heated at their area of contact by electrical resistance as shown in Figure 2.2. Then the electrodes are pressed against the metal pieces by mechanical or hydraulic pressure as shown in Figure 2.3.

The electrodes must possess high electrical and thermal conductivity and they retain the strength at high temperature. So, they are made of pure copper for a limited amount of service and alloys of copper or tungsten or molybdenum alloys for extended service life. The electrode pressure can be in the range of up to 2 *kN*. Electrodes are cooled by water during the operation to prevent overheating.

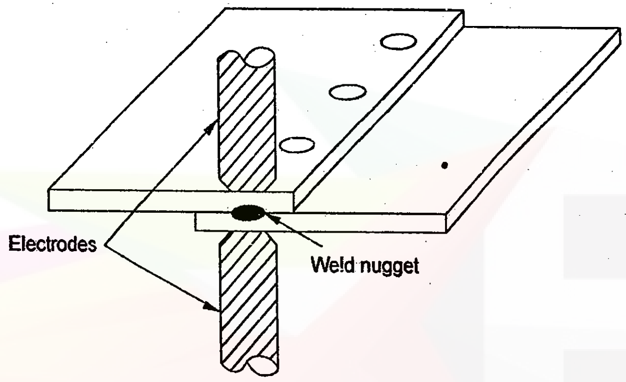

Figure 2.2 Spot welding

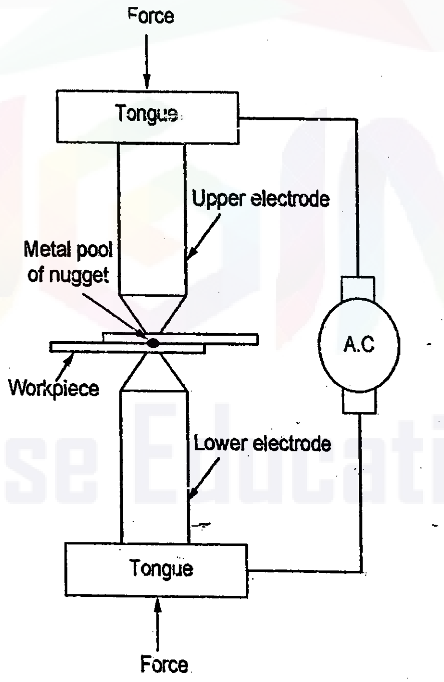

Figure 2.3 Principle of resistance spot welding

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Spot welding can be done on metal strips up to 12 *mm* thick. All combination of ductile metals and alloys can be spot-welded. It is used for fabricating all types of sheet metal structures where the mechanical strength rather than water or air tightness is required.

2.2.1. Types of Spot Welders

There are three types of spot welding machines used in resistance welding such as

(i) Rocker arm spot welder

(ii) Press type spot welder

(iii) Portable type spot welder.

(i) Rocker arm spot welder:

In this type, the bottom electrode is kept as stationary and the top electrode is kept as movable one. The movement is transferred to the top electrode through an arm which is hinged about a pivot point. Usually, the rocker arm is actuated by foot pedal or air or hydraulic cylinder or electric motor. These types of welders are available with throat depth ranging from 12 *inch* to 48 *inch* and transformer capacity is ranging from 10 *kVA* to 20 *kVA*. The schematic of an air-operated rocker arm spot welding machine is shown in Figure 2.4.

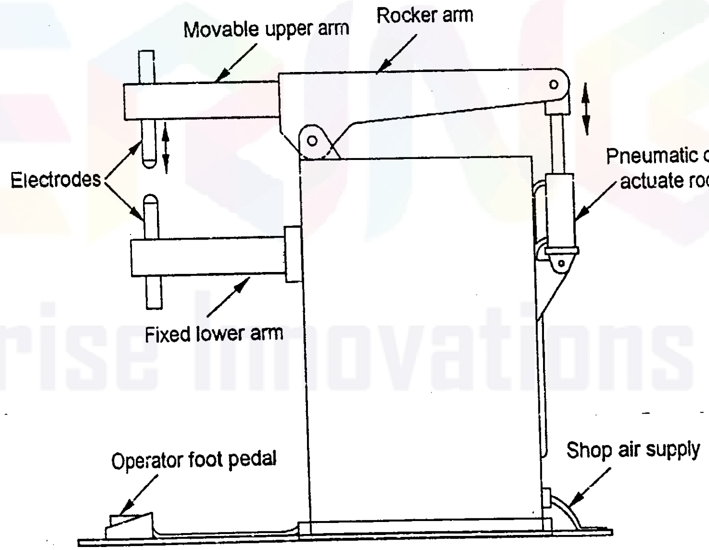

Figure 2.4 Air-operated rocker arm spot welding machine

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(ii) Press type spot welders:

In this type of spot welding machine, the movement of top electrode is controlled directly by using pneumatic or hydraulic cylinders as shown in Figure 2.5. Height of the lower electrode is adjustable by using jack screw. It has strong cast steel machine frame body which facilitates mounting of hydraulic cylinders, movable table and screw jack. These welders are mostly preferred for heavy duty applications. For example, heavy sections of massive structures are welded by this type of welder.

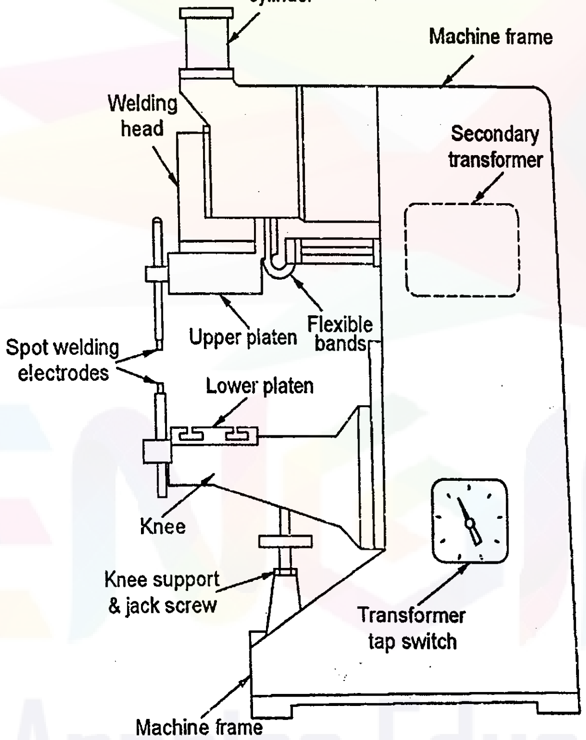

Figure 2.5 Press type spot welding machine

(iii) Portable spot welders:

Portable spot welders are mostly preferred for the parts to be welded which have large movement. They have spring loaded upper handle to apply required pressure, transformers, timers, electrode holders (jaws), electrodes and controls as shown in Figure 2.6.

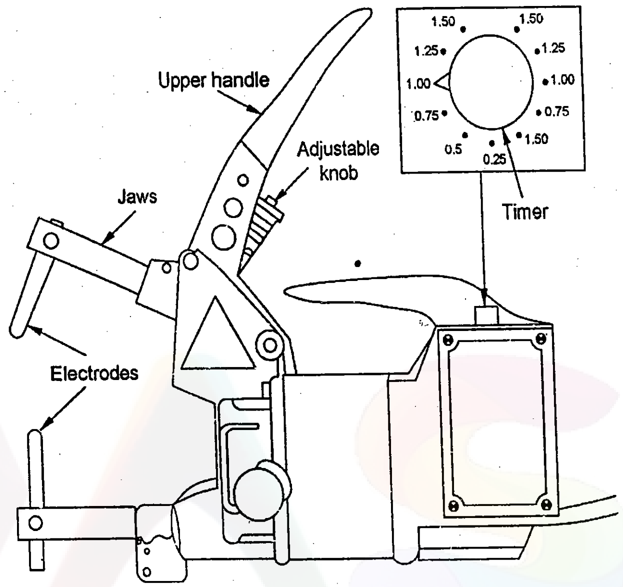

Figure 2.6 Portable spot welding machine

2.2.2. Sequence of a Resistance Spot Welding Cycles

A sequence of spot resistance welding follows four steps to control the spot welding. The steps are given below.

(i) Squeezing

(ii) Welding

(iii) Holding

(iv) Off or releasing.

Figure 2.7 illustrates the sequence of operation of a resistance spot welding cycles.

(i) Squeezing:

First, the foot switch is closed and the pressure is applied. The welding process time interval between initial application of the electrode force on the work and the first application of weld current is called *squeezing time*. The squeezing time helps to prevent the electrodes to build up right pressure on the workpiece.

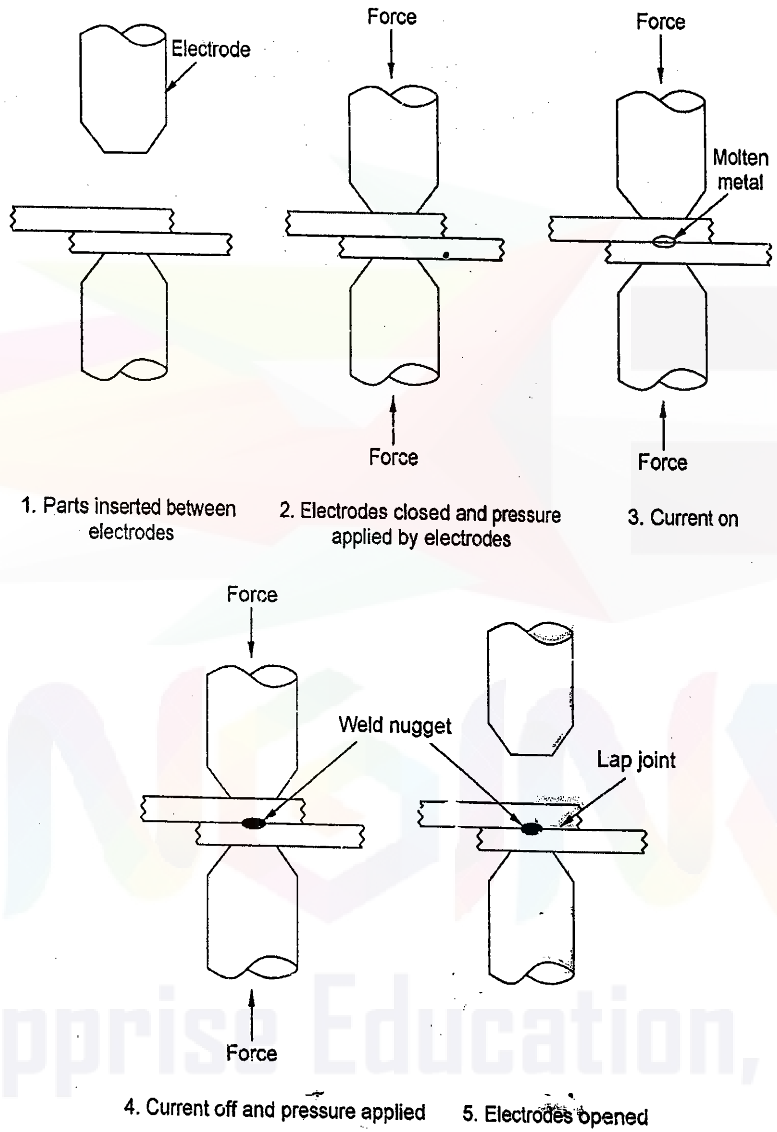

Figure 2.7 Spot welding sequence

(ii) Welding:

The current flows during welding. The time during which welding current is applied to the work in making a weld is called *weld time*.

(iii) Holding the forge:

The electrodes continue pressure on the parts to be welded but the welding current stops. The time during which electrode force is maintained on the work after the last cycle of welding current ceases is called *hold time*. It is necessary to allow the weld nugget to solidify before releasing the welded parts.

(iv) Off and releasing:

In this stage, the electrode pressure reduced gradually to separate the part and electrodes. It is the time during which the electrodes are off the work in a repeat cycle. The term is only applicable where the weld sequence is repetitive. *Off time* is the time necessary to move the work between weld sequences.

Figure 2.8 describes the characteristics of current and pressure in spot welding sequence.

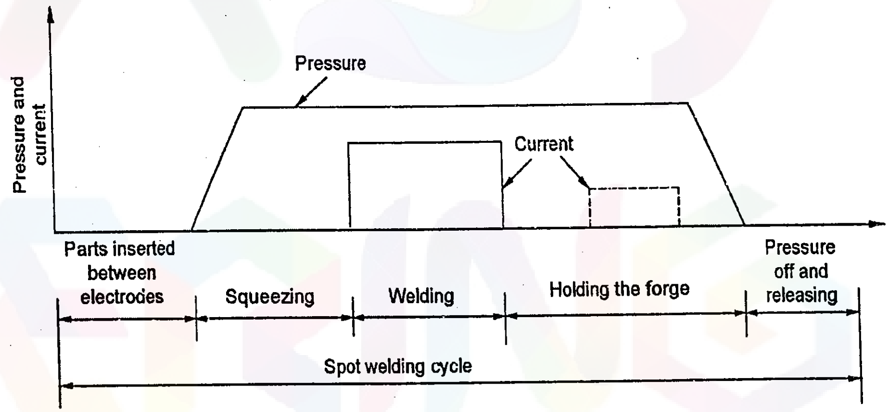

Figure 2.8 Characteristics of current and pressure in spot welding sequence

2.2.3. Electrodes for Spot Welding

Electrodes used in resistance welding must carry high current and pressure. So, they are essentially having the following properties.

(i) It should have high electrical conductivity.

(ii) It should have high thermal conductivity.

(iii) It should have high resistance to deformation under large pressure.

(iv) It should retain physical properties at elevated temperatures.

(v) It should not pick up metal from the surface of the workpiece.

2.2.4. Shapes of Electrodes

Various shapes of electrodes used for spot welding are shown in Figure 2.9. The selection of electrode shape is based on the thickness and portion of the parts to be welded.

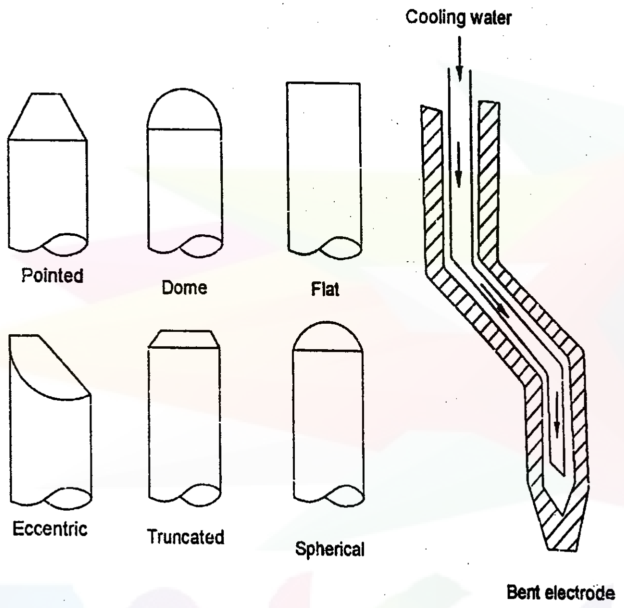

Figure 2.9 Electrode shapes for spot welding

2.2.5. Electrode Force

Electrode force is most commonly provided by pneumatic or hydraulic systems. This force is the result of pressure applied to the piston of a cylinder connected directly to the welding head.

The actual amount of electrode force depends on the effective line pressure, weight of the head and the piston diameter. Most welders have electrode force charts on the side of the machine, tabulating air pressure vs. electrode force. If there is no chart available for the machine, the following formula is used to calculate the approximate total weld force.

Electrode force, $F = \pi D^2 P / 4$

where

D is the piston diameter

P is the line pressure.

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2.2.6. Cooling of Electrode

Electrodes used in resistance welding should be cooled properly in order to avoid loosing hardness and deterioration. Normally, it is done by circulating water through a central tube arranged inside the electrode. The coolant is normally water. In the cooling tube, the cooling water is transported to the electrode base. Figure 2.10 shows the cooling water circulation in the electrodes.

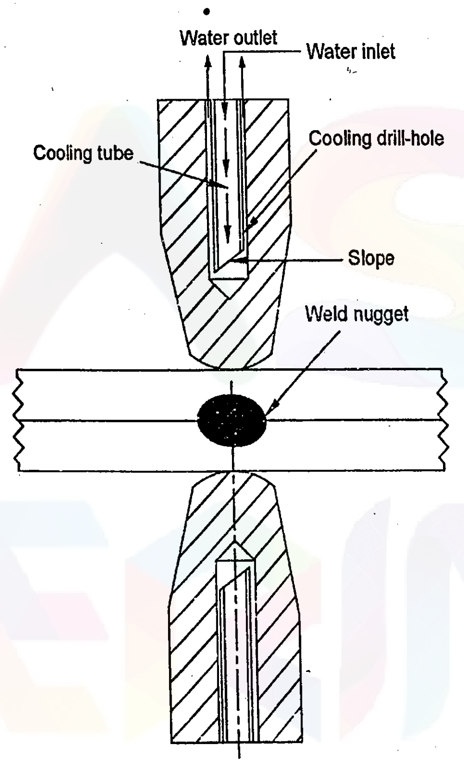

Figure 2.10 Cooling of electrodes

2.2.7. Advantages, Limitations and Applications of Spot Welding

Advantages:

1. Spot welding is quick and easy.
2. There is no need to use any fluxes or filler metal to create a joint by spot welding and there is no dangerous open flame.
3. Spot welding can be performed without any special skill.

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4. Automated machines can spot weld in factories to speed up production.
5. The rate of production is high.
6. Spot welding can be used to join many different metals and it can join different types to each other.
7. Sheets as thin as 1/4 inch can be spot welded and multiple sheets may be joined together at the same time.
8. The procedure involves less amount maintenance cost.
9. Ability of the worker does not influence the quality of spot welds obtained by this procedure.
10. The process is usually free from burn and splash.
11. Spot welding is more economical.
12. No edge preparation is required.
13. Small heat affected zone is produced.
14. It eliminates warping and distortion of parts.

Limitations:

1. It can create only localized joins which may not be particularly strong.
2. The electrodes have to be able to reach both sides of the pieces of metal that are being joined together.
3. Warping and a loss of fatigue strength can occur around the point where the metal has been spot welded.
4. It is suitable for thin sheets only.
5. Equipment used in spot welding is costly.

Applications:

1. It is used in joining killed carbon steel, low alloy steel, high alloy steel, titanium, etc.
2. It is frequently used in the creation of auto body components with a robot arm moving the spot welding device about the stationary auto frame. Typical car body has about 10,000 spot welds.
3. It is widely used in mass production of automobiles, appliances, metal furniture and other products made of sheet metal.
4. It is used in manufacture of sheet metal goods.

5. It is used in assembling sheet metal to steel structures.
6. It is used in making cookware and muffler.
7. Other applications include appliances and metal furniture i.e. virtually anything involving the joining of sheet metal.

2.3. SEAM WELDING OR RESISTANCE SEAM WELDING (RSW)

Seam welding is a variation of resistance spot welding. In spot welding, if both bottom and top electrodes are replaced by rotating wheels it is called *seam welding*. In resistance seam welding, the welding electrodes are motor driven wheels as opposed to stationary rods. The result is a 'rolling' resistance weld or non-hermetic seam weld. The spot welding is not continuous one whereas seam welding is used to produce continuous joint between two overlapping pieces of sheet metal.

In *seam welding*, overlapping sheets are gripped between two wheels or roller disc electrodes and current is passed to obtain either the continuous seam i.e. overlapping weld nuggets or intermittent seam i.e. weld nuggets are equally spaced. Welding current may be continuous or in pulse form.

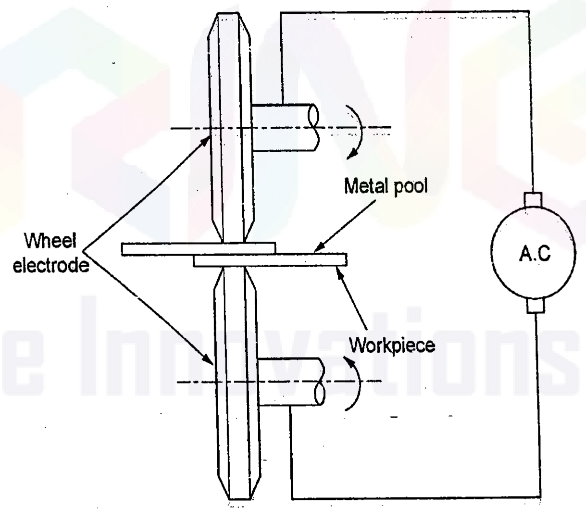


Figure 2.11 Seam welding

The electrically conducting rollers produce spot weld when the current reaches a high value. This process can be carefully controlled to produce continuous seam. The workpieces are placed between two rotating wheel electrodes as shown in Figure 2.11. When electric current is passed through electrodes high heat is produced on the workpieces between wheels. At the same time, the pressure is applied to complete the weld. The workpiece is continuously moved in between the wheels. Thus, the leak proof continuous seam is achieved by supplying coolant to the electrodes. Finally, it speeds up the welding process.

Resistance seam welding can be inappropriate where sharp corners in the seam are required. To prevent warping of parts as the seam is created, good workpiece fixturing is necessary with this method. Surfaces must be kept very clean.

2.3.1. Types of Seam Welding

The following four types of resistance seam welding are possible.

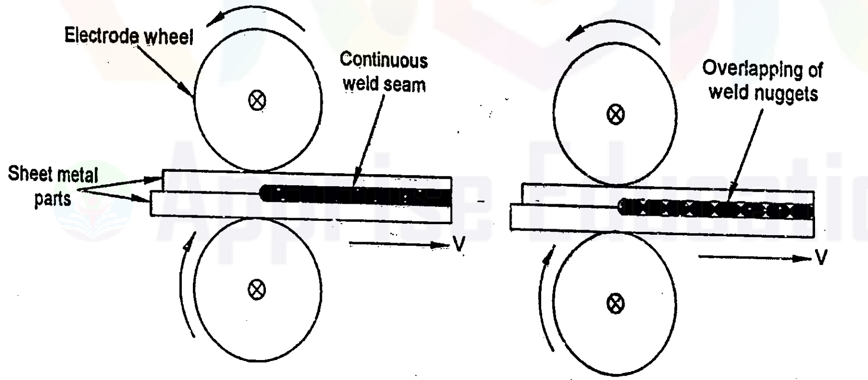
(a) Conventional resistance seam-welding

(b) Overlapping spot seam weld

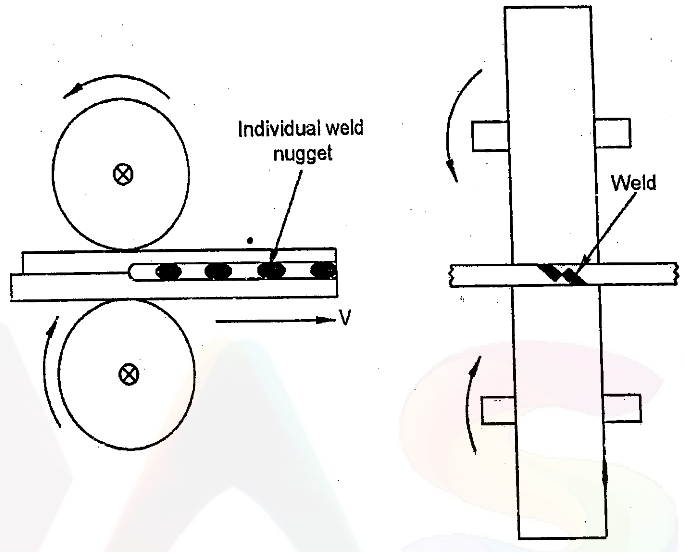
(c) Roll spot welds

(d) Mash-seam welding.

Overlapping of weld nuggets may vary from 10 to 50 %. When it is approaching around 50 %, then it is termed as *continuous weld* as shown in Figure 2.12 (a). Overlap welds are used for air or water tightness. Roll-Spot mode makes a series of welds in a close succession as shown in Figure 2.12 (c) whereas the AC will continuously deliver energy to the weld spot. Roll-Spot upgrade is ideal for projects needing multiple welds in close proximity but it does not need a true hermetic seal. In mash seam resistance welding, only edges of the workpieces which are prepared in wedge shape are overlapped as shown in Figure 2.12 (d).



(a) Conventional resistance seam welding *(b) Overlapping spot in a seam weld*



(c) Roll spot welding *(d) Mash-seam welding*

Figure 2.12 Types of resistance seam welding

2.3.2. Electrode Shapes of Seam Welding

Figure 2.13 illustrates different types of electrode roll shapes used for seam welding. The selection of particular type of electrode depends on the material to be welded, joint requirements, force exerted during welding etc.

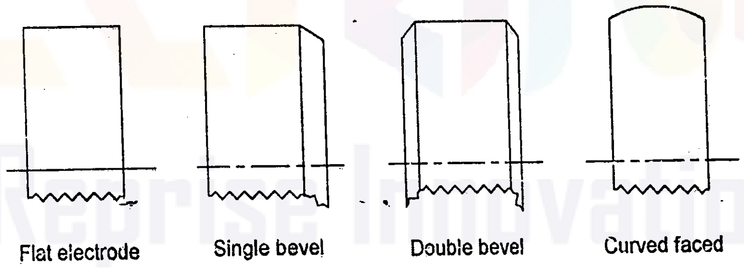


Figure 2.13 Electrode shapes of seam welding

2.3.3. Advantages, Limitations and Applications of Spot Welding

Advantages:

1. Gas tight as well as liquid tight joints can be made.

2. The overlap is less than spot or projection welding.
3. The production of single seam weld and parallel seams can be got simultaneously.
4. This method is efficient energy use.
5. Filler materials are not required and hence, there are no associated gases and fumes.
6. It produces clean welds.

Limitations:

1. The welding process is restricted to a straight line or uniformly curved line.
2. The metals sheets having thickness more than 3*mm* can cause problems while welding.
3. The design of the electrodes may be needed to change to weld metal sheets having obstructions.
4. It requires complex control system to regulate the travel speed of electrodes as well as the sequence of current to provide satisfactorily overlapping welds. The welding speed, spots per inch and timing schedule are all dependent on each other.
5. Relatively higher current is thus required for seam welding than for spot welding.
6. The workpieces to be welded should overlap sufficiently to prevent metal flowing out from the edges of the pieces during welding under pressure.

Applications:

1. It is used to make tin cans, leak proof tanks, automobile mufflers, gasoline tanks, drums, radiators, household utensils, transformers, refrigerators, evaporators and condensers, automobile bodies etc. It is also used for welding thin sheets.
2. Circumference weld is possible in rectangular or square or even in circular shapes.
3. Most of the metals can be welded.
4. Butt welding can be done for producing seam welded pipes and tubes.

2.4. PROJECTION WELDING

Projection welding is an electric resistance welding process that uses small projections, embossments or intersections on one or both components of the weld to localize the heat and pressure.

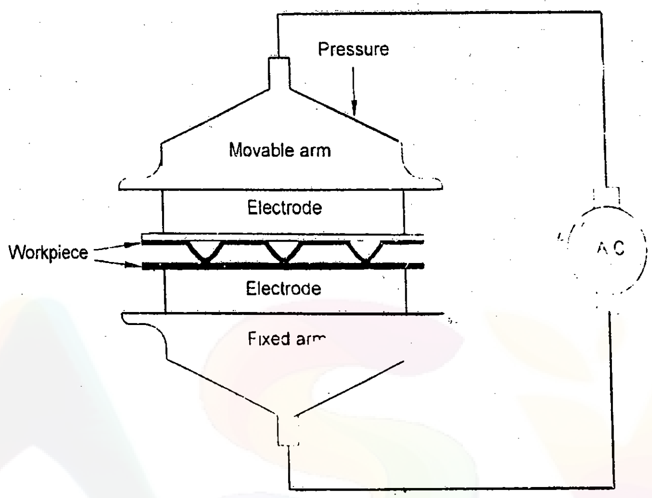


Figure 2.14 Projection welding

Projection welding is one kind of resistance welding which is developed from spot welding. In this type of welding, a series of spots are welded at a time. The metal pieces to be welded are placed between two metal arms which act as electrodes. One of the workpieces has projections on its surface. The workpieces are clamped between arms. When AC power is supplied, the welding current passes through these projections.

The heat is produced at the contact point of the base metal because of high electrical resistance. Now, the workpieces are pressed together by bringing down the upper electrode. The projections are made into flat under pressure and the two pieces are joined together by a strong weld at all points of contact. The surface at the projection must be clean before welding. There should not be any scale, dirt and grease on the surface. An un-cleaned surface will reduce the resistance to the current flow. So, the joint will be weaker.

Projection welding is used for joining thin sheet metals of thickness up to 3*mm*. It is used in automobile industries. A wire or rod may be easily welded on its length of a flat surface. This welding process is used in mass production.

2.4.1. Difference Between Spot Welding and Projection Welding

S.No.	*Parameters*	*Spot welding*	*Projection welding*
1.	Electrode diameter	Up to 20 *mm*	More than 20 *mm*

2.	Electrode tip face	Convex	Flat
3.	Electrode life	Less	Longer
4.	Nugget origination	Electrodes	Projections
5.	Number of welding nugget	One	Several
6.	Follow-up distance	Small	Big
7.	Problems of distributing current and force	No	Yes

2.4.2. Advantages, Limitations and Applications of Projection Welding

Advantages:

1. More than one weld can be made simultaneously.
2. It can weld metals of thickness which is not suitable for spot welding.
3. Projection welding electrodes have a longer life when compared to spot welding electrodes because the projection welding electrodes have to withstand less wear and less heating.
4. Resistance projection welding is not limited to sheet to sheet joints.
5. Projection welding can be done at specific points which are desired to be welded.
6. In difficult welding work, projection welding gives a better heat balance.
7. Projection welding saves electricity because it needs less current to produce heat. So, it reduces the shrinkage and distortion defects.
8. Heat treated parts can be easily welded without affecting the heat treatment.
9. Parts with different thermal conductivities and mass can also be welded.
10. Welds can be varied without producing flash or upset at the joint.
11. Welding current and pressure required is less.
12. It is more suitable for automation.
13. Filler metals are not used. Therefore, clean weld joints are produced.

Limitations:

1. All types of metals cannot be welded using projection method. Metal thickness and composition are the challengeable task.
2. Projections cannot be made in thin workpieces.

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3. All the metals are not strong enough to support the projections. Some brasses and coppers cannot be welded satisfactorily using projection welding.
4. There is an extra operation required called forming of projection.
5. Projections need to have same heights for an appropriate welding.
6. The area which is less than 650 mm^2 cannot be welded by projection welding process.
7. Projections cannot be made in thin workpieces.
8. Thin workpieces cannot withstand the electrode pressure.
9. Equipment is costly.

Applications:

1. It is used to make press-tools.
2. This process is more suitable for cross welding of a number of wires or rods which is commonly used to make wire fencing, shopping carts and stove grills.
3. Projection welding is mainly used in automobile sector.
4. Fasteners can be welded to surfaces when the fastener has machined or formed projections on its head.
5. It is used in refrigeration works such as condensers, gratings, racks etc.

2.5. RESISTANCE BUTT WELDING

It is one kind of resistance welding. There are two types of resistance butt-welding, namely,

1. Upset butt welding
2. Flash butt welding.

2.5.1. Upset Butt Welding

For making upset welding, edges of the workpiece should be cleaned perfectly and flatten. The parts to be welded are clamped in copper jaws as shown in Figure 2.15. The jaws act as electrodes. Both workpieces edges are prepared and butted together. There may be some gap between parts but it should be such that no arcing takes place. Then the jaws are brought together in a solid contact when the current flows through the point of contact of jaws to form a locality of high electric resistance. At this point, the applied pressure upsets or forges the parts together.

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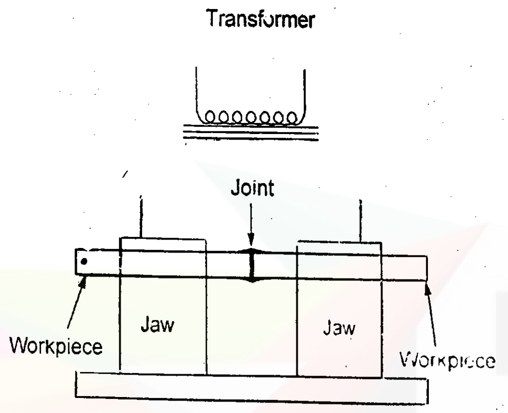

Figure 2.15 Upset butt-welding

Advantages:

1. Upset butt-welding is more suitable for welding many alloys which are difficult to weld using fusion welding.
2. The metal retains base metal characteristics because the base metal does not melt during welding.
3. The welded joint is stronger because the hot working structure is maintained.
4. The introduction of composite materials and inclusion of secondary materials on the base metal are almost minimal.
5. Upset welding is mainly adapted to fabricate very large structures compared to conventional resistance welding.

Applications:

1. This process is mainly used for welding nonferrous materials of smaller cross section such as bars, rods, wires, tubes etc.
2. Upset welding is used to make closure of capsules, small vessels and containers.
3. It is applied in welding steel rails.

2.5.2. Flash Butt Welding

The welding process in which the ends of rods are heated and fused by an arc struck between them and forged to produce a weld is called *flash butt welding.*

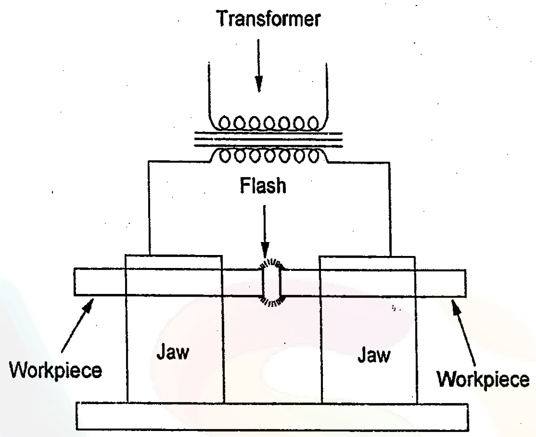

Figure 2.16 Flash butt welding

In this process, the parts to be welded are clamped in copper jaws of the welding machine. One of these jaws is stationary and the other one is made as movable. They act as electrodes. The jaws are water-cooled when they are connected to the heavy current electric power supply. The workpieces are brought together in a slight contact. When the current flows through the workpieces, an electric arc or flash is produced. The ends reach fusing temperature and power is switched off. Now, the ends are forced together by applying mechanical force to complete the weld. In this welding, a small projection is produced around the weld. That projection is finished by grinding. Welded parts are often annealed to improve the toughness of the weld. This process is used for the part having larger cross section. This process is suitable for welding steel and ferrous alloy other than cast iron.

Advantages:

1. Many dissimilar metals with different melting temperature can be flash welded.
2. Flash butt welding allows fast joining of large and complex parts.
3. Power consumption is less.
4. Clean welds can be made.

Applications:

1. Butt welding is used in automobile construction of the body, axles, wheels frames etc. Non-ferrous alloys such as lead, tin, zinc, antimony, bismuth and their alloys cannot be welded by this method.

2. It is also used in welding motor frames, transformers tanks and many types of sheet steel containers such as barrels and floats.

2.6. PERCUSSION WELDING

It is one type of resistance butt-welding process. The parts to be welded are clamped in copper jaws of the welding machine in which one clamp is fixed and other one is movable. The movable clamp is backed up against the pressure from a heavy spring. The jaws act as electrodes. Heavy electric current is connected to the workpieces.

Now, the movable clamp is released rapidly and it moves forward at high velocity. When the two parts are approximately 1.6 *mm* apart, a sudden discharge of electrical energy is released thereby causing an intense arc between two surfaces. The arc is extinguished by the percussion blow of the two parts coming together with sufficient force to complete in 0.1 second. No upset or flash occurs at the weld. This method is primarily employed to join dissimilar metals. This method is limited to small areas of about 150 to 300 mm^2.

Welding energy, $E = \frac{1}{2} CV^2$

where E = energy in watt-seconds (Joules)

C = capacitance in farads

V = voltage.

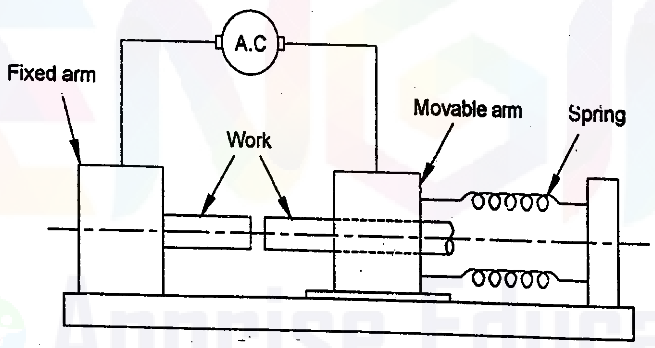

Figure 2.17 Percussion welding

Amount of energy required to make joint depends on the following factors.

(i) Cross-sectional area of joint

(ii) Properties of work metal or metals

(iii) Depth to which metal is melted on workpieces.

Advantages:

1. The time cycle involved is very short.
2. Shortness of arc limits melting and heating.
3. Heat-treated and cold worked materials can be welded without annealing.
4. No filler metal is required.
5. No cast structure is produced at interface.
6. Charging rate is low and controlled.
7. It can tolerate some contamination on faying surface.
8. Welding of dissimilar metal and copper to steel is possible.
9. These welders have a long wear life for welding jaws due to very short relatively low current welding pulse.
10. Welding of metals with high melting point such as tungsten, molybdenum etc. are possible by this method.

Limitations:

1. The welding process is limited to butt joints.
2. Total area is limited.
3. Similar metals can usually be joined more economically by other processes.
4. The process is usually confined for joining of dissimilar metals not normally considered weldable.
5. Welding is typically dirtier and less smooth than resistance welding.
6. With nib start percussive arc welding, a starting nib must be cut onto workpieces.
7. The workpieces must be free of oil or dirt.

Applications:

1. It is used for fine wire leads to filaments such as in lamps and electrical components.
2. The method is also used to weld pins, studs, bolts and so on.

2.7. STUD WELDING

It is one kind of resistance welding process. An electric arc is produced between stud and flat surface of the workpiece. The arc melts the end of the stud and the pressure is applied on the stud to fix it on the work metal surface.

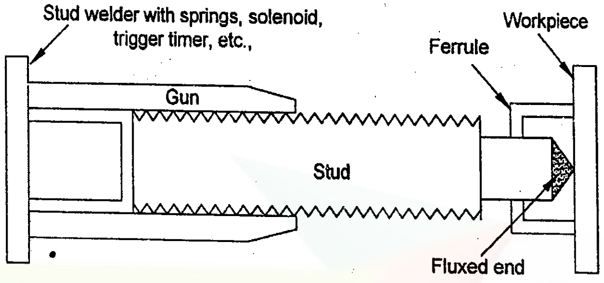

Figure 2.18 Stud welding

A special welding gun is used for stud welding which consists of spring, solenoid, trigger, timer etc. The stud is placed in the welding gun. The front end of the gun is held against the work surface. When the trigger of the gun is pressed, welding current flows between end of the stud and work surface. An arc is produced between the gap of the stud and work. It melts the end of the stud. A molten pool is formed on the work surface. Now, the melted end of the stud is pressed on the molten pool of work and it gets welded to the work. The front end of the stud has a flux coated conical surface. The flux protects the welding from atmospheric effects. The ferrule is used to guide and locate the stud to the proper position. The process is automatic and it is used for welding metal studs on bodies without drilling and tapping. The time required for welding is approximately one second. This process is used in mass production.

Advantages:

1. The welded joint is stronger than the parent material or the stud.
2. Deep weld penetration is possible.
3. High speed welding of studs on thin steel sheets is possible.
4. It limits down time.
5. It cuts labour and material cost.
6. It is user friendly and easy to operate.
7. Machine is equipped with effective safety operations for user.
8. It allows fast attachment.
9. Sound welds are readily made with good process design and control.
10. Practically, no edge preparation is necessary.
11. The process is suitable for both indoor and outdoor works.

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12. It has very low distortion by extremely short welding time.
13. Welds produced are sound, uniform, ductile, corrosion resistant and they have good impact value.
14. The process involves less maintenance cost.
15. Skill of the operator does not influence the quality of spot welds obtained by this process.
16. The process is normally free from smoke and spatter.
17. There are no holes. Hence, there is no leaking or weakening of the sheet.

Applications:

1. Stud welding is used in fixing fluid, air lines, wiring looms, machine guards, handles, insulations and fireproofing materials.
2. Stud welding is used for applications where access cannot be made to the reverse side of an assembly such as mounting circuit boards, rails, instruments, earth points and many different components.
3. In the automotive industry, the process is used to assemble heat shields, power steering and dashboard components, instrument panels, insulation, exhaust systems, lighting systems, brake lines, trim and electrical wire routing.
4. In the farm equipment industry, it is used to assemble fenders, brackets, cabs, spreaders, shrouding, thresher teeth, wiring and hose management parts. It is also used in lawn and garden equipment such as tractors, mowers and seeders.
5. In the construction equipment industry, it is used to make cover plates, non-skid devices and wiring and hose management parts.
6. In the commercial appliance industry, it is used in commercial dishwashers, bottle washers, cooking equipment and griddle plate assemblies.
7. Furniture manufacturers use it for metal household and office furniture, lawn furniture, shelving and racks.
8. Assemblers of fabricated metal products use arc stud welding in barbecue equipment, enclosures, plumbing apparatus, insulation enclosures, heating, ventilation and air-conditioning units, and water storage systems.
9. In the industrial equipment industry, arc stud welding is used to assemble inspection cover plate attachments, enclosures, flow indicators, material handling equipment and controls. It is also used for power transformer tanks and transducers.

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10. Shipbuilders use it to attach insulation, wire management devices and hatch covers.
11. Jewelry such as earrings and pins are made.
12. Cookware such as utensils, pots, pans and handles are made.

2.8. LOW-FREQUENCY ELECTRIC RESISTANCE WELDING

Low-frequency electric resistance welding is an obsolete method of welding seam in oil and gas pipelines. It was figured out in the 1970s but as of 2015 some pipelines built with this method remained in service.

Electric Resistance Welded (ERW) pipe is manufactured by cold-forming a sheet of steel into a cylindrical shape. Electric current is passed between two edges of the steel to heat the steel to a point at which the edges are forced together to form a bond without the use of welding filler material. Initially, this manufacturing process uses low frequency AC current to heat the edges.

Advantages:

1. The low frequency process produces high quality weld.
2. Process takes more time.

Limitations:

1. It is no longer used to manufacture pipe.
2. It is more prone to selective seam corrosion, hook cracks and inadequate bonding of seams.

2.9. HIGH FREQUENCY RESISTANCE WELDING

High-Frequency Resistance Welding (HFRW) describes a group of processes that use high frequency electric current to concentrate the welding heat at the needed location.

The process is similar to seam welding but it uses high frequency current. The required frequency is up to 450*kHz*. The required frequency is passed between electrodes in contact with the edges of a strip forming a tube when it passes though forming pressure rolls. Figure 2.19 shows schematic of high frequency resistance weld used for making pipes. The pressure rolls apply the required welding pressure. The required welding heat is governed by the current passing through work and speed of tube movement.

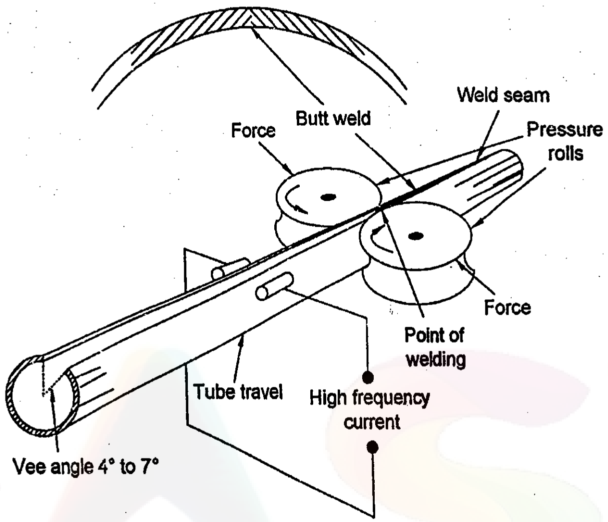

Figure 2.19 High frequency resistance welding

High-Frequency current in metal conductors tends to flow at high densities along surfaces at a shallow depth known as *skin effect*. Due to this, only a small amount of metal is heated at the welding interface. The processes produce welds at high speeds at very high energy efficiency. They are generally prepared for welding in a continuous roll forming strip mill where the flat strip is gradually shaped to a round form. In the weld area, open edges of the formed strip are brought together by pressure rolls to form a vee shape with the apex at the weld point. The preferred vee angle for roll forming is between 4° to 7°.

Advantages:

1. High-Frequency resistance welding is more efficient because the distance between point of weld and sliding contacts is shorter and there are no induction losses.
2. It is suitable for long production runs where coils of strip are butt welded which is an end to end welding process to avoid the need to stop and restart the line.
3. It needs less energy efficient than contact welding.
4. Weld quality is not sensitive to the presence of air around the weld.

Limitations:

1. The contact wear requires maintenance and replacements.
2. It cannot be used at slow speeds or as a manual process.
3. The stop and restart will cause visual objectionable discontinuities.

Applications:

1. The predominant application of this type of welding is continuous manufacturing of pipe and tubing.
2. It is more suitable for high speed welding of a large range of sizes and materials.
3. Steels, stainless steels, aluminum, copper, brass and titanium are successfully welded by High-Frequency resistance welding processes.
4. It is used in making tubing, I-beams and wheel rims.

2.10. OTHER RESISTANCE WELDING

(a) Single-sided (One-sided) resistance welding:

It is a special resistance welding process where the weld is made with only one electrode accessing from one side to the weld zone with or without a backing plate from the other side. In this case, low weld force is usually used which limits the single-sided spot welding to joining of relatively thin sheets. It may be useful for welding components with the limitation of electrode access from both sides.

(b) Resistance weld bonding:

It is a combined joining process with adhesive bonding and resistance welding. The adhesive is applied to the faying surfaces of sheets to be welded and subsequently resistance spot weld is made through sheets before curing adhesives. The joint can have good strength from the spot welding and good stiffness from the adhesive bonding.

(c) Cross wire welding:

It is a resistance welding process for joining bars or wires in cross joints by directly applying opposing forces with usually flat electrodes. The current and the heat generation are localized at the contact points of the crossed bars or wires. Cross wire welding is widely used in construction and electrical industry as well as for manufacturing of metal wire nets and shopping trolleys etc.

(d) Indirect welding:

It is a special resistance welding process where a single weld is made with one electrode directly connecting to the weld zone while the other electrode is offset at a distance but it still conducts the current along the workpiece.

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(e) Series welding:

It is a special resistance welding process where two welds are made at the same time with two electrodes offset at a distance but still conducting the current along the workpieces between two welds.

(f) Micro resistance welding:

It refers to the resistance welding processes for joining micro or miniaturized components which in principle can be any of above-mentioned process variants but in a micro scale.

2.11. TWO MARK QUESTIONS AND ANSWERS

1. *What is the principle of resistance welding?*

Resistance welding processes are pressure welding processes in which heavy current is passed for short time through the area of interface of metals to be joined with the application of pressure.

2. *Classify resistance welding.*

(a) Spot welding
(b) Seam welding
(c) Projection welding
(d) Resistance Butt welding
(e) Flash Butt welding
(f) Percussion welding.

3. *What are the features of resistance welding?*

(i) No flux such as solder is necessary. So, welded parts can be easily recycled.

(ii) Easy operation as only pressing buttons facilitates process automation and it does not require trained skills unlike arc welding and gas welding.

(iii) As this welding is performed efficiently in a short period of time, it is suited for a high-volume production of low-cost products.

(iv) Since welding is done in short time duration, it gives less heat-affected area on workpieces by resulting a beautiful appearance with less indentation.

(v) Electric facility is required in some cases due to use of large current. Optimum welding parameters must be figured out before actual welding since those

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parameters depend on material and thickness of parts to be welded. Welding condition setting must be prepared.

(vi) Visual inspection is difficult because the welded portion cannot be checked from outside.

4. *State the factors involved in deciding weld quality.*

- The amount of current that passes through the work.
- The pressure that the electrodes transfer to the work.
- The time the current flows through the work.

5. *List down the most influential parameters in resistance welding.*

1) Welding current
2) Welding time
3) Welding force
4) Contact resistance
5) Materials properties
6) Surface coatings
7) Geometry and dimensions
8) Welding machine characteristics.

6. *State the functions of electrode in resistance welding.*

(i) Electrodes keep the parts aligned and in place.

(ii) They are used to apply the required pressure to develop the correct surface resistance at the interface for containing the molten metal to avoid weld expulsion and to forge the nugget near the end of the cycle.

(iii) They convey the electric welding current to the electrodes.

(iv) They also dissipate excess heat to avoid the surface melting.

7. *Mention the advantages of resistance welding.*

1. Less skill is required to operate the resistance welding machine.
2. This type of welding is well suited for mass production as it gives a high production rate.
3. There is no need of using consumables such as brazing materials, solder or welding rods in this process except electrical power and a relatively smaller electrode wear.

4. Heating the workpiece is confined to a very small part which results less distortion.
5. It is possible to weld dissimilar metals as well as metal plates of different thickness.

8. *State the limitations of resistance welding.*

1. Certain resistance welding processes are limited only to lap joints.
2. Spot welds have low tensile and fatigue strength.
3. Equipment is not portable as it is heavy.
4. The cost of equipment is high.

9. *What are the applications of resistance welding?*

1. Resistance welding is used in mass production for welding sheet metal, wire and tubes.
2. It is used in welding bars, boxes, cans, rods pipes and frames metals of medium and high resistance materials such as steel, stainless steel, monel metal and silicon bronze which are easy to weld.
3. It is used in welding aircraft and automobile parts.
4. It is used for making cutting tools.
5. It is used for making fuel tanks of cars, tractors etc.
6. It is used for making wire fabrics, grids, grills, mesh weld, containers etc.

10. *What is the minimum distance maintained between two successive spot welds made by resistance welding? Why?*

The minimum distance of 150*mm* and maximum distance of 300 *mm* between two successive spot welds or the acceptable distance of 16 times of thickness of metal to be welded because the shunt current flowing through already formed weld spot reduces the efficiency of the welding process.

11. *What is meant by nuggets in electrical resistance welding?*

The point at which the molten metal is created between for short period of time due to maximum heat generation is called *nugget*.

12. *Classify spot welders.*

(i) Rocker arm spot welder

(ii) Press type spot welder

(iii) Portable type spot welder.

13. What is the sequence of a resistance spot welding cycles?

(i) Squeezing

(ii) Welding

(iii) Holding

(iv) Off or releasing.

14. Define squeezing time.

The welding process time interval between initial application of the electrode force on the work and the first application of weld current is called *squeezing time*.

15. What is meant by welding time?

The time during which welding current is applied to the work in making a weld is called *weld time*.

16. How can we define the term "Holding time" in spot resistance welding?

The time during which electrode force is maintained on the work after the last cycle of welding current ceases is called *hold time*.

17. State the properties of electrodes used in spot resistance welding.

1. It should have high electrical conductivity.
2. It should have high thermal conductivity.
3. It should have high resistance to deformation under large pressure.
4. It should retain physical properties at elevated temperatures.
5. It should not pick up metal from the surface of the workpiece.

18. How is electrode force calculated?

Electrode force, $F = \pi D^2 P/4$

where

D is the piston diameter

P is the line pressure.

19. Write down the advantages of spot resistance welding.

1. Spot welding is quick and easy.
2. There is no need to use any fluxes or filler metal to create a join by spot welding and there is no dangerous open flame.

3. Spot welding can be performed without any special skill.
4. Automated machines can spot weld in factories to speed up production.
5. The rate of production is high.

20. State the limitations of spot resistance welding.

1. It can create only localized joins which may not be particularly strong.
2. To achieve small cost of building, the weld manufacture cost is not very high.
3. The electrodes have to be able to reach both sides of the pieces of metal that are being joined together.
4. Warping and a loss of fatigue strength can occur around the point where the metal has been spot welded.

21. Mention the various applications of spot resistance welding.

1. It is used in joining killed carbon steel, low alloy steel, high alloy steel, titanium etc.
2. It is used in manufacture of sheet metal goods.
3. It is used in assembling sheet metal to steel structures.
4. It is used in making cookware and muffler.
5. Other applications include appliances and metal furniture i.e. virtually anything involving the joining of sheet metal.

22. What is seam welding?

In spot welding, if both bottom and top electrodes are replaced by rotating wheels it is called *seam welding*.

23. How is the seam welding used as an application of spot welding?

The metal to be welded is moved between electrodes and electric pulses create spots of molten metal that overlap to form the continuous seam.

24. Classify seam welding.

(a) Conventional resistance seam-welding

(b) Overlapping spot in a seam weld

(c) Roll spot welds

(d) Mash-seam welding.

25. Draw the shapes of electrodes used in seam resistance welding.

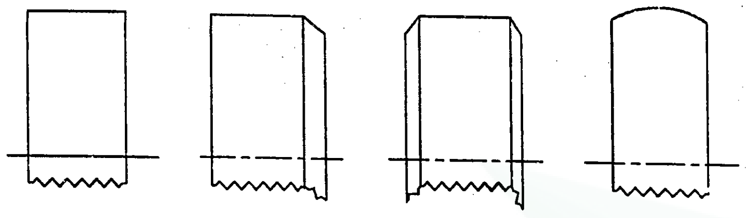

Figure 2.20 Electrode shapes of seam welding

26. Mention any two advantages and limitations of seam resistance welding.

Advantages:

1. The production of single seam weld and parallel seams can be got simultaneously.
2. Filler materials are not required and hence, there are no associated gases and fumes.

Limitations:

1. The welding process is restricted to a straight line or uniformly curved line.
2. The metals sheets having thickness more than 3*mm* can cause problems while welding.

27. State any two applications of seam welding.

1. It is used to make tin cans, leak proof tanks, automobile mufflers, gasoline tanks, drums, radiators, household utensils, transformers, refrigerators, evaporators and condensers, automobile bodies etc. It is also used for welding thin sheets.
2. Circumference weld is possible in rectangular or square or even in circular shapes.

28. What do you understand by projection welding?

Projection welding is an electric resistance welding process that uses small projections, embossments or intersections on one or both components of the weld to localize the heat and pressure.

29. What is the primary work taken before welding the parts in projection welding method?

In one of the plate to be welded, projections are formed (ups and downs) which is held on a movable arm and the flat plate is held in a fixed arm. The movable arm is pressed towards the fixed arm to complete the weld.

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30. Differentiate between spot welding and projection welding.

S.No.	*Parameters*	*Spot welding*	*Projection welding*
1.	Electrode diameter	Up to 20 *mm*	More than 20 *mm*
2.	Electrode tip face	Convex	Flat
3.	Electrode life	Less	Longer
4.	Nugget origination	Electrodes	Projections
5.	Number of welding nugget	One	Several
6.	Follow-up distance	Small	Big
7.	Problems of distributing current and force	No	Yes

31. Mention any two advantages and applications of projection welding.

Advantages:

1. It can weld metals of thickness which is not suitable for spot welding.
2. Projection welding electrodes have a longer life when compared to spot welding electrodes because the projection welding electrodes have to withstand less wear and less heating.

Applications:

1. It is used to make press-tools.
2. This process is more suitable for cross welding of a number of wires or rods which is commonly used to make wire fencing, shopping carts and stove grills.

32. What are the types of resistance butt welding?

(a) Upset butt welding

(b) Flash butt welding.

33. Write down the advantages and applications of resistance butt welding.

Advantages:

1. Upset butt-welding is more suitable for welding many alloys which are difficult to weld using fusion welding.
2. The metal retains base metal characteristics because the base metal does not melt during welding.

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Applications:

1. This process is mainly used for welding nonferrous materials of smaller cross section such as bars, rods, wires, tubes etc.
2. Upset welding is used to make closure of capsules, small vessels and containers.

34. What is meant by flash butt welding?

The welding process in which the ends of rods are heated and fused by an arc struck between them and forged to produce a weld is called *flash butt welding*.

35. Differentiate between upset butt welding and flash butt welding.

Upset butt welding	*Flash butt welding*
The weld is completed by contacting two ends of the workpiece which are rotated with very high rpm and by contacting suddenly.	The weld is completed by contacting two ends of the workpiece which are rotated with very high *rpm* and when the contact is just made flash will occur. This flash is used to melt the portion to be welded

36. State the advantages and applications of flash butt welding.

Advantages:

1. Many dissimilar metals with different melting temperature can be flash welded.
2. Flash butt welding allows fast joining of large and complex parts.
3. Power consumption is less.
4. Clean welds can be made.

Applications:

1. Butt welding is used in automobile construction of the body, axles, wheels frames etc. Non-ferrous alloys such as lead, tin, zinc, antimony, bismuth and their alloys cannot be welded by this method.
2. It is also used in welding motor frames, transformers tanks and many types of sheet steel containers such as barrels and floats.

37. What are the factors affecting welding energy in percussion welding?

(i) Cross-sectional area of joint

(ii) Properties of work metal or metals

(iii) Depth to which metal is melted on workpieces.

38. Write down the applications of percussion welding.

1. It is used for fine wire leads to filaments such as in lamps and electrical components.
2. The method is also used to weld pins, studs, bolts and so on.

39. What do you infer about stud welding?

It is one kind of resistance welding process. An electric arc is produced between stud and flat surface of the workpiece. The arc melts the end of the stud and the pressure is applied on the stud to fix it on the work metal surface.

40. Mention any two advantages and applications of stud welding?

Advantages:

1. Deep weld penetration is possible.
2. High speed welding of studs on thin steel sheets is possible.
3. It limits down time.

Applications:

1. In the automotive industry, the process is used to assemble heat shields, power steering and dashboard components, instrument panels, insulation, exhaust systems, lighting systems, brake lines, trim and electrical wire routing.
2. In the farm equipment industry, it is used to assemble fenders, brackets, cabs, spreaders, shrouding, thresher teeth, wiring and hose management parts. It is also used in lawn and garden equipment such as tractors, mowers and seeders.
3. In the commercial appliance industry, it is used in commercial dishwashers, bottle washers, cooking equipment and griddle plate assemblies.

41. State the advantages and applications of low-frequency electric resistance welding.

Advantages:

1. The low frequency process produces high quality weld.
2. It is more prone to selective seam corrosion, hook cracks and inadequate bonding of seams.

Limitations:

1. It is no longer used to manufacture pipe.
2. The high frequency process is still being used to manufacture pipe for the use in new pipeline construction.

42. What is high-frequency resistance welding?

High-Frequency Resistance Welding (HFRW) describes a group of processes that use high frequency electric current to concentrate the welding heat at the needed location.

43. Write down the limitations of high-frequency resistance welding.

1. The contact wear requires maintenance and replacements.
2. It cannot be used at slow speeds or as a manual process.
3. The stop and restart will cause visual objectionable discontinuities.

44. What are the applications of high-frequency resistance welding?

1. It is more suitable for high speed welding of a large range of sizes and materials.
2. Steels, stainless steels, aluminum, copper, brass and titanium are successfully welded by High-Frequency resistance welding processes.

2.12. SOLVED QUESTIONS AND ANSWERS

1. What is the working concept of Electric resistance welding? Explain in detail with its advantages and limitations.

   Refer chapter **2.1.2** in page **2.2.**

2. Write short notes on weldability in resistance welding.

   Refer chapter **2.1.4** in page **2.7.**

3. Explain the resistance spot welding process with a neat sketch.

   Refer chapter **2.2** in page **2.9.**

4. Explain any two types of spot welders in detail.

   Refer chapter **2.2.1** in page **2.11.**

5. Describe the sequence of a resistance spot welding cycles with neat sketches.

   Refer chapter **2.2.2** in page **2.13.**

6. Discuss the procedure involved in calculating the welding force in spot welding process.

   Refer chapter **2.2.5** in page **2.16.**

7. Explain how electrodes are cooled during welding.

   Refer chapter **2.2.6** in page **2.17.**

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8. Explain the seam welding process with a neat sketch.

   Refer chapter **2.3** in page **2.19.**

9. With neat sketches discuss the various types of seam welding processes.

   Refer chapter **2.3.1**in page **2.20.**

10. Enumerate the principle involved in projection welding.

    Refer chapter **2.4** in page **2.22.**

11. Differentiate between spot welding and projection welding.

    Refer chapter **2.4.1** in page **2.23.**

12. Explain the working of upset welding process.

    Refer chapter **2.5.1** in page **2.25.**

13. Describe the working of flash butt welding process with a neat sketch.

    Refer chapter **2.5.2** in page **2.26.**

14. Explain percussion welding process.

    Refer chapter **2.6** in page **2.28.**

15. State its advantages and limitations of percussion welding process.

    Refer page **2.29.**

16. Explain stud welding procedure with a sketch.

    Refer chapter **2.7** in page **2.29.**

17. Write short notes on low-frequency electric resistance welding.

    Refer chapter **2.8** in page **2.32.**

18. Describe the working of high-frequency resistance welding process with its neat sketch.

    Refer chapter **2.9** in page **2.32.**

END of Unit 2

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UNIT – 3

SOLID STATE WELDING PROCESSES

Cold welding, Diffusion bonding, Explosive welding, Ultrasonic welding, Friction welding, Forge welding, Roll welding and Hot pressure welding processes - advantages, limitations and applications.

3

SOLID STATE WELDING PROCESSES

3.1. SOLID STATE WELDING

Solid state welding is a group of welding processes which produces coalescence at temperature below the melting point of base materials being welded without the addition of brazing filler metal. Metallurgical bond is created without melting the base metals. In this welding, heat may or may not be applied. These processes are sometimes called *solid state bonding processes*.

This group of welding processes includes the following types:

(i) Cold welding
(ii) Diffusion bonding
(iii) Explosive welding
(iv) Ultrasonic welding
(v) Friction welding
(vi) Forge welding
(vii) Roll welding
(viii) Hot pressure welding.

In ali of these welding processes, time, temperature and pressure individually or in combination produce coalescence of the base metal without significant melting. Solid state welding is the oldest welding process and some of them are the newest. One of the solid state welding processes, called friction welding, is shown in Figure 3.1. In this *friction welding*, one of the workpiece is rotating at high speed and the other is stationary. When the stationary workpiece is forced to rotating workpiece at high pressure, the weld is formed due to friction between these two surfaces.

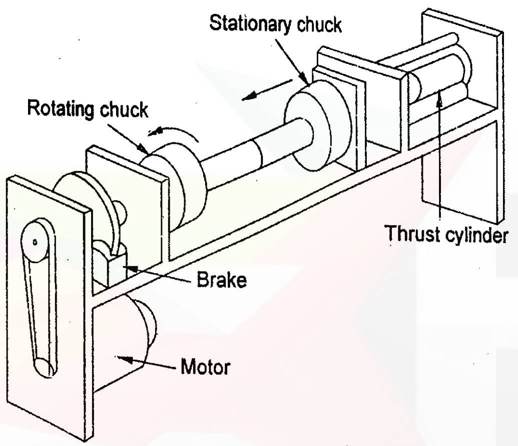

Figure 3.1 Solid state welding

3.1.1. Advantages, Limitations and Applications of Solid State Welding

Advantages:

1. The base metal does not melt and form a nugget.
2. The metals being joined retain their original properties. Hence, there is no heat-affected zone problems involved.
3. Metallurgical purity is maintained.
4. Dissimilar metals can be bonded.
5. It eliminates liquid phases.
6. It can be applied at different temperatures and under different stresses.
7. Weld is free from microstructure defects.
8. There is no use of filler material, fluxes and shielding gas required.

Limitations:

1. Surface preparation is necessary.
2. Joint design is limited.
3. Elaborate and expensive equipment may be required.
4. Non-destructive inspection is very limited.
5. Equipment is expensive.

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Applications:

1. Bonding of stainless steel liners in aluminum fry pans.
2. Aluminum cladding bonded to uranium fuel rods.
3. Ultrasonic and thermo-compression bonding in microelectronics industry.
4. Friction welding in aerospace and automotive applications.
5. Intake / exhaust automatic valves.

3.2. COLD WELDING

Cold pressure welding is a form of solid state welding which is unique because it is carried out at ambient temperature. Other forms of solid state welding are conducted at elevated temperature.

Cold welding is a bonding process during which two solids are forced to form a single piece by applying adequate pressure as shown in Figure 3.2. In other words, cold welding is a solid-state welding process in which joining of metals takes place without fusion/heating at the interface of two parts to be welded. Cold welding is also known as *contact welding*. In fusion-welding processes, no liquid or molten phase is present at the joint. In cold welding, metals are joined together without using flux.

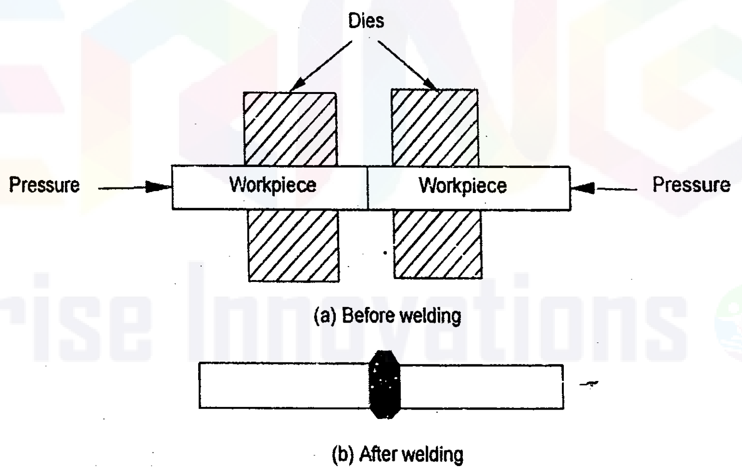

Figure 3.2 Cold welding

The welding of parts is done by extreme high pressure or by contact in a high vacuum with no application of heat. Pressure is applied to points to be welded at temperature below

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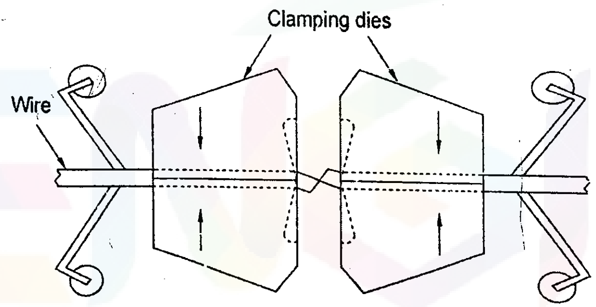
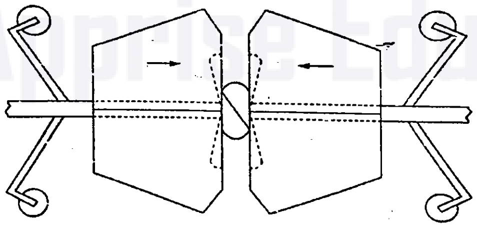
the recrystallization temperature of metals to be welded. This applied pressure brings the atoms on the interface to be welded into such close contact that they diffuse across the interface and a cold pressure weld is made. The atoms of metals are held together by *metallic bond*. The metallic bond can be described as a 'cloud' of free and negatively charged atoms into a unit as a result of attractive forces.

All metals are surrounded by surface layers (oxide) which must be disrupted if they need to be welded. Cold pressure welding carried out at ambient temperature relies upon the use of high compressive pressure 1400 to 2800 N/mm^2 for Aluminium and at least double that value for copper. It provides interfacial deformations of 60% to 80% that break the oxide layers to expose fresh and uncontaminated metal makes contact. In this state, take over to interatomic forces produce the weld.

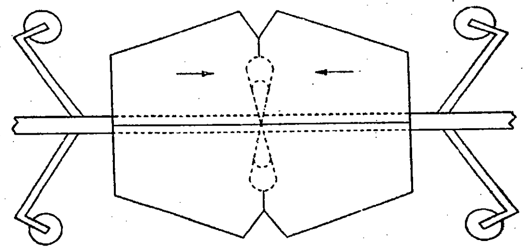
During cold welding, both surfaces continue to remain in solid phase throughout this forced adhesion process. The parts to be welded are first cleaned. A short section of parts to be welded is sheared as shown in Figure 3.3(a). The parts are clamped in a die with some initial extension. A forging force is applied to compiete welding. Various stages of multiple upset cold welding of wires are shown in Figure 3.3. Figure 3.4 shows the parts to be welded before welding and after welding has been carried out.



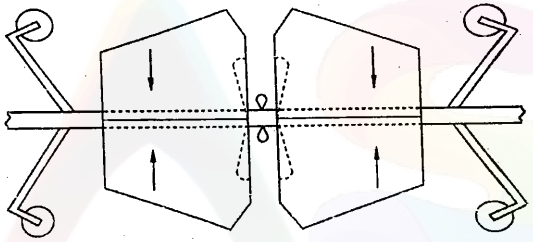
(a) Stage 1



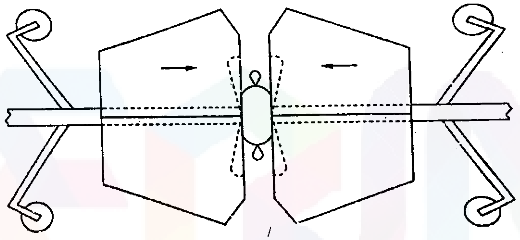
(b) Stage 2



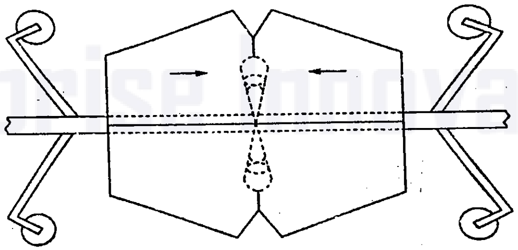
Stage 3



(c) Stage 4

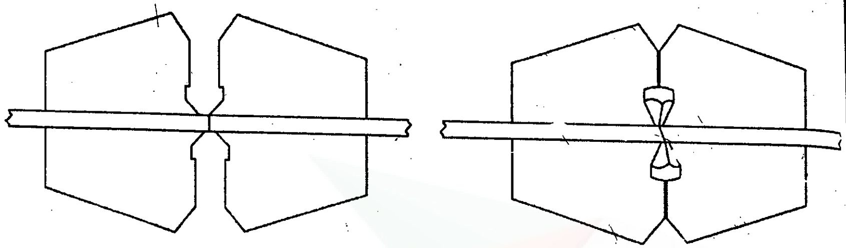


(d) Stage 5



(e) Stage 6

Figure 3.3 Stages in multiple upset cold welding



(a) Before welding (b) After welding

Figure 3.4 Cold welded parts

It is a method used for relatively ductile metals such as aluminium, copper cupro-nickel, gold, silver, platinum, lead, zinc, tin and lead-tin alloys, nickel, palladium and cadmium etc., and it is particularly suited to welds in circular wire section. Dissimilar materials and materials of different sizes can all be welded.

Both butt and lap joints can be cold welded. Where the application demands the joining of lapped sheets to themselves or bars, a series of small welds can be used. When calculating strength, the designer should consider that at least half the thickness of one of the sheets will be lost due to the applied pressure. Butt joints are primarily used for joining wires and rods in diameters from 0.5*mm* up to 12*mm*.

The dies play an important role in a cold butt weld process. First, they must grip the material firmly. Therefore, the inside of the cavity is either etched or made with an electric pencil. The gap between two faces or noses of the die is also important. If it is too large, the material will just collapse or bend away. This dimension is taken care of during manufacture and it cannot be changed. Dies can also be manufactured to suit various profiles as long as the profile allows the die to be made in two halves.

3.2.1. Characteristics of Cold welding

(i) A cold weld is generally stronger than the parent material and has the same electrical characteristics.

(ii) At least one of the metals must be ductile without excessive work-hardening.

(iii) Total absence of applied heating occurs.

(iv) Surface preparation is important.

(v) Both workpieces can be similar or dissimilar metals.

(vi) Both workpieces should be cleaned.

(vii) Short sections on the workpieces should sheared off.

3.2.2. Advantages, Limitations and Applications of Cold Welding

Advantages:

1. There are no thermal effects on the parts being joined and the process is fast.
2. As the process is performed at ambient temperature, there are no thermal effects on the parts being joined.
3. The weld zone is not only metallurgically homogeneous but the metal is work hardened and stronger than the adjacent areas.
4. It is simple and inexpensive to operate once dies have been produced.
5. The process is fast.
6. It is virtually no deformation.
7. The ends of the wire or rod need no surface preparation to weld and the alignment of the two butt ends is automatic as the material is placed on the die.
8. Parts are joined without contamination from sparks or dusts and vapours.

Limitations:

1. As the welds are made in the solid state, they are difficult to inspect.
2. The thickness of the parts is reduced significantly at the weld where the contact surfaces are sheared together.
3. It is highly specialized type of welding with respect to joint design and materials to be welded.
4. While the speed is an advantage to assemblers, it can also be a limitation.
5. When a body moving that fast meets another, it will try to displace it.

Applications:

1. It is used for joining of wire, foil to wire, wire to bi-metals and sealing of heat sensitive containers such as those containing explosives.
2. Rod coils are butt welded to permit continuity in post-weld drawing to smaller diameters.
3. It is used for joining components where heating is not possible such as magnets.
4. In the electronics industry, cold welding processes are used to seal tin plated steel crystal cans and copper packages for heat sensitive semiconductor devices.

5. An interesting application of the process is underground wire servicing where joins need to be made in hostile environments such as in the presence of explosive gases.
6. Cold welding is a hermetic sealing process widely used in the crystal, transistor and high powered solid state electronic switching industries.

3.3. DIFFUSION WELDING

It is a solid state welding process that uses heat and pressure, usually in a controlled atmosphere, with sufficient time for diffusion and coalescence to occur. In this process, moderate pressure of about 10 *MPa* is applied to carefully cleaned surfaces of the workpieces at an elevated temperature below the melting point of the metals to result primarily from diffusion. Atoms diffuse across the interface to form the bond. Diffusion involves the migration of atoms across the joint due to concentration gradients. This process requires temperatures of about $0.6T_m$ (T_m is the melting temperature of the metal) in order to have a high diffusion rate between parts being joined. Here, plastic deformation at surfaces is minimal and primary coalescence mechanism is solid state diffusion.

When joining two materials of similar crystalline structure occurs, diffusion bonding is performed by clamping two pieces to be welded with their surfaces abutting each other. Prior to welding, these surfaces must be machined to smooth finish and kept free from chemical contaminants or other debris. Mostly, surface treatment including polishing, etching and cleaning as well as diffusion pressure and temperature are important factors regarding to process of diffusion bonding. Surface roughness value, R_a of less than 2 micron and waviness of less than 400 micron are preferred. Oxides need to be removed.

Diffusion bonding is performed under controlled atmosphere to prevent oxidation. Sometimes, a layer of filler material is needed to achieve good bonding. Any intervening material between two metallic surfaces, as shown in Figure 3.5, may prevent adequate diffusion of material because the strength of the welding depends on pressure, temperature, time of contact and cleanliness of the metal.

The example for diffusion welding is bonding of gold over copper. First, a thin layer of gold foil is obtained by hammering. Once clamped, the gold foil is then placed over copper and then the weight is placed on top of it, usually for many hours. In diffusion welding, the pressure may be applied by dead weights or by a press using differential gas pressure or by high-pressure autoclaves because this method allows for exact measurements of load on the parts. The assembly is then placed in a furnace and left until a good bond is obtained. The

parts are usually heated in a furnace or by electrical resistance. Figure 3.6 illustrates the heating of diffusion bonding by using electrical resistance method. Diffusion bonding must be done in a vacuum or inert gas environment when using metals that have strong oxide layers such as copper.

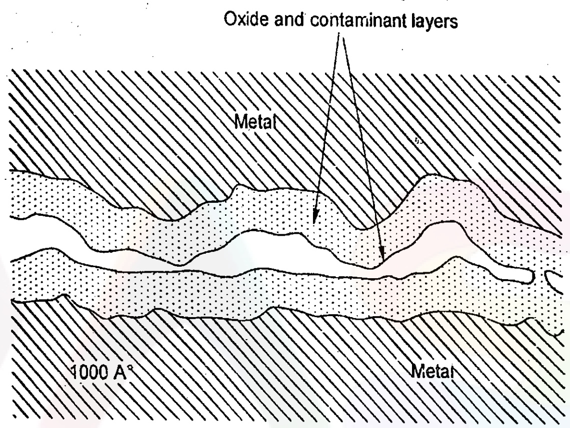


Figure 3.5 Oxide and contaminant layers on metal surface

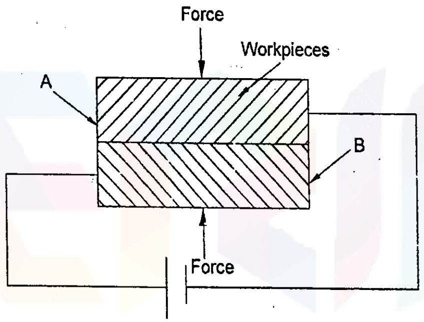


Figure 3.6 Schematic of diffusion welding heating by electrical resistance

The diffusion welding can be used to join either similar or dissimilar metals. For joining dissimilar metals, a filler layer of different metal is often sandwiched between base metals to promote diffusion. It is also used in reactive metals such as, titanium, zirconium, refractory metal alloys; bonding steel to tungsten, steel to niobium, stainless steel to titanium and gold to copper alloys. The diffusion welding process is slower process when compared to other welding processes.

3.3.1. Stages in Diffusion Welding

Diffusion bonding occurs in three simplified stages as follows:

Stage 1: Deformation and interfacial boundary formation

Before the surfaces come to complete contact, very small surface defects (asperities) on the two surfaces will contact and plastically deform. As these small surface defects deform, they interlink for forming interfaces between two surfaces.

Stage 2: Grain boundary migration and pore elimination

Both elevated temperature and pressure cause an accelerated creep in the materials, grain boundaries and raw material migrate. The gap between two surfaces is reduced to isolated pores.

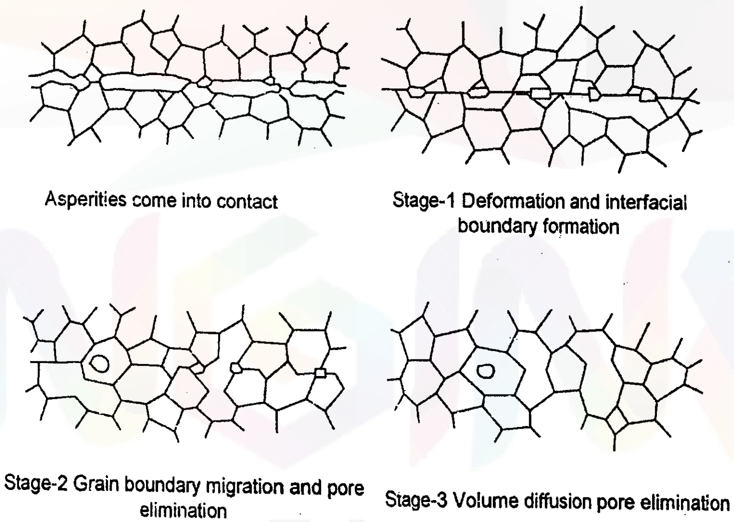


Figure 3.7 Stages in diffusion welding

Stage 3: Volume diffusion pore elimination

Material begins to diffuse across the boundary of the abutting surfaces, blends this material boundary and creates a bond.

3.3.2. Process Variables in Diffusion Welding

The following six groups of variables affect the diffusion welding process:

(i) Surface preparation

(ii) Temperature

(iii) Time

(iv) Pressure

(v) Special metallurgical effects

(vi) Use of interlayers.

(i) Surface preparation:

The surfaces of parts to be diffusion welded are thoroughly prepared before the welding takes place. Surface preparation involves more than just cleanliness. It has the following steps:

1. Generation of an acceptable finish or smoothness.
2. Removal of chemically combined films, oxides etc.
3. Cleansing of gaseous, aqueous or organic surface films.

The initial surface finish is attained by machining, abrading, grinding or polishing. A correctly prepared surface is flat. Flatness and smoothness are needed to assure that the interfaces to be welded have necessary compliance without excessive deformation. Machine finishing, grinding or abrasive polishing are usually sufficient to avoid warpage and distortion. A special preparation for curved surface parts is required for appropriate contour matching of surfaces.

Chemical etching or pickling is generally used as a pre-weld surface preparation. It has the effects of removal of non-metallic surface films in the form of oxides and removal of part or all cold worked layers which appears during preliminary surface preparation. The advantages of oxide removal are obvious because it is very difficult to adhere two oxidized surfaces.

(ii) Temperature:

The main process parameters are time, temperature and pressure. Out of these four parameters, temperature is the most considerable one because of the following reasons.

(i) Temperature is always changing and relatively easy to measure and control.

(ii) Temperature change may greatly affect the results because of the nature of diffusion welding process and effects of temperature on plasticity, diffusivity, oxide solubility etc.

(iii) Temperature changes are relatively inexpensive and they will improve the economics of the operation by shortening cycles.

(iv) Other factors such as allotropic transformation, recrystallization, solution of precipitates and oxides are all temperature dependent and hence temperature must be controlled for varying these factors as desired.

Joint quality can also be increased with increase in diffusion welding temperature.

(iii) Time:

Time is a dependent process parameter. Time is related to temperature and pressure because the diffusional reactions are linear or sometimes, it is parabolic with time. If there is increase in temperature, it shortens the time required for diffusion welding. Time may differ from a few seconds to several hours based on the length of the weld needed for the particular structures. Also, the welding time varies based on both thermal inertia and mechanical inertia. If inertia problems are less, the welding time will drastically reduce. So, the potential production rates are increased to reduce the time of weld for economic reasons.

(iv) Pressure:

The second important parameter in diffusion welding is pressure. It is easy to deal than time and temperature. At the same time, pressure greatly affects the diffusion welding process. The pressure intensity directly affects the initial deformational of bond formation. The increased pressure constantly produces better results for any value of time-temperature value. Higher pressure leads to increase interface deformation and breakdown. Pressure significantly affects the recrystallization behaviour. Also, the increased pressure increases the local deformation thereby reducing the localized recrystallization temperature. On the other hand, it can be stated that the increased deformation accelerates the process of recrystallization at a given diffusion welding temperature.

Maintaining uniform pressure throughout the process is very important. Diffusion welds generally take place with large faying surfaces which are curvilinear or discontinuous. Some components are assembled by diffusion welding alone because of its geometric factors. In those cases, the pressure should be uniform to provide the assurance for consistency of bond formation in all areas.

(v) Metallurgical factors:

A number of specialized metallurgical events can become important factors in determining the process parameters for diffusion welding. They can set limits on the

remaining parameters for a variety of reasons. The most important are allotropic transformation, recrystallization and surface behaviour.

Hardened steels, titanium alloys, zirconium alloys and cobalt alloys undergo allotropic transformation. Recrystallization occurs after a cold welded metal is heated to a sufficiently high temperature. The heating temperature is usually greater than 0.4 times the melting temperature of the metal which is the usual range for almost all diffusion welds. Hence, during diffusion welding, the part is recrystallized.

Surface oxides should also be considered in process parameter analysis. Alloys with different compositions change much in the nature of oxides to their surfaces. Beryllium, aluminium, chromium and other active elements form firm surface oxides. Alloys having high surface oxides are more difficult to weld than those which form less stable oxide films such as copper, nickel, gold etc. Tenacious films make diffusion welding more difficult and they need more elaborate pre-weld surface preparation. Titanium and zirconium dissolve their own oxides at common diffusion welding temperatures even though the films are initially adherent.

(vi) Diffusion welding with interlayers:

The use of interlayers is growing in diffusion welding applications. Interlayers have some advantages in making diffusion welds and they have some disadvantages of decreased strength or stability. They are used due to the following reasons.

(i) To mollify the effect of diffusion welding parameters by using a lower strength intermediate layer or one containing a diffusing element.

(ii) To modify surface conditions by using an electroplate or intermediate foil with fewer problems regarding oxide films.

(iii) To minimize distortion with a soft interlayer by confining deformation to low-strength intermediate.

(iv) To solve alloying compatibility problems when joining dissimilar metals.

Intermediate layers are also used to promote melting at the interface which is similar to brazing. Copper interlayers can produce thin, temporary liquid layers in joints between titanium or zirconium alloys to promote joint formation. Boron will do the same with nickel alloys. When it is used re-solidification and homogenization, the suitable thermal treatment during or after diffusion welding is called for. It prevents damaging effects such as in-service melting or embrittlement.

3.3.3. Factors Influencing Diffusion Welding

The relation between temperature and activation energy and diffusion coefficient is given by the following equation.

$$\text{Diffusion coefficient, } D = D_o e^{\frac{Q}{KT}}$$

where D = Diffusion coefficient

D_o = Diffusion constant

Q = Activation energy

T = Absolute temperature, and

K = Boltzmann's constant.

Also, the relationship between diffusion length, diffusion coefficient and time can be written as

$$\text{Diffusion length, } X = C\sqrt{D \times t}$$

where C = Constant

D = Diffusion coefficient, and

t = Time.

Steady state diffusion is determined by the amount of diffusion flux that passes through the cross sectional area of the mating surfaces. According to *Fick's first law of diffusion*, diffusion coefficient can be written as

$$\text{Diffusion flux, } J = -D\left(\frac{dC}{dx}\right) \quad \text{.... (3.1)}$$

where J = diffusion flux

D = Diffusion coefficient, and

dC/dx = Concentration gradient through the materials in question. The negative sign is a product of the gradient.

Again diffusion flux can be written on the basis of another *Fick's law*,

$$\text{Diffusion flux, } J = \left(\frac{M}{At}\right) \quad \text{.... (3.2)}$$

where M = Mass or amount of atoms,

A = Cross sectional area, and

t = Time required.

Equating equations (3.1) and (3.2) and rearranging,

$$\text{Time, } t = -\left(\frac{1}{D}\right)\left(\frac{M}{A}\right)\left(\frac{dC}{dx}\right)^{-1}$$

As mass and area are constant for a given joint, time required is largely dependent on the concentration gradient which changes by only incremental amount through the joint and the diffusion coefficient. The applied pressure during welding also produces a significant effect in the welding process.

3.3.4. Advantages, Limitations and Applications of Diffusion Welding

Advantages:

1. Plastic deformation at surface is minimal.
2. Dissimilar materials may be welded.
3. Welds of high quality are obtained.
4. There is no limitation in the thickness of workpieces.
5. The bonded surface has the same physical and mechanical properties as the base material.
6. The diffusion bonding is able to help us to build high precision components with complex shapes. Also, the diffusion is flexible.
7. The diffusion bonding method can be used wildly, joining either similar or dissimilar materials and also important in processing composite materials.
8. The process is not extremely hard to approach and the cost to perform the diffusion bonding is not high.
9. The diffusion bonding process is able to produce high quality joints in which no discontinuity and porosity exist in the interface.

Limitations:

1. It is a time consuming process due to low productivity.
2. Time required for diffusion can range from seconds to hours.
3. Very thorough surface preparation is required prior to welding process.

4. The mating surfaces must be precisely fitted to each other.
5. It requires relatively high initial investments in equipment.

Applications:

1. It is used in joining of high-strength and refractory metals based on titanium in aerospace and nuclear industries.
2. Diffusion welding is most commonly used to join sheet metal structures in nuclear and electronics industries.

3.4. EXPLOSIVE WELDING

Explosive welding (EXW) is a solid state (solid-phase) welding process that uses a controlled application of large pressure generated by the detonation of applied explosives. In explosive welding, welded parts (plates) are metallurgically bonded as a result of oblique impact pressure exerted on them by a controlled detonation of an explosive charge.

The following terms are frequently used in the explosive welding.

(i) *Cladding metal or cladder* is the thinner plate that is either in direct contact with the explosive or it is shielded by a flyer plate from the explosive.

(ii) *Flyer plate* is a sacrificial plate placed between cladder and explosive to protect the cladder metal.

(iii) *Interlayer* is a thin metal layer which is sometimes placed between cladder and base plate to enhance joining.

(iv) *Base plate or backer* is the plate that the cladder is being joined.

(v) *Anvil* is the surface on which backer rests during the joining operation.

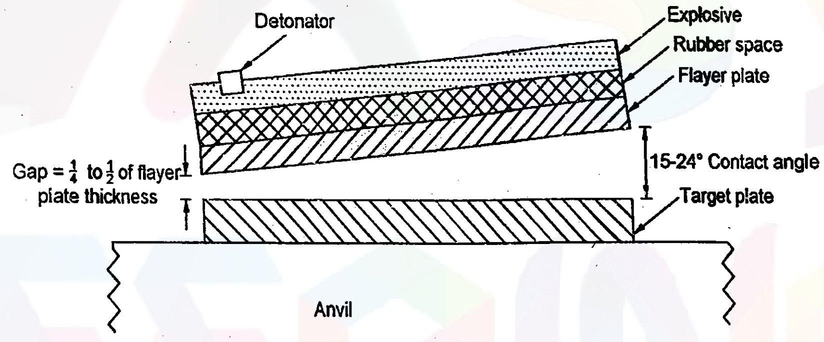
(vi) *Standoff* is the distance between cladder and base plate prior to the joining operation.

(vii) *Bond window* is the range of process variables such as velocity, dynamic bend and standoff distance that result in a successful weld.

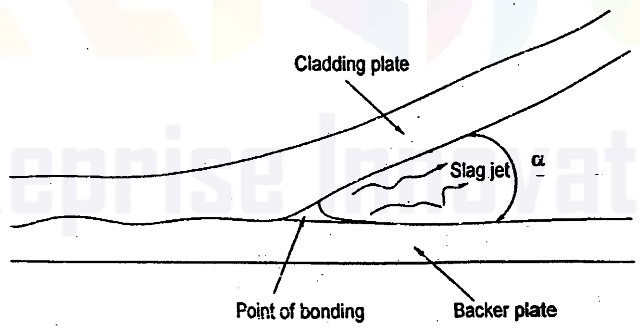
(viii) *Bonding operation* is the detonation of the explosive which results in the weld.

Before welding, the surface to be welded must be cleaned. To carry out the welding process, one of the parts to be welded is kept as stationary and the other one is made as movable. The movable part is called *flayer plate*. The base plate kept as stationary is rested on an anvil and the flyer plate is located above the base plate with an angled or constant interface clearance as shown in Figure 3.8 (a). On top of the flyer plate, the rubber spacer is

placed to avoid the rapid effect of burnt explosives. Explosives are placed on this rubber spacer with a detonator. Detonation starts at an edge of the plate and propagates at high velocity along the plate. The flyer plate moves towards the base plate at very high velocity (4 to 5 *km/s*) due to the impact of kinetic energy in the form compressive stress during detonation of explosives to collide with a stationary part to be joined. The maximum detonation velocity is about 120% of the material sonic velocity. The compressive stress is in the order of thousands of *MPa*. The material at the intersection points behaves similar to a viscous fluid after explosion. The slags (oxides, nitrides and other surface contaminants) are expelled by the metallic jet created just ahead of the bonding front as shown in Figure 3.8 (b). It also creates wavy surface as shown in Figure 3.9. During bonding, normal inter-atomic and intermolecular force takes place between these two surfaces. During the process, the surrounding material is work hardened by the shockwave and there is no metallurgical changes occur.



(a) Arrangement of component



(b) Propagation of slag jet

Figure 3.8 Principle of explosive welding

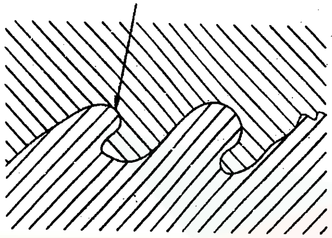
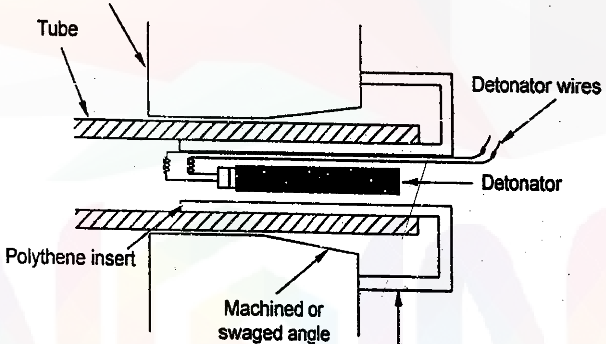
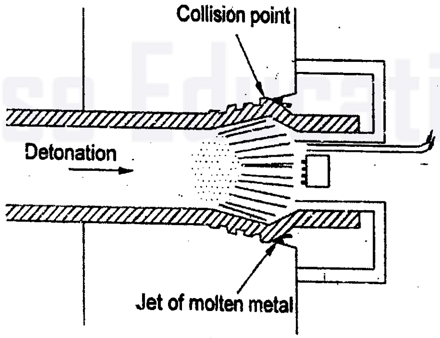


Figure 3.9 Interface of the weld surface

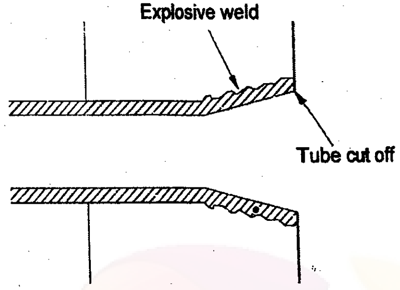
Figure 3.10 illustrates the explosive welding process of tube details during three stages such as before welding, during welding and after welding.



(a) Before welding



(b) During welding



(c) Completed weld

Figure 3.10 Process of explosive welding

The welds made are sound and allow higher operating pressure and temperature than with fusion welding. The explosive used for welding is Trimonite. It must have a low detonation velocity, below the velocity of sound in the material and there is no limit to the joint area.

For the tube plate welds, several charges can be simultaneously fired and the explosive is being in cartridge form. The explosive should be of pre-fabricated shape and cheap. The charge is electrically fired from a fuse head on the inner end of the charge and it initiates the explosion to the detonation front and then it is passing progressively through the charge.

The size of the charge depends upon the following variables.

(i) Surface finish

(ii) Angle of inclination of tube and plate

(iii) Yield strength

(iv) Melting point of the materials

(v) Tube thickness, and

(vi) Diameter.

Most of the commercial metals and alloys may be bonded (welded) by explosive welding. The following combination of dissimilar metals may be joined by explosive welding:

- Copper to steel
- Nickel to steel
- Aluminum to steel

- Tungsten to steel
- Titanium to steel
- Copper to aluminum.

3.4.1. Types of Explosive Waves

There are following two types of waves generated during explosive welding.

(i) Deflagration

(ii) Detonation.

(i) Deflagration:

Deflagrations travel at subsonic velocities depending on the rates of chemical reaction, thermal diffusion and mass diffusion. The deflagration velocity may vary during progression. Typical deflagrations are gas-air mixtures in a gas stove, fuel-air mixtures in an internal combustion engine and gunpowder in a firearm or pyrotechnic device.

(ii) Detonation:

A detonation travels at supersonic velocity exceeding the sonic velocity of the undetonated explosive. The detonation wave consists of a shock front that compresses and heats the explosive followed by a region of rapid chemical reaction.

3.4.2. Advantages, Limitations and Applications of Explosive Welding

Advantages:

1. It ensures high quality bonding such as high strength, no distortions, no porosity and no change of the metal microstructure.
2. There is no heat-affected zone (HAZ) other than weld surface.
3. There is no diffusion.
4. Only, minor melting occurs.
5. Differences in material melting temperatures and coefficients of thermal expansion do not affect the final product.
6. Combination of dissimilar metals, copper to stainless steel, aluminium to steel or titanium to steel can be easily welded.
7. Explosive welding is much suited to cladding application.
8. Process is simple and rapid. It also gives close thickness tolerance.

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9. Low melting point and low impact resistance materials cannot be effectively welded.
10. Large surfaces may be welded.
11. It is less costly.
12. Surface preparation is not required.
13. Large areas can be bonded quickly and the weld itself is very clean due to surface material of both metals.
14. Minimum fixturing/jigs are needed.
15. There is no effect on parent material properties.
16. Small quantity of explosive is used.

Limitations:

1. Brittle materials cannot be processed.
2. Only, simple shape parts may be bonded.
3. Thickness of flyer plate is limited.
4. Safety and security aspects of storage and using explosives are difficult.
5. Metals must have high enough impact resistance and ductility.
6. The geometrics welded must be simple in the shape of flat, cylindrical and conical shapes.
7. The cladding plate cannot be too large.
8. Noise and blast can require worker protection, vacuum chambers and buried in sand/water.
9. The use of explosives in industrial areas will be restricted by the noise and ground vibrations caused by the explosion.
10. Area should be cleaned and sound grounded for explosion.
11. Licenses are necessary to hold and use explosives.

Applications:

1. This process is applied to welding of tubes and tube plates in heat exchangers, feedwater heaters and boiler tubes to clad tube plates.
2. The tubes may be of steel, stainless steel or copper, aluminium brass and bronze tubes in naval brass tube plates are welded.

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3. It is used for manufacturing clad tubes and pipes, pressure vessels, aerospace structures, heat exchangers, bi-metal sliding bearings, ship structures and weld transitions.
4. It is used to clad thick plates with corrosion resistant layers where other techniques (e.g. roll bonding) are not practical.
5. It is used in tube plugging.
6. It is used in remote joining in hazardous environments.
7. It is used in fixing cooling fins.
8. It is also used in cryogenic industries.

3.5. ULTRASONIC WELDING

Ultrasonic welding is a solid state welding process in which two work pieces are bonded as a result of a pressure exerted to welded parts combined with application of high frequency acoustic vibration (ultrasonic). It uses the principle of conversion of high frequency electrical energy into high frequency mechanical energy. This mechanical energy is a vertical motion excess of 15000 cycles/second. Ultrasonic vibration causes friction between parts which results in a closer contact between two surfaces with simultaneous local heating of the contact area. Interatomic bonds formed under these conditions provide strong joint.

The components to be joined are held together under pressure and subjected to vibrations, usually at a frequency of 15 *kHz* to 60*kHz*. The vibrations produced by a welding sonotrode or sonometer or horn are used to soften or melt the thermoplastic material at the joint line. Welding times are lower than 3 *seconds*. The welding can proceed with or without the application of external heat. Thickness of the welded parts is limited by the power of the ultrasonic generator.

3.5.1. Ultrasonic Welding Equipment

Ultrasonic welding equipment consists of a machine press, generator, converter or transducer, booster, sonotrode or horn and component support tooling. A schematic of an ultrasonic welding machine is shown in Figure 3.11.

(i) Generator:

The generator converts electrical power from the single-phase mains to the correct frequency and voltage for the transducer to convert into mechanical vibrations. The microprocessor unit controls the welding cycle and feeds back the key welding information to

the user, via the user interface. The user interface also allows the operator to enter the required welding parameters.

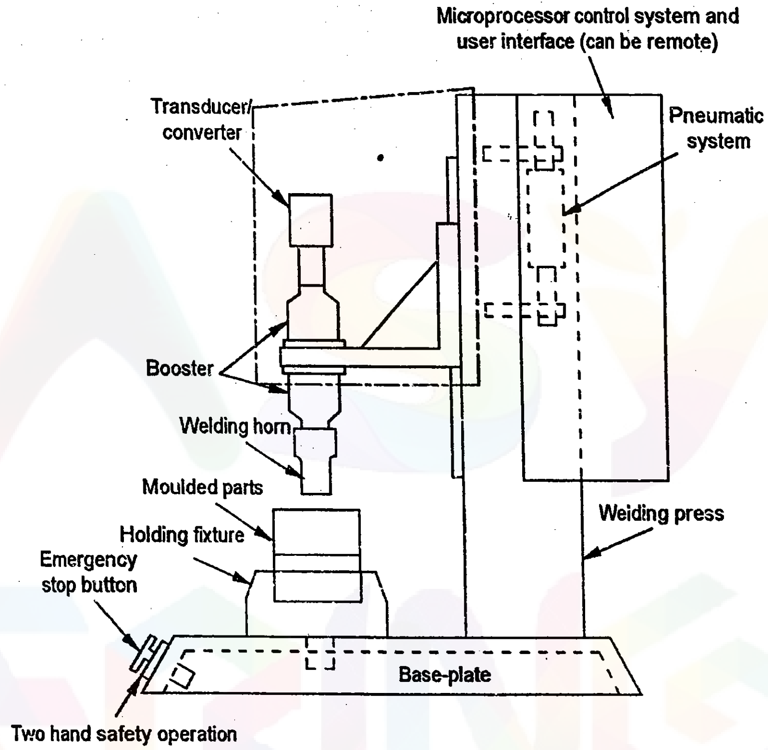

Figure 3.11 Ultrasonic welding

(ii) Machine press:

The machine stand is designed to hold the welding system or stack and it applies the force necessary for welding. It consists of a base-plate to hold the tooling jig and a pneumatic cylinder to apply the force. The machine has a pressure gauge and regulator for adjustment of the welding force. There is also a flow control valve to allow adjustment of the speed at which the welding head approaches the component being welded.

Some equipment manufacturers have introduced an electromagnetic force application system in place of the traditional pneumatic cylinder. It gives a better control of the approach rate and it can be beneficial when welding small or delicate components.

(iii) Welding stack.

It is a part of the machine that provides the ultrasonic mechanical vibrations. It is generally a three-part unit consisting of transducer, booster and welding horn which are mounted on the welding press at the centre-point of the booster section. The stack is a tuned resonator similar to a musical instrument tuning fork. In order to function, the resonant frequency of the tuned welding stack must closely match the frequency of the electrical signal from the generator (within 30*Hz*).

(iv) Transducer:

The *transducer* is also known as *converter* which converts the electrical energy from the generator to the mechanical vibrations used for the welding process. Transducers are made of piezo-electric materials.

A piezo-electric material increases its length when current flows through a coil surrounding the device and it changes the alternating electric field into mechanical movement. Examples of piezo-electric materials are quartz, tourmaline and Rochelle salt.

Transducer consists of a number of piezo-electric ceramic discs sandwiched between two metal blocks, usually titanium.

Between each of the discs there is a thin metal plate which forms the electrode. As the sinusoidal electrical signal is fed to the transducer via the electrodes, the discs expand and contract, and produce an axial and peak-to-peak movement of 15 to 20μm.

Transducers are delicate devices and they should be handled properly. Once elements are broken, the transducer will not function.

(v) Booster:

The booster section of the welding stack serves two purposes, primarily to amplify the mechanical vibrations produced at the tip of the transducer and transfer them to the welding horn. Its secondary purpose is to provide a location for mounting the stack on the welding press. The booster expands and contracts as the transducer apply ultrasonic energy.

The booster similar to other elements in the welding stack is a tuned device. Therefore, it must resonate at a specific frequency in order to transfer the ultrasonic energy from the transducer to the welding horn. In order to function successfully, the booster must be either one half of a wavelength of ultrasound in the material from which it is manufactured or it multiples of this length. Normally, it is one half the wave length.

(vi) Welding horn:

The welding horn is the element of the welding stack that supplies energy to the component being welded. A typical welding horn is shown in Figure 3.12. Design of the welding horn is critical to successful welding.

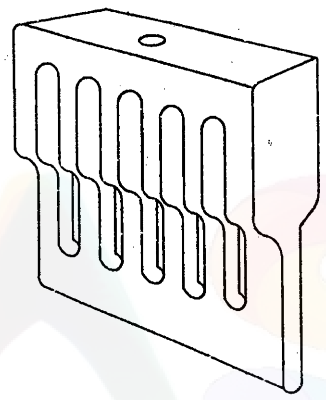

Figure 3.12 Welding horn

The horn is specially designed to have the correct sonic properties and it transmits pressure to welded surfaces and it vibrates to make the weld. It must have good mechanical strength which makes the weld. It can be of cylindrical shape, bar shape or more complex shapes according to the parts to be welded. The horn can be made of steel alloy, aluminium alloy or titanium which all have good ultrasonic properties.

Aluminium welding horns tend to be used for low volume applications since wear can be a particular problem with this material. Some welding horns have specially hardened tips to reduce wear during welding.

As with the booster element, the length of the welding horn must be either one half of a wavelength of ultrasound in the material from which it is manufactured or multiples of this length. It ensures that there is sufficient amplitude at the end of the welding horn to effect welding.

The amplitude is typically between 30 and 120μm. The shape of the welding horn is important since stress caused by axial expansion and contraction of the horn could lead to cracking in high amplitude applications. In some applications, the welding horn is manufactured with slots in the axial direction. It is to ensure the maximum vibration amplitude in the longitudinal direction.

The tip of the welding horn delivers the ultrasonic energy to the component being welded. The tip should be specifically designed to match the component. It ensures the maximum energy transfer between horn and the component. Usually, the tip of the horn is profiled to match contours of the component.

(vii) Support tooling:

Finally, the base of the machine press supports the tooling which holds the components during welding operation. The support tooling is designed to prevent the movement of a lower component while the ultrasound is applied. It is machined to match the contours of the component surface intimately.

3.5.2. Working of Ultrasonic Welding Equipment

In ultrasonic welding, electrical power supply is applied to a transducer at a frequency of 50 to 60 *Hz* into a high frequency electrical supply operating at 20, 30 or 40 *kHz*. Here transducer converts electrical energy into mechanical energy. This electrical energy is supplied to the transducer which converts to mechanical energy at ultrasonic frequencies.

The vibrating energy is then transmitted through the booster that increases the amplitude of the acoustic wave. The acoustic waves are then transmitted to the horn. The horn is an acoustic tool that transfers the vibrating energy directly to the components being assembled and it additionally applies a welding pressure.

The vibrations are transmitted through the workpiece to the joint area. The parts are "scrubbed" together under pressure at 20,000 *cycles per second*. Here, the vibrating energy is converted to heat through friction. It then softens or melts the thermoplastic and joins the components together. As the atoms are combined between components to be welded, a real metallurgical bond is made. Most of the thermoplastic materials can be ultrasonic weldable.

The sequence of operations is as follows:

Step 1:

The parts to be welded are placed into a locating holder.

Step 2:

The ultrasonic tool descends to apply a clamping pressure between the weld parts

Step 3:

When ultrasonic power flows for a given time, the tool then vibrates at a frequency 1-40*kHz*.

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Step 4:

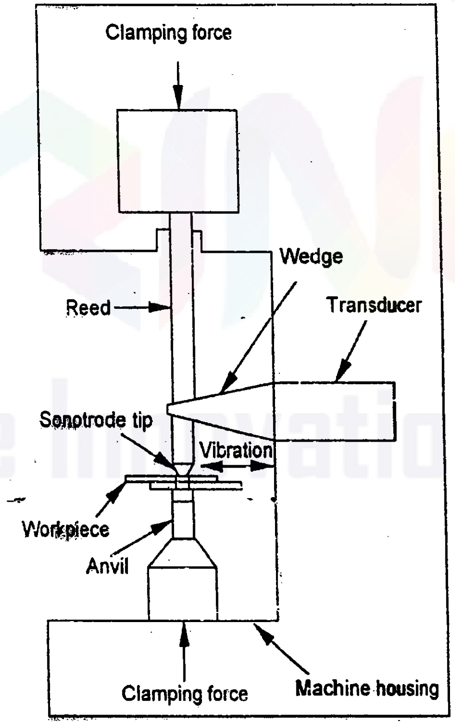
The base metals are then mechanically mixed causing a metallurgical bond between parts. The parts are immediately welded. There is no hold time or curing time.

Step 5:

Force is removed and machine deloaded.

3.5.3. Wedge-Reed Ultrasonic Welding System

The Wedge-Reed system, shown in Figure 3.13(a), integrates high vibratory force and low vibratory amplitude force in a shear mode that is analogous to the interface of the materials to be welded. In ultrasonic metal welding, this shear mode plays an important role. A vertical vibrating reed used by the wedge-reed system is powered by a wedge-shaped assembly of coupler and transducer vertical to the reed. Since the static clamping force lies directly on top of the parts to be welded, it is possible to achieve high clamp force without stalling or bending stress. This system is designed for high impedance metal welding.



(a)

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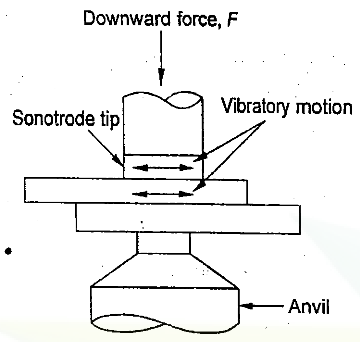

(b)

Figure 3.13 Wedge-reed ultrasonic welding system

Two components are held together and oscillatory shear stresses of ultrasonic frequency are applied to interface to cause coalescence as shown in Figure 3.13(b). Oscillatory motion breaks down any surface films to allow intimate contact and strong metallurgical bonding between surfaces.

In this system, the vibratory force is roughly three times and the vibratory amplitude is one-third when compared to a standard lateral drive system working at the same level of power. It results in an impedance value which is nine times more than the lateral drive system.

Since the load impedance is also determined by the density of the material to be welded, this system offers an improved impedance match to a metal weldment when compared to a lateral drive system.

3.5.4. Welding Parameters for Ultrasonic Welding

There are a number of parameters that must be selected correctly in order to achieve good ultrasonic welds. These include vibration amplitude, welding mode, clamping pressure, weld time and hold time. The most important parameters such as vibration amplitude and welding modes are discussed here.

(i) Amplitude:

Successful welding depends on the proper amplitude of vibration occurring at the tip of the welding horn. For any booster/horn combination, the amplitude is fixed. Amplitude selection is based on the thermoplastic being welded such that the proper degree of melting is

achieved. In general, semi-crystalline materials require more energy and therefore, more horn tip amplitude as compared to amorphous materials.

Process control on modern ultrasonic welding machines can allow the amplitude to be profiled. High amplitude may be used to initiate melting and followed by a lower amplitude to control the viscosity of the molten material.

(ii) Welding modes:

Welding by time is termed as an *open-loop process*. The components to be welded are assembled in the tooling fixture before the welding horn descends and makes contact. The ultrasound is then applied to the assembly for a fixed duration of time, typically between 0.2 to 1.0 *seconds*. This process gives no indication of successful welding.

It works on the principle that a fixed weld time results in a fixed amount of energy being applied to the joint. It gives a controlled amount of melt. In reality, the power drawn to maintain amplitude is never the same from one cycle to the next. It is due to factors such as the fit between components. Since energy is a function of power and time and time is fixed, the energy applied will vary from one component to the next. For mass production, where consistency is important, it is undesirable.

Welding by energy is a *closed loop process* which gives a feedback control. The ultrasonic machine software measures the power being drawn and it adjusts the exposure time so that the desired energy input to the joint is delivered.

The assumption with this process is that if the energy consumed is the same for every weld, the quantity of molten material in the joint is the same each time. However, in reality, there are energy losses within the welding stack and especially at the interface between welding horn and component. As a result, some components may receive more energy than others with the possibility of inconsistent weld strength.

Welding by distance allows components to be joined by a specific weld depth. This mode operates independent of time, energy or power drawn and it compensates for any tolerance variation in the moulded components. Thus, it gives the best guarantee that the same amount of material in the joint is melted each time. Limits can be set on the amount of energy used or the time taken to make the weld for the purposes of quality control.

3.5.5. Energy Required for Ultrasonic Welding

Energy required to weld a given workpieces by ultrasonic welding increases with material hardness and thickness. The relationship for spot welding can be written as

$$E_a = 63(Ht)^{3/2}$$

where E_a = Acoustical energy in joule

H = Vicker's micro-hardness number

t = Material thickness adjacent to active in inches.

This equation holds good for aluminium, steel, nickel and copper for the thickness upto 0.81 *mm*.

3.5.6. Design Recommendations for Ultrasonic Welding of Plastics

(i) Surfaces of the workpieces to be joined should be free of distortion and warpage.

(ii) Bead or narrow raised sections called *energy indicators* are moulded on one of the surfaces of the workpieces.

(iii) Step joints are more preferable to reduce the unwanted flash and to increase the joint strength.

(iv) It is not recommended to bevel one surface of the joint.

(v) The initial contact area between mating surfaces should be small to concentrate and decrease the total energy (and thus the time) needed to start and complete melting.

(vi) A means for aligning the mating parts should be provided. Features such as pins and sockets, steps or tongues and grooves should be used for alignment rather than vibrating horn and/ fixture to ensure proper repeatable alignment and to avoid marking.

(vii) Horn contact directly over the joint area should be accommodated in order to smit the mechanical energy to the joint area while reducing the propensity for part marking.

3.5.7. Advantages, Limitations and Applications of Ultrasonic Welding

Advantages:

1. Since no bulk heating of the work pieces is involved, there is no danger of any mechanical or metallurgical bad effects.
2. The process is excellent for joining thin sheets to thick sheets.
3. Local plastic deformation and mechanical mixing result into sound welds.

4. Dissimilar metals may be joined.
5. High quality weld is obtained.
6. The process can be integrated into automated production lines.
7. Moderate operator skill level is enough.
8. The process is fast, economical and automated.
9. It is used in mass production up to 60 *parts per minute*.
10. It ensures increased flexibility and versatility.
11. It produces high strength joints.
12. Very thin materials can be welded.

Limitations:

1. Only small and thin parts may be welded.
2. Work pieces and equipment components may fatigue at reciprocating loads provided by ultrasonic vibration.
3. Work pieces may bond to the anvil.
4. It is not suitable for ductile materials since they yield under the stresses.
5. It needs specially designed joints.
6. Ultrasonic vibrations can damage electrical components.
7. Tooling costs for fixtures are high.

Applications:

1. Ultrasonic welding is used mainly for bonding small workpieces in electronics, manufacturing communication devices, medical tools and watches.
2. It is used in automotive, medical and toy production.
3. It is used in health care industries due to clean welds.
4. Ring-type continuous welds can be used for hermetic sealing.
5. It is used in sealing and packaging, aircraft, missiles and fabrication of nuclear components.
6. It is also used in armatures, slotted commuters, starter motor armatures, joining of braded brush wires, brush plates and wire terminals.
7. Ultrasonic welding is used in the automotive industry to fabricate headlamp parts, dashboards, buttons and switches, fuel filter, fluid vessels, seat-belt locks, electronic key fobs, lamp assemblies and air ducts.

8. In electronic appliances such as switches, sensors and data storage keys are fabricated using ultrasonic welding.
9. Ultrasonic welding is also used to make medical parts such as filters, catheters, medical garment and masks.
10. It is used in welding of tubes to sheets in solar panels.
11. Packing applications such as blister packs, pouches, tubes, storage containers and carton spouts can be fabricated using ultrasonic welding.

3.6. FRICTION WELDING

Principle:

Friction welding is a solid state welding process in which coalescence is achieved by frictional heat combined with pressure as shown in Figure 3.14. The heat is obtained through mechanical friction between rubbing surfaces of workpieces in relative motion to one another.

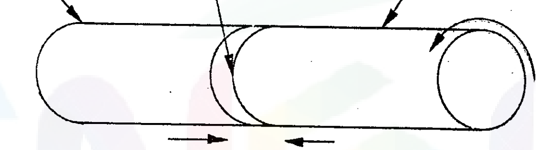

Figure 3.14 Principle of friction welding

Working:

Initially, the components to be welded are held in chucks or clamps. One part is rotated at high speed (1500 to 3000 *rpm*) using rotating chuck and other part is held stationary using stationary chuck as shown in Figure 3.15. During welding, the stationary chuck is moved and contacted with the rotating component under pressure. The heat is produced between contact surfaces. This heat is used to weld the components under pressure. Pressure is used to generate sufficient heat to reach a bonding temperature within a few seconds. The pressure during welding varies between 40 *MPa* to 450 *MPa*. The heat is concentrated and localized at the interface. Grain structure is refined by hot work and there is little diffusion across the interface. During this period, the rotation is stopped and pressure is retained or increased to complete the weld. Then, the metal is slowly extruded from the weld region to form an upset. For stopping the relative motion, the brake system is used.

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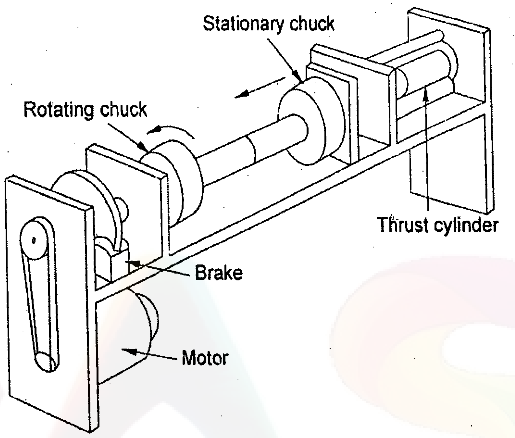

Figure 3.15 Friction welding machine

When properly carried out, no melting occurs at faying surfaces during welding. No filler metal, flux or shielding gases are normally used. Process can be fully automated. It is possible to weld solid steel bars up to 250*mm* in outside diameter by using friction welding.

Variety of metals can be joined by this process as well as it gives variety of metals combination which cannot be joined by conventional process. The materials that can be welded using friction welding are listed as follows.

1. Brass and Bronze
2. Copper and Nickel
3. Lead
4. Ceramics
5. Titanium alloys
6. Stainless steel
7. Tungsten
8. Vanadium
9. Aluminium and aluminium alloys
10. Magnesium alloys.

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3.6.1. Sequence of Operation in Friction Welding

The sequence of operation in the friction welding process (Figure 3.16) is as follows:

Step 1: Component fitted to rotating chuck is rotated at high speed.

Step 2: Component fitted to stationary chuck is brought into contact under an axial force.

Step 3: As axial force is increased, the flash begins to form.

Step 4: Component fitted to rotating chuck comes to stop as the weld is completed.

The flash can subsequently be removed by machining or grinding.

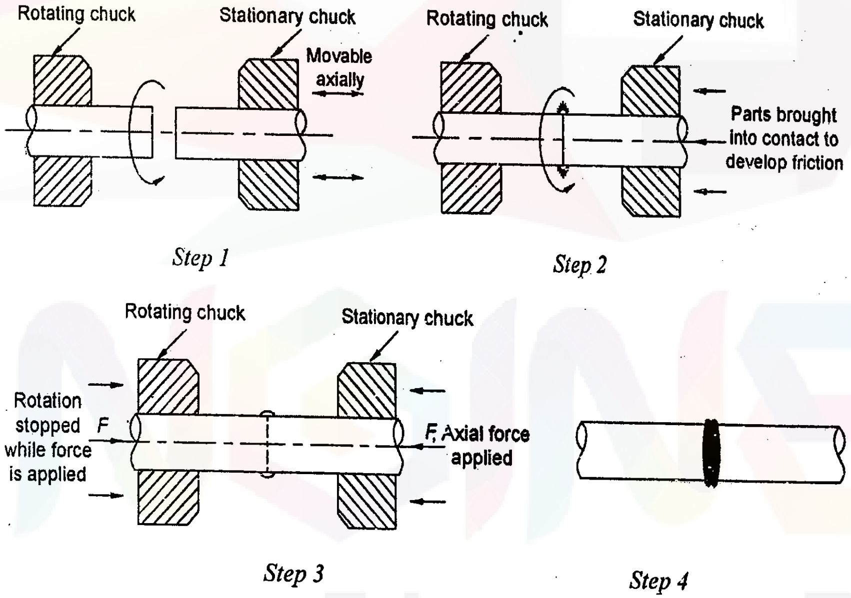

Figure 3.16 Sequence of operation in friction welding

3.6.2. Types of Friction Welding

There are three types of friction welding as follows:

(i) Continuous-drive or spin friction welding

(ii) Inertia friction welding

(iii) Linear friction welding.

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In *continuous-drive or spin friction welding*, one part is driven at constant *rpm* against stationary part to cause friction heat at interface. At proper temperature, the rotation is stopped and parts are forced together.

In *inertia friction welding*, the energy for frictional heating is supplied by the kinetic energy of a flywheel. Rotating part is connected to flywheel and it is brought up to the required speed. Then, flywheel is disengaged from drive, and spinning and stationary parts are pressed together by a normal force. As friction at the interface increases, it heats the surface. The axial force is then increased which slows down the flywheel. The weld is completed when the flywheel stops.

In *linear friction welding*, oscillating chuck is used. Figure 3.17 illustrated the principle of linear friction welding. In this process, parts are joined by a linear reciprocating motion. In this application, one part is moved across the face of the other part using a balanced reciprocating mechanism. It is used for non-round shapes as compared to spin welding. Material should be of high shear strength to carry out linear friction welding.

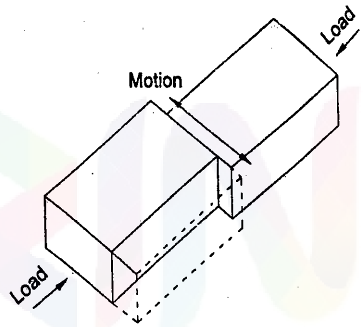

Figure 3.17 Linear friction welding

3.6.3. Process Parameters in Friction Welding

The process parameters involved in friction welding are as follows.

1. Power required (25*KVA* to 175 *KVA*),
2. Peripheral speed of the rotating component (1500 to 3000 *rpm*),
3. Axial pressure applied (40 *MPa* to 450 *MPa*), and
4. Time of duration of the operation (2 to 30 *sec*).

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By adjusting power required, peripheral speed and pressure applied, time can be reduced to the lowest possible value consistent with a good weld.

Shape of friction zone in friction welding as a function of the force applied and the rotational speed is shown in Figure 3.18.

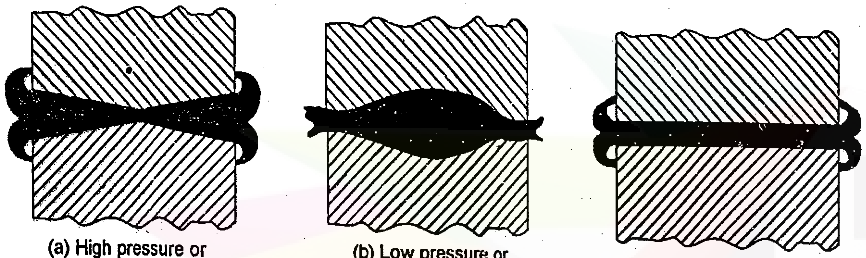

Figure 3.18 Shape of friction zone in friction welding

3.6.4. Difference between Friction Welding and Inertia Welding

S. No.	*Friction welding*	*Inertia welding*
1.	Power flows from electric motor.	Power flows from flywheel.
2.	Size of the motor limits the power.	Power is independent of the size of the motor.
3.	Heat is produced by sliding motion.	Heat is produced by intermolecular bonding.
4.	Friction speed is very important.	Speed of the flywheel is very important.

3.6.5. Control Systems in Friction Welding

1. Time control:

It is the control in which after a given set time period after contact of the faces, the rotation is stopped and forge pressure is applied.

2. Burn-off to length:

When the parts contact, heating and forging take place within a given pre-determined length through which the axially moving component moves.

3. Burn-off control:

A pre-determined shortening of the component is measured off by the control system when minimum pressures are reached.

4. Forging to length:

An axially moving work holder moves up to a stop during the forging operation irrespective of the state of the weld.

The basic joints are made by friction welding as follows:

1. Bar-belt joint
2. Bar-ball joint
3. Tee-butt joint.

3.6.6. Advantages, Limitations and Applications of Friction Welding

Advantages:

1. Power consumption is low.
2. The operation is easy and it uses simple equipment.
3. Parameters are easily determined.
4. Less time is required.
5. It is smooth and clean process.
6. Heat is quickly dissipated.
7. There is no need of using flux and filler metal.
8. There is no possibility of the driving unit stalling before the flywheel energy is dissipated.
9. It easily joins dissimilar metals.
10. The full surface of the cross section is made up of both metals, airtight and absent of voids.
11. Friction welds have higher strength than other means of joining.
12. Friction welds often cost less.
13. Friction welds minimize the Heat Affected Zone (HAZ) as compared to conventional flash welding.
14. Friction welding minimizes the need to clean furnace residues from the entire part during post welding.

15. Consistent and repetitive process of complete metal fusion occurs.
16. Joint preparation is minimal.
17. There is no distortion and warping.
18. It greatly increases design flexibility.
19. It is environmentally friendly process i.e. no fumes, gases or smoke generated.
20. It reduces machining labor thereby reducing perishable tooling costs while increasing capacity.
21. Full surface weld gives superior strength in critical areas.
22. It reduces raw material costs in bi-metal applications.
23. Reactive materials can be welded.

Limitations:

1. It is used only for joining small parts. Heavy components are not possible to weld.
2. There is a possibility of heavy flash out.
3. Heavy rigid machines are required due to high thrust pressure.
4. Process is restricted to flat and angular butt welds.
5. Only limited shapes of joints can be welded.
6. Equipment cost is high.
7. In case of tube welding process, the process becomes complicated.
8. In case of high carbon steels, it is difficult to remove flash.

Applications:

1. Because of high quality of the weld obtained, the process is widely accepted in aerospace and automobile industry for critical parts.
2. In aerospace industry, turbine blade joining, seamless joining etc. are produced using friction welding.
3. In automobile industry, bimetallic engine valve, axle shafts, universal joint yoke, gear hub etc. are produced using friction welding.
4. In consumer goods manufacturing, it is used for producing hand tools, sports equipment.
5. It is used in production cutting tools such as tapers, reamers and drills.
6. It is used for making simple forgings.

7. It is ideal for welding the spindles of the automobiles axle to its cage, welding piston eye to shaft and welding drill pipe to drill rod.

3.7. FORGE WELDING

Forge welding is a solid state welding process in which components to be joined are heated to red hot working temperature and then hammered them together. It may also consist of heating and forcing the metals together with presses or other means by creating enough pressure to cause plastic deformation at the weld surfaces. The process is one of the simplest methods of joining metals and it has been used since ancient times. The temperature required to forge weld is typically 50 to 90% of the melting temperature. Low carbon steel parts are heated to about 1000°*C*. Before forge welding is done, the parts are cleaned to prevent entrapment of oxides in the joint.

Forge welding is adaptable for being able to join a host of similar and dissimilar metals. Forge welding between similar materials is caused by a solid-state diffusion. It results in a weld that consists of only the welded materials without any filler or bridging materials. Forge welding between dissimilar materials is caused by the formation of a lower melting temperature eutectic between materials. Due to this, the weld is often stronger than the individual metals.

Forge welding is used in general blacksmith shops and for manufacturing metal art pieces and welded tubes. Mainly, automated forge-welding is a common manufacturing process in industries.

3.7.1. Materials Welded by Forge Welding Process

Many metals can be forge-welded such as high and low-carbon steels. Iron and hypoeutectic cast-irons can be forge-welded. Some aluminum alloys and copper-based alloys can also be forge-welded. Titanium alloys are commonly forge-welded.

3.7.2. Forge Welding Process

The oldest forge-welding process is the manual-hammering method. Manual hammering is done by heating the metal to the proper temperature, overlapping the weld surfaces and then striking the joint repeatedly with a hand-held hammer. The weld surfaces will be formed for the proper joint and then struck with a hammer to join them. The joint is often formed to allow space for the flux to flow out by beveling or rounding the surfaces slightly and hammered in a successively outward fashion to squeeze the flux out. The hammer blows are used not as hard as for shaping and preventing the flux from being flaming out of the joint at the first blow.

After developing mechanical hammers, forge welding could be accomplished by heating the metal and then placing it between mechanized hammer and anvil. Mechanical-hammers are operated by compressed air, electricity, steam, gas engines and many other means.

Another method of forge welding is done with a die in which the pieces of metal are heated and then forced into a die which provide both the pressure for the weld and keep the joint at the finished shape. Roll welding is another forge welding process where the heated metals are overlapped and passed through rollers at high pressures to create the weld.

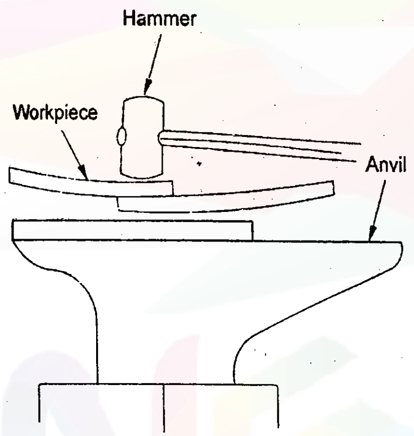

Figure 3.19 Manual forge welding process

Modern forge-welding is automated using computers, machines and sophisticated hydraulic-presses to produce a variety of products of various alloys. For example, the seam of a steel pipe is forge-welded during forming process. Diffusion bonding is a common method for forge welding titanium alloys in the aerospace industry. In this process, the metal is heated while under force of a press or die. Beyond a specific critical-temperature, the impurities burn out and the surfaces join. Another method is a flash welding. It is a resistance forge-welding technique where the press or die is electrified passing high current through the alloy to create the heat for the weld.

3.7.3. Flux used in Forge Welding Process

Flux is used to keep the welding surfaces from oxidizing which would produce a poor quality weld and to extract other impurities from the metal. The flux mixes with the oxides

that form and lowers the melting temperature and viscosity of oxides. It enables the oxides to flow out of the joint when two pieces are beaten together. A simple flux can be made from *borax*. Sometimes, they are made with the addition of powdered iron-filings. The oldest flux used for forge welding was *fine silica sand.*

Flux uses different combinations and various amounts of iron fillings, borax, ammoniac, balsam of copaiba, cyanide of potash and soda phosphate.

3.7.4. Advantages, Limitations and Applications of Forge Welding

Advantages:

1. Good quality weld may be obtained.
2. Parts of intricate shape may be welded.
3. No filler material is required.

Disadvantages:

1. Only low carbon steel may be welded.
2. High level of operator's skill is required.
3. Welding process is slow.
4. Weld may be contaminated by the coke used in a heating furnace.

Applications:

1. It is used in the production of pattern-welded blades.
2. It is used in the manufacture of shotgun barrels.
3. In some cases, the forge-welded objects are acid-etched to expose the underlying pattern of metal which is unique to each item and it provides aesthetic appeal.

3.8. ROLL WELDING

Roll welding is a solid state welding process in which pressure sufficient to cause coalescence is applied by means of rolls, as shown in Figure 3.20, either with or without external heat. If the welding is done without applying heat, it is called *cold roll welding* and if the heat is used for welding, it is called *hot roll welding*. This process is similar to forge welding except the pressure applied by means of rolls rather than by means of hammer blows. Coalescence occurs at the interface between two parts by means of diffusion at the faying surfaces. Parts to be welded should be ductile and free of work hardening. Before the welding is carried out, the surface to be joined should be cleaned. If the parts to be welded are small, the pressure applied by rolls is done by using simple hand operated tools. For heavier sizes of parts, power presses are used to apply pressure.

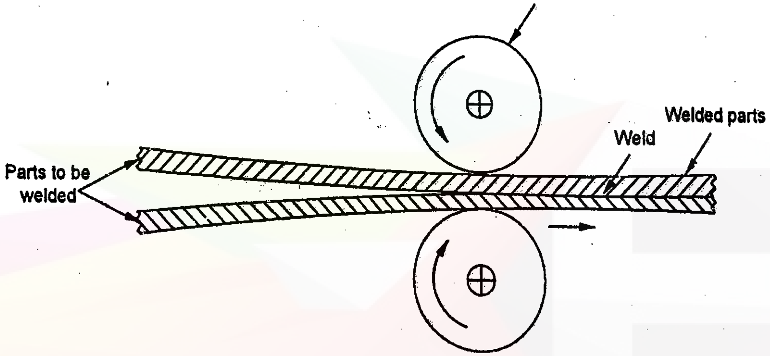

Figure 3.20 Principle of roll welding

One of the major uses of this process is the cladding of mild or low-alloy steel with a high-alloy material such as stainless steel. It is also used for making bimetallic materials for the instrument industry.

Advantages:

1. Metals such as soft aluminium, copper, gold and silver can be easily welded by roll welding.
2. The operation is easy and it uses simple equipment.
3. There is no need of using flux and filler metal.
4. Environmentally friendly process i.e. no fumes, gases, or smoke generated.
5. It is smooth and clean process.
6. Less time is required.

Limitations:

1. It needs extreme pressure to perform the welding process.
2. The cost of equipment is high.
3. Weld quality is less as compared to fusion welding.
4. It is limited to welding of flat shapes.

Applications:

1. It is used in cladding of stainless steel to mild steel for corrosion resistance.

2. It is used in making bimetallic strips.
3. Roll welding is used to produce sandwich strips to convert it into coins.

3.9. HOT PRESSURE WELDING PROCESS

Hot pressure welding is a solid state welding process which produces coalescence of materials with heat and the application of pressure sufficient to produce macro-deformation of the base metal. During welding, the coalescence occurs at the interface between parts because of pressure and heat applied to produce an appreciable/noticeable deformation. The deformation of surface crashes the surface oxide film and it increases the areas of clean metal. Welding this metal to the clean metal is accomplished by diffusion across the interface. Therefore, the coalescence of the faying surface occurs.

This type of operation is normally carried in closed chambers where vacuum or a shielding medium may be used. It is used primarily in the production of weldments for the aerospace industry. The variation in this process is the hot isostatic pressure. It means, the pressure is applied by means of a hot inert gas in a pressure vessel. Generally, heat is applied by flames of oxy-fuel torches directed on the end surfaces of solid bars or hollow sections to be joined.

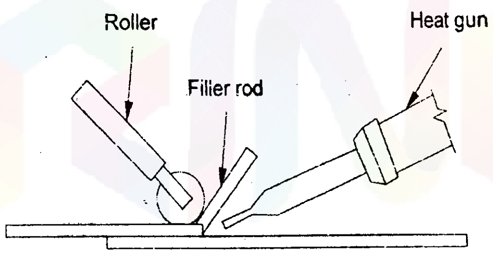

Figure 3.21 Principle of hot pressure welding

Hot-pressure-welding is similar to both friction welding and flash welding although the source of heating is different. The surfaces should be machined square and cleaned for obtaining the best results. Some beveling is used to control the amount of upset. The process can be performed by a manual operation.

The materials to be welded must exhibit hot ductility or forgeability. Therefore, cast iron cannot be hot pressure welded. The materials commonly joined by hot pressure welding are carbon steels, low alloy steels and certain nonferrous metals. Some dissimilar materials combinations are weldable by hot pressure welding.

Materials that immediately form on the surface adherent oxides upon heating are highly challengeable in air by this process. Aluminum alloys and stainless steels are carried in a vacuum chamber.

There are five cycles that hot pressure welding undergoes as follows (Figure 3.22).

(i) Cycle 1: Load phase

(ii) Cycle 2: Melt phase

(iii) Cycle 3: Open phase

(iv) Cycle 4: Seal phase

(v) Cycle 5: Unload phase.

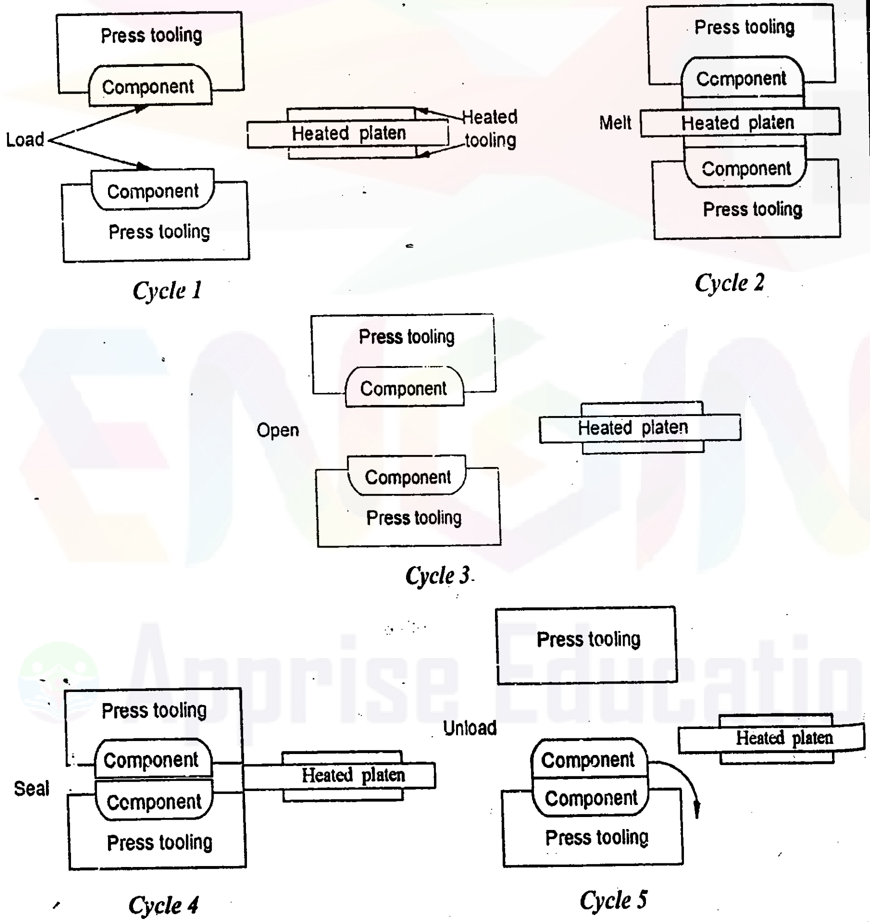

Figure 3.22 Cycles in hot pressure welding

Advantages:

1. Welding process is simple.
2. It needs simple joint preparation.
3. It is relatively low cost equipment.
4. It ensures quick weld production.
5. High quality joints are produced.
6. There is no filler metal needed.
7. Minimally skilled operators are required.

Limitations:

1. Not all metals are weldable.
2. It is not easily automated.
3. Length of cycle is dependent on time for heating.
4. Removal of flash and bulge are required after welding.
5. Only simple sections are readily butt weldable.

Applications:

1. It is used in aerospace industry.
2. It is used in plastic welding.
3. It is used for producing medical devices.
4. It is used in ship building.
5. It is used in automotive industries.

3.10. TWO MARK QUESTIONS AND ANSWERS

1. Define solid state welding.

Solid state welding is a group of welding processes which produces coalescence at temperature below the melting point of base materials being welded without the addition of brazing filler metal.

2. Classify solid state welding.

(i) Cold welding

(ii) Diffusion bonding

(iii) Explosive welding

(iv) Ultrasonic welding

(v) Friction welding

(vi) Forge welding

(vii) Roll welding

(viii) Hot pressure welding.

3. *Mention the advantages of solid state welding.*

1. The base metal does not melt and form a nugget.
2. The metals being joined retain their original properties. Hence, there is no heat-affected zone problems involved.
3. Metallurgical purity is maintained.
4. Dissimilar metals can be bonded.

4. *State the limitations and applications of solid state welding.*

Limitations:

1. Surface preparation is necessary.
2. Joint design is limited.
3. Elaborate and expensive equipment may be required.
4. Non-destructive inspection is very limited.
5. Equipment is expensive.

Applications:

1. Bonding of stainless steel liners in aluminum fry pans.
2. Aluminum cladding bonded to uranium fuel rods.
3. Ultrasonic and thermo-compression bonding in microelectronics industry.
4. Friction welding in aero-space and automotive applications.
5. Intake / exhaust automatic valves.

5. *What is meant by cold welding?*

Cold pressure welding is a form of solid phase welding which is unique because it is carried out at ambient temperature.

6. *Write down the characteristics of cold welding.*

(i) A cold weld is generally stronger than the parent material and has the same electrical characteristics.

(ii) At least one of the metals must be ductile without excessive work-hardening.

(iii) Total absence of applied heating occurs.

(iv) Surface preparation is important.

(v) Both workpieces can be similar or dissimilar metals.

(vi) Both workpieces should be cleaned.

(vii) Short sections on the workpieces should be sheared off.

7. *State any advantages and applications of cold welding.*

Advantages:

1. There are no thermal effects on the parts being joined and the process is fast.
2. As the process is performed at ambient temperature, there are no thermal effects on the parts being joined.

Applications:

1. It is used for joining of wire, foil to wire, wire to bi-metals and sealing of heat sensitive containers such as those containing explosives.
2. In the electronics industry, cold welding processes are used to seal tin plated steel crystal cans and copper packages for heat sensitive semiconductor devices.

8. *What are the disadvantages of cold welding?*

1. As the welds are made in the solid state, they are difficult to inspect.
2. The thickness of the parts is reduced significantly at the weld where the contact surfaces are sheared together.
3. It is highly specialized type of welding with respect to joint design and materials to be welded.
4. While the speed is an advantage to assemblers, it can also be a limitation.
5. When a body moving that fast meets another, it will try to displace it.

9. *What is diffusion welding?*

Diffusion welding is a solid state joining process in which the strength of the joint results primarily from diffusion.

10. *Write down the stages involved in diffusion welding.*

Stage 1: Deformation and interfacial boundary formation.

Stage 2: Grain boundary migration and pore elimination.

Stage 3: Volume diffusion pore elimination.

11. List down the process variables that affect diffusion welding process.

(i) Surface preparation

(ii) Temperature

(iii) Time

(iv) Pressure

(v) Special metallurgical effects

(vi) Use of interlayers.

12. Name the steps involved in surface preparation.

1. Generation of an acceptable finish or smoothness.
2. Removal of chemically combined films, oxides etc.
3. Cleansing of gaseous, aqueous or organic surface films.

13. Why is temperature the most considerable one in diffusion welding?

1. Temperature is always changing and relatively easy to measure and control.
2. Temperature change may greatly affect the results because of the nature of diffusion welding process and effects of temperature on plasticity, diffusivity, oxide solubility etc.
3. Temperature changes are relatively inexpensive and they will improve the economics of the operation by shortening cycles.
4. Other factors such as allotropic transformation, recrystallization, solution of precipitates and oxides are all temperature dependent and hence temperature must be controlled for varying these factors as desired.

14. What are the advantages of diffusion welding?

1. Plastic deformation at surface is minimal.
2. There is no limitation in the thickness of workpieces.
3. The bonded surface has the same physical and mechanical properties as the base material.
4. The diffusion bonding is able to help us to build high precision components with complex shapes. Also, the diffusion is flexible.

15. Mention the limitations of diffusion welding.

1. It is a time consuming process due to low productivity.

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2. Time required for diffusion can range from seconds to hours.
3. Very thorough surface preparation is required prior to welding process.
4. The mating surfaces must be precisely fitted to each other.
5. It is relatively high initial investments in equipment.

16. List down the applications of diffusion welding.

1. It is used in joining of high-strength and refractory metals based on titanium in aerospace and nuclear industries.
2. Diffusion welding is usually used on sheet metal structures such as nuclear and electronics industries.

17. Define explosive welding.

Explosive welding (EXW) is a solid state (solid-phase) welding process that uses a controlled application of large pressure generated by the detonation of applied explosives.

18. What are the variables which affect the size of explosives?

(i) Surface finish

(ii) Angle of inclination of tube and plate

(iii) Yield strength

(iv) Melting point of the materials

(v) Tube thickness, and

(vi) Diameter.

19. Name the types of explosive waves.

(i) Deflagration

(ii) Detonation.

20. Mention the applications of explosive welding.

1. This process is applied to welding of tubes and tube plates in heat exchangers, feedwater heaters and boiler tubes to clad tube plates.
2. The tubes may be of steel, stainless steel or copper, aluminium brass and bronze tubes in naval brass tube plates are welded.
3. It is used for manufacturing clad tubes and pipes, pressure vessels, aerospace structures, heat exchangers, bi-metal sliding bearings, ship structures and weld transitions.

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4. It is used to clad thick plates with corrosion resistant layers where other techniques (e.g. roll bonding) are not practical.
5. It is used in tube plugging.
6. It is used in remote joining in hazardous environments.
7. It is used in fixing cooling fins.
8. It is also used in cryogenic industries.

21. What is meant by ultrasonic welding?

Ultrasonic welding is a solid state welding process in which two work pieces are bonded as a result of a pressure exerted to welded parts combined with application of high frequency acoustic vibration (ultrasonic).

22. List down the components of ultrasonic equipment.

(i) Generator
(ii) Machine press
(iii) Welding stack
(iv) Transducer
(v) Booster
(vi) Welding horn
(vii) Support tooling.

23. How is energy required for ultrasonic welding calculated?

Energy required to weld a given workpieces by ultrasonic welding increases with material hardness and thickness. The relationship for spot welding can be written as

$$E_a = 63(Ht)^{3/2}$$

where E_a = Acoustical energy in joule

H = Vicker's micro-hardness number

t = Material thickness adjacent to active in inches.

This equation holds good for aluminium, steel, nickel and copper for the thickness upto 0.81 *mm*.

24. State the applications of ultrasonic welding.

1. Ultrasonic welding is used mainly for bonding small work pieces in electronics, manufacturing communication devices, medical tools and watches.

2. It is used in automotive, medical and toy production.
3. It is used in health care industries due to clean welds.
4. Ring-type continuous welds can be used for hermetic sealing.
5. It is used in sealing and packaging, aircraft, missiles and fabrication of nuclear components.

25. What do you infer about friction welding?

Friction welding is a solid state welding process in which coalescence is achieved by frictional heat combined with pressure.

26. Write down the materials which can be welded by friction welding.

1. Brass and Bronze
2. Copper and Nickel
3. Lead
4. Ceramics
5. Titanium alloys
6. Stainless steel
7. Tungsten
8. Vanadium
9. Aluminium and aluminium alloys
10. Magnesium alloys.

27. Write down the sequence in friction welding.

The sequence of operation in the friction welding process is as follows:

Step 1: Component fitted to rotating chuck is rotated at high speed.

Step 2: Component fitted to stationary chuck is brought into contact under an axial force.

Step 3: As axial force is increased, the flash begins to form.

Step 4: Component fitted to rotating chuck comes to stop as the weld is completed.

28. Classify friction welding.

(i) Continuous-drive or spin friction welding
(ii) Inertia friction welding
(iii) Linear friction welding.

29. List down the parameters which affect ultrasonic welding.

1. Power required (25*KVA* to 175 *KVA*),
2. Peripheral speed of the rotating component (1500 to 3000 *rpm*),
3. Axial pressure applied (40 *MPa* to 450 *MPa*), and
4. Time of duration of the operation (2 to 30 sec).

30. Differentiate between friction welding and inertia welding.

S. No.	Friction welding	Inertia welding
1.	Power flows from electric motor.	Power flows from flywheel.
2.	Size of the motor limits the power.	Power is independent of the size of the motor.
3.	Heat is produced by sliding motion.	Heat is produced by intermolecular bonding.
4.	Friction speed is very important.	Speed of the flywheel is very important.

31. What are the control parameters used in friction welding?

1. Time control
2. Burn-off to length
3. Burn-off control
4. Forging to length.

32. Note down the advantages of friction welding.

1. Power consumption is low.
2. The operation is easy and it uses simple equipment.
3. Parameters are easily determined.
4. Less time is required.
5. It is smooth and clean process.
6. Heat is quickly dissipated.

33. Mention the limitations of friction welding.

1. It is used only for joining small parts. Heavy components are not possible to weld.
2. There is a possibility of heavy flash out.

3. Heavy rigid machines are required due to high thrust pressure.
4. Process is restricted to flat and angular butt welds.

34. State the applications of friction welding.

1. Because of high quality of the weld obtained, the process is widely accepted in aerospace and automobile industry for critical parts.
2. In aerospace industry, turbine blade joining, seamless joining etc. are produced using friction welding.
3. In automobile industry, bimetallic engine valve, axle shafts, universal joint yoke, gear hub etc. are produced using friction welding.
4. In consumer goods manufacturing, it is used for producing hand tools, sports equipment.

35. Define forge welding.

Forge welding is a solid state welding process in which components to be joined are heated to red hot working temperature and then hammered them together.

36. What are the materials welded by forge welding process?

Many metals can be forge-welded such as high and low-carbon steels. Iron and hypoeutectic cast-irons can be forge-welded. Some aluminum alloys and copper-based alloys can also be forge-welded. Titanium alloys are commonly forge-welded.

37. Note down the applications of forge welding.

1. It is used in the production of pattern-welded blades.
2. It is used in the manufacture of shotgun barrels.
3. In some cases, the forge-welded objects are acid-etched to expose the underlying pattern of metal which is unique to each item and it provides aesthetic appeal.

38. How can we define the term "Roll welding"?

Roll welding is a solid state welding process in which pressure sufficient to cause coalescence is applied by means of rolls either with or without external heat.

39. Mention any two advantages and limitations of roll welding.

Advantages:

1. Metals such as soft aluminium, copper, gold and silver can be easily welded by roll welding.
2. The operation is easy and it uses simple equipment.

Limitations:

1. It needs extreme pressure to perform the welding process.
2. The cost of equipment is high.

40. What are the applications of roll welding?

1. It is used in cladding of stainless steel to mild steel for corrosion resistance.
2. It is used in making bimetallic strips.
3. Roll welding is used to produce sandwich strips to convert it into coins.

41. What is hot pressure welding?

Hot pressure welding is a solid state welding process which produces coalescence of materials with heat and the application of pressure sufficient to produce macro-deformation of the base metal.

42. Mention the various applications of hot pressure welding.

1. It is used in aerospace industry.
2. It is used in plastic welding.
3. It is used for producing medical devices.
4. It is used in ship building.
5. It is used in automotive industries.

3.11. SOLVED QUESTIONS AND ANSWERS

1. Explain the principle of solid state welding with a neat sketch.

   Refer chapter **3.1** in page **3.1**.

2. Discuss the working principle of cold welding process with their sketches.

   Refer chapter **3.2** in page **3.3**.

3. Describe the principle involved in diffusion welding.

   Refer chapter **3.3** in page **3.8**.

4. Discuss the various stages in diffusion welding with their neat sketches.

   Refer chapter **3.3.1** in page **3.10**.

5. What are the process parameters involved in diffusion welding and explain in detail.

   Refer chapter **3.3.2** in page **3.10**.

6. Discuss how explosive welding process is carried out.

   Refer chapter **3.4** in page **3.16**.

7. Enumerate the working of ultrasonic welding with a neat sketch.

   Refer chapter **3.5.2** in page **3.26**.

8. Explain the working of wedge-reed ultrasonic welding system.

   Refer chapter **3.5.3** in page **3.27**.

9. Write short notes on welding parameters in ultrasonic welding.

   Refer chapter **3.5.4** in page **3.28**.

10. Explain how energy required for ultrasonic welding is calculated.

    Refer chapter **3.5.5** in page **3.29**.

11. Write short notes on design recommendations for ultrasonic welding of plastics.

    Refer chapter **3.5.6** in page **3.30**.

12. What is friction welding? Give their advantages and limitations.

    Refer chapter **3.6** in page **3.32**.

13. Describe with neat sketches various sequence in friction welding.

    Refer chapter **3.6.1** in page **3.34**.

14. Explain process parameters involved in friction welding.

    Refer chapter **3.6.3** in page **3.35**.

15. Describe forge welding process with a neat sketch.

    Refer chapter **3.7.2** in page **3.39**.

16. Explain the principle of roll welding with a neat sketch.

    Refer chapter **3.8** in page **3.41**.

17. Enumerate the principle of hot pressure welding with a neat sketch.

    Refer chapter **3.9** in page **3.43**.

END of Unit 3

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UNIT – 4

OTHER WELDING PROCESSES

Thermit welding, Atomic hydrogen welding, Electron beam welding, Laser Beam welding, Friction stir welding, Under Water welding, Welding automation in aerospace, nuclear and surface transport vehicles.

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4

OTHER WELDING PROCESSES

4.1. THERMIT WELDING

Thermit or alumino-thermic is the name given to a mixture of finely divided metal oxide and aluminum powder. It is a mixture of aluminium and iron oxide in the ratio of 1:3. *Thermit welding* is a welding process utilizing heat generated by exothermic chemical reaction between components of the Thermit. The molten metal produced by the reaction acts as a filler material and joins the workpieces after solidification. The welding principle is the heat of the Thermit reaction used for welding in plastic state and mechanical pressure is applied for the joint.

Thermit welding is a fusion welding process. In this process, neither arc is produced to heat parts nor flames are used. For getting high temperature, the exothermic reaction is used. To obtain exothermic reaction, the commonly utilizing composition of iron oxide red powder (Fe_3O_4) with aluminium powder (Al) gives aluminium oxide powder (Al_2O_3) and iron (Fe). To heat the metal, it requires no external source of heat or current. The intense heat is released because of the chemical action not only melt the iron but also it raises the molten metal to a temperature of about 2800°C. Molten metal obtained by Thermit reaction is poured into the refractory cavity made around the joint. The aluminium oxide floats at the top of the molten metal as a slag. The crucible is then tapped and the superheated metal runs around the parts to be welded which are contained in a mould. The high temperature of iron results in excellent fusion with the parts to be welded.

Quality of welding is depending on the chemical reaction between iron oxide and aluminium. The reaction in Thermit welding is given by the following eauation.

$$8Al + 3Fe_3O_4 = 4Al_2O_3 + 9Fe + \text{Heat}$$

This reaction takes place about 30 *seconds* only and the heat liberation temperature is about 2800°*C*. It is twice the melting temperature of steel.

The ends which are to be welded are thoroughly cleaned of scale and rust so that there is a gap between them for the molten metal to penetrate well into the joint. If the parts are thick, the mould cavity may be preheated to improve welding and dry the mould. Other thermit mixtures are aluminium and copper oxide (for welding copper cables). It is similar to a casting process.

Figure 4.1 illustrates the arrangement of various components of thermit welding process.

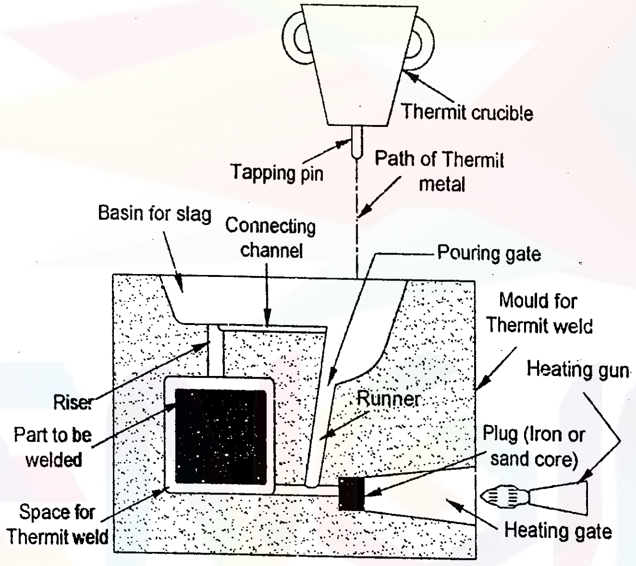


Figure 4.1 Thermit welding

4.1.1. Mould Preparation

The following steps are carried to prepare the mould for thermit weld.

1. Wax is poured in the joint and wax pattern is formed where the weld is to be obtained.
2. A moulding flask is kept around the joint and sand is rammed carefully around the wax pattern.
3. Pouring basin, sprue and riser are made.

4. A bottom opening is provided to run off the molten wax.
5. The wax is melted through the opening at the bottom which is used to preheat the joint and make it ready for welding.
6. The igniting mixture (barium peroxide or magnesium) is placed at the top of the Thermit mixture and is ignited by means of a heated rod or acetylene gas.
7. Complete reaction takes place and molten metal is produced.
8. Strength of Thermit welded joint is same as forged metal without any defects.

4.1.2. Classification of Thermit Welding

Thermit welding process is classified into the following two types.

1. Pressure welding process
2. Non pressure welding process.

1. Pressure welding process:

During pressure welding process, the parts to be welded are butted and enclosed in a mould. The mould can be easily removed after welding the metals. First, the heated iron slag is poured to the mould and the aluminium oxide is poured on the parts to be welded. It will create the heating of parts and then the pressure is applied on the workpiece to join.

2. Non-pressure welding:

In this process, the parts to be welded are lined up in parallel and a groove is taken in the parts. The wax pattern is formed in and around the welding parts. Then sand is rammed around the wax pattern and mould is completed with gate, runner and riser around the joint area. Then the mould is heated and wax is melted, it will give a space between joints. Finally, the heated iron slag and aluminium are poured into mould after solidification of liquid metal. Thus, the joint is made without the application of pressure.

4.1.3. Operation of Thermit Welding

The edges of the workpiece are cut flat and cleaned to remove dirt, grease and other impurities to obtain a sound weld. A gap of about 1.5 - 6 *mm* is left between edges of the two workpieces. A wax heated to its plastic state is poured in the gap between workpieces to be joined and allowed to solidify. Excess wax solidified around the joint is removed. A mould box is placed around the joint and packed with sand providing necessary gates and risers. A hole or heating gate is made in the mould connecting to the joint.

The wax material is melted out by means of a flame directed into the heating gate so that it leaves a cavity at the joint which will later be occupied by the molten metal. The heating gate is then closed with a sand core or iron plug.

Thermit is placed in a furnace and it is ignited. So, the chemical reaction takes place. Due to this, liquid and slag are formed. Exothermic reaction occurs to form molten iron and slag which floats at the top. The temperature resulting from this reaction is approximately 2500°C. The plug at the bottom of the crucible is opened and the molten metal is poured into the cavity. The molten metal acts as a filler metal, melts the edges of the joint and fuses to form a weld. After the weld joint cools and solidifies, the mould is broken, risers are cut and the joint is finished by machining and grinding.

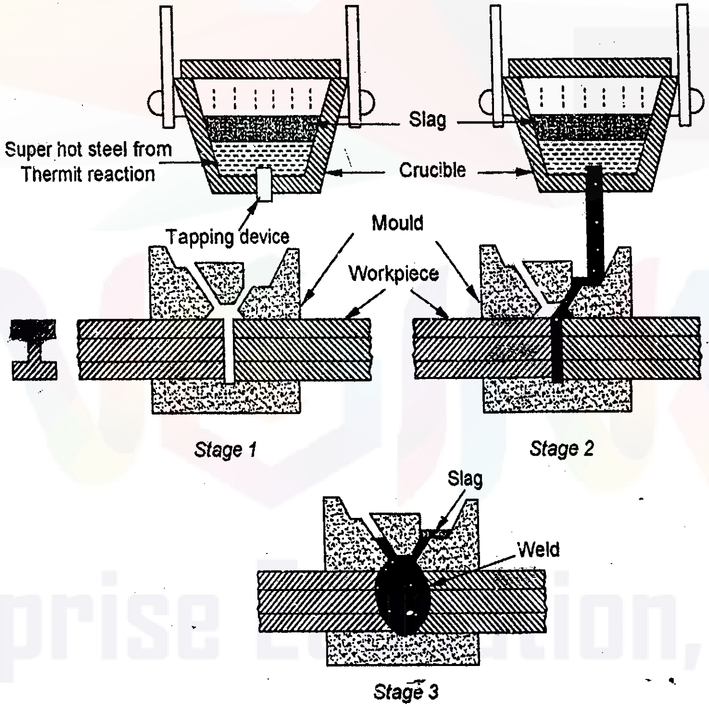


Figure 4.2 Stages in Thermit welding

Various stages in Thermit welding are shown in Figure 4.2.

1. Thermit is ignited.
2. Crucible is tapped, and superheated metal flows into mould.
3. Metal solidifies to produce weld joint.

Advantages:

1. No external power source is required (Heat of chemical reaction is utilized).
2. Very large heavy section parts may be joined.
3. The process uses simple and inexpensive equipment.
4. The process is best suitable particularly in remote locations where sophisticated welding equipment and power supply cannot be arranged.
5. It can weld complex shapes.

Limitations:

1. It is not possible for low melting points.
2. Only ferrous (steel, chromium, nickel) parts may be welded.
3. High skill operators are required.
4. Welding rate is slow.
5. It reduces the risks to operate.
6. Deposition rate is low.
7. High temperature process may cause distortions and it changes the grain structure in the weld region.
8. Weld may contain gas (Hydrogen) and slag contaminations.
9. High level of fume occurs.

Applications:

1. This process is used for welding of damaged wobblers and large broken crankshafts.
2. It is used in steel rolling mills.
3. It is used to restore the broken teeth on gears.
4. It is used to weld non-ferrous metals.
5. Joints in pipes, rails, shafts are made in this process.
6. Automobile parts are welded by this process.
7. It is used in welding and repairs of large forgings, and broken castings.
8. It is used in welding of thick structural sections.
9. It is used in rail repairs and joining tracks on site.
10. It is used in welding cable conductors.

4.2. ATOMIC HYDROGEN WELDING

Atomic Hydrogen Welding (AHW) is a combination of electric arc and gas welding technique. It is a thermo-chemical arc welding process in which the workpieces are joined by heat obtained on passing a stream of hydrogen through an electric arc struck between two tungsten electrodes.

The arc supplies the energy for a chemical reaction to take place. During the process, more heat is released due to exothermic reaction. The electric arc efficiently breaks up the hydrogen molecules which recombine with tremendous release of heat with the temperature from 3400 to 4000°*C*. Without the arc, an oxy-hydrogen torch can only reach 2800°*C*. It is the third hottest flame after dicyanoacetylene at 4987°*C* and cyanogen at 4525°*C*. An acetylene torch merely reaches 3300°*C*. This device is called an *atomic hydrogen torch* or *nascent hydrogen torch* or *Langmuir torch*. The process was also known as *arc-atom welding*. Filler rod may or may not be used during welding process.

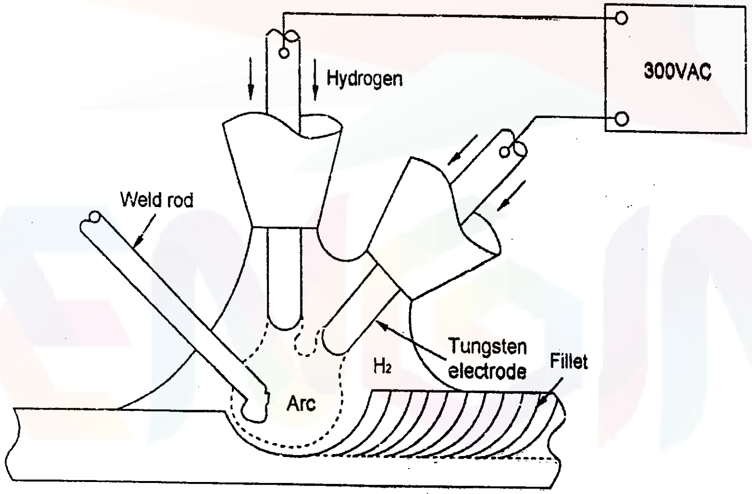


Figure 4.3 Principle of atomic hydrogen welding

The heat produced by this torch is sufficient to weld tungsten (3422°*C*) and most of the refractory metal. Hydrogen gas acts as a heating element as well as it acts as shielded gas to protect the molten liquid metal from oxidation and contamination by carbon, nitrogen or oxygen which can severely damage the properties of many metals. It eliminates the need of flux for this purpose.

The arc is independently maintained for the workpiece or parts being welded. The hydrogen gas is normally diatomic (H_2) but where the temperatures are over 6000°*C* near the arc. When the hydrogen strikes a relatively cold surface, it will recombine into its diatomic form releasing the energy associated with the formation of bond. The energy in AHW can easily be varied by changing the distance between arc stream and workpiece surface. This process is being replaced by gas metal-arc welding mainly because of the availability of inexpensive inert gases.

In this process, arc is maintained entirely independent of the work or parts being welded. The work is a part of the electrical circuit only to the extent that a portion of the arc comes in contact with the work at which time a voltage exists between work and each electrode.

It differs from shielded metal arc welding in which the arc is independent of base metal making electrode holder as a mobile without arc getting extinguished. Thus, heat input to the weld could be controlled by manually to control weld metal properties.

The process has the following special features.

- High heat concentration is obtained.
- Hydrogen acts as a shield against oxidation.
- Filler metal of base composition could be used.
- Most of its applications can be met by MIG process. Therefore, it is not commonly used.

4.2.1. Working of Atomic Hydrogen Welding

The equipment consists of a welding torch with two tungsten electrodes inclined and adjusted to maintain a stable arc as shown in Figure 4.4. Annular nozzles around the tungsten electrodes carry the hydrogen gas supplied from gas cylinders.

AC power source is suitable as compared to DC because equal amount of heat will be available at both electrodes. A transformer with an open circuit voltage of 300 *V* is required to strike and maintain the arc.

The workpieces are cleaned to remove dirt, oxides and other impurities to obtain a sound weld. Hydrogen gas supply and welding current are switched ON. An arc is struck by bringing two tungsten electrodes in contact with each other and instantaneously separated by a small distance of 1.5 *mm*. Therefore, the arc still remains between two electrodes.

As the jet of hydrogen gas is passed through the electric arc, it disassociates into atomic hydrogen by absorbing large amounts of heat supplied by the electric arc.

H_2àßH + H = 422 *kJ* (Endothermic Reaction)

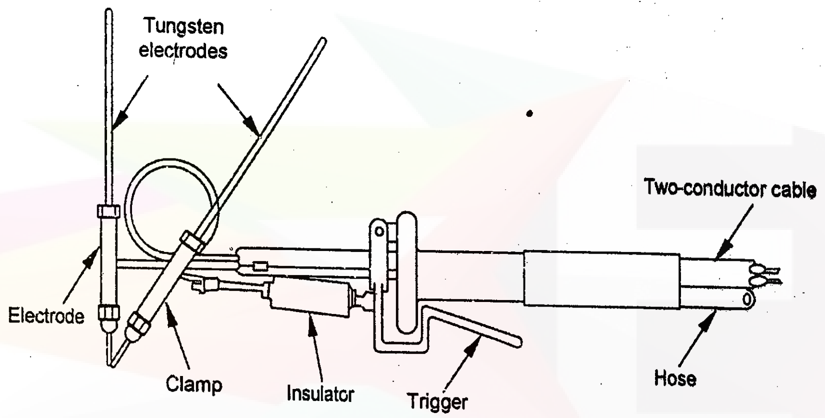


Figure 4.4 Schematic of atomic hydrogen welding

Thus, the heat absorbed can be released by recombination of hydrogen atoms into hydrogen molecule (H_2). Recombination takes place as the atomic hydrogen touches the cold workpiece liberating a large amount of heat.

$H + H$ à H_2 + 422 *kJ* (Exothermic reaction)

4.2.2. Advantages, Limitations and Applications of Atomic Hydrogen Welding

Advantages:

1. Welding process is faster.
2. During the process, intense flame is obtained which can be concentrated at the joint. Hence, less distortion occurs.
3. There is no requirement of separate flux and shielding gas or flux. The hydrogen envelop itself prevents oxidation of the metal and tungsten electrode. It also reduces the risk of nitrogen pick-up.
4. Workpiece do not form a part of the electric circuit. Hence, problems such as striking the arc and maintaining the arc column are eliminated.
5. Welding of thin materials is also possible which may not be successfully carried out by metallic arc welding.

6. The workpiece does not form a part of the electrical circuit. The arc remains between two tungsten electrodes and it can be moved to other places easily without getting extinguished.

Limitations:

1. The cost of welding is high when compared to the other process.
2. Welding process is limited to flat positions only.
3. The process cannot be used for depositing large quantities of metals.
4. Welding speed is less when compared to metallic arc or MIG welding.

Applications:

1. These welding processes are used in welding of tool steels which contains tungsten, nickel and molybdenum.
2. They are used in joining parts, hard surfacing and repairing of dies and tools.
3. Atomic hydrogen welding is used where rapid welding is necessary in stainless steels, non-ferrous metals and other special alloys.

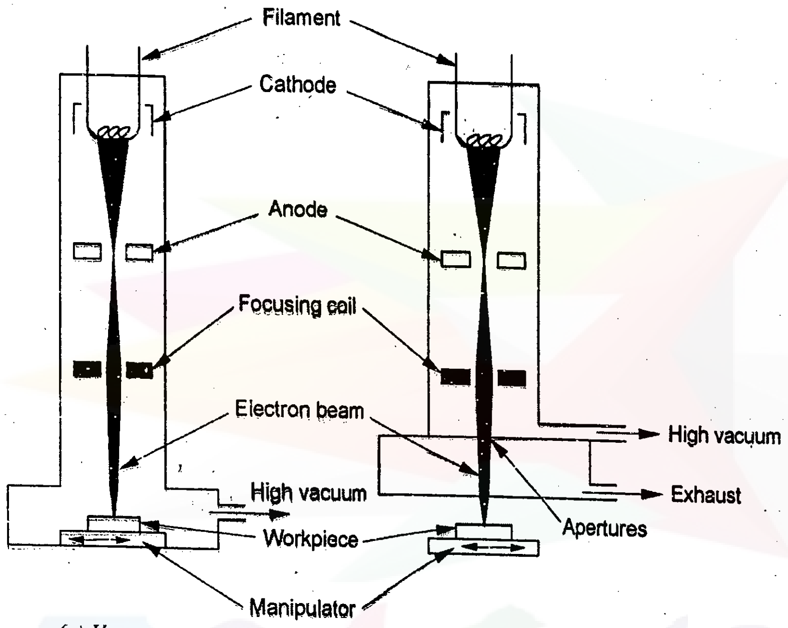
4.3. ELECTRON BEAM WELDING (EBM)

Electron Beam Welding (EBW) is a fusion welding process in which a beam of high-velocity electrons is used for producing high temperatures and melting the workpiece to be welded. The electrons strike the workpiece and their kinetic energy is converted into thermal energy by releasing heat which is used to heat the metal so that the edges of workpiece are fused and joined together forming a weld.

4.3.1. Working Principle

If a filament of tungsten or tantalum is heated to high temperature in a vacuum either directly by means of an electric current or indirectly by means of an adjacent heater, a great number of electrons are given off from the filament. These electrons carry a negative charge which is passed through the anode hole. The greater is the filament current, the higher will be the temperature and greater will be the electron emission.

If a metal disc with a central hole is placed near the filament and charged to a high positive potential relative to the filament, the emitted electrons are attracted to the disc because of their kinetic energy pass through the hole as a divergent beam. So, the filament is the cathode and the disc is the anode. The electron beam is focused by the focusing lens. The focus is done electrostatically or magnetically by means of coils situated adjacent to the beam and through which a current is passed. The beam is now convergent and it can be spot focused. The basic arrangement of an electron 'gun' is done which is similar to television tubes and electron microscopes.



(a) Vacuum (b) Atmosphere

Figure 4.5 Electron beam welding

When the focused electron beam strikes the workpiece, the kinetic energy of this electron beam is converted into heat energy. This heat energy is used to weld the metals. The kinetic energy of an electron is $mV^2/2$,

where m is the mass of an electron (9.1×10^{-28} g)

V is its velocity.

The electron mass m is small but increasing the emission from the filament by raising the filament current increases the number of electrons and hence, it produces the mass effect because the kinetic energy varies directly as the square of the velocity V, accelerating the electrons up to velocities comparable with the velocity of light by using anode voltages (up to 200 kV), greatly increases the beam energy. The smaller the spot into which the beam is focused, greater will be the energy density. So, it is possible to weld holes. The beams are

focused about 0.25 mm to 1mm diameter and the power density is of 10 kW/mm^2. Aluminium material has focusing length of about 40mm and steel has about 30 mm.

Accelerating voltage is in the range of 20-200 kV and welding current is about a few milliamperes. As the accelerating voltage is increased, the intensity of X-rays emitted from anode increases. Focusing coils can concentrate the beam on a spot of a few micron in diameter. With this concentrated spot, there is a threshold voltage above which the beam penetrates the metal and when the work is traversed relative to the beam. A weld bead of narrow width relative to the plate thickness is formed.

When the beam strikes a metal surface X-rays are generated, adequate precautions must be taken for screening personnel from rays. If the beam emerges into the atmosphere, energy is reduced by collision of electrons with atmospheric molecules and focus is impaired. Hence, the operation is carried out in vacuum. The vacuum may be created either in the gun chamber or in a separate steel component chamber fixed to the gun chamber. Welding in non-vacuum atmospheric conditions requires much greater power than the vacuum method because of the effects of the atmosphere on the beam and the greater distance from gun to work. A shielding gas may be required around the weld area.

Welds made with this process on thicker sections are narrow with deep penetration with minimum thermal disturbance. At present, welds are performed in titanium, niobium, tungsten, tantalum, beryllium, nickei alloys (e.g. nimonic), inconel, aluminium alloys and magnesium, mostly in the aero and space research industries.

The variables which are controlled in the electron beam welding are as follows:

1. Voltage
2. Speed
3. Distance between beam gun and workpiece.

4.3.2. Vacuum Levels in EBW

There are three levels of vacuum levels in EBW as follows:

1. High-vacuum welding:

Welding is carried out in the same vacuum chamber as the beam generation is to produce the highest quality weld.

2. Medium-vacuum welding:

Welding is done in a separate chamber but partial vacuum reduces pump-down time.

3. Non-vacuum welding:

Welding is done at or near atmospheric pressure with work positioned close to electron eam generator. It requires vacuum divider to separate work from beam generator.

4.3.3. Advantages, Limitations and Applications of EBW

Advantages:

1. High quality weld is produced.
2. Deep welding is possible.
3. Clean and bright weld can be obtained.
4. High speed operation can be achieved.
5. Dimensional accuracy is good.
6. Energy loss is very less.
7. Very small part can be welded.
8. There is no need of using electrodes.
9. High-quality welds, deep and narrow profiles are produced.
10. It has limited heat affected zone and low thermal distortion.
11. Accurate control over welding conditions is possible by control of electron emission and beam focus.
12. No flux or shielding gases is needed.
13. Filler metal is not required.
14. Because of the vacuum conditions, it is possible to weld more reactive metals successfully.
15. This type of weld is more suitable for welding dissimilar materials.
16. Tight continuous weld can be produced.

Limitations:

1. The welding cost is high.
2. Skilled persons are required.
3. It is limited to small size welding.
4. Welding should be carried out in vacuum seal only.
5. It is a time consuming process.

6. The weld suffers from contamination if it is performed in atmospheric condition.
7. Precise joint preparation and alignment are required.
8. X-ray irradiation occurs.
9. As EBW generates X-rays there must be protection against radiation hazards.

Applications:

1. Dissimilar metals can be welded.
2. Refractory and reacting metals can be welded.
3. It is used in aircrafts, missile, nuclear component, gears and shafts.
4. It is suitable for large scale.
5. It is used in cams.

4.4. LASER BEAM WELDING (LBM)

The word laser stands for Light Amplification by the Stimulated Emission of Radiation (LASER). It is stronger coherent monochromatic beam of light which can be highly concentrated with a very small beam divergence.

The focused laser beam has the highest energy concentration of any known source of energy. The laser beam is a source of electromagnetic energy or light that can be projected without diverging and it can be concentrated to a precise spot. The beam is coherent which is of a single frequency.

The coherent light emitted by the laser can be focused and reflected in the same way as a light beam. The focused spot size is controlled by a choice of lenses and the distance from it to the base metal. The spot can be made as small as 0.076 *mm* to large areas 10 times as big. A sharply focused spot is used for welding and cutting operations. The large spot is used for heat treating. Laser welding is suitable for welding deep in narrow joints with depth-to-width ratio ranging from 4 to 10.

Laser beam welding (LBW) is a welding process which produces coalescence of materials with the heat obtained from the application of a concentrated coherent light beam impinging upon the surfaces to be joined. It is a non-contact process that requires access to the weld zone from one side of the parts being welded. It is also a thermoelectric process accomplished by material evaporation and melting.

Laser-beam welding (LBW) utilizes a laser beam as the heat source. Light energy is converted into heat energy. Here, the light energy is produced from the laser source such as ruby rod in the form of monochromatic light. If the beam can be focused onto small area, it has high energy for deep penetrating capability. Beam focusing is achieved by various lens arrangements because this focusing ensures high density which can be achieved by laser beams. LBW does not require a vacuum chamber. So, Heat Affected Zone (HAZ) is smaller and thermal damage to the adjacent part is negligible.

4.4.1. Working Principle

The working principle of a laser welder is shown in Figure 4.6. An intense green light is made to fall on a special man-made ruby of 10 *mm* in diameter having 0.05% by weight of chromium oxide. The green light pumps the chromium atoms to a higher state of energy. Each excited atoms emits red light which is in phase with colliding red light wave.

The red light gets continuously amplified. The parallel ends of the rod are mirrored to enhance and bounce the red light back and forth within the rod. After reaching the critical intensity, the chain reaction of collisions becomes strong enough to cause a burst of red light. The mirror at the front of the rod is only a partial reflector which allows the burst of light to escape through it. Due to electrical discharge from capacitors, the flash tube converts the electrical energy into light flashes. When ruby rod is exposed to the intense light flash, the chromium atoms of crystal excited and pumped to a high energy level beam. This high energy level is immediately reduced to intermediate and dropped to original state with the evolution of red fluorescent light.

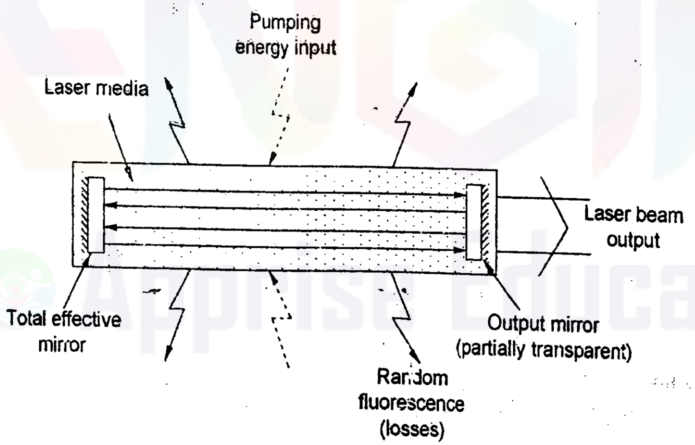


Figure 4.6 Principle of laser

The laser light is not only intense but also can be readily focused without loss of intensity. The laser light is focused by the focusing lens to the workpiece in the form of coherent monochromatic light as shown in Figure 4.7. When this light energy is impacted to the workpiece, it will convert into heat energy. This heat energy is sufficient to melt the materials to be welded.

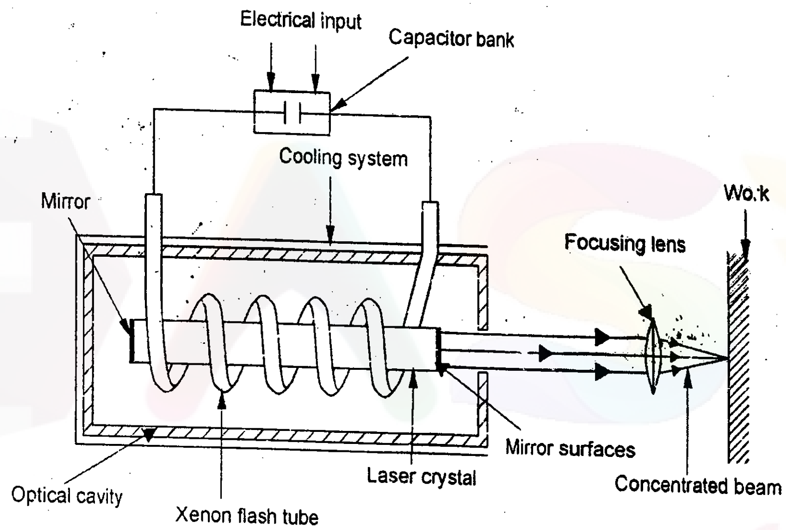


Figure 4.7 Laser beam welding

The schematic of laser beam welding is shown in Figure 4.8 below.

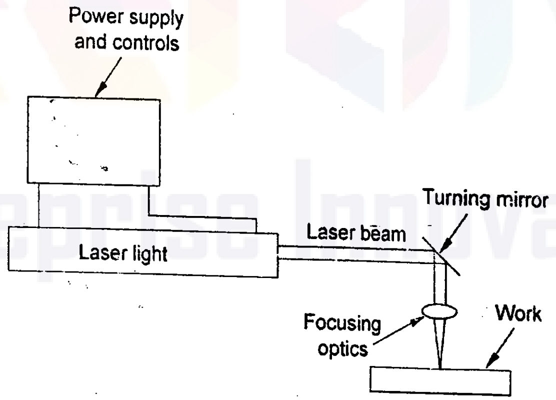


Figure 4.8 Schematic of laser welding set up

4.4.2. Laser Beam Welding Characteristics

The welding characteristics of the laser and electron beam are similar. The concentration of energy by both beams is similar with the laser having a power density in the order of $10^6 W/cm^2$. The power density of the electron beam is only slightly greater. It is compared to a current density of only 10^4 W/cm^2 for arc welding. Power level is up to $100 kW$. Welding speed is up to $250 ft/min$. It can weld the foil up to 1 *inch* plate.

Lasers are used for materials that are difficult to weld using other methods, hard to access areas and extremely small components. Inert gas shielding is needed for more reactive materials.

Laser beam welding has a tremendous temperature differential between molten metal and base metal immediately adjacent to the weld. Heating and cooling rates are much higher in laser beam welding than arc welding and heat-affected zones are much smaller.

4.4.3. Primary Types of Lasers used in Welding

The various laser forms that are generally used are as follows:

1. Liquid laser
2. Gas laser
3. Carbon dioxide laser
4. Solid-state laser
5. Ruby laser, and
6. Semi-conductor laser.

(i) Liquid laser:

A liquid-crystal laser is a laser that uses a liquid crystal as the resonator cavity to allow the selection of emission wavelength and polarization from the active laser medium. The lasing medium is usually a dye dopped into the liquid crystal. The tuning range is several tens of nanometers. Self-organization at micrometer scales reduces manufacturing complexity compared to using layered photonic meta-materials. Operation may be either in continuous wave mode or pulsed mode.

(ii) Gas lasers:

A mixture of gases is used such as helium and nitrogen. There is also carbon dioxide (CO_2) laser. These lasers use a low-current, high-voltage power source to excite the gas mixture using a lasing medium. They are operated in a pulsed or continuous mode.

(iii) Carbon dioxide lasers:

They use a mixture of high purity carbon dioxide with helium and nitrogen as the lasing medium. CO_2 lasers are also used in dual beam laser welding where the beam is split into two equal power beams.

(iv) Solid state lasers:

YAG type and ruby lasers operate at 1 *micrometer* wavelengths. They can be pulsed or operate continuously. Pulsed operation produces joints similar to spot welds but with complete penetration. The pulse energy is 1 to 100 *J*. Pulse time is 1 to 10 *milliseconds*.

(v) Ruby lasers:

A ruby laser is a solid-state laser that uses a synthetic ruby crystal as its gain medium. Ruby lasers produce pulses of coherent visible light at a wavelength of 694.3 *nm* which is a deep red color. Typical ruby laser pulse lengths are on the order of a millisecond.

(vi) Semiconductor lasers:

Semiconductor lasers are lasers based on semiconductor gain media where the optical gain is usually achieved by stimulated emission at an inter-band transition under conditions of a high carrier density in the conduction band. They consist of complex multi-layer structures requiring nanometer scale accuracy and an elaborate design.

4.4.4. Types of Laser Beam Welding

(i) Pulsed laser beam welding:

A pulse of focused laser energy beam when incident on a metallic surface is absorbed within a very small area and it may be treated as a surface heating phenomenon. Thermal response beneath the focused spot depends upon heat conduction. If the laser pulse is too short when compared to thermal diffusion time, the pulse energy remains at the surface and rapid localized heating occurs for little depth of penetration. This accumulation of heat at the surface causes metal to vaporize from the surface.

In this welding, the bottom lower surface should reach the melting temperature before the upper surface reaches the vaporization point. Therefore, thermal diffusivity and pulse duration control ensure the depth of successful porosity free welds.

(ii) Continuous wave laser beam welding:

Lasers such as solid state and CO_2 are capable of making high speed continuous metal welds. This continuous power supplied with continuous wave laser beam makes high power carbon dioxide laser with deep penetration capability. There is a precise control of energy delivery to highly localized regions. It is good for narrow gap geometrics and it permits welding without using filler metal. It reduces the amount of filler metal. Deep penetration welds are similar to EBW process.

4.4.5. Advantages, Limitations and Applications of Laser Beam Welding

Advantages:

1. There is no need of electrodes and power.
2. Even very small holes can also be welded.
3. There is no vacuum requirement such as electron beam.
4. Accuracy is greater.
5. There is no heat loss.
6. Neat and clean surface finish can be obtained.
7. Laser beam welding can be used to weld dissimilar metals which are difficult to weld.
8. X-rays are not generated by the beam and hence it is safe.
9. Laser beam can be manipulated using the principles of optics to permit easy automation.
10. Cooling rates are high due to low energy inputs per unit weld length. Also, the problems associate with welding can be rectified by pre- or post-heat treatment processes.
11. Ruby lasers are used for spot welding of thin gauge metals.
12. Electrical efficiency of the process is 10-20% only.
13. Better quality weld can be produced. It produces less tendency for incomplete fusion, spatter, porosity and distortion.
14. It ensures precise working with exact placing of the energy spot welding of complicated joint geometry.
15. It produces low thermal distortion.
16. It produces cavity-free welds.
17. It needs low post weld operation times.
18. Large working distance is possible.

19. No filler metals are necessary.
20. Works with high alloy metals without difficulty.

Limitations:

1. Welding process is slow.
2. Limited depth of weld can be done.
3. It is not suitable for large production.
4. Capital cost for equipment is high.
5. Optical surfaces of the laser are easily damaged.
6. Maintenance cost is high.
7. Rapid cooling rate may cause cracking in some metals.

Applications:

1. Thin metals about 0.5 *mm* to 1.5 *mm* thick can be welded. It includes welding of foils, stents, sensor diaphragms and surgical instruments.
2. It can joint dissimilar metals such as copper, nickel, chromium, stainless steel, titanium and columbium.
3. It is very much useful in electronic components welding.
4. It is used in aircraft components joining.
5. In automotive industry, it is mostly used for welding transmission components.
6. It is very much useful in joining metal alloys.
7. Laser beam welding of high-strength aluminium alloys is used for aerospace and automotive applications.
8. With slight modifications, the process can be used for gas-assisted cutting and surface heat treating and alloying applications.

4.5. FRICTION STIR WELDING

Friction Stir Welding (FSW) is a solid state welding process in which a rotating tool is fed along the joint line between two workpieces. It is used to join two facing surfaces. During welding, heat is generated due to friction and the metal is mechanically stirring to form the weld seam. FSW differs from normal friction welding in such a way by generating friction heat by a separate wear-resistant tool instead of the parts between them.

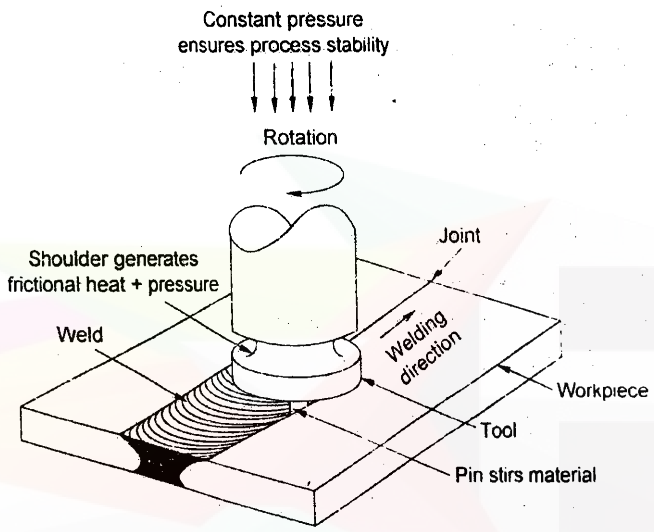


Figure 4.9 Principle of friction stir welding

In friction stir welding process, the rotating tool consists of a cylindrical shoulder and a smaller probe or pin projecting beneath it, as shown in Figure 4.9, is used. During welding, the shoulder rubs against the top surfaces of two parts thereby developing friction heat and the pin or probe simultaneously generates additional heat by mechanical mixing of the metal along the butt surfaces. At the same time, the probe has been designed in order to perform the mixing perfectly. Typical tool profiles used in friction stir welding are shown in Figure 4.10. The heat is produced by the combination of friction and mixing. During the process, the metal will not melt but it softens. The softening of metal takes place up to a highly plastic condition. When the tool moves forward along the joint, the leading surface of the rotating probe is forcing the metal around it. Then, the developed force forges the metal into a weld seam. So, the shoulder helps to limit the plasticized metal flowing around the probe.

Since workpiece does not melt, problems such as porosity, solidification cracks and thermal distortion are non-existent.

It is extremely important to identify appropriate combinations of tool geometry, tool rotational speed and welding speed to ensure a proper material flow. The harder is the workpiece material, the stronger has to be the tool material because the tool experiences severe atmosphere of stress and temperature. The commercial use of FSW for hard alloys still remains intangible.

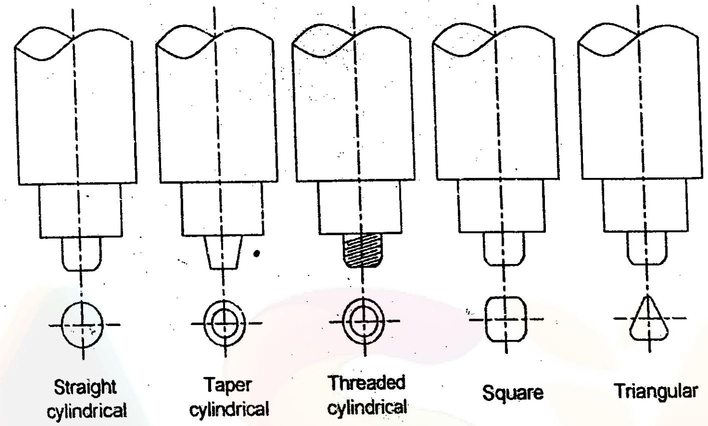
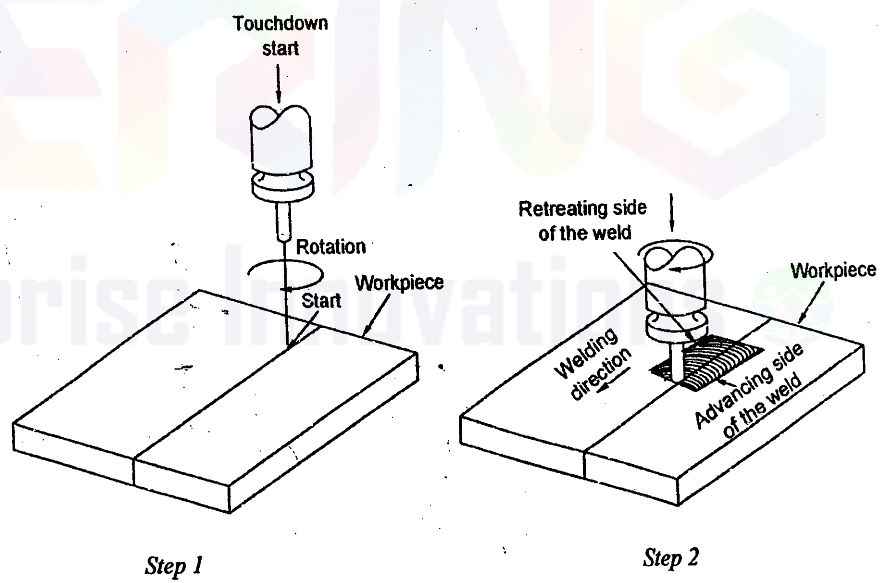
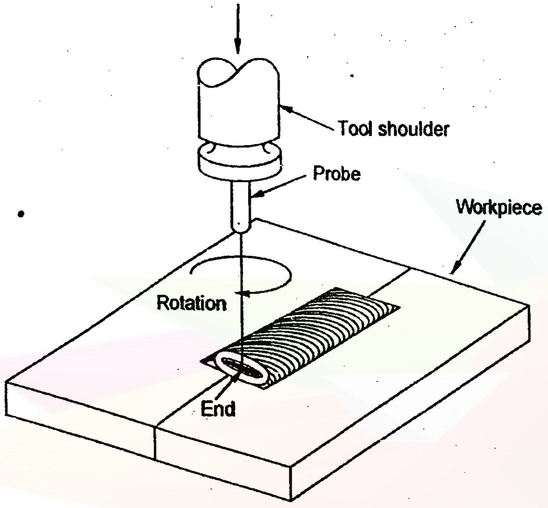


Figure 4.10 Typical tool profiles used in friction stir welding

FSW process is used in aerospace, automotive, railway, and shipbuilding industries. The main applications are butt joints on large aluminium parts. Sometimes, steel, copper and titanium as well as polymers and composites are also joined by using FSW.

Figure 4.11 illustrates various steps followed in performing friction stir welding which is already described earlier in detail.





Step 3

Figure 4.11 Steps in friction stir welding

4.5.1. Materials Used in Friction Stir Welding Process

Variety of metals can be joined by this process which cannot join by conventional processes.

(i) Aluminum and Aluminum alloys

(ii) Brass

(iii) Cast iron

(iv) Ceramic

(v) Copper

(vi) Lead

(vii) Bronze

(viii) Steel alloys

(ix) Magnesium and Magnesium alloys

(x) Vanadium.

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4.5.2. Microstructural Features

The solid-state nature of FSW process combined with its unusual tool and asymmetric nature results a highly characteristic microstructure. The microstructure can be divided into the following zones.

(i) The stir zone is a region of heavily deformed material that roughly corresponds to the location of the pin during welding. The grains within the stir zone are roughly equiaxed and often an order of magnitude smaller than grains in the parent material. A unique feature of the stir zone is the common occurrence of several concentric rings which is referred to an "onion-ring" structure.

(ii) The flow arm zone is on the upper surface of the weld and it consists of material which is dragged by the shoulder from the retreating side of the weld around the rear of the tool and deposited on the advancing side.

(iii) Thermo-Mechanically Affected Zone (TMAZ) occurs on either side of the stir zone. In this region, the strain and temperature are lower and the effect of welding on the microstructure is correspondingly smaller.

4.5.3. Welding Forces

During welding a number of forces act on the tool. They are as follows:

(i) *Downward force:*

This force is necessary to maintain the position of the tool at or below the material surface. Some friction-stir welding machines operate under load control but in many cases, the vertical position of the tool is preset. So, the load varies during welding.

(ii) Traverse force:

This force acts parallel to the tool motion and it is positive in the traverse direction. Since this force arises as a result of the resistance of the material to the motion of the tool, it decreases as the temperature of the material around the tool increases.

(iii) Lateral force:

It acts perpendicular to the tool traverse direction and it is defined as positive towards the advancing side of the weld.

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(iv) Torque:

Torque is required to rotate the tool. The amount of torque depends on the downward force and friction coefficient (sliding friction) and the flow strength of the material in the surrounding region.

4.5.4. Flow of Material

During friction stir welding process, some materials rotate around the pin or probe for atleast one rotation and this material movement produces "onion-ring" structure in the stir zone. The material motion occurs by two processes:

(i) Material on the advancing front side of a weld enters into a zone that rotates and advances with the probe. This material is very highly deformed and sloughs off behind the probe to form arc-shaped features when viewed from top (i.e. down the tool axis). The copper entered the rotational zone around the pin where it was broken up into fragments. These fragments are only found in the arc shaped features of material behind the tool.

(ii) The lighter material comes from the retreating front side of the probe and it is dragged around to the rear of the tool and fills in the gaps between arcs of advancing side material. This material does not rotate around the probe and lower level of deformation resulted in a larger grain size.

4.5.5. Generation and Flow of Heat

For welding process, it is desirable to increase the travel speed and minimise the heat input as it increases productivity and possibly reduce the impact of welding on the mechanical properties of the weld. At the same time, it is necessary to ensure that the temperature around the tool is sufficiently high to permit adequate material flow and prevent flaws or tool damage.

When the traverse speed is increased, there is less time for heat to conduct ahead of the tool and the thermal gradients are larger. At some point, the speed will be so high that the material ahead of the tool will be too cold and the flow stress is too high to permit adequate material movement. It results flaws or tool fracture. If the "hot zone" is too large, then there is scope to increase the traverse speed. Therefore, the productivity also increases.

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4.5.6. Friction Stir Welding Cycle

The welding cycle can be split into several stages.

(i) Dwell:

The material is preheated by a stationary rotating tool to achieve a sufficient temperature ahead of the tool to allow the traverse. This period may also include the plunge of the tool into the workpiece.

(ii) Transient heating:

When the tool begins to move, there will be a transient period where the heat production and temperature around the tool alter in a complex manner until steady-state is reached.

(iii) Pseudo steady-state:

Although fluctuations in heat generation occur, the thermal field around the tool remains effectively constant.

(iv) Post steady-state:

Near the end of the weld, heat may "reflect" from the end of the plate leading to additional heating around the tool.

Heat generation during friction-stir welding arises from two main sources such as friction at the surface of the tool and deformation of the material around the tool.

4.5.7. Advantages, Limitations and Applications of Friction Stir Welding

Advantages:

1. It ensures the good mechanical properties of the weld joint.
2. It avoids toxic fumes, warping, shielding issues and other problems associated with arc welding.
3. It permits less distortion or shrinkage on joints.
4. It provides good weld appearance.
5. Improved safety is obtained due to the absence of toxic fumes or the spatter of molten material.
6. There is no use of consumables.
7. It can be easily automated on simple milling machines due to lower setup costs and less training.
8. It can be operated in all positions as there is no weld pool.

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9. Generally, it ensures a good weld appearance and minimal thickness.
10. It can be used for thinner materials with same joint strength.
11. It produces low environmental impact.
12. General performance and cost benefits are from switching from fusion to friction.
13. Simplicity of operation and simple equipment are obtained.
14. It requires less time to perform welding.
15. Only less surface impurities and oxide films are produced.
16. Heat affected zone is small as compared to conventional flash welding.
17. Dissimilar metals can be joined.
18. High quality weld can be obtained.
19. Pores are minimized.
20. There is no use of shielding gases.
21. There is no surface cleaning required.

Limitations:

1. An exit hole remains the same after the tool is withdrawn from the work.
2. Large down forces are required with heavy-duty clamping necessary to hold the plates together.
3. It is less flexible than manual and arc processes.
4. It produces slower traverse rate than some fusion welding techniques although this may be offset if fewer welding passes are required.
5. Process is restricted to flat and angular butt welds.
6. It can be used only for joining small parts.
7. It requires heavy rigid machine due to high thrust pressure.
8. In case of tube welding process, it becomes complicated.
9. In case of high carbon steels, it is difficult to remove flash.

Applications:

Friction stir welding processes are mainly used in the following industries.

1. Automobile: Bimetallic engine valve, universal joint yoke, gear hub etc.
2. Aerospace: Turbine blade joining, seamless joining etc.
3. Consumer: Hand tools and sports equipment.

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4. Industrial machines: Spindles, tapers and tools.
5. Medical: Stainless steel joining of containers.
6. Mining/Drilling: Twist drills.
7. It is used in hydraulic equipment.
8. It is used in rolling stock for railways, general fabrication, robotics and computers.

4.6. UNDERWATER WELDING

Underwater welding usually refers to the *wet welding technique* where there is no mechanical barrier that separates the welding arc from water. It is also known as *submerged water arc welding*. For deep water welds and other applications where high strength is necessary, *dry water welding* is most commonly used.

It is a unique form of welding process and it has got multiple applications which are rare to be worked upon by other conventional methods of welding. Large numbers of offshore structures such as oil drilling rigs, pipelines, platforms are installed, during normal usage or during storms and collisions which are unpredictable. The failure of some of the elements may occur and any repair work requires the use of underwater welding.

Water proof welding electrodes are used which are quite unique and work as normal electrodes do in normal working conditions.

In general, the integrity of underwater welds is difficult especially wet underwater welds because defects are difficult to detect. For the structures being welded by wet underwater welding process, inspection following welding may be highly challengeable than welds deposited in air.

The diving tender should always maintain a written record of the following parameters in order to repeat during the next welding.

(i) The welding amperage as read from the tong meter.
(ii) Both open and closed-circuit voltage as read from the volt meter.
(iii) Electrode diameter, type, manufacturer and waterproofing material.
(iv) Electrical polarity.
(v) Length of welding cable.
(vi) Depth of work site.

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Applications of underwater welding:

(i) Under water welding is applied in marine applications and installation of offshore oil pipelines.

(ii) It is also used to apply weld repair on massive ships inside the water.

4.6.1. Risks associated with Underwater Welding

(i) The risks of underwater welding include the risk of electric shock to the welder. The welding equipment ought to be properly insulated to prevent it and the voltage of the welding equipment should be controlled.

(ii) Underwater welders must also consider the safety issues that normal divers face about the risk of decompression sickness due to the increased pressure of inhaled breathing gases.

(iii) Heat created by burning or torch can ignite trapped gases. Trapped gases need to be removed by venting or jetting gas. In closed spaces, small amount of gas can get trapped and remained with the diver. Gas must be vented if it can be trapped. Vent holes are drilled to allow the gas to escape to the surface.

(iv) Another risk is associated with wet underwater welding which is buildup of hydrogen and oxygen pockets in the weld because these are potentially explosive. When using grinders or drills sufficient heat can ignite hydrocarbons causing an explosion. Material being burned might contain pockets that can trap burning gas. Gasses need to be properly vented. The solution is to slow down the drill bit to avoid generating the heat levels required to ignite any gas.

4.6.2. Characteristics of Underwater Welding Arc

The welding arc does not behave underwater as it does on the surface and the activity of the gas bubble is particularly important to successful completion of the underwater weld. When the arc is struck, the combustion of the electrode and the detachment of water create a gas bubble or envelope as shown in Figure 4.12. As the pressure within the bubble increases, it is forced to leave the arc and meet with the surrounding water while another bubble forms to take its place. When this pressure head becomes greater than the capillary force, the bubble will break down. Therefore, if the electrode is being too far from the work, the weld will be destroyed as the gases explode and blow through. If the travel speed is too slow, the bubble will collapse around the weld and destroy the possibility of producing an effective weld.

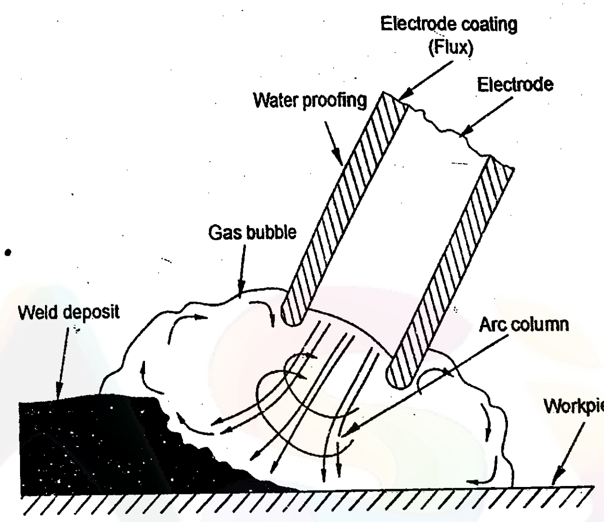

Figure 4.12 Underwater welding arcs

4.6.3. Classification of Underwater Welding

The two main categories of underwater welding techniques are as follows:

(1) Wet underwater welding

(2) Dry underwater welding.

4.6.4. Wet Underwater Welding

In wet welding, both weldment and welder are exposed to water. Wet welding is performed by the diver-welder normally using surface diving or saturation diving techniques using the manual metal arc welding process with electrodes specially coated with insulating varnishes to keep them dry.

Current is supplied by a generator directly to the welding torch head. Interchangeable collets hold electrodes of required diameters and they are tightened by the twist-grip control which is also used to eject the stub when electrodes are changed. Watertight glands and washers prevent seepage of water into the body of the torch which is tough rubber covered thus reducing the danger of electric shock.

In underwater welding, arc stability is less due to the large volumes of gas and steam which are evolved making vision difficult and as a result touch welding is generally used. The presence of water in the immediate vicinity of the weld except at the molten pool under the arc stream results in the very rapid quenching of the weld metal which produces a hard narrow heat affected zone and it can give a rise to severe hydrogen cracking. Weld properties are inferior to air welds. Standard air welding equipment can be used. There is no fit-up time. This process is more convenient in welding the parts which are located under the water. At present, this method is used for non-critical welds and critical welding is being carried out under dry conditions.

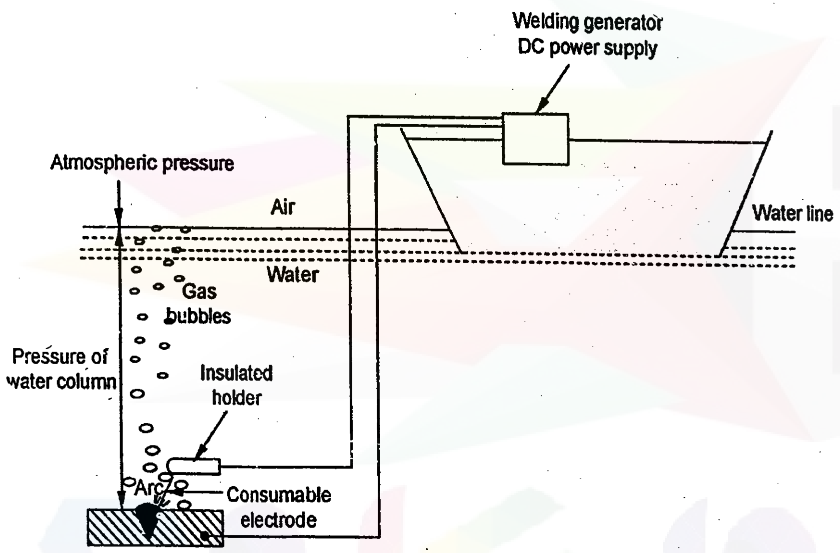

Figure 4.13 Underwater wet-welding

Specially designed electrodes are used to perform wet welding and power supply is cated on the surface connecting to the welder with the help of cables and hoses as shown in Figure 4.13. However, similar to open air welding, wet welding is also performed manually. Wet welding is the most effective, efficient and economical method used as it provides an increased freedom of movement.

Advantages of wet underwater welding:

1. Welders can reach positions inaccessible by other methods.
2. Process is fast.
3. Cost of welding is very low.
4. It has more freedom of repair design and fit-up.

5. Standard welding equipment can be used.
6. The welding process is speedy due to readily available machine, equipment and no enclosures.

Limitations of wet underwater welding:

1. Quenching effect is produced at the weld surface due to direct contact of the arc and molten weld-pool with water.
2. Both porosity and hardness also increase.
3. It produces low visibility to the operator.
4. Inspection of welds is very difficult as compared to open air welding. So, producing a good quality of weld is very difficult task.

4.6.5. Dry Underwater Welding

Dry underwater welding, also known as *hyperbaric welding*, is carried out by creating a chamber filled with a mixture of helium and oxygen gases for breathing purposes near the welding area, as shown in Figure 4.14, where the structure is to be welded and the welder is supposed to work from inside the chamber. TIG welding process is mostly employed in dry underwater welding and the weld joints created are of high quality which meets code requirements. However, all types of arc welding process such as shield metal arc welding, MIG welding and flux cored arc welding can be applied in this technique.

Dry chambers are used to provide safety and isolated environment to weld underwater. These specially designed chambers provide not only a pleasant environment to breathe-in but also a clean environment by regular discharge of hazardous gases which are produced as a result of welding procedure.

At the same time, the elevated pressure may cause problems. Thus, hyperbaric welding process is limited to particular depth of water where a welder can sustain himself to operate easily without any operational problem.

Advantages of dry underwater welding:

1. Higher welder safety is ensured in a chamber, less immune to ocean currents and marine animals.
2. High quality weld joints are produced as compared to open air weld joints.
3. All inspections and preparations are done visually.

4. Non Destructive Testing (NDT) is also facilitated by dry welding which is pretty much important for ensuring weld quality.
5. Good surface monitoring is ensured.

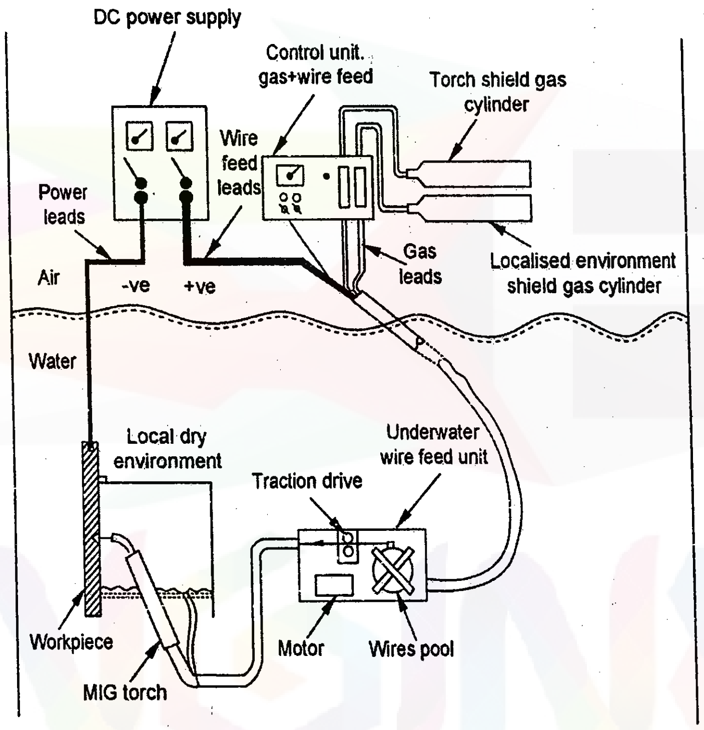

Figure 4.14 Dry underwater welding

Limitations of dry underwater welding:

1. The process requires huge number of complex equipment.
2. The operator needs to be more and specifically trained.
3. The process is costly which requires an element of precision welding.
4. Cost of process is higher and the welder needs a proper training.
5. Equipment is complex.
6. More deep and energy are required.
7. It cannot be weld if the weld spot is at unreachable places.

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4.6.6. Comparison of Underwater Welding Over Normal Air Welding

(i) Electrodes are painted for waterproofing.

(ii) Electrode core wire is usually similar to air welding but for high strength steel, a core wire of stainless steel or special steel is required.

(iii) Waterproofed flux coated or iron-oxide covered electrodes are used in underwater welding.

(iv) The gap between electrode and work is not maintained in underwater welding because the electrode is lifted due to the pressure of water during arc but the gap is maintained between electrode and work in air welding.

(v) Underwater welding arc is surrounded by steam and gases but it is not in the case of air welding.

(vi) Cooling rate of the part can be controlled in air welding by changing the energy input but it is difficult in underwater welding.

(vii) Hydrogen and oxygen levels are high in underwater welding but it is normal in air welding.

(viii) Electrode holder also insulated in underwater welding to avoid electric shock.

4.7. WELDING AUTOMATION IN AEROSPACE INDUSTRIES

Aerospace manufacturing is unique and specialized. The parts are complex and often gigantic. While it may come as a surprise, this industry has begun to rely more and more on the standard 6-axis industrial robot, not specialized machinery.

Welding robots are very precise, move smoothly at considerable speed through a programmed path. Being computer-based, they can be programmed and have sensors to follow the seam and apply corrections to the welding parameters.

Reasons for implementation of welding robots in aerospace industry:

The following are the reasons for implementation of welding robots in aerospace industry:

(a) Robotics automation is economical:

Aerospace manufacturers are attracted to robot's cost-effectiveness. The typical 6-axis articulated robot is far more affordable than a custom-built machine and it performs just as effectively. Companies that appropriate for a reconditioned robot can expect to save even more i.e., up to 50%-60% less than the cost of a new robot.

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(b) Usability and robotics automation:

Compared to setting up customized machines, robotics automation is easy to deploy. Six-axis robots are quick to set up, program and put into production.

(c) Flexible automation with 6-axis robots:

Robots are well-suited for aerospace manufacturing because they offer application and work envelope flexibility.

For changing the tool and programming, 6-axis robot is ready for a new application. This flexibility makes robotics automation very attractive to aerospace manufacturers.

Aerospace part production is different than automotive part production. Parts are not only more complicated, requiring more precision and slowed manufacturing but also aerospace parts are created in smaller batches. Industrial robots are well-suited because of their versatility.

(d) Robotics automation and the aerospace worker:

Sometimes, building an aerospace craft gets a bit cramped. Industrial robots make cramped and painstaking tasks similar to closing up wing spaces much more ergonomic and quick.

Without assistance of industrial robots, aerospace worker similar to automotive worker must endure repetitive welding, deburring and other tasks. Now, aerospace manufacturers avoid such repetitive movement injury and strain by letting robotics automation handle the dull work.

4.7.1. Automated Robotic Welding System

There are number of different configurations of automated robotic welding systems exist. Most of the systems have same basic principle of operations and they have many elements in common. One such a system, called *parallel multi-sensor system*, is explained here.

A multi-sensor system represents neither the utilization of many sensors with the same physical nature nor many independent measurement systems but mainly sensor fusion is the extraction of global information coming from the interrelation data given by each sensor. Some examples are the simultaneous acquisition of parameters of the automatic MIG welding process or the direct observation of the welding pool related to the control of current, voltage, wire speed and torch welding speed.

Various components of the multi-sensor automated robotic welding system are as follows:

1. Sensor guided welding cell:

The main tasks in welding automation are the guiding of the robot movements, allowing the welding torch to be always inside the welding joint and controlling the welding parameters such as current, voltage, wire feed rate, heat input, etc.

For the control of welding processes, in an integrated intelligent welding cell, a video system has been coupled to the torch for direct observation of the welding pool and a sensor is for optical seam tracking put at the front of the torch. The main goal was the acquisition and processing of all information of the welding process in the similar way of a welder. Figure 4.15 shows a diagram of the physical construction of the sensor system and its main functions. The sensors were used in such a way that they allow not only process control but also automatic and detailed recording of the quality of the process.

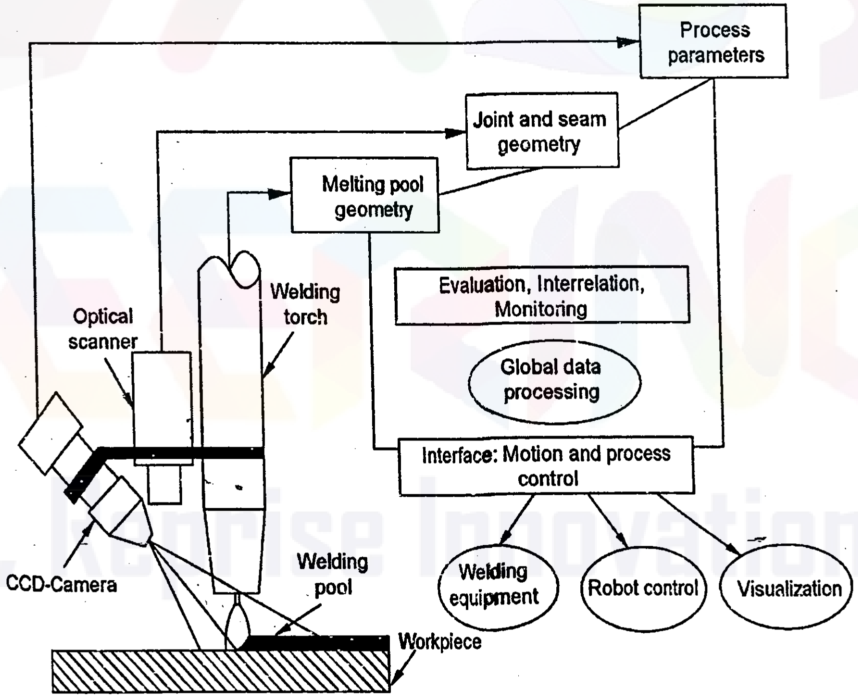

Figure 4.15 Functional main units of multi-sensor automated robotic welding system

The components of the sensor guided welding cell are described as follows:

(i) Welding joint sensor:

A system of optical sensoring has been developed in order to allow the gathering of information about the geometry of the welding joint in aiming to set right the position of the welding torch as well as the control of the welding process. This system uses, as measurement principle, triangulation scanning to obtain the shape of the gap in the welding joint as shown in Figure 4.16.

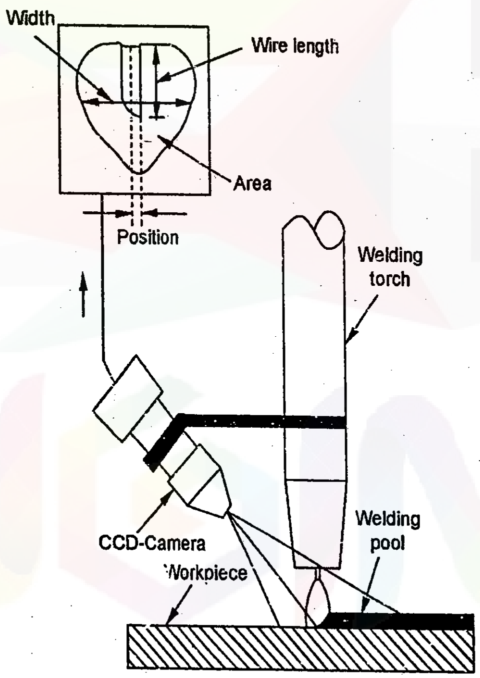

Figure 4.16 Welding joint optical sensor

(ii) Data acquisition system:

It is important to develop the data acquisition system with a high measurement confidence. So, two triangulation procedures for acquisition of the distance of the welding plate in each scanning are used. This special construction allows the compensation of imperfections in data caused by shadows in the surface topology or by the influence of reflection conditions. According to the quality of the received signal (diffuse reflection, opaque surface etc.), light intensity adaptation can be made. The signal conditioning control of the sensor implemented by the parallel processing architecture is shown in Figure 4.17. A

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master processor is in-charge of the parallel processing coordination and evaluation of the distance signal sequence giving at the end of the welding joint geometry.

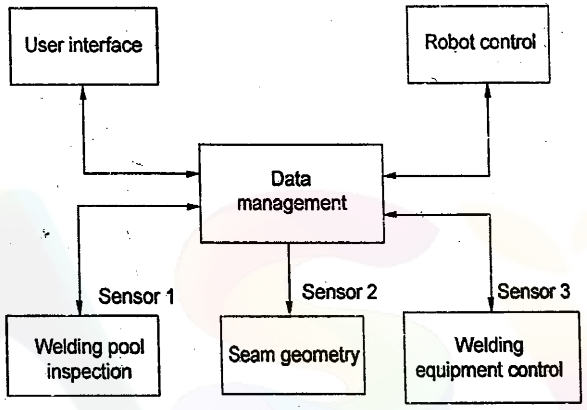

Figure 4.17 Input/output architecture of parallel multi-sensor system

(iii) Sensor system for robot non-linear control:

To implement the non-linear control of the robot, resolvers were coupled to each joint axis to measure the respective joint position. Pressure sensors coupled to each cylindrical chamber of both hydraulic drivers give access to the pressure difference that drives each robot joint. In general, sensors supply environment and task-related information in a coordinate system which is different than robot kinematics. It is then processed to robot joint coordinate system.

(iv) Manipulators:

A manipulator is a device holding the workpiece and it is moved around for better access and welding positions.

Advantages of a manipulator:

(1) A manipulator can easily be moved around the workpiece for the best welding positions.

(2) A manipulator can reduce the variation in the lead and lag angles of the tip.

(3) Welding can be performed in a stable flat welding position by a synchronized and simultaneous control of a robot and manipulator.

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(4) Any hard-to-reach positions ~~can be~~ accessed more easily.

(5) A manipulator increases the working range of a fixed floor mounted robot or an inverted robot.

(v) Multi-sensor integration:

Besides the acquisition and parallel processing of information coming from very different sensors, another key point is the integration of the information. This data fusion concerns the consideration of all relevant aspects of a manufacturing process.

The information flow can be grouped in three phases such as process monitoring data, validation of this information and the interrelation of variables to obtain process parameters and actuating signals.

Typical process parameters such as welding pool width, voltage, current, torch velocity etc. are combined using a process model to obtain a complete description of the welding state. The multi-sensor can deliver specific process information and global values concerning:

(a) Motion control based on local path tracking

(b) Process control and monitoring

(c) Quality control.

2. Robot and its controller:

The robot is typically comprised of a large number of links and linkages which are interconnected by gears, chains, belts and screws. The majority of industrial robots are actuated by linear, pneumatic, hydraulic actuators or electric drives (AC/DC motors).

In an arc welding robot system, the torch is attached to the wrist of the robot which has two or three axes of motion such as YAW, PITCH and ROLL similar to human wrist. With regard to system design, the important issues are listed below.

(i) Robot work envelope

(ii) The reach of the robot tip

(iii) The number of joints

(iv) The travel velocity

(v) The repeatability

(vi) Accuracy

(vii) Resolution of motion.

4.7.2. Features of Automation in Aerospace Industry

Welding in the aeronautic industry is experiencing exciting developments. The widespread application of computers and the improved knowledge and design of new materials are shaping the way welding is implemented for process and product designs. There is a general trend to reduce the use of rivets in structural components in airplanes. Diffusion welding, laser beam welding and electron beam welding are used to join the materials in these cases. In military airplanes, electron beam welding is continually gaining importance in the joining of titanium alloys. In large commercial planes, laser beam welds are posed to replace rivets in large parts of the fuselage. Some new processes developed for the space industry also show a promise for the aeronautic industry. Among them: friction stir welding and variable polarity plasma arc welding which are already used for critical applications in rockets are of primary important.

The nature of welding in the aeronautical industry is characterized by low unit production, high unit cost, extreme reliability and severe operating conditions.

These characteristics point towards more expensive and more concentrated heat sources such as plasma arc, laser beam and electron beam welding as the processes of choice for welding of critical components.

Advantages of automated welding:

Successful application of mechanised /automated systems can offer a number of advantages. They include the following:

(a) Increased productivity

(b) Consistent weld quality

(c) Predictable welding production rates

(d) Reduced variable welding costs

(e) Lower part costs.

Limitations of automated welding:

Even though automated welding systems offer a number of advantages, it has following limitations.

(a) It needs higher capital investment than for manual welding equipment.

(b) A need for more accurate part location and orientation are required.

(c) More sophisticated arc movement and control devices are needed.

(d) Maintenance cost of equipment is more.

4.7.3. Welding Processes used in Aeronautic Industry

(i) Friction Welding (FRW):

In this process, joining of the metals is achieved through mechanical deformation. Since there is no melting, defects associated with melting-solidification phenomena are not present and unions as strong as the base material can be made. This process can join components with a relatively simple cross section. It is used for joining aluminum landing gear components. Linear friction (fretting) welding is used as an alternative for the manufacture and repair of high temperature alloy blocks for jet engines.

(ii) Friction Stir welding (FSW):

It is a solid-state process that joins metals through mechanical deformation. In this process, a cylindrical shouldered tool with a profiled probe is rotated and slowly plunged into the joint line between two pieces of sheet or plate material which are butted together. This process can weld unweldable aluminum alloys such as the 2xxx and 7xxx series used in aircraft structures. The strength of the weld is 30%-50% than with arc welding

(iii) Flash Welding (FW):

FW is a melting and joining process in which a butt joint is welded by flashing action of a short arc and application of pressure. It is capable of producing welds as strong as the base material. This process can weld aluminum and temperature resistant alloys without especial surface preparation or shielding gas. It can join sections with complicated cross sections and it is used in the aeronautical industry to join rings for jet engines made out of temperature resistant alloys and extruded aluminum components for the landing gear.

(iv) Gas Metal Arc Welding (GMAW) or MIG welding:

This process is one of the most popular welding processes in the world because its flexibility and low cost. It is not used extensively in the aeronautic industry. This process is the main welding process used for the construction of the fuel and oxidizer tanks for the Saturn V rocket. One of the current applications of MIG is in the automatic welding of the vanes of the Patriot missile. This application benefits from the low cost of MIG while extreme reliability is not as important as in manned airplanes.

(v) Gas Tungsten Arc Welding (GTAW) or TIG welding:

GTAW can use a more intense heat source than GMAW. So, it can produce welds with less distortion at a similar cost. For most structural critical applications, this process cannot compete with other welding methods such as electron beam welding, laser beam welding or plasma arc welding. TIG welding was used together with MIG welding to weld 2014 and 2219 aluminum alloy in the fuel and oxidizer tanks in the Saturn V rocket.

(vi) Plasma Arc Welding (PAW):

PAW uses a constricted arc between a non-consumable electrode and the weld pool (transferred arc) or between electrode and constricting nozzle (non-transferred arc). If the heat intensity of the plasma is high enough, this process can operate in a keyhole mode which is similar to the laser or electron beam welding although with smaller maximum penetration.

(vii) Laser Beam Welding (LBW):

This process together with electron beam welding can deliver the most concentrated heat sources for welding with the advantages of higher accuracy, weld quality and smaller distortions. This process is used for welding and drilling of jet engine components made of heat resistant alloys such as Hastelloy X. Laser-processed combustors are used in the Pratt & Whitney jet engines.

Laser beam welding will soon replace riveting in the joining of stringers to the skin plate in the Airbus 318 and 3XX aircraft 20.

(viii) Electron Beam Welding (EBW):

The high intensity of the electron beam generates welds with small heat affected zone. The characteristic makes this process especially suitable for welding titanium alloys which cannot be welded in an open atmosphere. Titanium alloys are widely used in military aircraft because of its light weight, high strength and performance at elevated temperatures. The application of EBW to the welding of titanium components for military aircraft has been expanding constantly. Critical titanium structural components are being EBW welded this way for the Eurofighter and Boeing's F-22.

(ix) Diffusion Welding (DFW):

It is a solid-state welding process that produces a weld by the application of pressure at elevated temperature with no macroscopic deformation or relative motion of the pieces. The aeronautic industry is the major user of DFW.

(x) Resistance Welding:

Resistance welding in the aerospace industry is utilized to join parts made of certain metals that possess high strength and lightweight properties.

4.8. WELDING AUTOMATION IN NUCLEAR SECTOR

(i) Remote welding in nuclear sites:

Most nuclear reactors have restricted physical access to pipe work so a remote automated weld head is far safer and more accurate than a manual system. Additionally, in nuclear applications, weld integrity and ability to adapt to exotic materials are critical. The accuracy and consistently high quality welds achieved by the automated weld head, power sources and control systems are now essential to the nuclear industry.

Automated orbital welding technology was first established in 1976 and its welding systems now provide a range of applications for the nuclear industry from secure seals on 3013 high level waste containers to precision welding for reactor tube sheets, turbine shafts, reactor piping, vessel maintenance and repair and superheated steam generator piping.

(ii) Narrow gap welding process:

The conventional welding technique such as shield metal arc welding has been mostly applied to the piping system of the nuclear power plants. This welding technique causes the overheating and welding defects due to the large groove angle of weld. On the other hand, the Narrow Gap Welding (NGW) technique has many merits such as reduction of welding time, shrinkage of weld, small deformation of the weld due to the small groove angle and welding bead width as compared to the conventional welds.

Narrow gap welding allows the butt joining of very thick components while limiting welding time and residual deformations. Narrow gap welding is broadly used in nuclear industry for the fabrication of reactor vessels, steam generators and pressurizers. It is also used in pressure vessel, boiler and heavy machinery industry. Specific welding machines have been designed for various technologies used in narrow gap welding such as submerged arc welding, TIG and MIG processes. Other narrow gap welding technologies involving lasers are being developed.

The narrow gap welding process is designed to meet the quality, mechanical properties and overall cost requirements of heavy wall fabrication. It is a submerged arc process designed to weld thick walled steel which uses a narrow gap plate preparation.

The process is appropriate for both flat and circumferential welding. A multi-layer technique is recommended in place of one large pass per layer. It minimizes undercut, trapped or mechanically locked slag and concave weld profiles. The narrow gap process produces a multi-layer weld with uniform side wall penetration, maintaining low parent metal dilution and low heat input.

Narrow gap processes are made possible by several new submerged arc flux/electrode combinations and a specially designed deep groove nozzle assembly. Only the recommended flux/electrode combinations should be used. When properly selected electrodes are used to meet the job requirements, these flux/electrode combinations will deliver excellent welding characteristics and mechanical properties. When following the recommended procedures, very good bead shape and self-releasing slag will result.

The narrow gap process results in lower welding cost by reducing the volume of weld metal required for heavy plate thicknesses. The cost of consumables, welding time and preparation time is also reduced when compared to more conventional methods.

Industry applications of narrow gap welding process:

1. Steam generators of power plant
2. Petrochemical industries
3. Shipbuilding
4. Heavy machinery fabrication
5. Nuclear reactor vessel manufacturing.

Benefits:

1. Minimum joint preparation and minimum joint volume.
2. Good mechanical properties.
3. Low heat input.
4. Low parent metal dilution and small heat affected zone.
5. High quality weld can be produced without turning plate.
6. Simple "off-the-shelf" equipment solution.
7. Low distortion.

(iii) Turn-key welding solutions:

Reliable operation and integrity of nuclear pressure equipment are of great importance for the safety of nuclear facilities.

Precision motion for welding operations is essential to ensure consistent and reliable operation. Non-precision motion can cause inconsistent welds which may lead to premature component failure by resulting in facility damages, expensive component replacement/rework and losses in productivity.

Quality assurance measures should be built into an automated welding system to verify welds which are performed within the system's programmed welding parameters. If no in-process quality assurance measures are used, then small but potentially ruinous variations may pass undetected during welding operations thereby resulting in a faulty or less than ideal part. Safety is a main concern in the nuclear industry. Great measures are taken to establish and maintain high standards to protect employees and operators.

Turn-key welding solutions which are designed for nuclear applications offer variety of benefits. It is easy-to-use interface and precise controls provide a complete solution for even most high tolerance applications. This welding system is used for critical applications in the nuclear industry. Turn-key TIG process has been used globally as a solution to complex welding applications and strict nuclear code requirements. Turn-key welding solution controls include encoder-based servo motor driven axes for precise and repeatable motion. This level of precision ensures that parts will be welded consistently and reliably.

Controller of turn-key welding is configurable with data acquisition and tolerance checking software. The software collects data for each axis of motion as well as each welding parameter. If any of the parameters is out of the tolerance range, then the program is automatically terminated. Controller is designed for operation either at the weld zone or in a safe environment remotely. The operator has complete control in either location which is essential for the nuclear industry.

The nuclear world of welding brings many complex alloys into consideration such as the many variations of stainless steel, chrome and nickel alloys used in both commercial and military projects throughout the world. So, automated welding improves safety and productivity in nuclear industry.

4.9. WELDING AUTOMATION IN SURFACE TRANSPORT VEHICLES

Welding in automotive industry:

Resistance welding in the automotive industry is probably the most common. During vehicle assembly, there are three resistance welding processes such as spot welding, projection welding and seam welding mostly used.

Projection welding in automotive industry is utilized for the fastening of screw machine parts to metal including studs and nuts. It is also used to join wires and bars that must be crossed.

Spot welding is utilized for joining sheet metal parts to a vehicle. Resistance spot welding is particularly advantageous in the automotive industry due to its ability to provide rapid, high volume manufacturing, operational ease, safety, low environmental impact, cost efficiency as well as stable and repeatable results.

Resistance seam welding is utilized as a part of the automotive after-treatment system. MIG welding machines are usually employed for this process. Two primary design considerations for resistance seam welding in the automotive industry include porosity probability and finished weld surface condition requirements.

(i) Body welding:

The manufacture of a car is done in three stages such as

(i) Body construction

(ii) Surface treatment (Surface painting)

(iii) Vehicle assembly.

The galvanized steel panels for the body shell which are first welded together. It was a pure labour-intensive process because it was done manually. So, this welding was mainly depending on the skill of the welder. In a modern car assembly plant, robots perform this task on the body and welds. So, the process is highly automated which produces homogeneous and high quality weld. Simultaneously, it saves the labour cost.

(ii) Welding in railway industry:

Resistance welding in the railway industry is advantageous due to its ability to provide high structural integrity, aesthetic qualities and high productivity. Resistance welding is used throughout the process of railway car fabrication. It is also used for joining railway rails as well as joining different materials in railway switches.

Most modern railways use Continuous Welded Rail (CWR) which is also referred to as *ribbon rails*. In this form of track, the rails are welded together by utilising flash butt welding to form one continuous rail that may be for several kilometres long. Welded rails are more expensive to lay than jointed tracks but they have much lower maintenance costs.

The preferred process of flash butt welding involves an automated track-laying machine running a strong electrical current through the touching ends of two pieces of rails to be joined. The ends become white hot due to electrical resistance and they are then pressed together forming a strong weld. *Thermit welding* is used to repair or splice together existing CWR segments in remote areas. It is a manual process requiring a reaction crucible and form to contain the molten iron.

Joints are used in continuous welded rail when necessary, usually for signal circuit gaps. Instead of a joint that passes straight across the rail, two rail ends are cut at an angle to give a smoother transition. In extreme cases, such as at the end of long bridges, a breather switch gives a smooth path for the wheels while allowing the end of one rail to expand relative to the next rail.

Robot welding is the use of mechanized programmable tools (robots) which completely automate a welding process by both performing the weld and handling the part. Processes such as gas metal arc welding while often automated are not necessarily equivalent to robot welding since a human operator sometimes prepares the materials to be welded. Robot welding is commonly used for resistance spot welding and arc welding in high production applications such as automotive industry.

Robot arc welding is growing quickly just recently and it guarantees about 20% of industrial robot applications. The major components of arc welding robots are the manipulator or the mechanical unit and the controller which acts as the robot's "brain". The robot may weld a pre-programmed position be guided by machine vision or by a combination of two methods.

4.10. TWO MARK QUESTIONS AND ANSWERS

1. *What is the principle of Thermit welding?*

Thermit welding is a welding process utilizing heat generated by exothermic chemical reaction between components of the Thermit. The molten metal produced by the reaction acts as a filler material and joins the workpieces after solidification. The welding principle is the heat of the Thermit reaction used for welding in plastic state and mechanical pressure is applied for the joint.

2. *What is the composition of Thermit?*

Thermit consists of one part of aluminium and three parts of iron oxide.

3. *Give the reaction in Thermit welding.*

$$8Al + 3Fe_3O_4 = 4Al_2O_3 + 9Fe + \text{Heat}$$

4. *Classify Thermit welding.*

1. Pressure welding process
2. Non pressure welding process.

5. *Mention the stages in Thermit welding.*

1. Thermit is ignited.
2. Crucible is tapped, and superheated metal flows into mould.
3. Metal solidifies to produce weld joint.

6. *What are the advantages of Thermit welding?*

1. No external power source is required (Heat of chemical reaction is utilized).
2. Very large heavy section parts may be joined.
3. The process uses simple and inexpensive equipment.
4. The process is best suitable particularly in remote locations where sophisticated welding equipment and power supply cannot be arranged.
5. It can weld complex shapes.

7. *State the limitations of Thermit welding process.*

1. Only ferrous (steel, chromium, nickel) parts may be welded.
2. High skill operators are required.
3. Welding rate is slow.
4. It reduces the risks to operate.
5. Deposition rate is low.

8. *Write down the applications of Thermit welding process.*

1. Thermit welding process is used for welding damaged wobblers and large broken crankshafts.
2. It is used in steel rolling mills.
3. It is used to restore the broken teeth on gears.
4. Joints in pipes, rails, shafts are made in this process.
5. It is used in welding and repairs of large forgings, and broken castings.

9. *What is atomic hydrogen welding?*

Atomic Hydrogen Welding (AHW) is a combination of electric arc and gas welding technique. It is a thermo-chemical arc welding process in which the workpieces are joined by heat obtained on passing a stream of hydrogen through an electric arc struck between two tungsten electrodes.

10. *Mention the features of atomic hydrogen welding.*

- High heat concentration is obtained.
- Hydrogen acts as a shield against oxidation.
- Filler metal of base composition could be used.
- Most of its applications can be met by MIG process. Therefore, it is not commonly used.

11. *State the advantages of atomic hydrogen welding.*

1. Welding process is faster.
2. During the process, intense flame is obtained which can be concentrated at the joint. Hence, less distortion occurs.
3. There is no requirement of separate flux and shielding gas or flux. The hydrogen envelop itself prevents oxidation of the metal and tungsten electrode. It also reduces the risk of nitrogen pick-up.
4. Workpiece do not form a part of the electric circuit. Hence, problems such as striking the arc and maintaining the arc column are eliminated.
5. Welding of thin materials is also possible which may not be successfully carried out by metallic arc welding.

12. *Write down the limitations and applications of atomic hydrogen welding.*

Limitations:

1. The cost of welding is high when compared to the other process.
2. Welding process is limited to flat positions only.
3. The process cannot be used for depositing large quantities of metals.
4. Welding speed is less when compared to metallic arc or MIG welding.

Applications:

1. These welding processes are used in welding of tool steels which contains tungsten nickel and molybdenum.
2. They are used in joining parts, hard surfacing and repairing of dies and tools.
3. Atomic hydrogen welding is used where rapid welding is necessary in stainless steels, non-ferrous metals and other special alloys.

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13. *Define electron beam welding.*

Electron Beam Welding (EBW) is a fusion welding process in which a beam of high-velocity electrons is used for producing high temperatures and melting the workpiece to be welded. The electrons strike the workpiece and their kinetic energy is converted into thermal energy by releasing heat which is used to heat the metal so that the edges of workpiece are fused and joined together forming a weld.

14. *How is electron beam focused?*

The electron beam is focused by passing through the "magnetic lens".

15. *List down the variables which control EBM.*

1. Voltage
2. Speed
3. Distance between beam gun and workpiece.

16. *What are the vacuum levels in EBM?*

1. High-vacuum welding
2. Medium-vacuum welding
3. Non-vacuum welding.

17. *Write down the advantages of EBM.*

1. High quality weld is produced.
2. Deep welding is possible.
3. Clean and bright weld can be obtained.
4. High speed operation can be achieved.
5. Dimensional accuracy is good.

18. *Mention the limitations of EBM.*

1. The welding cost is high.
2. Skilled persons are required.
3. It is limited to small size welding.
4. Welding should be carried out in vacuum seal only.
5. It is a time consuming process.
6. The weld suffers from contamination if it is performed in atmospheric condition.

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19. *For what commercial applications EBW process can be more economical?*

1. Dissimilar metals can be welded.
2. Refractory and reaching metals can be welded.
3. It is used in aircrafts, missile, nuclear component, gears and shafts.
4. It is suitable for large scale.
5. It is used in cams.

20. *What is meant by laser beam welding?*

Laser beam welding (LBW) is a welding process which produces coalescence of materials with the heat obtained from the application of a concentrated coherent light beam impinging upon the surfaces to be joined.

21. *List down the types of laser forms.*

1. Liquid laser
2. Gas laser
3. Carbon dioxide laser
4. Solid-state laser
5. Ruby laser, and
6. Semi-conductor laser.

22. *Classify laser beam welding.*

(i) Pulsed laser beam welding

(ii) Continuous wave laser beam welding

23. *What are the basic components of the laser welding?*

Electrical storage unit, capacitor bank, triggering device, flash tube, and lasing material.

24. *What are the most commonly used lasing materials?*

Ruby rod (Aluminium oxide with Chromium) and carbon dioxide.

25. *Write down the applications of laser beam welding.*

1. Thin metals about 0.5 *mm* to 1.5 *mm* thick can be welded. It includes welding of foils, stents, sensor diaphragms and surgical instruments.
2. It can joint dissimilar metals such as copper, nickel, chromium, stainless steel, titanium and columbium.

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3. It is very much useful in electronic components welding.
4. It is used in aircraft components joining.

26. *What is friction stir welding?*

Friction Stir Welding (FSW) is a solid state welding process in which a rotating tool is fed along the joint line between two workpieces. It is used to join two facing surfaces.

27. *Write down any four materials which can be welded by friction stir welding.*

(i) Aluminum and Aluminum alloys

(ii) Brass

(iii) Cast iron

(iv) Ceramic.

28. *What are the stages in friction stir welding cycle?*

(i) Dwell

(ii) Transient heating

(iii) Pseudo steady-state

(iv) Post steady-state.

29. *Mention the advantages of friction stir welding.*

1. Improved safety is obtained due to the absence of toxic fumes or the spatter of molten material.
2. There is no use of consumables.
3. It can be easily automated on simple milling machines due to lower setup costs and less training.
4. It can be operated in all positions as there is no weld pool.

30. *State the limitations of friction stir welding.*

1. An exit hole remains the same after the tool is withdrawn from the work.
2. Large down forces are required with heavy-duty clamping necessary to hold the plates together.
3. It produces slower traverse rate than some fusion welding techniques although this may be offset if fewer welding passes are required.
4. Process is restricted to flat and angular butt welds.

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31. What are the applications of friction stir welding?

Friction stir welding processes are mainly used in the following industries.

1. Automobile: Bimetallic engine valve, universal joint yoke, gear hub etc.
2. Aerospace: Turbine blade joining, seamless joining etc.
3. Consumer: Hand tools and sports equipment.
4. Industrial machines: Spindles, tapers and tools.

32. What is called underwater welding?

Underwater welding usually refers to the *wet welding technique* where there is no mechanical barrier that separates the welding arc from the water. It is also known as *submerged water arc welding.*

33. List down the parameters which diving welder should maintain.

(i) The welding amperage as read from the tong meter.
(ii) Both open and closed-circuit voltage as read from the volt meter.
(iii) Electrode diameter, type, manufacturer and waterproofing material.
(iv) Electrical polarity.
(v) Length of welding cable.
(vi) Depth of work site.

34. What are the applications of underwater welding?

(i) Underwater welding is applied in marine applications and installation of offshore oil pipelines.
(ii) It is also used to apply weld repair on massive ships inside the water.

35. Classify underwater welding.

(1) Wet underwater welding
(2) Dry underwater welding.

36. What are the advantages of wet underwater welding?

1. Welders can reach positions inaccessible by other methods.
2. Process is fast.
3. Cost of welding is very low.
4. It has more freedom of repair design and fit-up.

37. Mention the limitations of wet underwater welding.

1. Quenching effect is produced at the weld surface due to direct contact of the arc and molten weld-pool with water.
2. Both porosity and hardness also increase.
3. It produces low visibility to the operator.
4. Inspection of welds is very difficult as compared to open air welding. So, producing a good quality of weld is very difficult task.

38. State the advantages of dry underwater welding.

1. Higher welder safety is ensured in a chamber, less immune to ocean currents and marine animals.
2. High quality weld joints are produced which are well compared to open air weld joints.
3. All inspections and preparations are done visually.
4. Non Destructive Testing (NDT) is also facilitated by dry welding which is pretty much important.
5. Good surface monitoring is ensured.

39. List down the limitations of dry underwater welding.

1. The process requires huge number of complex equipment.
2. The operator needs to be more and specifically trained.
3. The process is costly which requires an element of precision welding.
4. Cost of process is higher and the welder needs a proper training.
5. Equipment is complex.

40. Compare underwater welding and air welding.

(i) The gap between electrode and work is not maintained in underwater welding because the electrode is lifted due to the pressure of water during arc but the gap is maintained well between electrode and work in air welding.
(ii) Underwater welding arc is surrounded by steam and gases but it is not in the case of air welding.
(iii) Cooling rate of the part can be controlled in air welding by changing the energy input but it is difficult in underwater welding.

(iv) Hydrogen and oxygen levels are high in underwater welding but it is normal in air welding.

(v) Electrode holder also insulated in underwater welding to avoid electric shock.

41. State the reasons of implementing welding robots in aerospace industry.

1. Robotics automation is economical
2. Compared to setting up customized machines, robotics automation is easy to deploy. Six-axis robots are quick to set up, program and put into production.
3. Robots are well-suited for aerospace manufacturing because they offer application and work envelope flexibility.
4. Sometimes, building an aerospace craft gets a bit cramped. Industrial robots make cramped and painstaking tasks similar to closing up wing spaces much more ergonomic and quick.
5. For changing the tool and programming, 6-axis robot is ready for a new application. This flexibility makes robotics automation very attractive to aerospace manufacturers.

42. What are the advantages of using manipulator in robotic welding in aerospace industry?

1. A manipulator can easily be moved around the workpiece for the best welding positions.
2. A manipulator can reduce the variation in the lead and lag angles of the tip.
3. Welding can be performed in a stable flat welding position by a synchronized and simultaneous control of a robot and manipulator.
4. Any hard-to-reach positions can be accessed more easily.
5. A manipulator increases the working range of a fixed floor mounted robot or an inverted robot.

43. Mention any two advantages and limitations of automated welding.

Advantages:

(a) Increased productivity

(b) Consistent weld quality

Limitations:

(a) A need for more accurate part location and orientation are required.

(b) More sophisticated arc movement and control devices are needed.

44. List down the types of welding used in aerospace industry.

1. Friction Welding (FRW)
2. Friction Stir welding (FSW)
3. Flash Welding (FW)
4. Gas Metal Arc Welding (GMAW) or MIG welding
5. Gas Tungsten Arc Welding (GTAW) or TIG welding
6. Plasma Arc Welding (PAW)
7. Laser Beam Welding (LBW)
8. Electron Beam Welding (EBW)
9. Diffusion Welding (DFW)
10. Resistance Welding.

45. Write down the industry applications of narrow gap welding process.

1. Steam generators of power plant
2. Petrochemical industries
3. Shipbuilding
4. Heavy machinery fabrication
5. Nuclear reactor vessel manufacturing.

46. What are the benefits of narrow gap welding process?

1. Minimum joint preparation and minimum joint volume.
2. Good mechanical properties.
3. Low heat input.
4. Low parent metal dilution and small heat affected zone.
5. High quality weld can be produced without turning plate.
6. Simple "off-the-shelf" equipment solution.
7. Low distortion.

4.11. SOLVED QUESTIONS AND ANSWERS

1. What is the principle of thermit welding? Explain with a neat sketch of the thermit welding arrangement.

   Refer chapter **4.1.3** in page **4.3**.

2. Describe the working of atomic hydrogen welding with neat sketches.

   Refer chapter **4.2.1** in page **4.7**.

3. Explain the principle of operation, advantages and limitations of electron beam welding.

   Refer chapter **4.3.1** in page **4.9** for operation and chapter **4.3.3** in page **4.79** for advantaged and limitations.

4. Explain the method of laser beam welding and give their applications.

   Refer chapter **4.4.4** in page **4.17** for methods and chapter **4.4.5** in page **4.18** for applications.

5. Explain friction stir welding process with a neat sketch.

   Refer chapter **4.5** in page **4.19**.

6. Write short notes on microstructural features in friction stir welding.

   Refer chapter **4.5.2** in page **4.23**.

7. Discuss the procedure involved in friction stir welding cycle.

   Refer chapter **4.5.6** in page **4.25**.

8. Explain the principle involved in underwater welding.

   Refer chapter **4.6** in page **4.27**.

9. Discuss the risks associated with underwater welding.

   Refer chapter **4.6.1** in page **4.28**.

10. Write short notes on characteristics of underwater welding arc.

    Refer chapter **4.6.2** in page **4.28**.

11. Classify underwater welding.

    Refer chapter **4.6.3** in page **4.29**.

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12. Explain the working of wet underwater welding with a neat sketch.

    Refer chapter **4.6.4** in page **4.29**.

13. Describe the working of dry underwater welding with a neat sketch.

    Refer chapter **4.6.5** in page **4.31**.

14. Compare underwater welding over normal air welding.

    Refer chapter **4.6.6** in page **4.33**.

15. Explain automated robotic welding system and key features of automation.

    Refer chapter **4.7** in page **4.33**.

16. Write short notes on welding automation in nuclear sector

    Refer chapter **4.8** in page **4.42**.

17. Discuss the welding automation in surface transport vehicles.

    Refer chapter **4.9** in page **4.44**.

END of Unit 4

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UNIT – 5

DESIGN OF WELD JOINTS, WELDABILITY AND TESTING OF WELDMENTS

Various weld joint designs – Weldability of Aluminium, Copper, and Stainless steels. Destructive and non-destructive testing of weldments.

5

DESIGN OF WELD JOINTS, WELDABILITY AND TESTING OF WELDMENTS

5.1. WELDED JOINTS

Welded joints are classified according to the relative positions of two components to be joined. There are five basic types of welded joints.

(i) Butt joint:

It is used to join the ends or edges of two plates as shown in Figure 5.1. The surfaces of plates are located in the same plane. The edges of the plates are beveled depending on their thickness. Table 5.1 indicates the thickness of plates for which different types of butt joints are used.

Table 5.1

Types of joints	*Thickness of plate (mm)*
Square butt joint	1 - 6
Single V butt joint	6 - 20
Double V butt joint	12 - 60
Single U butt joint	20 - 60
Double U butt joint	30 - 60

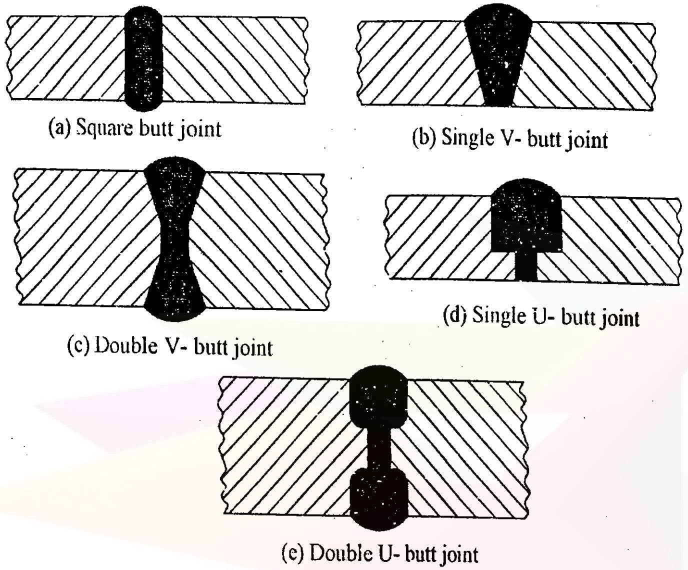

Figure 5.1 Types of butt welded joints

(ii) Lap joint:

In a lap joint, the two plates are overlapped each other for a certain distance. Then the edge of each plate is welded to the surface of the other surface as shown in Figure 5.2. Such a weld is also called *fillet weld.* A fillet weld consists of approximately triangular cross-section joining two surfaces at right angle to each other. Sometimes, it may also be reinforced to increase the load capacity of the weld per unit length as shown in Figure 5.2.

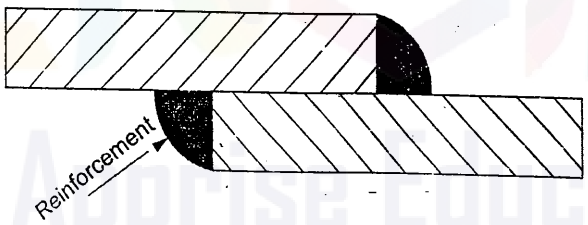

Figure 5.2 Lap joint

(iii) Tee - joint:

The two plates are arranged in 'T' shape i.e. located at right angle to each other and the overlapping edges are welded by fillet weld as shown in Figure 5.3.

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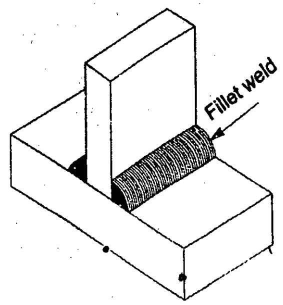

Figure 5.3 Tee joint

(iv) Corner joint:

In this type of joint, two plates are arranged at right angle in such a manner that it forms an angle i.e. L-shape as shown in Figure 5.4. The adjacent edges are joined by a fillet weld.

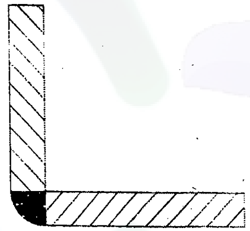

Figure 5.4 Corner joint

(v) Edge joint:

For plates of thickness less than 6 *mm*, the ends of the overlapping plates can be directly welded at the edges as shown in Figure 5.5. Such joints are called *edge joint*.

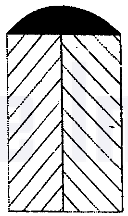

Figure 5.5 Edge joint

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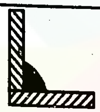
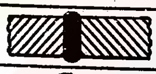
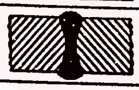
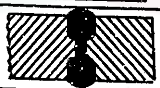
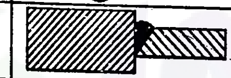
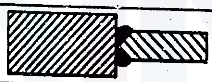
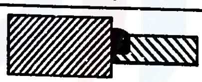
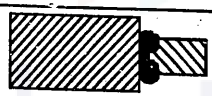
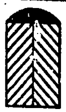
5.2. BASIC WELD SYMBOLS

Table 5.2 shows various types of welded joints and their symbols according to the IS: 813-1961.

Table 5.2 Basic weld symbols

S.No	Name of joint	Joint	Symbol
1	Fillet		
2	Square butt		
3	Single V- butt		
4	Double V- butt		
5	Single U- butt		
6	Double U- butt		
7	Single bevel butt		
8	Double bevel butt		
9	Single-J butt		
10	Double-J butt		
11	Spot		
12	Sealing run		
13	Bead (Edge or seal)		

Source: Welding Handbook, American Welding Society, 1950

5.3. DESIGN CONSIDERATIONS IN WELDING

1. ***Design for welding:***

It refers that the product should be designed from the start as a welded assembly, but not as a casting or forging or other formed shape.

2. ***Design for minimum parts:***

Welded assemblies should consist of fewest numbers of parts possible. Example: It is usually more cost efficient to perform simple bending operations on a part than to weld an assembly from flat plates and sheets.

(a) Arc welding design guidelines:

1. Good fit-up of parts is to maintain dimensional control and minimize distortion. Sometimes, machining is required to achieve satisfactory fit-up.
2. Assembly must allow access for welding gun to reach welding area.
3. Design of assembly should allow flat welding to be performed as much as possible since it is the fastest and most convenient welding position.

(b) Resistance welding design guidelines:

1. Low-carbon steel sheet up to 0.125 (3.2 *mm*) is ideal metal for resistance spot welding.
2. Additional strength and stiffness can be obtained in large flat sheet metal components by the following methods.
   - (i) Spot welding reinforcing parts into them
   - (ii) Forming flanges and embossments.
3. Spot welded assembly must provide access for electrodes to reach welding area.
4. Sufficient overlap of sheet metal parts is required for electrode tip to make proper contact.

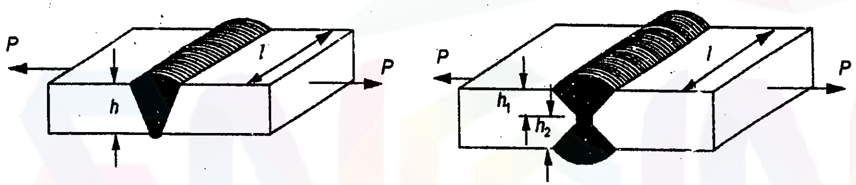
5.4. DESIGN OF BUTT WELD JOINTS

Butt-welded joints are designed for tensile or compressive forces. The type of butt joint formed between two plates and the minimum weld size depends on the thickness of plate. Table 5.3 gives the guidelines for selection of minimum weld size of butt joints.

Table 5.3 Minimum weld size for butt joints

Plate thickness (mm)	*Minimum size of weld (mm)*
3 – 5	3
6 – 8	5
10 – 16	6
18 – 24	10
26 – 35	15
Over 38	20

Consider a single V-butt joint subjected to a tensile load P as shown in Figure 5.6 (a). In case of butt joint, the length of the leg or size of weld is equal to the throat thickness (h) which is equal to thickness of plate. For design purpose, the length of weld is taken equal to width of plate. While calculating weld throat, the reinforcement of weld is not taken into consideration.



(a) Single V-butt joint *(b) Double V-butt joint*

Figure 5.6 Types of V-butt joints

Tensile strength of a single V-groove butt joint is given by

$$P = \text{Stress} \times \text{Area}$$

$$P = \sigma \times h\, l \qquad \dots (5.1)$$

where h = Weld size

l = Length of weld = Width of the plate

σ = Allowable or working tensile stress of the weld.

Figure 5.6(b) shows a double V-groove butt weld subjected to a tensile load P. h_1 and h_2 are weld throat thickness of V at the top and bottom.

Area of weld, $A = (h_1 + h_2) \times l$

Tensile strength at a double V-groove butt joint is given by

$$P = (h_1 + h_2)\, l \times \sigma \qquad \dots (5.2)$$

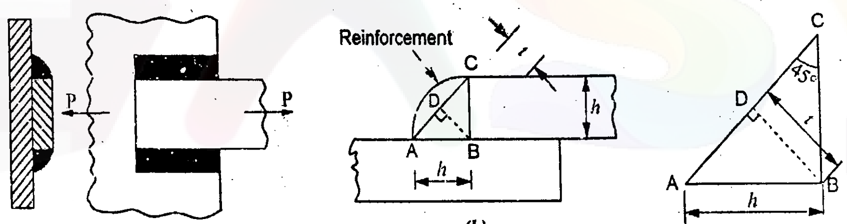
5.5. DESIGN OF FILLET WELDS

There are two types of fillet welds as follows.

(i) Longitudinal or parallel fillet weld

(ii) Transverse fillet weld.

(i) Longitudinal or parallel fillet weld:



(a) *(b)* *(c)*

Figure 5.7 Double parallel fillet weld

As already explained, two plates are placed over each other and fillet welding is done along the longitudinal axis (along the length). Figure 5.7 (a) shows the double parallel fillet weld subjected to tensile force P. These types of welds are designed for shear strength. The size of weld (h) is taken as throat thickness because the failure of joint often occurs more across the throat.

Throat thickness can be calculated as follows:

From Figure 5.7 (c), $AB = BC = h$ = size of weld.

$$\theta = 45°$$

BD, which is perpendicular to AC, is called throat thickness (t)

In a triangle BDA,

$$\frac{BD}{AB} = \sin\theta$$

$$BD = AB \sin\theta = h \sin 45° = 0.707\, h$$

Throat thickness, $t = 0.707h$

Tensile strength, P = Area of weld × Shear stress

For single parallel fillet:

$$P = A \times \tau$$

$$P = 0.707\, h \times l \times \tau \qquad \text{... (5.3)}$$

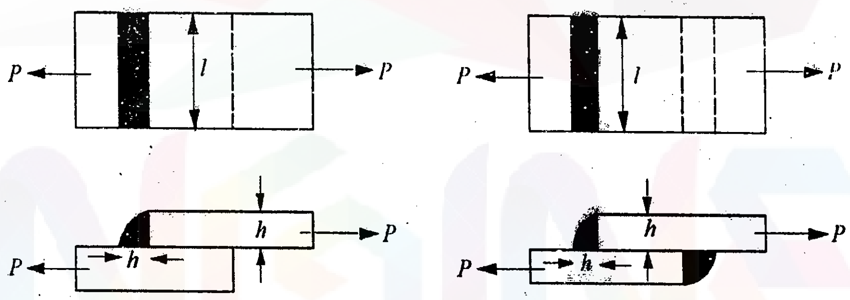
For double parallel fillet:

$$P = 2 \times 0.707\, h \times l \times \tau$$

$$P = 1.414\, h\, l\, \tau \qquad \text{... (5.4)}$$

(ii) Traverse fillet welds:

In a transverse fillet weld, the load acts perpendicular to the longitudinal axis of the plate as shown in Figure 5.8.



(a) Single transverse fillet weld *(b) Double transverse fillet weld*

Figure 5.8 Transverse fillet weld

The transverse fillet welds are designed for tensile strength.

For single transverse fillet welds:

Tensile strength, $P = A \times \sigma$

$$P = 0.707 \times h \times l \times \sigma \qquad \text{... (5.5)}$$

For double transverse fillet welds:

$$P = 2 \times 0.707 \times h \times l \times \sigma$$

$$P = 1.414\, h\, l\, \sigma \qquad \text{... (5.6)}$$

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(iii) Combination of single transverse and fillet welds:

Figure 5.9 shows a single fillet transverse and double fillet parallel joint subjected to a tensile force P, the strength equation is given by

$$P = P_{transverse} + P_{parallel} = 0.707 h l_1 \sigma + 2 \times 0.707 \times h l_2 \tau$$

where $l_1 \Rightarrow$ lengths of transverse fillet weld

$l_2 \Rightarrow$ length of parallel fillet weld

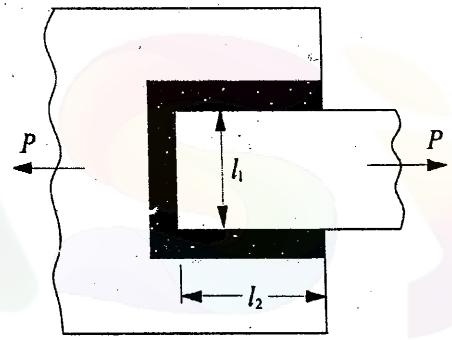
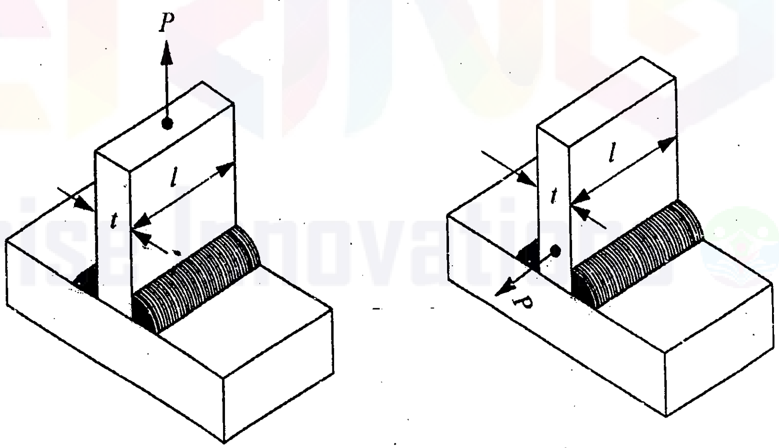


Figure 5.9 Combination of transverse and parallel fillet welds

5.6. DESIGN OF TEE JOINT

When two plates are joined together at right angle to each other, it is called *tee joint.*



(a) Force perpendicular to the plane of weld *(b) Force parallel to the plane of weld*

Figure 5.10 Tee joint

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(i) When tee joint is subjected to a tensile force perpendicular to the plane of weld as shown in Figure 5.10 (a), it will be designed for tensile strength. The design procedure is same as that of transverse fillet weld and the strength equation for double fillet-welded joint is given by

$$P = 1.414\, h\, l\, \sigma$$

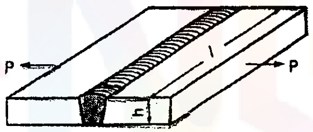
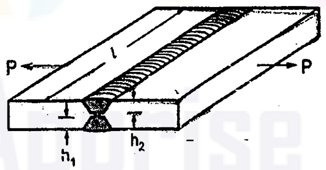
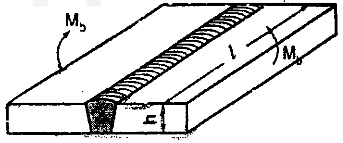
(ii) Figure 5.10(b) shows a tee joint in which a load acts parallel to the plane of the weld with small eccentricity. This type of joint is designed for shear strength. The strength equation for double fillet weld joint is given by

$$P = 1.414\, h\, l\, \tau$$

Similarly, the design stress values of different welded connections are found and summarized in Table 5.4.

> *Note:* The design strength equations for various types of welded joints for different loading condition are given in *PSG Design Data Book* (PSGDB) Page 11.5. It can be directly used wherever necessary.

Table 5.4 Weld stress formulae

S. No.	Type of weld and loading	Formulae for weld stress
1.		$\sigma = \dfrac{P}{hl}$
2.		$\sigma = \dfrac{P}{(h_1 + h_2)l}$
3.		$\sigma = \dfrac{6\, M_b}{h^2 l}$

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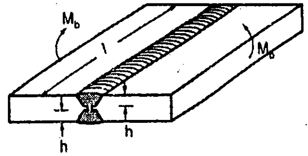
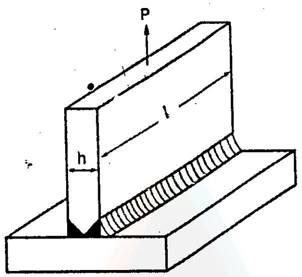
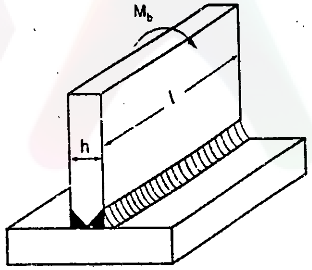
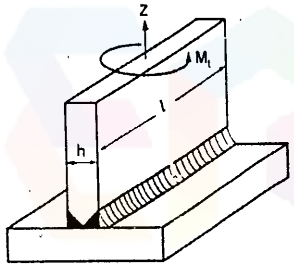
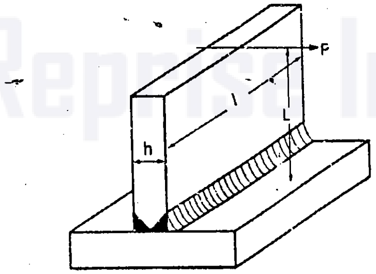
S. No.	Type of weld and loading	Formulae for weld stress
4.		$\sigma = \dfrac{3T\, M_b}{lh(3T^2 - 6Th + 4h^2)}$
5.		$\sigma = \dfrac{P}{hl}$
6.		$\sigma = \dfrac{6\, M_b}{h^2 l}$
7.		$\tau = \dfrac{4.24\, M_t}{h\, l^2}$
8.		$\sigma = \dfrac{6\, PL}{h^2 l}$ $\tau = \dfrac{P}{l\, h}$

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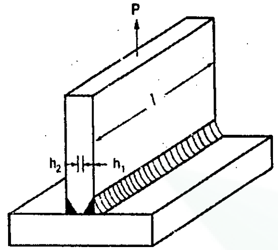
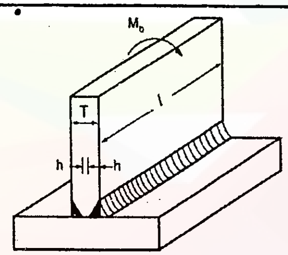
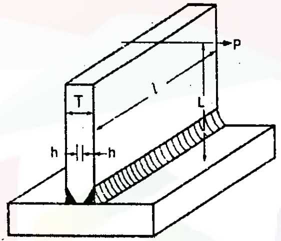
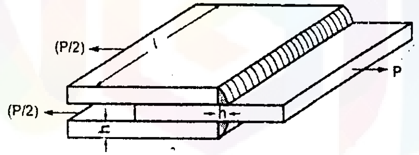
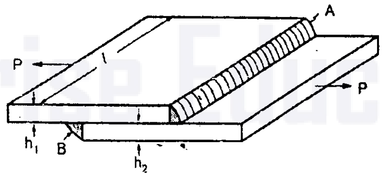
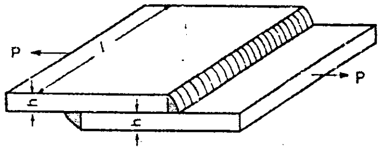
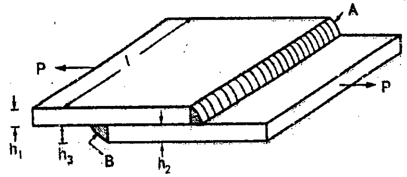
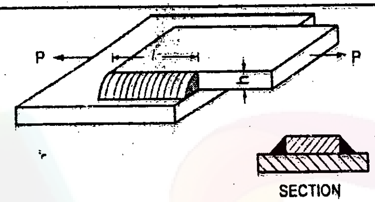
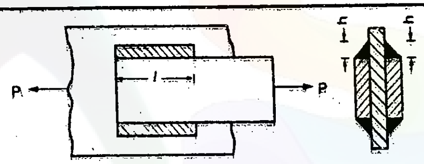
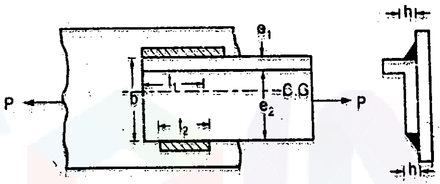
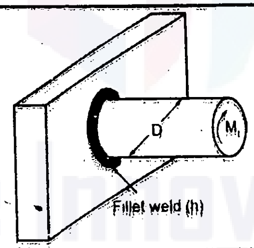
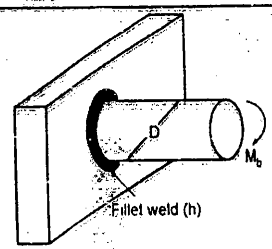
9.		$\sigma = \dfrac{P}{(h_1 + h_2)l}$
10.		$\sigma = \dfrac{3T\ M_b}{lh(3T^2 - 6Th + 4h^2)}$
11.		$\sigma = \dfrac{3T\ PL}{lh(3T^2 - 6Th + 4h^2)}$ $\tau = \dfrac{P}{2\ l\ h}$
12.		$\sigma = \dfrac{0.707\ P}{hl}$
13.		Stress in weld A equals stress in weld B $\sigma = \dfrac{1.414\ P}{(h_1 + h_2)l}$
14.		$\sigma = \dfrac{0.707\ P}{hl}$ Both plate same thickness

15.		Weld A $\sigma = \dfrac{1.414\ P}{(h_1 + h_2)l}$ Weld B $\sigma = \dfrac{1.414\ Ph_2}{(h_1 + h_2)l\,h_3}$
16.		$\sigma = \dfrac{0.707\ P}{hl}$
17.		$\sigma = \dfrac{0.354\ P}{hl}$
18.		$\sigma = \dfrac{1.414\ P}{h(l_1 + l_2)}$ *or* $l_1 = \dfrac{1.414\ P\ e_2}{\sigma h b}$; $l_2 = \dfrac{1.414\ P\ e_1}{\sigma h b}$
19.		$\tau = \dfrac{2.83 M_t}{h D^2 \pi}$
20.		$\sigma = \dfrac{5.66 M_b}{h D^2 \pi}$

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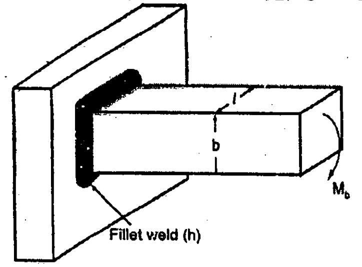
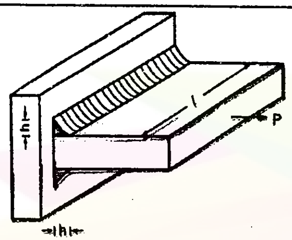
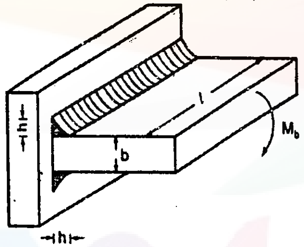
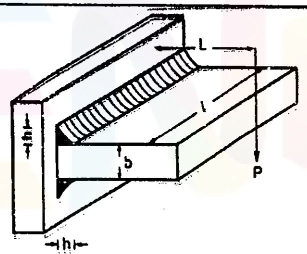
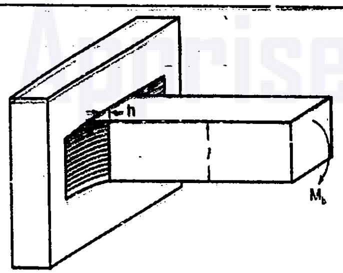
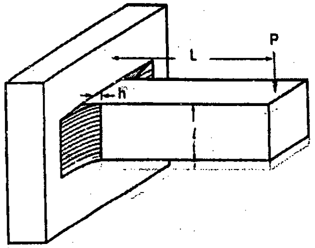
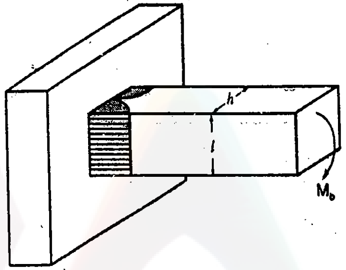
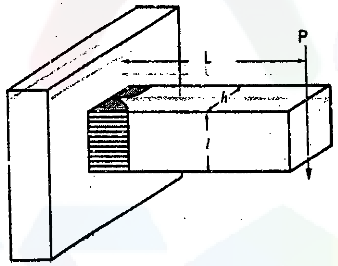
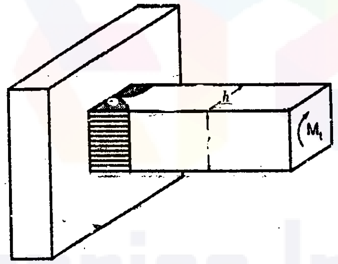
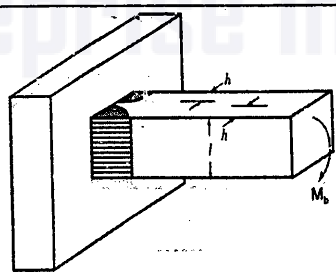
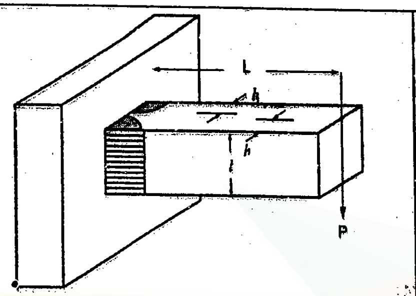
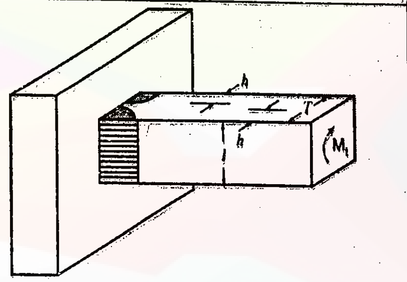
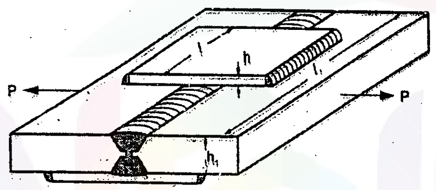
21.		$\sigma = \dfrac{4.24\,M_b}{h\left[b^2 + 3l(b+h)\right]}$
22.		$\sigma = \dfrac{0.707\,P}{h\,l}$
23.		$\sigma = \dfrac{1.414\,M_b}{h\,l(b+h)}$
24.		$\sigma_{max} = \dfrac{P}{hl(b+h)}\sqrt{2L^2 + \dfrac{(b+h)^2}{2}}$ $\tau_{avg} = \dfrac{0.707\,P}{h\,l}$
25.		$\sigma = \dfrac{4.24\,M_b}{h\,l^2}$

26.		$\sigma_{max} = \dfrac{4.24\,PL}{h\,l^2}$ $\tau_{avg} = \dfrac{0.707\,P}{h\,l}$
27.		$\sigma = \dfrac{6\,M_b}{h^2 l}$
28.		$\sigma = \dfrac{6\,PL}{h\,l^2}$ $\tau = \dfrac{P}{l\,h}$
29.		$\tau = \dfrac{M_t(3l + 1.8h)}{h^2\,l^2}$
30.		$\sigma = \dfrac{3\,M_b}{h^2 l}$

31.		$\sigma = \dfrac{3PL}{hl^2}$ $\tau = \dfrac{P}{2lh}$
32.		$\tau = \dfrac{M_t}{2(T-h)(l-h)h}$
33.		Fillet weld, $\sigma = \dfrac{1.414P}{2hl + h_1 l}$ Butt weld, $\sigma = \dfrac{P}{2hl + h_1 l}$
	σ = Normal stress τ = Shear stress M_b = Bending moment M_t = Twisting moment	P = External load L = Linear distance h = Size of weld l = length of weld

Source: Welding Handbook, American Welding Society, 1950.

5.7. STRENGTH OF WELDED JOINTS

The permissible stresses for standard structures are covered by National or International codes. During the design of such a welded joint, the designer uses the values of permissible stresses given in the relevant standards. In most of the cases, the strength of the weld deposit is higher than the strength of the connected parts. Examples of such cases are as follows:

(i) Components made of mild steel with less than 0.3% carbon,

(ii) Welding electrodes contains 0.15% carbon, and

(iii) Electrodes coated with flux thereby resulting in shielded welding.

The permissible stresses for various weld deposits may vary between 21-125N/mm^2 as given in Table 5.5.

Table 5.5 Design stresses (MPa) for welds made with mild steel electrodes

Type of weld and load		Bare electrodes		Coated electrodes	
		Steady load	Reversed load	Steady load	Reversed load
Butt joint	Tension	90	35	110	55
	Compression	100	35	125	55
	Shear	55	21	70	35
Fillet welds (All)		79	21	95	35

Source: Welding Handbook, American Welding Society, 1950.

When the components are made of high carbon steel or alloy steel, the weld deposit is weaker than the strength of the connected components. In such cases, properties of the weld deposit, namely the tensile strength or yield strength is considered as a criterion for determining permissible stresses. Table 5.6 shows the allowable static loads per linear *cm* of weld on mild steel fillet welds.

Table 5.6 Allowable static load per linear cm of weld on mild steel fillet welds

Size of weld, mm	Bare electrodes		Covered electrodes	
	Normal weld	Parallel weld	Normal weld	Parallel weld
2 × 3	1667*N*	1324*N*	2060*N*	1667*N*
5 × 5	2746*N*	2187*N*	3432*N*	2746*N*
6 × 6	3285*N*	2628*N*	4119*N*	3285*N*
8 × 8	4374*N*	3501*N*	5492*N*	4374*N*

10 × 10	5492N	4080N	6865N	5492N
12 × 12	6570N	5264N	8238N	6570N
14 × 14	7659N	6129N	9581N	7659N
15 × 15	8238N	6570N	10297N	8238N

Source: Welding Handbook, American Welding Society, 1950.

5.8. ECCENTRICALLY LOADED WELDED JOINTS

In many practical cases such as structural joints where the external load applied may not pass through the geometric centre, those joints are called *eccentrically loaded joints*. In eccentric loading of welded joints, two types of stresses are induced. One is direct shear stress while the other one may be bending or torsional shear stresses. There are three types of eccentric welded connections.

(i) Welded connections subjected to moment acting in a plane of the weld.

(ii) Welded connections subjected to moment acting in a plane normal to the plane of the weld.

(iii) Welded connections subjected to direct shear, bending and torsional loads.

Case (i): Welded connections subjected to moment acting in a plane normal to the plane of the weld (i.e. direct shear and bending stresses):

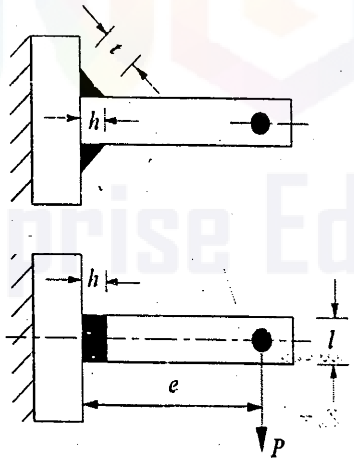


Figure 5.11 Eccentrically loaded weld

Consider a cantilever beam loaded shown in Figure 5.11. The forces acting on the joint are

(i) Direct shear force due to force P.

(ii) Bending stress due to bending moment ($P \times e$).

Stresses due to direct shear force will be shearing in nature i.e. same as discussed for a double parallel fillet weld. It is given by

$$P = 1.414hl\tau$$

$$\therefore \quad \tau = \frac{P}{1.414hl}$$

Bending stress due to bending moment may be calculated by bending stress equation

$$\frac{M_b}{I} = \frac{\sigma_b}{y}$$

$$\sigma_b = \frac{M_b \times y}{I} = \frac{M_b}{\frac{I}{y}} = \frac{M_b}{Z_w}$$

$$\sigma_b = \frac{P \times e}{Z_w} \qquad (\because M_b = P \times e)$$

where $M_b \Rightarrow$ Bending moment

$e \Rightarrow$ Eccentricity of load acting

$Z_w \Rightarrow$ Section modulus of weld

Assuming that failure of the weld take place at the minimum resisting area i.e., at the throat.

$$Z_w = \frac{1}{6} \times \text{Throat thickness} \times l^2$$

We know that, throat thickness, $t = 0.707h$

$$\therefore \quad Z_w = \frac{0.707hl^2}{6}$$

For both sides welded connection

$$Z_w = \frac{2 \times 0.707hl^2}{6}$$

The bending stress, $\sigma_b = \dfrac{P \times e}{2 \times \dfrac{0.707hl^2}{6}} = \dfrac{4.24Pe}{hl^2}$

Since it is a case of biaxial loading, resultant stress due to direct shear and bending stress is obtained by using maximum shear stress theory as

$$\tau_{res} = \frac{1}{2}\sqrt{\sigma_b^2 + 4\tau^2}$$

The resultant stress should not exceed τ_{max}.

Case (ii): Welded connections subjected to moment in the plane of the weld (i.e. direct shear and torsion)

Consider a generalized case of eccentric loading as shown in Figure 5.12. In such problems, the first step is to determine the centre of gravity of welds, treating the weld as a line. Let, two equal and opposite loads P_1 and P_2 are introduced at the centre of gravity 'G'. There are two stresses induced in this system.

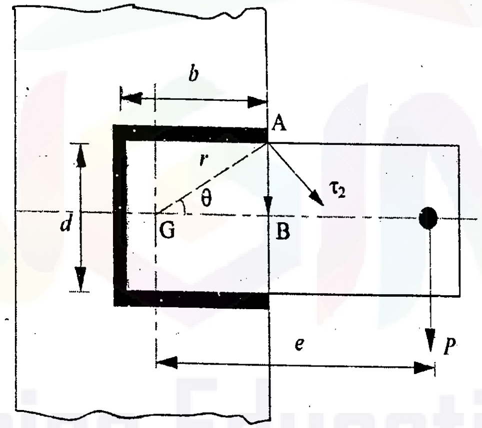


Figure 5.12

(i) Direct or primary stress due to load $P_1 = P$.

(ii) Secondary shear stress due to turning moment ($P \times e$) of load P which tends to rotate the joint about 'G'.

Total area of the weld is given by

$$A = 0.707\, h\,(2\,b + d)$$

Primary or direct shear stress due to load P,

$$\tau_1 = \frac{P}{A} = \frac{P}{0.707h(2b + d)}$$

Secondary shear stress due to twisting moment,

$$\tau_2 = \frac{M_t \times r}{J_w}$$

where M_t = Twisting moment = $P \times e$

r = radius at which the maximum shear stress will act

$= \sqrt{GB^2 + AB^2}$

J_w = polar moment of inertia of weld section (from Table 5.7 in Page 5.23 or PSGDB 11.5)

$$\tau_2 = \frac{P \times e \times r}{J_w}$$

The resultant stress can be calculated by using

$$\tau = \sqrt{\tau_1^2 + \tau_2^2 + 2\tau_1 \times \tau_2 \times Cos\theta}$$

where θ = Angle between primary and secondary stresses.

$$\cos\theta = \frac{GB}{GA} = \frac{GB}{r}$$

The resultant stress should not exceed τ_{max}.

Case (iii): Welded connections subjected to direct shear, bending and torsional loads

Consider a circular rod welded to the steel support plate on one end and the other end is connected with steel rectangular bar. The arrangement is shown in Figure 5.13.

The forces acting on the welded joint are:

(i) Direct shear force due to load P

(ii) Bending stress due to bending moment ($P \times e_2$)

(iii) Secondary shear stress due to twisting moment ($P \times e_1$)

Primary or direct shear stress due to load P,

$$\tau_1 = \frac{P}{A} = \frac{P}{\text{Area of weld}}$$

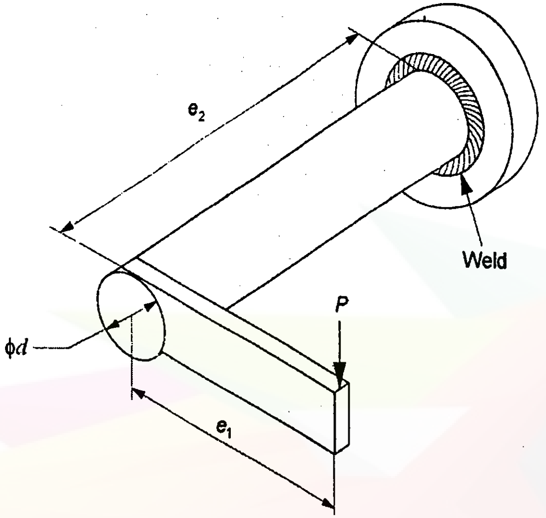


Figure 5.13

Secondary shear stress due to twisting moment ($P \times e_2$),

$$\tau_2 = \frac{M_t \times r}{J_w}$$

where M_t = twisting moment = $P \times e_2$

r = radius at which the maximum shear stress will act

J_w = polar moment of inertia of weld section (from Table 5.7 in Page 5.23 or PSGDB 11.5)

$$\therefore \quad \tau_2 = \frac{P \times e_2 \times r}{J_w}$$

Resultant shear stress due to τ_1 and τ_2 can be calculated by using

$$\tau = \sqrt{\tau_1^2 + \tau_2^2}$$

Bending stress due to bending moment may be calculated by bending stress equation

$$\sigma_b = \frac{P \times e}{Z_w} \qquad (\because M_b = P \times e)$$

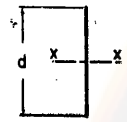
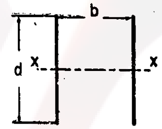
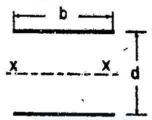
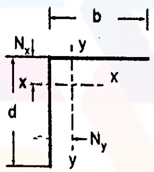
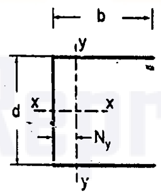
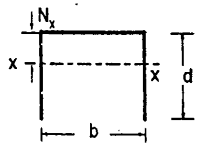
Resultant stress due to τ and σ_b is obtained by using maximum shear stress theory as

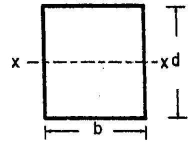
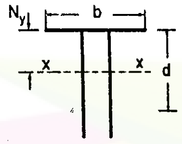
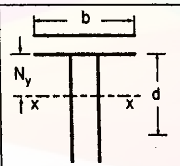
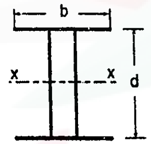
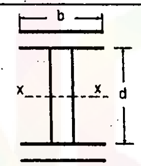
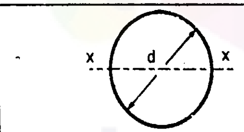
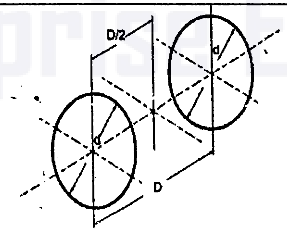
$$\tau_{res} = \frac{1}{2}\sqrt{\sigma_b^2 + 4\tau^2}$$

Resultant stress should not exceed τ_{max}.

Table 5.7 indicates the polar moment of inertia (J_w) and section modulus (Z_w) for som of weld sections (treated as line). (Also refer PSGDB 11.5 & 11.6).

Table 5.7 Properties of weld treated as a line

S.No.	Outline of welded joint	Bending about horizontal axis XX, Z_w	Twisting about centroidal axis, J_w
1.		$\frac{d^2}{6}$	$\frac{d^3}{12}$
2.		$\frac{d^2}{3}$	$\frac{d(3b^2+d^2)}{6}$
3.		bd	$\frac{b^3+3bd^2}{6}$
4.	 $N_y = \frac{b^2}{2(b+d)}$ $N_x = \frac{d^2}{2(b+d)}$	$\frac{4bd+d^2}{6}$, top; $\frac{d^2(4bd+d)}{6(2b+d)}$, bottom	$\frac{(b+d)^4-6b^2d^2}{12(b+d)}$
5.	 $N_y = \frac{b^2}{2b+d}$	$bd+\frac{d^2}{6}$	$\frac{(2b+d)^3}{12}-\frac{b^2(b+d)^2}{2b+d}$
6.	 $N_x = \frac{d^2}{b+2d}$	$\frac{2bd+d^2}{3}$, top; $\frac{d^2(2b+d)}{3(b+d)}$, bottom	$\frac{(b+2d)^3}{12}-\frac{d^2(b+d)^2}{b+2d}$

7.		$bd+\frac{d^2}{3}$	$\frac{(b+d)^3}{6}$
8.	 $N_y=\frac{d^2}{b+2d}$	$\frac{2bd+d^2}{3}$, top $\frac{d^2(2b+d)}{3(b+d)}$, bottom	$\frac{(b+2d)^3}{12}-\frac{d^2(b+d)^2}{b+2d}$
9.	 $N_y=\frac{d^2}{2(b+d)}$	$\frac{4bd+d^2}{6}$, top $\frac{4bd^2+d^3}{6b+3d}$, bottom	$\frac{d^3(4b+d)}{6(b+d)}+\frac{b^3}{6}$
10.		$bd+\frac{d^2}{3}$	$\frac{b^3+3bd^2+d^3}{6}$
11.		$\frac{2bd+d^2}{3}$	$\frac{2b^3+6bd^2+d^3}{6}$
12.		$\frac{\pi d^2}{4}$	$\frac{\pi d^3}{4}$
13.		$\frac{\pi d^2}{2}+\pi D^2$	

Source: Welding Handbook, American Welding Society, 1950.

Note: Since the weld is treated as line in the above Table 5.7, multiply the values of J_w and Z_w by the size of the weld 't' or 0.707h to obtain polar moment of inertia of the weld.

5.9. STRESS CONCENTRATION FACTOR

Stress concentration is present at the weldment because of abrupt change in cross section. The flow of force from one position of the assembly to other is shown in Figure 5.14. Lap joint with fillet weld subjected to tensile force is shown in Figure 5.14. Butt joint subjected to tensile force is shown in Figure 5.15. The stress concentration occurs at toe and heel points A and B. The stress concentration factor for different types of welds is given in Table 5.8.

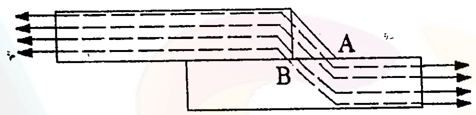


Figure 5.14 Lap joint

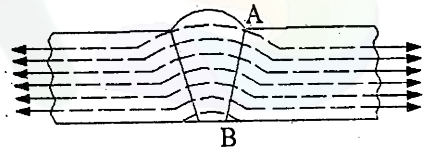


Figure 5.15 Butt joint

Table 5.8 Stress concentration factor for different types of welds

S. No.	*Type of weld*	*Stress concentration factor*
1.	Static load	1
	Reinforced butt weld	1.2
2.	Toe of transverse fillet weld or normal fillet weld	1.5
	End of parallel fillet weld or longitudinal weld	2.7
	T-butt joint with sharp corners	2.0

In case of fatigue loading, the stress concentration factor should be taken in to account.

Design stress ≤ Nominal stress × Stress concentration factor.

5.10. FATIGUE STRENGTH OF WELDING

Fatigue strength related to fatigue life could be expressed by the empirical relation

$$\sigma_{-1a} = \sigma_{-1b}\left(\frac{N_b}{N_a}\right)^C \quad \text{or}$$

$$N_a = N_b\left(\frac{\sigma_{-1b}}{\sigma_{-1a}}\right)^{1/C}$$

where σ_{-1a} = fatigue strength (known) for fatigue life N_a, MPa

σ_{-1b} = fatigue strength (allowable) for fatigue life N_b, MPa

C = constant

= 0.13 for butt welds

= 0.18 for plates in bending, axial tension or compression.

Allowable fatigue strength for fillet welds for 2,000,000 cycles is given by

$$\sigma_{-1a} = \frac{891.4}{1-\frac{1}{2}K}\ N/mm^2 \quad \text{or} \quad 1537.6 N/mm^2 \text{ whichever is less}$$

Allowable fatigue strength for fillet welds for 600,000 cycles is given by

$$\sigma_{-1a} = \frac{1238}{1-\frac{1}{2}K}\ N/mm^2 \quad \text{or} \quad 1537.6 N/mm^2 \text{ whichever is less}$$

Allowable fatigue strength for fillet welds for 100,000 cycles is given by

$$\sigma_{-1a} = \frac{1485}{1-\frac{1}{2}K}\ N/mm^2 \quad \text{or} \quad 1537.6 N/mm^2 \text{ whichever is less}$$

where $$K = \frac{\text{minimum stress}}{\text{maximum stress}} = \frac{\text{minimum load}}{\text{maximum load}}$$

The value of $K = +1$ for steady stress

$K = 0$ for the load varies in one direction

$K = -1$ for completely reversed loading.

5.11. WELDING SPECIFICATION

The welding symbol is used to convey the designer's idea to the welding operator by placing it to a suitable place of the drawings. The basic symbols used to specify the type of

weld (recommended by IS: 813-1961) are shown in Table 5.2. The complete weld symbol consists of the following elements as shown in Figure 5.16.

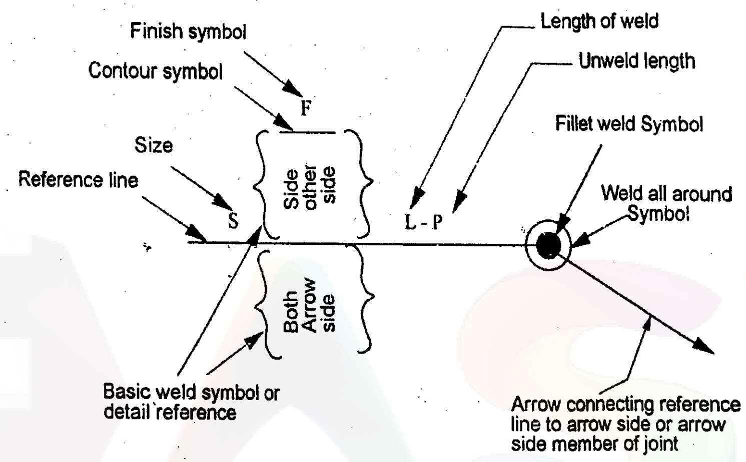
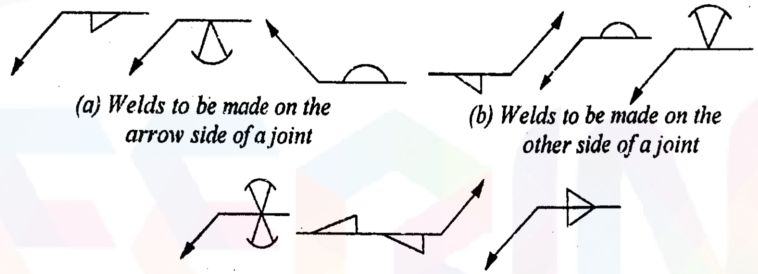


Figure 5.16 Standard location of weld symbols



(a) Welds to be made on the arrow side of a joint

(b) Welds to be made on the other side of a joint

(c) Welds to be made on both sides of a joint

Figure 5.17 Location of weld

(i) A basic symbol is to specify the type of weld.

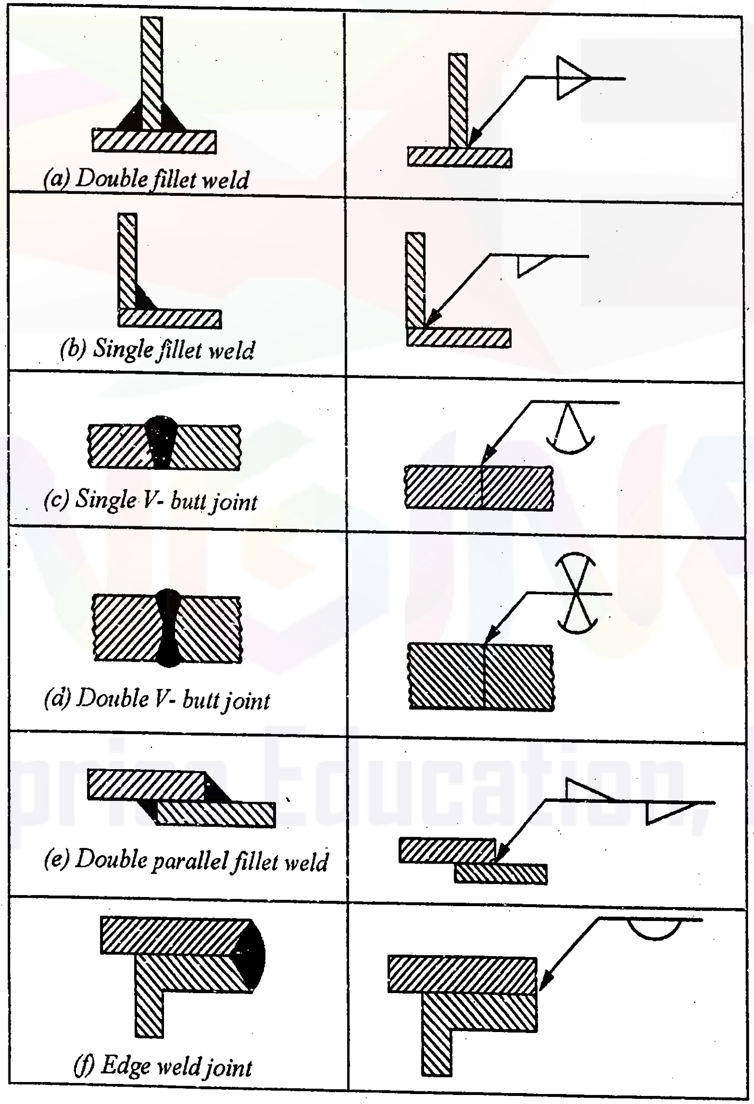
(ii) An arrow and a reference line indicate the location of the weld.

(iii) Supplementary symbols (refer Table 5.10) indicate special instructions.

(iv) Dimensions of the weld in cross section and length are also indicated.

(v) The notation of welds for various types of welded joins is illustrated in Table 5.9. The location of weld is indicated by an arrow and a reference line. When the weld symbol is above the reference line, the weld is made on the same side of the joint as the arrowhead shown in Figure 5.17 (a). When the weld symbol is above the reference line, the weld is made on the other side of the joint opposite the arrowhead shown in Figure 5.17 (b). If the weld symbol is both the side of reference line shown in Figure 5.17 (c) then both sides to be welded. The length of the weld is indicated on the right hand side of the symbol. If nothing is specified, it means that the weld is continuous along the entire length of the joint.

Table 5.9 Notations of Weld



(a) Double fillet weld

(b) Single fillet weld

(c) Single V- butt joint

(d) Double V- butt joint

(e) Double parallel fillet weld

(f) Edge weld joint

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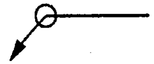
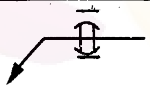
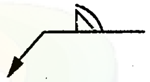
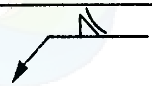
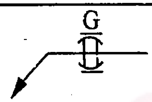
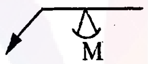
Table 5.10 Supplementary weld symbols

S.No.	Special Instructions	Drawing Representation	Symbol
1.	Weld all-round		○
2.	Site weld (field weld)		●
3.	Flush contour		—
4.	Convex contour		
5.	Concave contour		
6.	Grinding finish		G
7.	Machning finish		M
8.	Chipping finish		C

5.12. SOLVED PROBLEMS ON WELDED JOINTS

Problem 1

A plate 60 mm wide and 10 mm thick is welded to another plate by two parallel fillet welds as shown in Figure 5.18. Determine the safe load that the weld joint can carry. The allowable working stress in shear for the weld material is 75 N/mm².

Given data:

Width of the plate, $b = 60$ *mm*

Thickness of the plate, $t = 10$ *mm*

Allowable shear stress, $\tau = 75\ N/mm^2$

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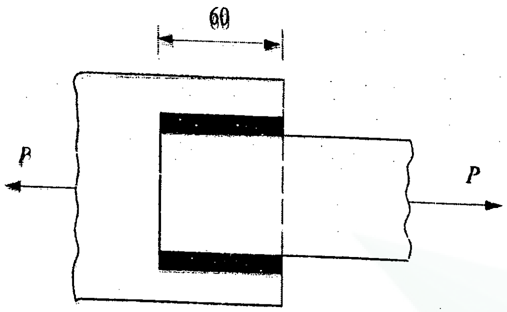

Figure 5.18

☺ Solution:

Since the thickness of the plate is 10 *mm*, we can assume the size of weld as 10*mm* i.e.

$$h = 10\ mm$$

Area of the weld, $A = 2 \times 0.707 \times h \times l = 2 \times 0.707 \times 10 \times 60$

$$A = 848.4\ mm^2$$

Allowable shear stress, $\tau = \dfrac{\text{Load}}{\text{Area}}$

$$75 = \frac{P}{848.4}$$

$$P = 63630\ N$$

Ans.

Problem 2

Find the size of the weld for the connection shown in Figure 5.19 if the tensile load acting on the connection is 120 kN. Assume the permissible shear stress on the weld as 75 MPa.

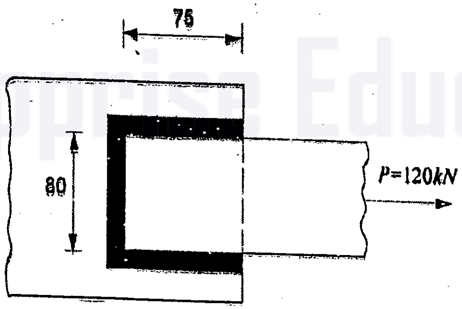

Figure 5.19

Given data:

Load, $P = 120\ kN = 120 \times 10^3\ N$

Permissible stress, $\tau = 75\ MPa = 75\ N/mm^2$

☺ Solution:

Area of the weld,

$$A = 0.707h\,(2\,b + d)$$

$$= 0.707 \times h \times (2 \times 75 + 80)$$

$$A = 162.61h$$

Permissible shear stress,

$$\tau = \frac{P}{A}$$

$$75 = \frac{120 \times 10^3}{162.61h}$$

$$h = 9.84 \text{ say } 10\ mm$$

Ans.

Problem 3

A plate 100 mm wide and 12.5 mm thick is to be welded to another plate by means of two parallel fillet welds. The plates are subjected to a load of 50 kN. Find the length of the weld so that the maximum stress does not exceed 56 N/mm². (Do the calculations under static loading).

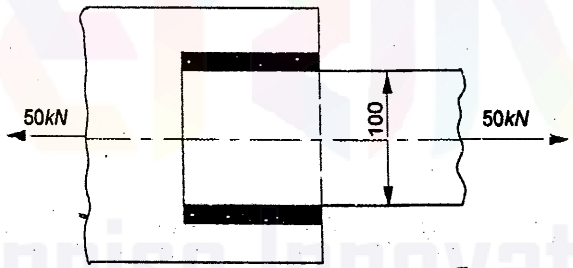

Figure 5.20

Given data:

Width of the plate, $b = 100\ mm$

Thickness of the plate, $h = 12.5\ mm$

Load, $P = 50\ kN = 50 \times 10^3 N$

Maximum stress, $\sigma = 56\ N/mm^2$

Solution:

This problem can be solved either of the following two methods. Students are advised to follow method 1 which is very simple. However, for understanding of the basic principle of stresses induced in the joint, method 2 is useful.

Method 1:

From Table 5.4 in Page 5.10 (or PSGDB 11.3), the stress induced in this type of welding is given by the equation,

$$\sigma_b = \frac{0.707P}{hl}$$

$$\therefore\ 56 = \frac{0.707 \times 50 \times 10^3}{12.5 \times l}$$

$$l = 50.5\ mm$$ **Ans.**

Method 2:

Since the thickness of the plate is 12.5 *mm*

Size of weld, $h = 12.5\ mm$

Area of the weld, $A = 2 \times 0.707 \times h \times l$

$$= 2 \times 0.707 \times 12.5 \times l$$

$$A = 17.675\ l\ mm^2$$

Maximum stress, $\tau = \dfrac{\text{Load}(P)}{\text{Area}(A)}$

$$56 = \frac{50 \times 10^3}{17.675l}$$

$$l = 50.52\ mm$$

Length of the weld, $l = 50.52\ mm$ **Ans.**

Problem 4

A plate 100 mm wide and 12.5 mm thick is to be welded to another plate by means of single transverse and double parallel fillet welds. Determine the length of weld run in each case if the joint is subjected to varying loads. The recommended design stress in tension is not to exceed 70 N/mm² and in shear 56 N/mm² for static loading.

Given data:

Width of the plate, $b = 100\ mm$

Thickness of the plate, $t = 12.5\ mm$

Design stress in tension, $\sigma_t = 70\ N/mm^2$

Design stress in shear, $\tau = 56\ N/mm^2$

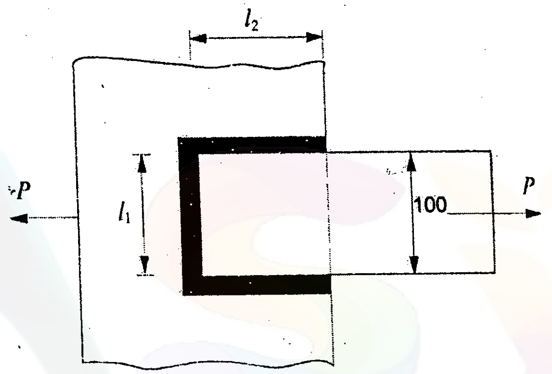

Figure 5.21

Solution:

In this case the single transverse weld is subjected to tensile stress and parallel fillet welds are subjected to shear stress.

(i) *Length of the weld in single transverse, l_1:*

Since the maximum weld size should not exceed thickness of the plate, weld size is assumed as the thickness of the plate for single transverse weld.

$$L_1 = d - t = 100 - 12.5 = 87.5\ mm$$ **Ans.**

(ii) *Length of each parallel fillet weld, l_2 (varying load):*

Maximum load that can be applied on the plate without failure is

Maximum load (P) = Area × tensile stress (σ_t)

$$= b \times t \times \sigma_t$$

$$= 100 \times 12.5 \times 70 = 87500\ N$$

In case of varying load, the stress concentration factor for

(i) Transverse weld = 1.5

(ii) Parallel fillet weld = 2.7 (from Table 5.8)

Permissible tensile stress, $\sigma_t = \dfrac{70}{1.5} = 46.67\ N/mm^2$

$\therefore$ Permissible shear stress, $\tau = \dfrac{56}{2.7} = 20.74\ N/mm^2$.

Load carried by single transverse weld,

$$P_1 = 0.707 \times h \times l_1 \times \sigma_t$$
$$= 0.707 \times 12.5 \times 87.5 \times 46.67$$
$$P_1 = 36089.04\ N$$

Load carried by double parallel fillet weld,

$$P_2 = 2 \times 0.707 \times h \times l_2 \times \tau$$
$$= 2 \times 0.707 \times 12.5 \times l_2 \times 20.74$$
$$P_2 = 366.58 l_2\ N$$

Maximum load, $P = P_1 + P_2 = 36112.234 + 366.58 l_2$

$$87500 = 36089.04 + 366.58 l_2$$
$$l_2 = 140.25\ mm$$

$\therefore$ Length of the weld in parallel fillet,

$$= l_2 + 12.5$$
$$= 140.25 + 12.5$$
$$l_2 = \mathbf{152.75}\ mm \quad \text{say } \mathbf{153}\ mm$$

Ans.

Problem 5

A spherical pressure vessel is made of 8 mm steel plate hemisphere butt welded together. The vessel is 5 m in diameter. Determine the allowable internal pressure to which the tank may be subjected if the permissible stress were limited to 70 N/mm².

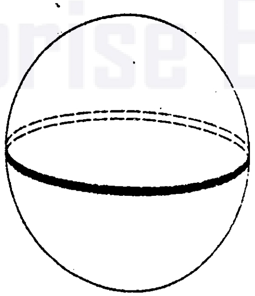

Figure 5.22

Given data:

Thickness of the plate, $t = 8\ mm$

Diameter of the vessel, $D = 5\ m = 5000\ mm$

Permissible stress, $\tau = 70\ N/mm^2$

☺ ***Solution:***

Area of the weld, $A = \pi \times D \times t = \pi \times 5000 \times 8 = \mathbf{125663.71}\ mm^2$

Maximum load that the vessel can carry,

$$P = \text{stress} \times \text{Area} = 70 \times 125663.71 = \mathbf{8.796 \times 10^6}\ N/mm^2$$

Maximum load of the vessel

$$= \text{Pressure} \times \text{Area of vessel} = p \times \frac{\pi}{4} \times (5000)^2$$

$$8.796 \times 10^6 = p \times \frac{\pi}{4} \times (5000)^2$$

Pressure, $p = \mathbf{0.448}\ N/mm^2$ **Ans.**

Problem 6

A 50 mm diameter solid shaft is welded to a flat plate by 8 mm fillet weld. Determine the maximum torque that the welded joint can sustain if the permissible shear stress intensity in the weld material is not to exceed 70 MPa.

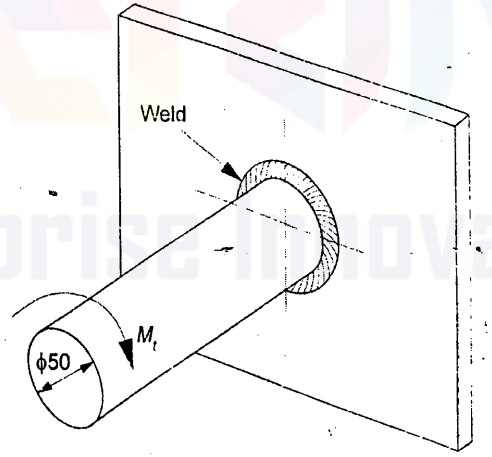

Figure 5.23

Given data:

Diameter of the solid shaft, $D = 50\ mm$

Weld size, $h = 8\ mm$

Permissible shear stress, $\tau = 70\ MPa$

☺ ***Solution:***

The maximum shear stress for this type of joint is given in Table 5.4 in Page 5.10 (or refers PSGDB 11.3)

$$\tau = \frac{2.83 M_t}{\pi h D^2}$$

$$70 = \frac{2.83 M_t}{\pi \times 8 \times 50^2}$$

$M_t = 1554144.78\ N\text{-}mm = \mathbf{1554.15\ N\text{-}m}$ **Ans.**

Problem 7

A circular shaft 60 mm in diameter is welded to a support plate by means of a fillet weld as shown in Figure 5.24. Determine the size of weld if the permissible shear stress in the weld is limited to 85 MPa.

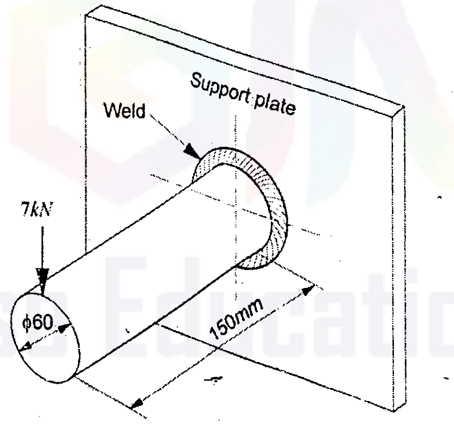

Figure 5.24

Given data:

Diameter of shaft, $D = 60\ mm$

Load, $P = 7\ kN = 7000\ N$

Permissible shear stress, $\tau = 85\ MPa = 85\ N\text{-}mm$

☺ ***Solution:***

This problem can be solved either of the following two methods. Students are advised to follow method 1 which is very simple. However, for understanding of the basic principle of stresses induced in the joint, method 2 is useful.

Method 1:

From Table 5.4 in Page 5.10 (or PSGDB 11.3), when a circular bar welded to the plate by filled weld all around the edge and subjected to bending moment M_b ($=P \times e$), the stress induced is given by the equation,

$$\sigma_b = \frac{5.66 M_b}{\pi D^2\ h}$$

Bending moment, $M_b = P \times e = 7000 \times 150 = 1050000\ N\text{-}mm$

Usually $\sigma_b = 2 \times \tau = 2 \times 85 = 170\ N\text{-}mm$

$$\therefore\ 170 = \frac{5.66 \times 1050000}{\pi \times 60^2 \times h}$$

$h = 3.09\ mm$ **Ans.**

Method 2:

This joint is subjected to direct shear stress and the bending stress.

Area of the weld, $A = t\,\pi\,D = 0.707\,h\,\pi\,D$

$= 0.707 \times h \times \pi \times 60 = 133\,h$

Direct shear stress, $\tau = \dfrac{P}{A} = \dfrac{7000}{133h} = \dfrac{52.526}{h}$

Bending moment, $M_b = P \times e = 7000 \times 150 = 1050000\ N\text{-}mm$

From Table 5.7 in Page 5.23 and considering thickness of weld

Section modulus, $Z_w = \dfrac{\pi D^2}{4} = \dfrac{\pi \times 0.707 \times h \times (60)^2}{4} = 1998.99\ h$

Bending stress, $\sigma_b = \dfrac{M_b}{Z_w} = \dfrac{1050000}{199899h} = \dfrac{525.26}{h}$

Maximum shear stress,

$$\tau_{max} = \frac{1}{2}\sqrt{\sigma_b^2 + 4\tau^2} = \frac{1}{2}\sqrt{\left(\frac{525.26}{h}\right)^2 + 4\left(\frac{52.526}{h}\right)^2}$$

$$85 = \frac{267.83}{h}$$

$$h = \frac{267.83}{85} = 3.15\ mm \quad \textbf{Ans.}$$

$\therefore$ Safe size of weld, $h = 3.15\ mm$ **Ans.**

Problem 8

A shaft of rectangular cross section is welded to a support plate by means of a fillet weld on its one end as shown in Figure 5.25. The other end is loaded by 25 kN. If the size of weld is 6mm, find the maximum normal and shear stress in the weld.

Given data:

Load, $P = 25\ kN = 25000\ N$

Eccentricity, $e = 500\ mm$

Cross section $= 100 \times 150\ mm$

Size of weld, $h = 6\ mm$

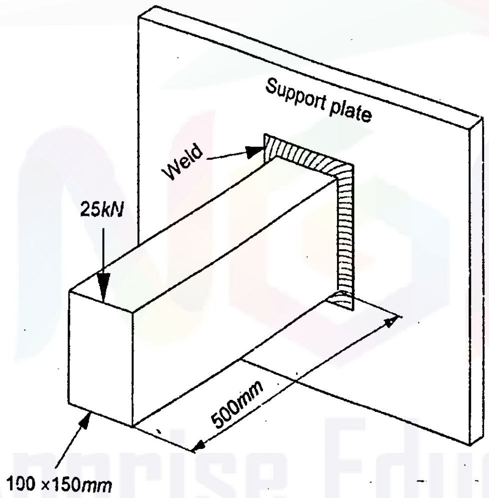

Figure 5.25

Solution:

The joint is subjected to direct shear and bending stress.

Throat area of the rectangular section

$$A = t\,(2\,b + 2\,d)$$

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$$= 0.707 \times 6 \times (2 \times 150 + 2 \times 100)$$

$$A = 2121\ mm^2$$

Direct shear stress, $\tau = \frac{P}{A} = \frac{25000}{2121} = 11.79\ N/mm^2.$

Bending moment, $M_b = P \times e = 25000 \times 500 = 12.5 \times 10^6\ N\text{-}mm.$

From Table 5.7 in Page 5.23, section modulus by considering the weld thickness

$$Z_w = t\left(bd + \frac{d^2}{3}\right)$$

$$= 0.707 \times 6 \times \left(100 \times 150 + \frac{150^2}{3}\right) = 95445\ mm^3$$

Bending stress, $\sigma_b = \frac{M_b}{Z_w} = \frac{12.5 \times 10^6}{95445} = 130.97\ N/mm^2$

Maximum normal stress:

$$\sigma_{max} = \frac{\sigma_b}{2} + \frac{1}{2}\sqrt{\sigma_b^{\,2} + 4\tau^2}$$

$$= \frac{130.97}{2} + \frac{1}{2}\sqrt{130.97^2 + 4 \times 11.79^2}$$

$$\sigma_1 = 132.02\ N/mm^2 \quad \textbf{Ans.}$$

Maximum shear stress:

$$\tau_{max} = \frac{1}{2}\sqrt{\sigma_b^{\,2} + 4\tau^2}$$

$$= \frac{1}{2}\sqrt{130.97^2 + 4 \times 11.79^2}$$

$$\tau_{max} = 66.54\ N/mm^2 \quad \textbf{Ans.}$$

Problem 9

A bracket of width 35 mm is welded to a machine frame as shown in Figure 5.26. The maximum load on the bracket is 1 tonne. Find the size of the weld at the top and bottom of the bracket if the maximum shear stress in the weld is equal to 50 N/mm².

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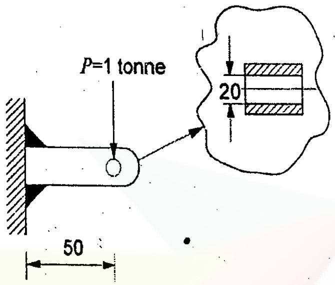

Figure 5.26

Given data:

Width of the bracket, $b = 35\ mm$

Maximum load, $P = 1\text{tonne} = 1000 \times 9.81\ N = 9810\ N$

Maximum shear stress, $\tau_{max} = 50\ N/mm^2$

☺ ***Solution:***

Area of the weld, $A = 2 \times 0.707 \times h \times l$

$$= 2 \times 0.707 \times h \times 35$$

$$A = 49.49h\ mm^2$$

Primary or direct shear stress,

$$\tau = \frac{\text{Load}(P)}{\text{Area}(A)} = \frac{9810}{49.49 \times h} = \frac{198.2}{h}\ N/mm^2$$

Eccentricity, $e = 50\ mm$

Bending moment, $M_b = P \times e = 9810 \times 50 = 490500\ N\text{-}mm$

From Table 5.7 in Page 5.23, section modulus by considering the weld thickness

$$Z_w = b \times d \times t = 35 \times 20 \times 0.707h = 494.9\ h$$

Bending stress, $\sigma_b = \dfrac{M_b}{Z_w} = \dfrac{490500}{494.9h} = \dfrac{991.11}{h}\ N/mm^2$

Maximum shear stress, $\tau_{max} = \dfrac{1}{2}\sqrt{\sigma_b^2 + 4\tau^2}$

$$= \frac{1}{2}\sqrt{\left(\frac{991.11}{h}\right)^2 + 4 \times \left(\frac{198.2}{h}\right)^2} = \frac{533.72}{h}$$

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Assume maximum shear stress in the weld is equal to 50 N/mm^2

$$50 = \frac{533.72}{h}$$

$h = 10.67\ mm$ **say 11 mm** **Ans.**

Problem 10

A welded joint shown in Figure 5.27 is subjected to an eccentric load of 2 kN. Find the size of weld, if the maximum shear stress in the weld is 25 MPa.

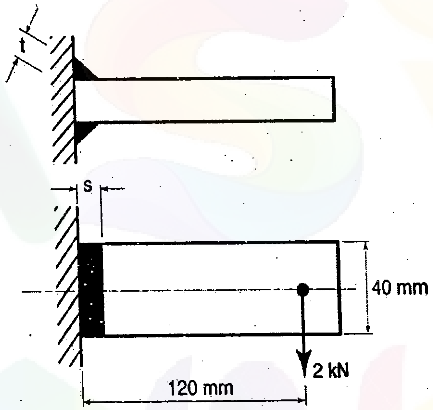

Figure 5.27

☺ ***Solution:***

Area of the weld, $A = 2 \times 0.707 \times h \times l = 2 \times 0.707 \times h \times 40 = 56.56\ h\ mm^2$

Primary or direct shear stress, $\tau = \dfrac{\text{Load}(P)}{\text{Area}(A)} = \dfrac{2000}{56.56 \times h} = \dfrac{35.36}{h}\ N/mm^2$

Eccentricity, $e = 120mm,$

Bending stress, $\sigma_b = \dfrac{4.24Pe}{hl^2} = \dfrac{4.24 \times 2000 \times 120}{h \times 40^2} = \dfrac{636}{h}$

Maximum shear stress, $\tau_{max} = \dfrac{1}{2}\sqrt{\sigma_b^2 + 4\tau^2}$

$$= \frac{1}{2}\sqrt{\left(\frac{636}{h}\right)^2 + 4\left(\frac{35.36}{h}\right)^2} = \frac{319.96}{h}$$

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Equating this to the allowable value of stress (25 *MPa*),

$$\frac{319.96}{h} = 25$$

$$h = 12.8\,mm = s$$

Weld size = **12.8 *mm*** **Ans.**

Problem 11

The bracket arrangement is shown in Figure 5.28. The protruding portion of this bracket consists of a 'T' cross section with the dimensions indicated and it is welded to a support plate. The load to be supported is 40 kN. Find the necessary weld size for the connection between the protruding portion and the support plate. The maximum shear stress in the weld should not exceed 100 N/mm².

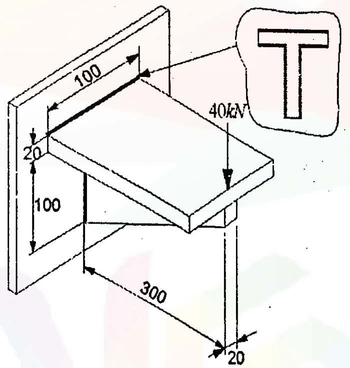

Figure 5.28

☺ ***Solution:***

The welded joint given in problem is subjected to direct shear and bending stress.

Area of weld, $A = (100 + 40 + 40 + (2 \times 100))\ 0.707 \times h = 268.66h\ mm^2$

Direct shear stress, $\tau = \frac{P}{A} = \frac{40000}{268.66h} = \frac{148.89}{h}\ N/mm^2$

Bending moment, $M_b = P \times e = 40000 \times 300 = 12 \times 10^6\ N\text{-}mm$

From Table 5.7 in Page 5.23 or PSGDB 11.6

$$Z_w = \frac{4bd + d^2}{3} \qquad (\because \text{ Load is on top})$$

If weld thickness is considered, then

$$Z_w = \left(\frac{4bd + d^2}{3}\right) \times 0.707h$$

$$= \left(\frac{4 \times 100 \times 120 + 120^2}{3}\right) \times 0.707 \times h = 14705.6h\ mm^3$$

Bending stress, $\sigma_b = \frac{M_b}{Z_w} = \frac{12 \times 10^6}{147056h} = \frac{816.02}{h}\ N/mm^2$

According to maximum shear stress theory, resultant stress,

$$\tau_{max} = \frac{1}{2}\sqrt{\sigma^2 + 4\tau^2}$$

$$= \frac{1}{2}\sqrt{\left(\frac{816.02}{h}\right)^2 + 4\left(\frac{148.89}{h}\right)^2} = \frac{434.33}{h}\ N/mm^2$$

It is given that $\tau_{max} = 100\ N/mm^2$

Equating the two values of τ_{max},

$$100 = \frac{434.33}{h}$$

$$\therefore \quad h = \frac{434.33}{100} = 4.34\ mm \quad \text{say } 5\ mm$$ **Ans.**

Problem 12

A plate 500 mm long and 20 mm thick is welded at right angle to another plate by 1 mm fillet weld as shown in Figure 5.29. Calculate the maximum torque that can be exerte by the plate if the permissible shear stress in weld material is 45 N/mm².

Given data:

Length of weld, $l = 500\ mm$

Size of weld, $h = 12\ mm$

Permissible shear stress, $\tau = 45\ N/mm^2$

☺ ***Solution:***

From Table 5.4 in Page 5.10 or PSGDB 11.3,

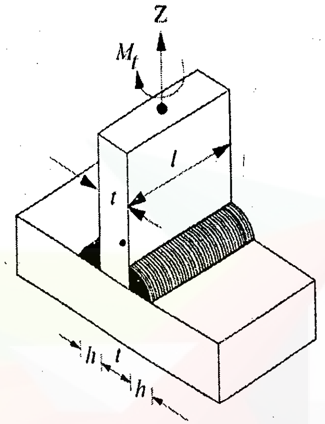

Figure 5.29

Maximum shear stress on this type of joint,

$$\tau = \frac{4.24 M_t}{hl^2}$$

$$45 = \frac{4.24 M_t}{12 \times (500)^2}$$

$M_t = 31.84 \times 10^6$ *N-mm* $= 31.84 \times 10^3$ *N-m* **Ans.**

Problem 13

A bracket shown in Figure 5.30 carries a load of 10 kN. Find the size of the weld if the allowable shear stress is not to exceed 75 N/mm².

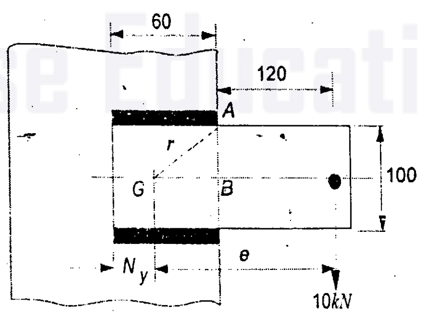

Figure 5.30

Given data:

Load, $P = 10\ kN = 10 \times 10^3\ N$

Allowable shear stress, $\tau = 75\ N/mm^2$

☺ ***Solution:***

Area of the weld, $A = 2 \times 0.707 \times h \times l$

$= 2 \times 0.707 \times h \times 60 = 84.84 \times h\ mm^2$

Primary or direct shear stress,

$$\tau_1 = \frac{\text{Load}(P)}{\text{Area}(A)} = \frac{10 \times 10^3}{84.84 \times h} = \frac{117.87}{h}\ N/mm^2$$

Eccentricity, $e = \frac{60}{2} + 120 = 150\ mm$

Twisting moment, $M_t = P \times e = 10 \times 10^3 \times 150 = 1500000\ N\text{-}mm$

$$GB = \frac{60}{2} = 30\ mm$$

$$AB = \frac{100}{2} = 50\ mm$$

$$r = \sqrt{GB^2 + AB^2} = \sqrt{(30)^2 + 50^2} = 58.3\ mm$$

$$\cos\theta = \frac{GB}{r} = \frac{30}{58.3} = 0.52$$

From Table 5.7 in Page 5.23 or PSGDB 11.5, polar moments of inertia by considering weld thickness,

$$J_w = \frac{(b^3 + 3bd^2)}{6} \times t$$

$$J_w = \frac{((60)^3 + 3 \times 60 \times (100)^2)}{6} \times 0.707 \times h$$

$$J_w = 237552 \times h\ mm^4$$

Secondary stress, $\tau_2 = \frac{M_t \times r}{J_w}$

$$= \frac{1500000 \times 58.3}{237552 \times h} = \frac{368.13}{h}\ N/mm^2$$

Resultant stress, $\tau = \sqrt{\tau_1^2 + \tau_2^2 + 2\tau_1\tau_2 Cos\theta}$

$$75 = \sqrt{\left(\frac{117.87}{h}\right)^2 + \left(\frac{368.13}{h}\right)^2 + 2\left(\frac{117.87}{h}\right)\left(\frac{368.13}{h}\right) \times 0.52}$$

$$75 = \frac{440.52}{h}$$

$$h = \frac{441.07}{75}$$

$h = 5.88\ mm$ say, $h = 6\ mm$ **Ans.**

Problem 14

A plate of 200 mm width and 600 mm long is welded to a vertical plate by placing it on the vertical plate to form a cantilever with projecting length of 480 mm and overlap between plates as 120 mm. Fillet weld is done on all three sides. A vertical load 30 kN is applied at the free end of the cantilever plate parallel to its width of 200 mm. If the allowable weld stress is 95 MPa, determine the weld size.

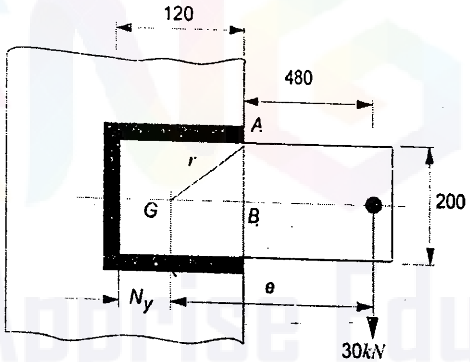

Figure 5.31

Given data:

Width of the steel plate, $d = 200\ mm$

Length of the plate, $L = 600\ mm$

Projecting length = 480 mm

Overlap between the plate = 120 mm

Vertical load, $P = 30\ kN = 30 \times 10^3\ N$

Allowable weld stress, $\sigma = 95\ MPa = 95 \times 10^6\ N/m^2 = 95\ N/mm^2$

☺ ***Solution:***

There are two stresses induced in this system.

(i) Primary shear stress (τ_1)

(ii) Secondary shear stress (τ_2) due to twisting moment (M_t)

Area of the weld, $A = 0.707h\,(2\,b + d)$

$$= 0.707 \times h \times (2 \times 120 + 200) = 311h\ mm^2$$

Primary stress, $\tau_1 = \frac{\text{Load}(P)}{\text{Area}(A)} = \frac{30 \times 10^3}{311h} = \frac{96.4}{h}\ N/mm^2$

From Table 5.7 in Page 5.23 (or PSGDB 11.5)

$$N_y = \frac{b^2}{2b + d} = \frac{120^2}{(2 \times 120) + 200} = 32.72 mm = 33\ mm$$

Eccentricity, $e = 480 + (120 - N_y) = 480 + (120 - 33) = 567\ mm$

Twisting moment, $M_t = P \times e = 30 \times 10^3 \times 567 = 17010000\ N\text{-}mm$

$$r = \sqrt{GB^2 + AB^2}$$

$$= \sqrt{(120 - N_y)^2 + \left(\frac{200}{2}\right)^2}$$

$$r = \sqrt{(120-33)^2 + 100^2} = 132.548\ mm$$

$$\cos\theta = \frac{GB}{r} = \frac{87}{132548} = 0.656$$

From Table 5.7 in Page 5.23 (or PSGDB 11.5) and considering the thickness of weld 't', the polar moments of inertia,

$$J_w = \left[\frac{(2b + d)^3}{12} - \frac{b^2(b + d)^2}{2b + d}\right] \times t$$

$$J_w = \left[\frac{(2\times120+200)^3}{12} - \frac{120^2(120+200)^2}{2\times120+200}\right]\times0.707\times h$$

$$J_w = 2649407.5h$$

Secondary stress, $\tau_2 = \dfrac{M_t \times r}{J_w} = \dfrac{17010000\times132548}{2649407.5h} = \dfrac{851}{h}\ N/mm^2$

Resultant stress, $\tau = \sqrt{\tau_1^2 + \tau_2^2 + 2\tau_1\tau_2 Cos\theta}$

$$95 = \sqrt{\left(\frac{96.4}{h}\right)^2 + \left(\frac{851}{h}\right)^2 + 2\left(\frac{96.4}{h}\right)\left(\frac{851}{h}\right)\times0.656}$$

$$95 = \frac{917.16}{h}$$

$$h = \frac{917.16}{95} = 9.65\ mm \quad \text{say } 10\ mm$$ **Ans.**

Problem 15

A bracket shown in Figure 5.32 carries a load of 'P'. Calculate the value of P if the weld size is 15 mm and the allowable stress is not to exceed 80 N/mm².

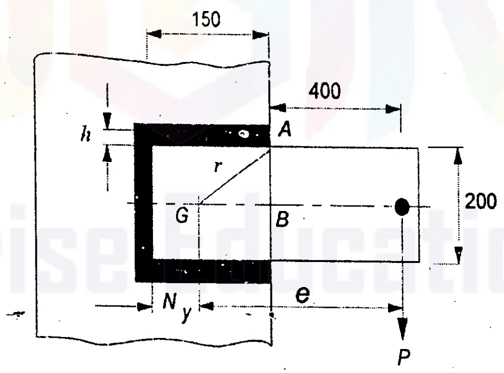

Figure 5.32

Given data:

Load = P

Weld size, $h = 15\ mm$

Allowable stress, $\sigma = 80\ N/mm^2$

Solution:

Area of weld, $A = 0.707\ h\ (2\ b + d)$

$= 0.707 \times 15 \times (2 \times 150 + 200) = 5302.5\ mm^2$

Primary shear stress, $\tau_1 = \dfrac{\text{Load}}{\text{Area}} = \dfrac{P}{53025} = 1.886\times10^{-4}P\ N/mm^2$

Eccentricity, $e = 400 + 150 - N_y$

From Table 5.7 in Page 5.23 (or PSGDB 11.5),

$$N_y = \frac{b^2}{2b+d} = \frac{150^2}{(2\times150)+200} = 45\ mm$$

$$e = 400 + (150 - 45) = 505\ mm$$

Twisting moment, $M_t = P \times e = P \times 505 = 505P\ \ N\text{-}mm$

$$r = \sqrt{GB^2 + AB^2} = \sqrt{105^2 + 100^2} = 145\ mm$$

$$[\because GB = 150 - N_y = 150 - 45 = 105mm]$$

$$\cos\theta = \frac{GB}{r} = \frac{105}{145} = 0.724$$

Secondary shear stress, $\tau_2 = \dfrac{M_t \times r}{J_w}$

From Table 5.7 in Page 5.23 (or PSGDB 11.5) and considering the thickness of weld 't', the polar moments of inertia,

$$J_w = \left[\frac{(2b+d)^3}{12} - \frac{b^2(b+d)^2}{2b+d}\right]\times t$$

$$J_w = \left[\frac{(2\times150+200)^3}{12} - \frac{150^2(150+200)^2}{2\times150+200}\right]\times 0.707\times15$$

$$J_w = 52008687.5mm^4.$$

$$\therefore \tau_2 = \frac{505\times P\times145}{52008687.5} = 1.408\times10^{-3}P\ \ N/mm^2$$

Resultant stress, $\tau = \sqrt{\tau_1^2 + \tau_2^2 + 2\tau_1\tau_2\cos\theta}$

$$80 = \sqrt{\left(1.886\times10^{-4}P\right)^2 + \left(1.408\times10^{-3}P\right)^2 + 2\times\left(1.886\times10^{-4}P\right)\times\left(1.408\times10^{-3}P\right)\times0.724}$$

$$80 = 1.55\times10^{-3}P \quad N/mm^2$$

$\therefore$ $P = 51612.9\ N = \mathbf{51.61\ kN}$ **Ans.**

Problem 16

A shaft of rectangular cross section is welded to a support by means of fillet welds as shown in Figure 5.33. The shaft carries a load of 25kN at its free end. Determine the size of the weld if the permissible shear stress in the weld is limited to 75 N/mm².

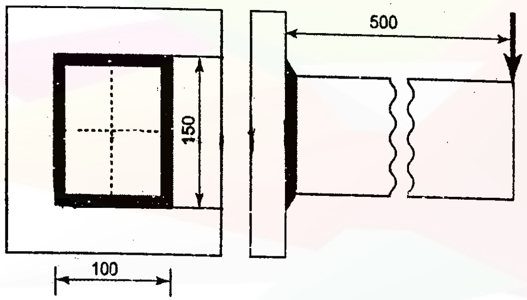

Figure 5.33

☺ ***Solution:***

The joint is subjected to direct shear and bending stress. Throat area of the rectangular section

$$A = t\,(2\,b + 2\,d)$$

$$= 0.707\times h\times(2\times150 + 2\times100) \qquad (\because t = 0707h)$$

$$A = 353.5h\ mm^2$$

Load, $P = 25kN$

Direct shear stress,

$$\tau = \frac{P}{A} = \frac{25000}{353.5h} = \frac{70.72}{h}$$

Bending moment,

$$M_b = P\times e = 25000\times500 = 12.5\times10^6\ N\text{-}mm$$

From Table 5.7 in Page 5.23, section modulus by considering the weld thickness

$$Z_w = t\left(bd + \frac{d^2}{3}\right) = 0.707\times h\times\left(100\times150 + \frac{150^2}{3}\right) = 15907.5h\ mm^3$$

Bending stress, $\sigma_b = \frac{M_b}{Z_w} = \frac{12.5\times10^6}{15907.5h} = \frac{785.793}{h}$

Maximum permissible shear stress,

$$\tau_{max} = \frac{1}{2}\sqrt{\sigma_b^{\,2} + 4\tau^2}$$

$$75 = \frac{1}{2}\sqrt{\left(\frac{785.793}{h}\right)^2 + 4\times\left(\frac{70.72}{h}\right)^2}$$

Size of weld, $h = \mathbf{5.32\ mm}$ **Ans.**

Problem 17

A circular bar is welded to a steel plate shown in Figure 5.34. The maximum load 15 kN is applied repeatedly. Determine the size of weld required for 10,000,000 cycles.

☺ ***Solution:***

The load in the structure produces direct shear load and bending load in the joint.

Direct shear stress, $\tau = \frac{P}{Area\ of\ weld}$

$$= \frac{15\times10^3}{\pi\times40} \qquad \left(\because A = \pi D,\ \text{Weld is treated as line}\right)$$

$$= 119.36\ N/mm^2$$

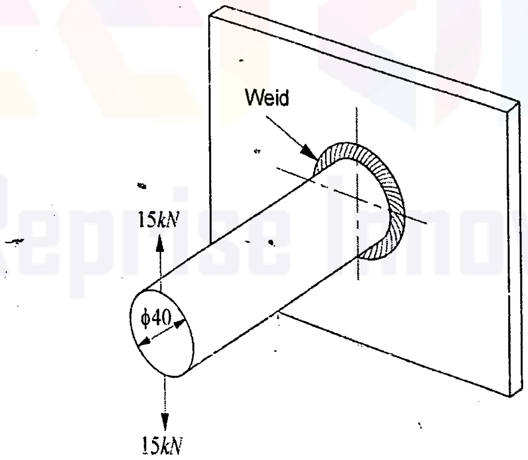

Figure 5.34

From Table 5.7 in Page 5.23 or PSGDB 11.4, for circular cross section

$$Z_w = \frac{\pi d^2}{4} \qquad \text{(Weld is treated as line)}$$

Bending stress, $\sigma_b = \frac{M_b}{Z_w} = \frac{P \times e}{Z_W}$

$$= \frac{15 \times 10^3 \times 250}{\frac{\pi}{4} \times 40^2} = 2984 \ N/mm^2$$

Resultant stress due to direct shear and bending stresses

$$\tau_{res} = \sqrt{\sigma_b^2 + \tau^2}$$

$$= \sqrt{(2984)^2 + (119.36)^2} = 2986.38 \ N/mm^2$$

The maximum stress varies from 2986.38 N/mm^2 in one direction to 2986.38 N/mm^2 in the opposite direction.

The allowable fatigue force/*mm* for 2,000,000 cycles is

$$\sigma_{-1a} = \frac{891.4}{1 - \frac{1}{2}K} \text{ or } 1537.6 \ N/mm^2 \text{ whichever is less.}$$

The value of $K = -1$ since the load is completely reversed.

$$\therefore \quad \sigma_{-1a} = \frac{891.4}{1 - \left(\frac{1}{2} \times -1\right)} = 594.27 \ N/mm^2$$

The allowable fatigue force per *mm* of weld for 10,000,000 cycles is

$$\sigma_{-1b} = 594.27 \left(\frac{2,000,000}{10,000,000}\right)^{0.13} = 482 \ N/mm^2$$

($\because$ $C = 0.13$ for butt joint)

The weld size can be obtained by dividing maximum shear stress to allowable fatigue force per *mm* of weld.

$$= \frac{298638}{482} = 6.19 \ mm \text{ say } 6.5 \ mm \qquad \textbf{Ans.}$$

Problem 18

Find the maximum shear stress induced in the weld of 6 mm size when a channel, as shown in Figure 5.35, is welded to a plate and loaded with 20kN force at a distance of 200mm.

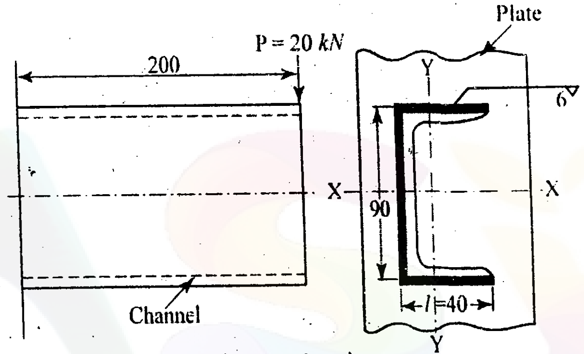

Figure 5.35

Solution:

The joint is subjected to direct shear and bending stress.

Throat area of the welded section,

$$A = t\,(2\,b + d)$$

$$= 0.707 \times 6 \times (2 \times 40 + 90) \qquad (\because t = 0707h)$$

$$A = 721.14 \ mm^2.$$

Load, $P = 20kN$

Direct shear stress, $\tau = \frac{P}{A} = \frac{20000}{721.14} = 27.73 \ N/mm^2$

Bending moment, $M_b = P \times e = 20000 \times 200 = 4 \times 10^6 N\text{-}mm$

From Table 5.7 in Page 5.23 or PSGDB 11.5 & 11.6, section modulus by considering the weld thickness

$$Z_w = t\left(bd + \frac{d^2}{6}\right) = 0.707 \times h \times \left(40 \times 90 + \frac{90^2}{6}\right) = 3499.65 \ mm^3$$

Bending stress, $\sigma_b = \frac{M_b}{Z_w} = \frac{4 \times 10^6}{3499.65} = 1142.97 N/mm^2$

Maximum permissible shear stress,

$$\tau_{max} = \frac{1}{2}\sqrt{\sigma_b^2 + 4\tau^2}$$

$$= \frac{1}{2}\sqrt{1142.97^2 + 4\times 27.73^2} = \mathbf{572.16\ N/mm^2} \qquad \textbf{Ans.}$$

Problem 19

A cylindrical beam of size 60 mm is attached to support by a complete circumferential fillet weld of 6 mm. Find (i) torque and (ii) bending moment that can be applied if limiting shear stress is 140 MPa.

Given data:

Diameter of the solid shaft, $D = 60\ mm$

Weld size, $h = 6\ mm$

Permissible shear stress, $\tau = 140\ MPa$

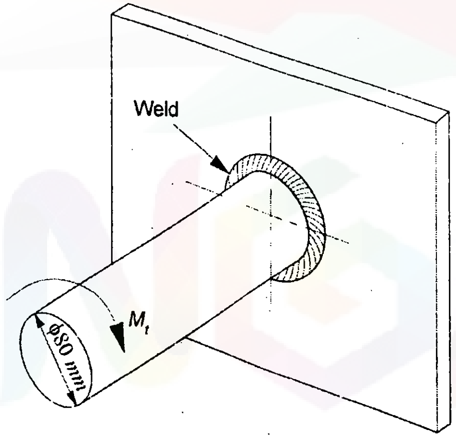

Figure 5.36

☺ *Solution:*

The maximum shear stress for this type of joint is given in Table.5.4 in Page 5.10 (or refer PSGDB 11.3)

$$\tau = \frac{2.83 M_t}{\pi h D^2}$$

$$140 = \frac{2.83 M_t}{\pi \times 6 \times 60^2}$$

$\therefore$ Torsion moment or Torque, $M_t = 3356952.72\ N\text{-}mm = \mathbf{3356.95\ N\text{-}m}$ **Ans.**

From Table 5.4 in Page 5.10 (or PSGDB 11.3), when a circular bar welded to the plate by filled weld all around the edge and subjected to bending moment M_b. Also, the stress induced is given by the equation,

$$\sigma_b = \frac{5.66 M_b}{\pi D^2 h}$$

Usually $\sigma_b = 2 \times \tau = 2 \times 140 = 280 N/mm^2$

$$\therefore \quad 200 = \frac{5.66 M_b}{\pi \times 60^2 \times 6}$$

$$\therefore \quad M_b = 2397823.37\ N\text{-}mm = \mathbf{2397.82\ N\text{-}m} \qquad \textbf{Ans.}$$

Problem 20

An eccentrically loaded plate is welded to a frame as shown in Figure 5.37. Design the welded joint if the tensile stress in the plate should not exceed 100 N/mm² and that in weld is 80 N/mm².

Given data:

Maximum stress, $\sigma = 80\ N/mm^2$

Maximum load, $P = 60\ kN = 60 \times 10^3\ N$

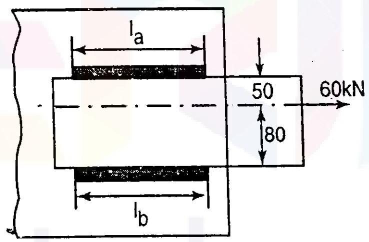

Figure 5.37

☺ *Solution:*

Since the tensile stress in the plate should not exceed 100 N/mm^2 the maximum thickness can be calculated by using the equation

$$\sigma = \frac{P}{A} = \frac{P}{b \times t}$$

$$100 = \frac{60\times10^3}{130\times t}$$

$t = 4.62$ *mm* say 5 *mm* plate

The size of weld should not exceed the thickness of the plate,

$h = t = 5$ ***mm*** **Ans.**

Length of the weld at the top, l_a (from Table 5.4 in Page 5.10 or PSGDB 11.3)

$$l_a = \frac{1.414\times P\times e_2}{\sigma\times h\times b}$$

$$= \frac{1.414\times60\times10^3\times80}{80\times5\times130} = 130.52 \text{ mm}$$

Actual length, $l_a = 130.52 + 5 = 135.52$ *mm*

Say, Length of the weld at the top,

$l_a = 140$ ***mm*** **Ans.**

Length of the weld at the bottom, l_b (from Table 5.4 in Page 5.10 or PSGDB 11.3)

$$l_b = \frac{1.414\times P\times e_1}{\sigma\times h\times b}$$

$$= \frac{1.414\times60\times10^3\times50}{80\times5\times130} = 81.58 \text{ mm}$$

Actual length, $l_b = 81.58 + 5 = 86.58$ *mm*

Say, Length of the weld at the bottom,

$l_b = 90$ ***mm*** **Ans.**

5.13. WELDABILITY

Weldability is also known as *joinability* of a material. It refers the ability to weld. It is defined as the capacity of a metal or combination of metals to be welded into a suitable structure, and for the resulting weld joint(s) to possess the required metallurgical properties to perform satisfactorily in intended service.

Many metals and thermoplastics can be welded but some are easier to weld. A material's weldability is used to determine the welding process and to compare the final weld quality to other materials. The three most common weldable metals are mild steel, stainless steel and aluminium.

Good weldability is characterized by the following characteristics:

(i) Ease with which welding is accomplished,

(ii) Absence of weld defects, and

(iii) Strength, ductility and toughness in welded joint.

5.13.1. Weldability Factors

Some metals or metal combinations can be readily welded by one process but they are difficult to weld by other processes. The weldablity of material depends on the following factors:

(i) Carbon Equivalent Value (CEV):

Carbon Equivalent Value (CEV) is used for rating of weldability of ferritic low alloy steels. It takes into account the equivalent additive effects of carbon and other alloying elements on a particular characteristic of steel. Steel with a low carbon equivalent has a better weldability than steel with a high value.

A commonly used formula to calculate CEV based on a publication of the International Institute of Welding (IIW) is as follows.

$$CEV = C + Mn/6 + (Cr + Mo + V)/5 + (Cu + Ni)/15$$

From this equation the weldability based on a range of CE values can be defined as follows:

Carbon equivalent value (CEV)	Weldability
Up to 0.35	Excellent
0.36–0.40	Very good
0.41–0.45	Good
0.46–0.50	Fair
Over 0.50	Poor

In welding, equivalent carbon content (CE) is used to understand how the different alloying elements affect the hardness of steel being welded.

Factors effecting weldability and parent metal composition:

If CEV - < 0.35, the steel is weldable using rutile electrode without any pre-heat.

If CEV - 0.35-0.45, either preheat or low hydrogen electrode is required.

If CEV - 0.45-0.55, both preheat and low hydrogen electrode is required.

If CEV - > 0.55, the steel is theoretically not weldable unless special care such as preheat, low hydrogen electrode and post weld heat treatment etc. are taken care of.

(ii) Hydrogen-induced cold cracking:

Hydrogen can be introduced to the weld via the filler metal, the base material or the atmosphere. While hydrogen is quite soluble in molten or nearly molten weld metal as the weld cools it will naturally begin to diffuse out of the area. Any hydrogen that remains in the weld then gathers around the martensitic crystals or other imperfections in the Heat Affected Zone (HAZ) by increasing the pressure on the microstructure and causing a crack. This hydrogen diffusion can take hours or days to occur. Hence, cold cracking is delayed appearance.

The weldability of steel with respect to hydrogen-induced cold cracking is inversely proportional to the hardenability of the steel. Materials prone to cold cracking include those with high carbon and high alloy levels which are also higher in strength. Such materials, especially thicker ones, are generally less ductile and tend to shrink after welding which causes additional residual stresses that lead to cracking.

(iii) Process factors:

The process factors on which weldability depends are type of electrode material, shielding gases, welding speed and cooling rate.

(iv) Other factors affecting weldability:

(i) Filler metal

(ii) Surface conditions

(iii) Parent metal composition

(iv) Parent metal thickness

(v) Weld metal composition

(vi) Welding process

(vii) Welding procedure.

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5.14. WELDABILITY OF ALUMINIUM

Aluminium and its alloys are routinely welded and brazed in industry by a variety of methods. Welding aluminium alloys is not more difficult or complicated than welding steel. It is different and requires specific training. Aluminium and its alloys are easy to weld.

The most common commercial aluminium and aluminium alloy welding methods use an electric arc with either a continuously fed wire electrode or a permanent tungsten electrode plus filler wire. The arc is protected by argon gas to shield the weld pool and electrode from surrounding atmosphere. Arc welding is easy to use, attains a high temperature, provides high heat input and easy to regulate.

The weldability of aluminium alloys varies significantly depending on the chemical composition of the alloy used because aluminium alloys are prone to hot cracking and to combat. So, welders increase the welding speed to lower the heat input. Preheating reduces the temperature gradient across the weld zone and thus, it helps reduce hot cracking but it can reduce the mechanical properties of the base. So, the proper selection of filler alloy is required. Also, aluminium alloys should also be cleaned before welding to remove all oxides, oils and loose particles from the surface to be welded.

The common families of aluminum alloys which can be readily welded are given below.

(i) 1XXX alloys: They are used to carry electrical current or for corrosion resistance in specific environments.

(ii) 3XXX alloys: They are used in heat exchangers and air conditioners.

(iii) 4XXX alloys: They are used as welding or brazing filler alloys. Sometimes, they are used as base materials.

(iv) 5XXX alloys: They are used in making 5356 filler metal.

(v) 6XXX alloys: They are the extrusion alloys although they are available in sheet and plate as well.

Some common aluminum alloys which cannot be readily welded are given below.

(i) 2XXX alloys: They are high-strength aerospace alloys in sheet or plate form. These alloys are unweldable using GTAW or GMAW because of hot cracking.

(ii) 7XXX alloys: They are a family of high-strength aerospace alloys.

(iii) 8XXX alloys and 9XXX alloys: Special alloys are rarely used in South Africa.

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The different wrought aluminium alloy families are split into two groups such as non-heat treatable and heat treatable. Unless the base metal is in the annealed or cast condition, fusion welding will decrease the strength of both heat and non-heat treatable alloys.

Various welding processes are used to join aluminium including the fusion methods GMAW (standard MIG, plasma and pulse) and GTAW (standard TIG and plasma). All methods are producing high quality, all-position welding, manual, mechanised or fully automatic. Also, resistance and advanced processes such as solid state and friction stir welding are used. A choice of process is based on technical and economic reasons.

For most structural economical and quality welds, TIG and MIG are recommended for aluminium. TIG welding is generally preferred for light gauge work up to 6 *mm* and for pipe work and intricate assemblies where excellent control over weld appearance and penetration is possible. Thicker material can be welded using TIG but very high current is needed and very slow welding speed is required. Butt, fillet, lap and edge welds are carried out using TIG welding. For welding two dissimilar thicknesses materials, TIG welding is preferred.

MIG welding is preferred for thicker sections having 75 *mm* where high productivity is needed for economic reasons. Limitations of MIG welding process are the controlling of penetration being difficult and edge welds are not possible. TIG welding is preferred for repair welding of aluminium castings but MIG is preferred when welding castings to sheet and plate and extrusions.

Good seam welds can also be used to weld aluminium and its alloys. Good TIG seams have a regular ripple finish. Also, there is a narrow and white de-oxidised zone on both sides of the seam. Good MIG seams have a uniform fine ripple finish on the seam with an excellent transition to the basic material.

Before welding aluminium, exposing the workpiece to preheat is good for better weldability. At the same time, too much preheat can degrade the mechanical properties of the aluminum.

When welding, the operator sets up residual stresses around the vicinity of the weld because the molten material shrinks as it solidifies. It distorts and creates dimensional instability. To avoid it in aluminum, operators perform stress relieving by heating the material hot enough to allow the aluminum atoms to move around.

5.15. WELDABILITY OF COPPER

Copper alloys can be welded with most of the conventional welding processes. Mainly, arc welding processes and gas shielded arc methods are the most common.

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Copper alloys:

There are three separate grades of pure copper:

(i) Oxygen-free copper:

It has less than 0.02% oxygen which is mostly used for pressure vessel and heat exchangers. Oxygen-free copper is the most readily weldable.

(ii) Copper oxides:

The use of tough pitch copper can result the embrittlement of the heat affected zones due to oxide films forming on the grain boundaries.

(iii) Phosphorus deoxidised copper:

It produces less porosity problem during autogenous welds.

5.15.1. Welding Processes for Copper and its Alloys

In manufacturing, copper is joined by arc welding. Arc welding can be performed using shielded metal arc welding (SMAW), gas-tungsten arc welding (GTAW), gas-metal arc welding (GMAW), plasma arc welding (PAW) and submerged arc welding (SAW).

Clean, grease-free wires and rods and high purity shield gases are required when TIG or MIG welding. Shielding gases for welding are argon, helium and nitrogen or mixes of two or more of these gases. Pure argon may be used for TIG welding up to a thickness of some 2 *mm* and for MIG welding, it is up to approximately 5 *mm*.

Shielded metal arc welding is used to weld a wide range of thickness of copper alloys. Covered electrodes for shielded metal arc welding of copper alloys are available.

TIG welding is the best suited for copper and copper alloys because of its intense arc which produces an extremely high temperature at the joint and a narrow heat-affected zone (HAZ). TIG is used to join coppers and copper alloys for thickness less than 3 *mm* while MIG is selected for section thickness above 3 *mm* and for joining of aluminum bronzes, silicon bronzes and copper-nickel alloys.

Plasma arc welding is more suitable for coppers and copper alloys. Argon, helium or mixtures of the two are used for welding of all alloys. Hydrogen gas should never be used when welding coppers.

Submerged arc welding is used for welding of thick gage material such as pipe formed from heavy plate can be achieved by continuous metal-arc operation under a granular flux. Commercially available fluxes should be used for copper-nickel alloys.

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5.15.2. Factors affecting Weldability of Copper Alloys

Several factors affect weldability of copper and its alloys. These factors are the thermal conductivity of alloy being welded, shielding gas, type of current used during welding, joint design, welding position, surface condition and cleanliness.

5.15.3. Filler Metals used in Welding Copper Alloys

Covered electrodes and bare electrode wire and rods are used for welding copper and copper alloys. Some of the filler metals are listed below.

(i) Copper filler metals

(ii) Copper-zinc filler metals

(iii) Copper-aluminium filler metals

(iv) Copper-nickel filler metals

(v) Copper-silicone filler metals.

Surface preparation is carried out for better weldability and to avoid the formation of oxides due to presence of foreign materials. Preheating is also done before welding. Post weld heat treatment of copper and copper alloys is carried out in order to anneal, stress relieve and avoid precipitation hardening.

5.16. WELDABILITY OF STAINLESS STEELS

The most popular welding process used on stainless steels is Gas Tungsten Arc Welding (GTAW or TIG). It is the most widely used process due to its versatility, high quality and aesthetic appearance of the finished weld. Pure argon is the most popular shielding gas but argon rich mixtures with the addition of hydrogen, helium or nitrogen are also employed for specific purposes.

Plasma Arc Welding (PAW) is also used to weld stainless steel. It is mainly used in a mechanised system where high speeds and high productivity autogenous welding of square edged butt joints are needed. PAW root weld is followed by multi-pass joint filling. Argon backing gas protection is necessary to maintain the corrosion resistance of the under bead.

Shielded Metal Arc Welding (SMAW or MMA) is the oldest of the arc processes. The most widely used, acid rutile coated electrodes produce a spray arc type metal transfer, self-releasing slag and a finely rippled aesthetic weld profile. They are primarily used in the down

hand position when producing fillet and butt welds. Electrodes with this coating type can be used in position but they are limited in application and size.

Gas Metal Arc Welding (GMAW or MIG) is the semi-automatic welding process which can be used manually or automated. It is employed for its high productivity features when welding thin material using 'short-circuit' metal transfer mode or 'spray arc' transfer with thicker material. Gas mixtures with the addition of oxygen, helium, carbon dioxide etc. are to improve the arc stability and weld bead 'wetting' characteristics.

Flux Cored Arc Welding (FCAW or FCW) produces higher rates of weld deposition and weld metal overlaying are possible. Significant reduction in post weld cleaning and dressing is possible.

Submerged Arc Welding (SAW) is a fully mechanised wire and flux powder shielded arc process capable of high deposition rate, fast travel speed and weld quality. It is used in continuous down hand fillet and butt welds in thicker section plate, pipe and vessels and also stainless steel cladding of mild steel components, particularly where long seams or extended runs are involved.

Electric Resistance Welding (ERW) method of resistance spot and seam welding is used in mass production welding of thinner stainless steel material where the overlap joint type of weld configuration is required.

Laser welding is very intense and it is capable of producing deep penetration welds in thick section stainless steel with minimal component distortion. The process employs high capital cost equipment and its use is reserved for mass production manufacturing.

5.16.1. General Guidelines to Weld Stainless Steel Parts

(i) Excessive heat input and high weld inter-pass temperature should be avoided to reduce high coefficient of thermal expansion and low conductivity. Otherwise, high heat input will result excessive distortion and residual stress.

(ii) Design criteria and metallurgical transformation due to welding may necessitate the selection of a non-matching welding consumable to achieve toughness levels at cryogenic temperatures or increased weld metal corrosion resistance.

(iii) It is important to reserve a fabrication facility exclusively for stainless steels wherever possible. In addition, protective handling equipment and tools should be used which are dedicated to stainless steel fabrication to avoid contamination from contact with carbon steels.

(iv) The consultation of the parent material or welding consumable supplier manufacturer is recommended.

(v) When shielding gas is required for updated information on recommended gas compositions, the supplier should be consulted by the person who takes welding.

(vi) When new grades of materials are to be welded, especially ferritic, martensitic and duplex alloys, for weld procedure information and filler material recommendations, manufacturer should be consulted.

(vii) Post weld dressing is done by using pickling pastes or other corrosive substances.

Table 5.11 below shows the weldability by process of aluminium and its alloys, copper and its alloys and stainless steels.

Table 5.11 Comparison of different welding processes

Material	*Arc welding*	*Oxy-acetylene welding*	*Electron beam welding*	*Resistance welding*
Aluminium and aluminium alloys	Commonly performed	Commonly performed	Commonly performed	Commonly performed
Copper and copper alloys	Commonly performed	Commonly performed	Commonly performed	Commonly performed
Stainless steel	Recommended	Commonly performed	Commonly performed	Recommended

5.17. DEFECTS IN WELDING

A welding defect is any flaw that compromises the usefulness of a weldment. The improper welding parameters, base metal and selection of method introduce defects in the weld metal. So, the defective weld causes failure in service conditions and damages to the properties the defects in weld depending on thickness, load, environment and size of the weld. The major defects which are causing in the weld are:

1. Lack of fusion
2. Lack of root penetration
3. Cracks
4. Cavity

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5. Porosity
6. Undercut
7. Distortion
8. Slag inclusion
9. Lamellar tearing
10. Overlapping
11. Imperfect shape or unacceptable contour
12. Miscellaneous defects.

1. Lack of fusion:

Lack of fusion is the poor adhesion of the weld bead to the base metal. The parameter mainly affects the welding current. If the current is very low, it is not sufficient to heat the metal all over the place. The wrong design of the weld also causes defects.

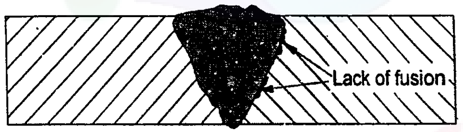

Figure 5.38 Lack of fusion

2. Lack of root penetration:

Lack of fusion is a weld bead in which fusion has not occurred throughout the cross section of joint due to improper penetration of the joint. Incomplete penetration forms channels and crevices in the root of the weld which can cause serious issues in pipes because corrosive substances can settle in these areas. This defect occurs due to too small root gap, too large size electrode, high travel speed and incorrect use of electrode.

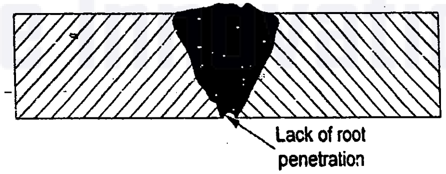

Figure 5.39 Lack of root penetration

3. Cracks:

Fracture-type interruptions are either in weld or base metal adjacent to weld. It is a serious defect because it is a discontinuity in the metal that significantly reduces strength. It is

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due to embrittlement or low ductility of weld and base metal combined with high restraint during contraction. In general, this defect must be repaired.

The cracks are mainly classified into the following two types:

1. Hot cracking.
2. Cold cracking.

Figure 5.40 shows different types of cracks in the weldment. Hot cracking also known as solidification cracking can occur with all metals and happens in the fusion zone of a weld. To diminish the probability of this type of cracking, excess material restraint should be avoided and a proper filler material should be utilized.

A heat-affected zone (HAZ) is a crack that forms a short distance away from the fusion line. It occurs in low alloy and high alloy steel. The exact causes of this type of crack are not completely understood but the dissolved hydrogen must be present.

Crater cracks occur in the crater when the welding arc is terminated prematurely. Crater cracks are normally shallow, hot cracks usually forming single or star cracks. These cracks usually start at a crater pipe and extend longitudinal in the crater.

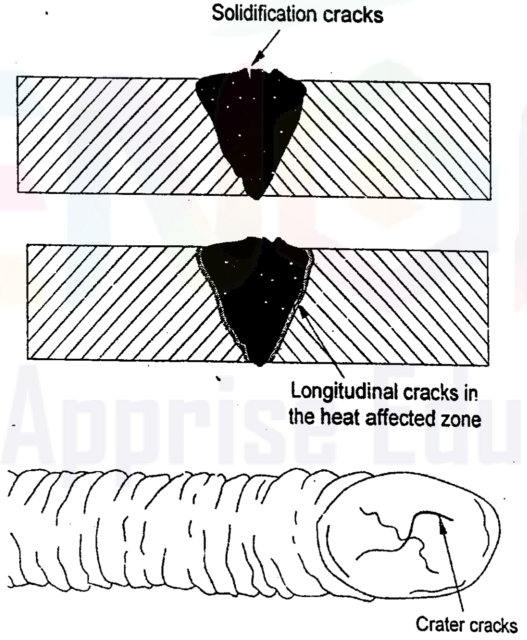

Figure 5.40 Various cracks

Hot cracking occurs at high temperature and cold cracking occurs at room temperature. The main causes of crack formation are:

1. Arc speed
2. Ductility
3. Solidification rate
4. Temperature.

Residual stresses can reduce the strength of the base material and it can lead to catastrophic failure through cold cracking. Cold cracking is limited to steels and it is associated with the formation of martensite as the weld cools. The cracking occurs in the heat-affected zone of the base material.

4. Cavity:

There are two cavity type defects that may present in the weldment.

(i) Porosity
(ii) Shrinkage voids.

(i) Porosity:

It is small voids in weld metal formed by gases entrapped during solidification as shown in Figure 5.41. It is caused by inclusion of atmospheric gases, sulfur in weld metal or surface contaminants. It is due to the presence of gases in the solidifying metal which are producing porosity. The gases are: oxygen, nitrogen and hydrogen. The parameters which are causing porosity are:

1. Arc speed
2. Coating of the electrode
3. Incorrect welding technique
4. Base metal composition.

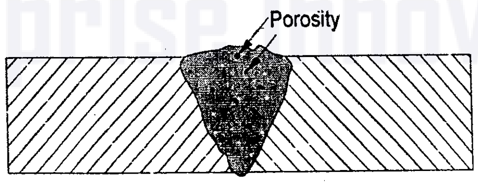

Figure 5.41 Porosity

The sources of hydrogen formed on the weld pool are electrode coatings. Then oxygen becomes as oxide form in the pool. Nitrogen enters in the form of atmospheric nitrogen.

(ii) Shrinkage voids:

Cavities are formed by shrinkage during solidification.

5. Undercut:

Undercut is a groove gets formed in the parent metal along the sides of the weld as shown in Figure 5.42. The main causes of the undercut are:

1. High current
2. Arc length
3. Electrode diameter
4. Inclination of electrode.

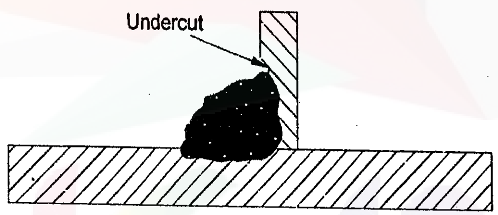

Figure 5.42 Undercut

6. Distortion:

Distortion is defined as the change in shape and difference between positions of two plates during the welding. The base metal under the arc melts and already welded base metal starts cooling. It will create a temperature difference in the weld and will cause distortion.

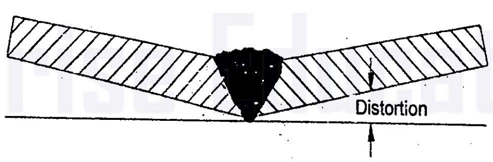

Figure 5.43 Distortion

The factors which are causing distortion are:

1. Arc speed
2. Number of passes

3. Stresses in plates
4. Joint type
5. Order of welding.

7. Slag inclusions:

During solidification of weld, any foreign materials present in the molten metal will not float. It will be entrapped inside the metal. So, it will lower the strength of the joint. Most common form is slag inclusions generated during arc welding processes that use flux instead of floating to top of weld pool and globules of slag become encased during solidification. Other forms are metallic oxides that form during welding of certain metals such as aluminum which normally has a surface coating of Al_2O_3.

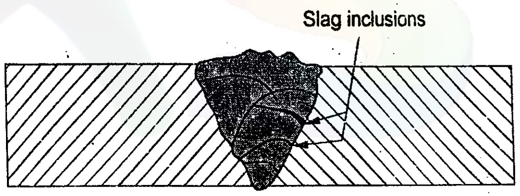

Figure 5.44 Slag inclusions

8. Lamellar tearing:

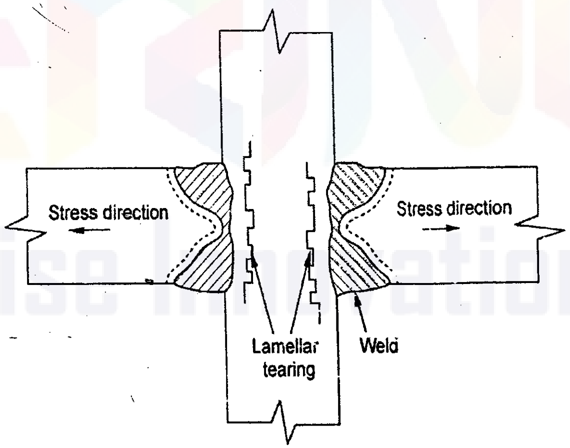

Figure 5.45 Lamellar tearing

It is mainly a problem with low quality steels. It occurs in plate that has a low ductility in the through thickness direction which is caused by non-metallic inclusions such as suphides and oxides that have been elongated during rolling process. These inclusions mean that the plate cannot tolerate the contraction stresses in the short transverse direction. It is seen in large structures. Lamellar tearing can occur in both fillet and butt welds but the most vulnerable joints are 'T' and corner joints where the fusion boundary is parallel to the rolling plane.

9. Overlap:

Overlap is the protrusion of the weld metal beyond the weld toe or weld root. It may occur because of fusion problem.

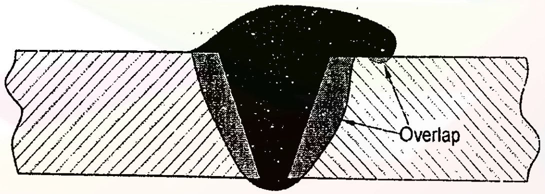

Figure 5.46 Overlap

The parameters which are causing overlap are:

1. Arc length
2. Arc speed
3. Joint type
4. Current.

10. Spatter:

Spatter is small droplets of electrode material which have been ejected from the arc which may or may not have fused to the parent plate. The main causes of spatter are high welding current, excessive arc length, damp electrodes, arc blow, incorrect electrode angle, incorrect polarity and poor gas shielding.

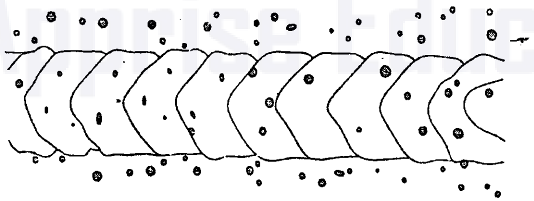

Figure 5.47 Spatter

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5.18. DESTRUCTIVE TESTING OF WELDMENT

As the name implies, Destructive Testing (DT) includes the methods of testing in which the weld is destroyed either during testing or to prepare test specimen in order to determine mechanical properties such as strength, toughness and hardness. This method of testing is used frequently for a number of applications. It is usually used for testing mass produced parts where sacrificing one or two components for testing is acceptable. Some of the other applications include welding procedure qualification and welder performance qualification testing, sampling inspection of production welds, research inspection, failure analysis work and assessing the suitability of weld joint for a particular application.

A number of destructive weld testing methods are used to determine weld integrity or performance. Some of the common methods of this type of welding inspection include the following tests:

(i) Acid etch test
(ii) Tensile test
(iii) Bend test
(iv) Nick break test
(v) Hardness test
(vi) Fatigue test.

5.18.1. Acid Etch Test

This type or physical weld testing is used to determine the soundness of a weld. This method of testing typically involves the removal of small samples of the welded joint. These samples are polished across their cross-section and then etched using some type of mild acid mixture, dependent on the base material used. Solutions of hydrochloric acid, nitric acid, ammonium per sulfate or iodine and potassium iodide are commonly used for etching carbon and low alloy steels. The acid attacks or reacts with the edges of cracks in the base or weld metal and discloses weld defects if present. It also accentuates the boundary between base and weld metal and in this manner, it shows the size of the weld which may otherwise be indistinct. This test is usually performed on a cross section of the joint.

Particular interest is often shown at the fusion line which is the transition between weld and base material. Various defects such as depth of penetration, lack of fusion, inadequate root penetration, internal porosity, cracking and inclusions can be detected during inspection

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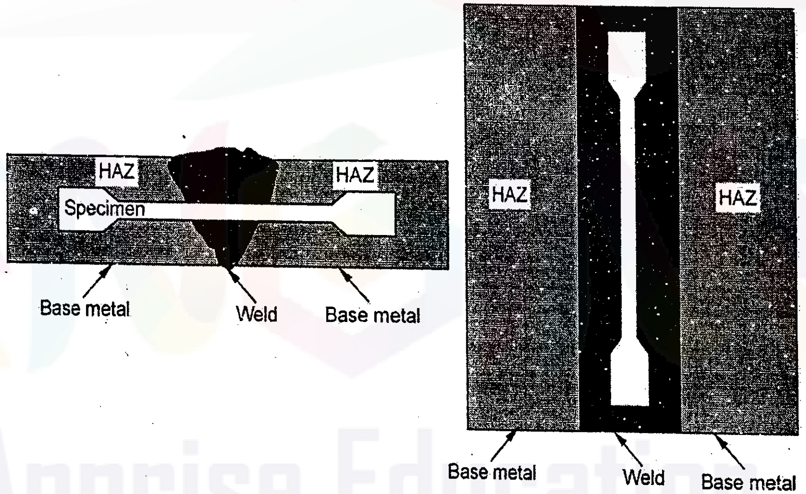
of the etched sample. This type of testing is often used extremely successfully to pinpoint welding problems such as crack initiation when used for failure analyses.

5.18.2. Tensile Test

This type of physical weld testing is used to measure the strength of a welded joint. Tensile properties of the weld joints are yield strength, ultimate strength and ductility which can be measured or calculated either in ambient condition or in special environment depending upon the requirement of the application using a tensile test. It is usually conducted at constant strain rate. The shearing strength of transverse and longitudinal fillet welds is determined by tensile stress on the test specimen. Since a large proportion of design is based on tensile properties of the welded joint, it is important that the tensile properties of the base metal, weld metal, bond between base and weld, and heat-affected zone (HAZ) conform to the design requirements.



(a) Transverse section of the weld *(b) Whole weld specimen*

Figure 5.48 Schematic of weld specimens for tensile test

Tensile properties of the weld joint are obtained in two ways.

(i) The specimen is tested from transverse direction of weld joint in which the cross section of the sample consists of base metal - weld - base metal as shown in Figure 5.48(a).

(ii) The weld metal specimen is tested as shown in Figure 5.48(b).

Tensile test results must be supported by respective engineering stress and strain diagram indicating modulus of elasticity, elongation at fracture and yield and ultimate strength. Tests results must include information on following parameters:

(i) Test conditions

(ii) Type of sample

(iii) Strain rate (*mm/min*)

(iv) Temperature or any other environment

(v) Topography, morphology and texture of the fracture surface indicating the mode of fracture and respective stress state.

Tensile strength of the welded joint is obtained by pulling the specimen to failure as shown in Figure 5.49. The test is carried out by gripping the ends of a suitably prepared standardized test specimen in a tensile testing machine called *Universal Testing Machine (UTM)*. The load is applied continuously in the increasing manner until the weld fails.

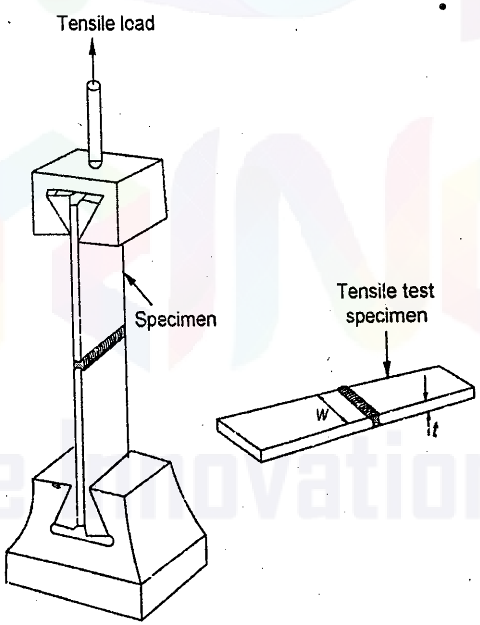


Figure 5.49 Tensile test

Both load and extension are measured and this data is plotted as a graph to view the behaviour of the weld. The plotted curve is called stress-strain curve.

From a plotted stress-strain curve, the following observations are made.

(i) Tensile strength is known as *ultimate tensile strength*. The corresponding stress is called *tensile stress*. Tensile strength is determined by dividing the maximum load required during testing by the cross-sectional area.

Ultimate tensile stress, $\sigma = P_{max}/A_c$

where P_{max} = Maximum load

A_c = Cross sectional area before testing.

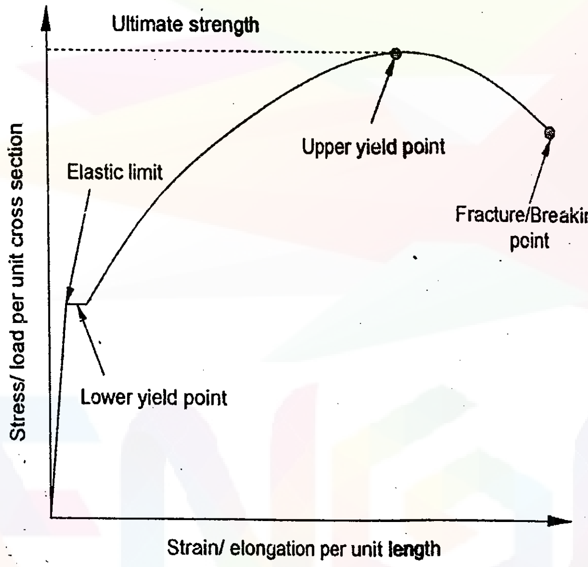


Figure 5.50 Stress-strain curve

(ii) The stress at which the deformation changes from elastic to plastic behaviour below a particular point is called *yield point*. The stress at this point is called *yield stress*.

(iii) After sometimes with continuous application of load, the weld fails at one point is known as *breaking point*. The load applied at that point is known as *breaking load* and the corresponding stress is called *breaking stress*.

5.18.3. Bend Test

Bend test is one of the commonly used destructive tests to determine the ductility and soundness (for the presence porosity, inclusion, penetration and other macro-size internal weld discontinuities) of the weld joint produced using under one set of welding conditions.

There are following two types of bend test:

(a) Free bend test

(b) Guided bend test.

(a) Free bend test:

The free bend weld testing approach has been devised to measure the ductility of the weld metal deposited in a weld joint. A physical weld testing specimen is machined from the welded plate with the weld located as shown in Figure 5.51(a).

Each corner lengthwise of the specimen shall be rounded in a radius not exceeding one-tenth of the thickness of the specimen. Two scribed lines are placed on the face 1.6 *mm* from the edge of the weld. The distance between these lines is measured and recorded as the initial distance *x* as shown in Figure 5.51 (b). The ends of the test specimen are then bent through angles of about 30° and these bends are being approximately one-third of the length in from each end. The weld is thus located centrally to ensure that all of the bending occurs in the weld.

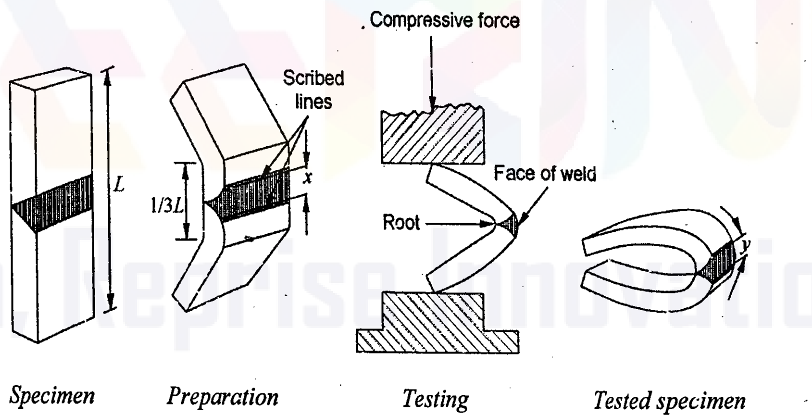


Figure 5.51 Free bend test

The specimen bent initially is then placed in a machine capable of exerting a large compressive force as shown in Figure 5.51 (c) and bent until a crack greater than 1.6 *mm* in any dimension appears on the face of the weld. If no cracks appear, bending is continued until the specimens 6.4 *mm* thick or under can be tested in vise.

After bending the specimen to the point where the test bend is concluded, the distance between scribed lines on the specimen is again measured and recorded as the distance *y*. Then percentage elongation is calculated. The usual requirements for passing this test are that the minimum elongation be 15% and that no cracks greater than 1.6 *mm* in any dimension exist on the face of the weld.

The free bend test is being largely replaced by the guided bend test where the required testing equipment is available.

(b) Guided bend test:

The quality of the weld metal at the face and root of the welded joint as well as the degree of penetration and fusion to the base metal are determined by means of guided bend tests. It also shows the efficiency of the weld.

This type of physical weld testing is made in a jig (Figure 5.52). These test specimens are machined from welded plates and the thickness of which must be within the capacity of the bending jig. The test specimen is placed across the supports of the die which is the lower portion of the jig. The plunger operated from above by a hydraulic jack or other device causes the specimen to be forced to assure the shape of the die.

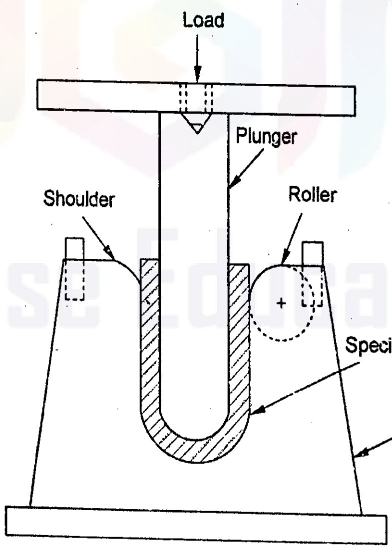
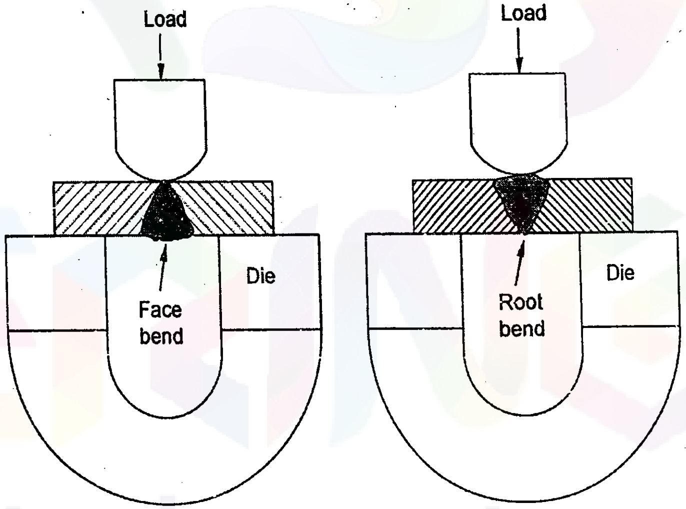


Figure 5.52 Guided bend test

For bend test, the load is increased until cracks start to appear on face or root of the weld for face and root bend test respectively and angle of bend at this stage is used as a measured of ductility of weld joints. Higher is bend angle greater is ductility of the weld. To fulfill the requirements of this test, the specimens must bend 180° and, to be accepted as passable, no cracks greater than 3.2 *mm* in any dimension should appear on the surface. Fracture surface of the joint from the face/root side due to bending reveals the presence of internal weld discontinuities if any.

Free bending of the weld joint can be done from face or root side depending upon the purpose. The *face bend tests* are made in the jig with the face of the weld in tension (i.e., on the outside of the bend) as shown in Figure 5.53 (a). The *root bend tests* are made with the root of the weld in tension (i.e., on outside of the bend) as shown in Figure 5.53 (b). The root side bending shows the lack of penetration and fusion if any at the root.



(a) Face bend *(b) Root bend*

Figure 5.53 Schematic of guided bend tests

5.18.4. Nick Bend Test

The nick break test has been devised to determine if the weld metal of a welded butt joint has any internal defects such as slag inclusions, gas pockets, poor fusion and oxidized or burnt metal.

The specimen is obtained from a welded butt joint either by machining or cutting with an oxyacetylene torch. Each edge of the weld at the joint is slotted by means of a saw cut through the center as shown in Figure 5.54. The piece thus prepared is bridged across two steel blocks and stuck with a heavy hammer until the section of the weld between slots fractures.

The metal thus exposed should be completely fused and free from slag inclusions. The size of any gas pocket must not be greater than 1.6 *mm* across the greater dimension and the number of gas pockets or pores per square inch (64.5 mm^2) should not exceed 6.

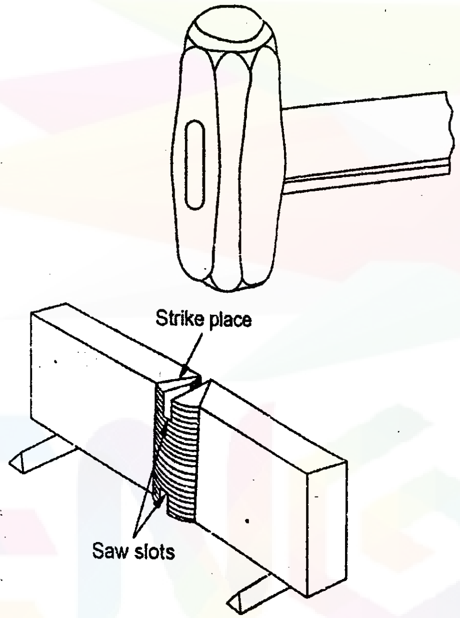


Figure 5.54 Nick break test

Another break test method is used to determine the soundness of fillet welds. It is the *fillet weld break test*. This type of testing involves breaking a sample fillet weld that is welded on one side only. A force, by means of a press or testing machine blows of a hammer, is applied to the apex of the V shaped specimen until the fillet weld ruptures. The surfaces of the fracture will then be examined for soundness. This type of weld inspection can detect such items as lack of fusion, internal porosity and slag inclusions. This testing method is often used in conjunction with the acid etch test.

5.18.5. Hardness Test

Hardness is defined as resistance to indentation and it is commonly used as a measure of resistance to abrasion or scratching. For the formation of a scratch or causing abrasion, a relative movement is required between two bodies and out of two one body must penetrate/indent into other body. Indentation is the penetration of a pointed object (harder) into other object (softer) under the external load. Resistance to the penetration of pointed object (indenter) into the softer one depends on the hardness of the sample on which the load is applied through the indenter.

All methods of hardness testing are based on the principle of applying the standard load through the indenter (a pointed object) and measuring the penetration in terms of diameter/diagonal/depth of indentation (Figure 5.55). High penetration of an indenter at a given standard load suggests low hardness.

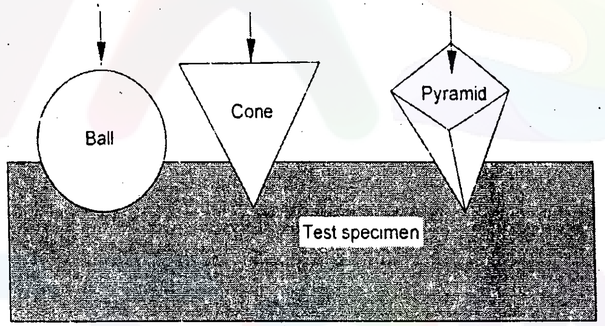


Figure 5.55

Various methods of hardness testing methods are as follows:

(i) Brinell hardness test

(ii) Rockwell hardness test

(iii) Vickers hardness test.

Various methods of hardness testing can be compared on the basis of following three criteria.

(i) Type of indenter

(ii) Magnitude of load

(iii) Measurement of indentation.

The following Table describes the limitations of these criteria for different types of hardness testing methods.

Parameter	***Brinell***	***Rockwell***	***Vickers***
Load	500-2000 kg	Minor: 10 kg Major: 60-200 kg	10-3000g
Indenter	Ball	Ball or Cone	Pyramid
Measurement	Diameter	Depth	Diagonal

Penetration due to applied normal load is affected by unevenness on the surface and presence of hard surface films such as oxides, lubricants, dust and dirt etc., if any. So, the surface should be cleaned and polished before hardness test.

In case of Brinell hardness test, full load is applied directly for causing indentation for measuring hardness but in case of Rockwell hardness test, minor load (10 kN) is applied first before applying major load. Minor load is applied to ensure the firm metallic contact between indenter and sample surface by breaking surface films and impurities, if any, present on the surface. Minor load does not cause indentation. Indentation is caused by major load only. Therefore, cleaning and polishing of the surface films become mandatory for accuracy in hardness test results in case of Brinell test method as the major load is applied directly.

(i) Brinell hardness test:

The test comprises forcing a hardened steel ball indenter into the surface of the sample using a standard load as shown in Figure 5.56. Steel ball of different diameters (D) is used as an indenter in Brinell hardness test. Diameter of indentation (d) is measured to calculate the projected area and determine the hardness.

Brinell hardness test results are expressed in the form of pressure generated due to load (P). It is calculated by the ratio of load applied and projected contact area. Load in the range of 500 to 3000 kg can be applied depending upon the type of material to be tested. Higher load is applied for hardness testing of hard materials as compared to soft materials.

$$\text{Brinell hardness number, } BHN = \frac{2P}{\pi D\left(D-\sqrt{(D^2-d^2)}\right)}$$

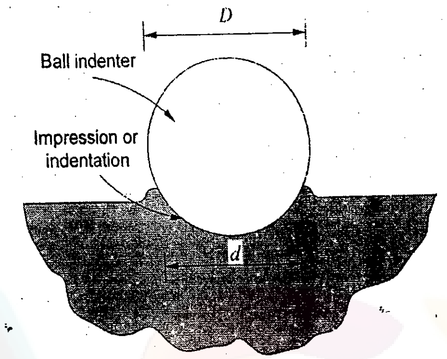


Figure 5.56 Brinell indentation

Rockwell hardness test:

In case of Rockwell hardness test, first minor load of 10 kg is applied and then major load of 50-150kg is applied on the surface of workpiece through the indenter and the same is decided by scale (A, B, C and D) to be used as per type of material to be tested. Minor load is not changed. Out of mainly scales, B and C scales are commonly used. Different indenter and major load are required for each scale. Steel ball and diamond cone are two types of indenters used in Rockwell testing. B scale uses hardened steel ball and major load of 90kg whereas C scale uses diamond cone and major load of 140kg accordingly hardness is written in terms of HRB and HRC respectively.

(iii) Vickers hardness test:

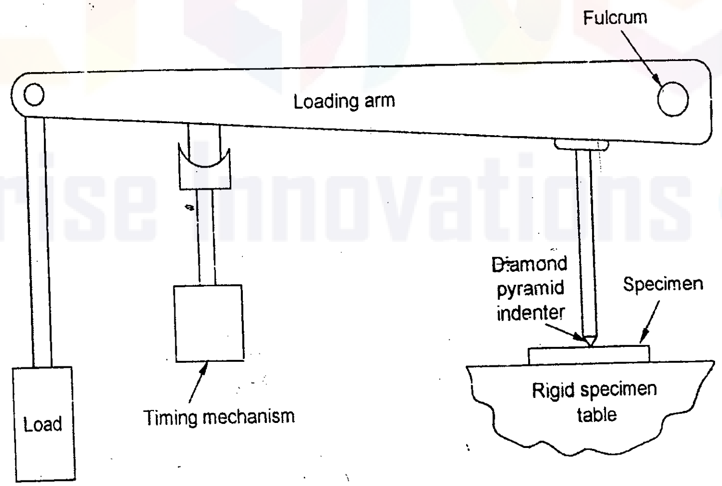


Figure 5.57 Schematic of Vickers hardness machine

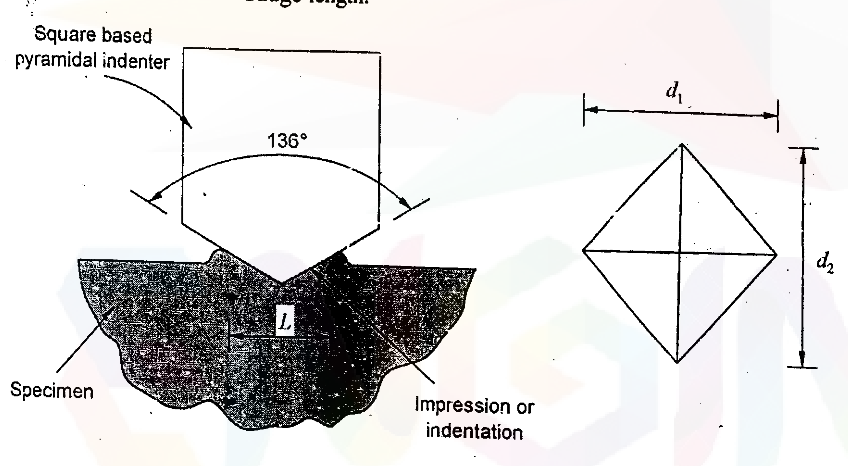
Vickers hardness test operates on similar principles of Brinell test. The major difference is the use of square pyramid shaped diamond indenter rather than a hardened steel ball and load ranging from 1 to 120 *kg*. The load is applied to the indenter by a simple weighted lever as shown in Figure 5.57. In older machines, an oil filled dash pot is used as a timing mechanism on more modern equipment which is electronically done.

Average length (L) of two diagonals of square indentation is used as a measure of hardness. Longer average diagonal length refers lower hardness. Vickers hardness number (VHN) or diamond pyramid hardness (DPH) is the ratio of load (P) and apparent area of indentation given by the relation

$$\text{Vicker's hardness number, } VHN = \frac{1.854P}{L^2}$$

where P = Applied load

L = Gauge length.



(a) Vickers indentation

(b) Measurement of impression or diagonals

Figure 5.58

5.18.6. Fatigue Test

A method for determining the behavior of materials under fluctuating loads. A specified mean load and an alternating load are applied to a specimen and the number of cycles required to produce failure (fatigue life) is recorded.

Generally, the test is repeated with identical specimen and various fluctuating loads. Loads may be applied axially, torsion or flexure. Depending on the amplitude of mean and

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cyclic load, the net stress in the specimen is in one direction through the loading cycle or reverse direction. The test specimen used for testing is shown in Figure 5.59. The specimen is fillet welded using a standard shop practice.

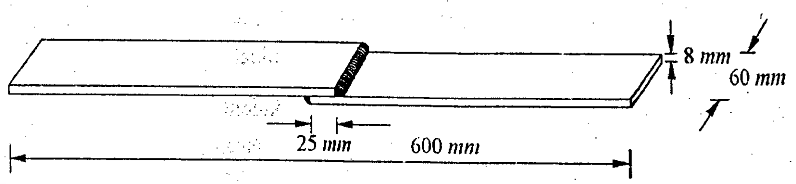

Figure 5.59 Test specimen used for fatigue testing

Rotating bending testing machine:

The type of S-N curve created by this machine is identified as a rotating-bending stress-controlled fatigue data curve. The rotating bending test machine (Figure 5.60) is used to create an S-N curve by turning the motor at a constant revolution per minutes or frequency. To create a failure on the specimen, a constant-stationary force is applied on the specimen who creates a constant bending moment.

A stationary moment applied to a rotating specimen causes the stress at any point on the outer surface of the specimen to go from zero to a maximum tension stress, back to zero and finally to a compressive stress. Thus, the stress state is one that is completely reversed in nature.

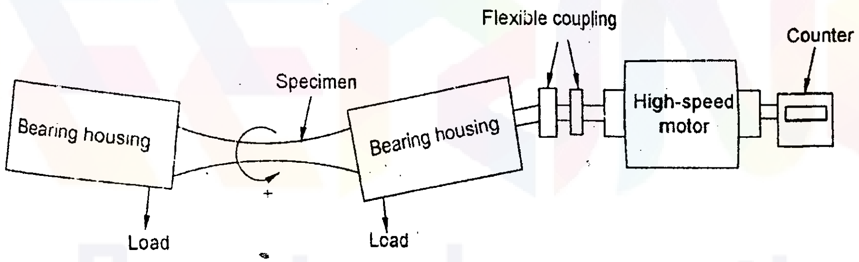

Figure 5.60 Rotating bending testing machine

Data from fatigue testing often are presented in an S-N diagram which is a plot of the number of cycles required to cause failure in a specimen against the amplitude of the cyclical stress developed. The cyclical stress represented may be stress amplitude, maximum stress or minimum stress. Each curve in the diagram represents a constant mean stress. Most fatigue tests are conducted in flexure, rotating beam or vibratory type machines.

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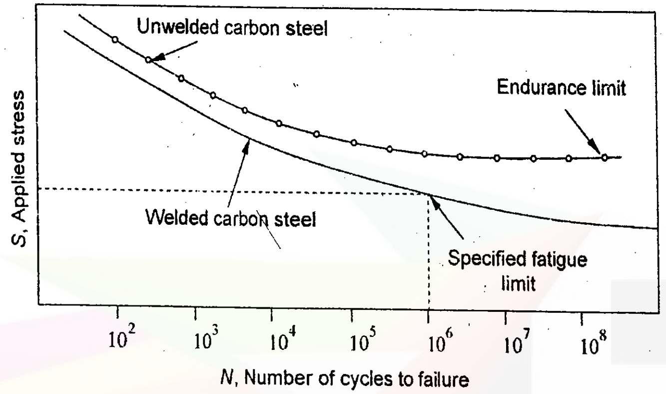

Figure 5.61 S/N curves for welded and unwelded specimens

5.19. NONDESTRUCTIVE TESTING OF WELDMENT

Non-destructive testing (NDT) is the examination of an object or material with technology that does not affect its future usefulness. It is an approach to testing that involves in evaluating the weld without causing physical damage. The terms *Nondestructive examination* (NDE), *Nondestructive inspection* (NDI), and *Nondestructive evaluation* (NDE) are also commonly used to describe this technology. As it allows inspection without interfering with a product's final use, NDT provides an excellent balance of quality control and cost-effectiveness.

The destructive tests are often used to determine the physical properties of materials such as impact resistance, ductility, yield and ultimate tensile strength, fracture toughness and fatigue strength but discontinuities and differences in material characteristics are more effectively found by NDT.

There are a variety of NDT methods that can be used to evaluate materials, components and welded joints. All NDT methods share several common elements. These elements are as follows.

- Some source of probing energy or some type of probing medium
- Discontinuity must cause a change or alteration of the probing medium
- Some means of detecting this change
- Some means of indicating this change

- Some means of observing and recording this indication so that an interpretation can be made.

A variety of non-destructive testing methods have been developed. Each one having advantages and limitations making it more or less appropriate for a given application. With the variety of NDT methods available, it is important to select the method that will provide the required assurance and results. The following five basic methods are commonly used to examine finished welds.

- Visual Inspection (VT)
- Dye-penetrant inspection or Liquid penetration inspection (LPI)
- Magnetic particle inspection (MPI)
- Radiographic inspection (RT)
- Ultrasonic inspection (UT).

5.19.1. Visual Inspection

Visual inspection is the oldest and most common form of NDT. It is most widely used welding inspection method. This inspection procedure may be greatly enhanced by the use of appropriate combinations of magnifying instruments, borescopes, light sources, video scanners and other similar devices.

The use of optical aids for visual inspection is beneficial and recommended. Optical aids magnify defects that cannot be seen by the unaided eye and also permit visual inspection in inaccessible areas.

Common defects such as spatter, excessive built-up, incomplete slag removal, lack of root penetration, distortion, undercut and surface cracks can be detected by a visual inspection of the welds. Cracks may also be detected by hitting the casting with a mallet and listening to the quality of the tone.

Visual inspection equipment:

The following visual inspection equipment are commonly used for inspecting welded joints.

- Simple magnifier
- Fillet gauges / weld gauge.

(a) Simple magnifier:

A single converging lens of the simplest form of a microscope is often referred to as a simple magnifier. Magnification of a single lens is determined by the equation

$$M = 10/f$$

where M is the magnification

f is the focal length of the lens in inches and

10 is a constant that represents the average minimum distance at which objects can be distinctly seen by the unaided eye.

Using the equation, a lens with a focal length of 5 *inches* has a magnification of 2 or is said to be a two-power lens.

(b) Fillet gauges / weld gauge:

Fillet gauges are used to measure the legs of the weld, convexity of weldment, concavity of weldment and flatness. The procedure for measuring these parameters is as follows:

To determine the size of a fillet weld, the weld gauge is placed against the toe of the fillet weld and pointer is slided out until it touches structure as shown in Figure 5.62. Now, the pointer indicates the size of the fillet weld.

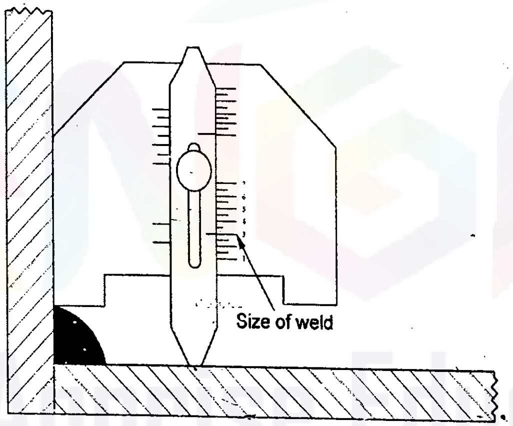

Figure 5.62 Determining size of a fillet weld

To check the permissible tolerance of convexity of the weldment, the weld gauge is placed against the structure and pointer is slided until it touches face of the fillet weld as shown in Figure 5.63. The maximum convexity should not be greater than indicated by maximum convexity scale as indicated by arrow for the size of filler being checked.

To check the permissible tolerance of concavity and underfill of the weldment, the weld gauge is placed against the structure and the pointer is slided until it touches face of the fillet weld as shown in Figure 5.64. If the pointer does not touch as shown, the fillet requires additional weld metal.

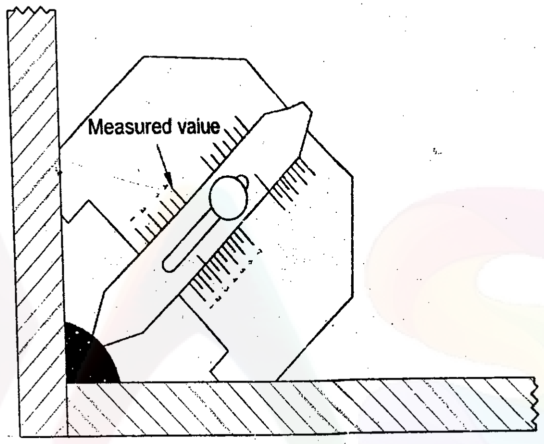

Figure 5.63 Checking the permissible tolerance of convexity

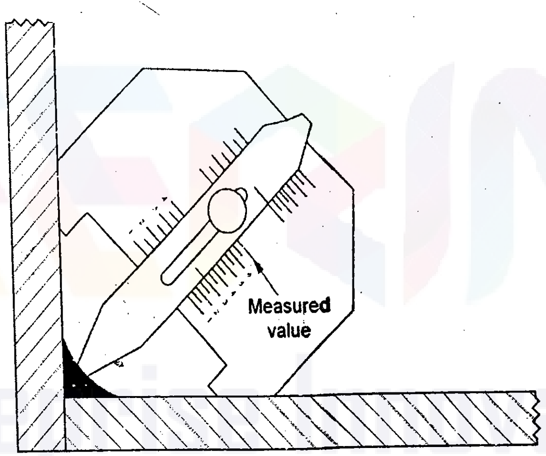

Figure 5.64 Checking the permissible tolerance of concavity and underfill

To check the permissible tolerance of reinforcement of the weldment, the weld gauge is placed in such a way that the reinforcement is between legs of gauge and the pointer is slided until it touches face of the fillet weld as shown in Figure 5.65.

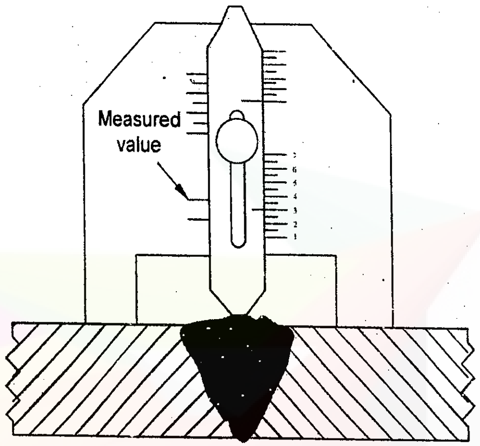

Figure 5.65 Checking permissible tolerance of reinforcement

Advantages:

1. It is simple, easy to apply and quickly carried out.
2. It is usually low in cost.

Limitations:

1. Only surface defects are detectable.
2. Welding inspector must also decide if additional tests are warranted.

5.19.2. Magnetic Particle Inspection

Magnetic particle inspection is a method of detecting invisible cracks and other defects in ferromagnetic materials such as iron and steel. It is not applicable to nonmagnetic materials.

Principle:

The inspection process consists of magnetizing the part and then applying ferromagnetic particles to the surface area are to be inspected. If a defect is present, the magnetic lines of force will be disturbed and opposite poles will exist on either side of the defect.

The magnetized particles form a pattern, as shown in Figure 5.66, in the magnetic field between opposite poles. This pattern known as "indication" assumes the approximate shape of the surface projection of the defect.

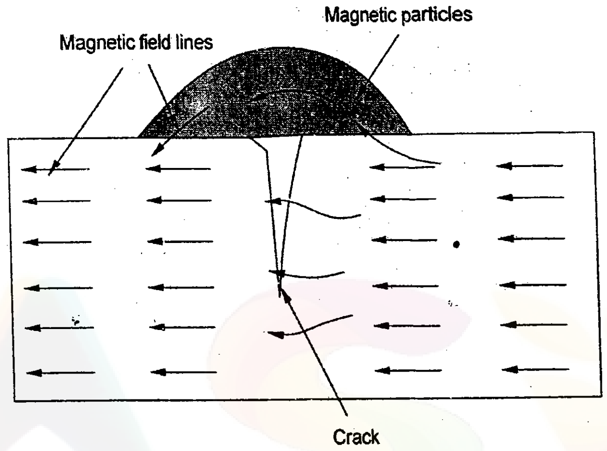

Figure 5.66 Magnetic particle testing

In this experiment, commercially available magnetic powder manufactured for NDT inspection will be used. A strong U shape magnet will be used to provide the necessary magnetic field at the inspected area.

This test is used to detect cracks, porosity and inclusions in the welding. It is mainly used for testing ferromagnetic materials (those that can be magnetized). Magnetic particle inspection can detect surface and near surface defects.

Steps used in the testing:

The following steps are applied during the inspection;

(a) The surface of the specimen is roughly cleaned wiping with a piece of textile.

(b) The fluorescent magnetic spray is applied on the surface being inspected.

(c) Magnetic field is applied with a strong magnet to the location of interest. . The iron powder is attracted to the crack and the iron powder will be gathered near the cracks.

(d) The spots where the fluorescent magnetic particles accumulated is inspected under UV light.

Advantages:

1. Large surface areas of complex parts can be inspected rapidly.
2. The test can detect surface and subsurface flaws.

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3. Surface preparation is less critical than it is in penetrant inspection.
4. Magnetic particle indications are produced directly on the surface of the part and form an image of the discontinuity.
5. Equipment costs are relatively low.

Limitations:

1. Only ferromagnetic materials can be inspected.
2. A proper alignment of magnetic field and defect is critical.
3. Large currents are needed for very large parts.
4. It requires relatively smooth surface.
5. Paint or other nonmagnetic coverings adversely affect sensitivity.
6. Demagnetization and post cleaning are usually necessary.

5.19.3. Dye-Penetrant Inspection or Liquid Penetrant Inspection

Penetrant inspection is used on nonporous metal and nonmetal components to find material discontinuities that are open to the surface and may not be evident to normal visual inspection. The dye-penetrant method is frequently used for the detection of surface breaking flaws in non-ferromagnetic materials. The basic purpose of penetrant inspection is to increase the visible contrast between discontinuity and its background.

Penetrant inspection will detect such defects as surface cracks or porosity. These defects may be caused by fatigue cracks, shrinkage cracks, shrinkage porosity, cold shuts, grinding and heat treat cracks. Penetrant inspection will also indicate a lack of bond between joined metals.

Principle:

Penetrant solution is applied to the surface of a pre-cleaned component. The liquid is pulled into surface-breaking defects by capillary action. Excess penetrant material is carefully cleaned from the surface. A developer is applied to pull the trapped penetrant back to the surface where it is spread out and it forms an indication. The indication is much easier to see than actual defect.

In this method, the surfaces to be inspected should be free from any coatings, paint, grease, dirt, dust, etc. Therefore, the surface should be cleaned with an appropriate way. Special care should be taken not to give additional damage to the surface to be inspected during cleaning process.

Penetrant materials come in two basic types:

Type 1 - Fluorescent penetrants:

They contain a dye or several dyes that fluoresce when exposed to ultraviolet radiation.

Type 2 - Visible penetrants:

They contain a red dye that provides high contrast against the white developer background. Fluorescent penetrant systems are more sensitive than visible penetrant systems because the eye is drawn to the glow of the fluorescing indication. However, visible penetrants do not require a darkened area and an ultraviolet light in order to make an inspection.

The visible penetrant kit consists of dye penetrant, dye remover emulsifier and developer. The fluorescent penetrant inspection kit contains a black light assembly as well as spray cans of penetrant, cleaner and developer. Commercially available cans of liquid penetrant dyes with different colors are used to reveal the surface defects.

The role of the developer is to pull the trapped penetrant material out of defects and spread it out on the surface of the part. So, it can be seen by an inspector. Developers used with visible penetrants create a white background. So, there is a greater degree of contrast between indication and surrounding background.

Steps used in the testing (Figure 5.67):

(a) The weld surface is cleaned with alcohol and let surface dry for 5 *minutes*.

(b) The liquid penetrant spray is applied to the surface and brush for further penetration and wait for 20 *minutes*.

(c) The surface is wiped with a clean textile and subsequently remover spray is applied to remove excess residues on the surface and wait for a few min.

(d) Apply the developer, spray at a distance of about 30*cm* from the surface. The developer will absorb the penetrant that infiltrated to the surface features such as cracks, splits, etc., and then it is reacted with it to form a geometric shape which is the negative of the geometry of the surface features from which the penetrant is sucked.

(e) The polymerized material may be collected on a sticky paper for future evaluation and related documentation, if needed.

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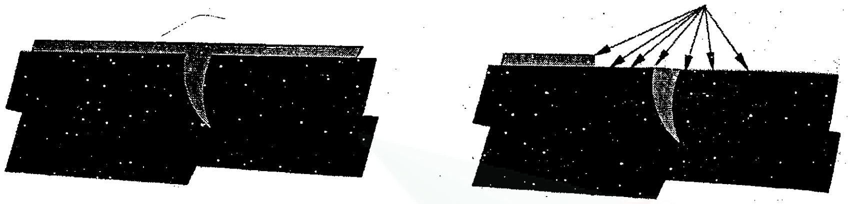
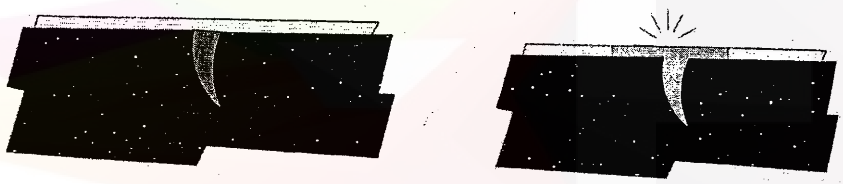


Step 1: Penetrant applied to the surface and enters defect

Step 2: Excess penetrant removed from surface



Step 3: Developer powder applied to draw penetrant out of crack

Step 4: Accentuated indication of crack as penetrant spreads around the opening

Figure 5.67 Dye-penetrant testing

Advantages:

1. It is highly sensitivity (small discontinuities can be detected).
2. Few material limitations (metallic and nonmetallic, magnetic and nonmagnetic, and conductive and nonconductive materials may be inspected).
3. Rapid inspection of large areas and volumes.
4. It is suitable for parts with complex shapes.
5. Indications are produced directly on the surface of the part and constitute a visual representation of the flaw.
6. It is portable (materials are available in aerosol spray cans)
7. Cost is low (materials and associated equipment are relatively inexpensive).

Limitations:

1. The defect must be open to the surface in order to let the penetrant get into the defect.
2. Only materials with a relatively nonporous surface can be inspected.
3. Pre-cleaning is critical since contaminants can mask defects.
4. The inspector must have direct access to the surface being inspected.

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5. Surface finish and roughness can affect inspection sensitivity.
6. Multiple process operations must be performed and controlled.
7. Post cleaning of acceptable parts or materials is required.
8. Chemical handling and proper disposal is required.

5.19.4. Radiographic Inspection

Radiography (X-ray) is an NDT method used to inspect material and components using the concept of differential adsorption of penetrating radiation. Each specimen under evaluation will have differences in density, thickness, shapes, sizes or absorption characteristics. Thus, the different amount of radiation is absorbed. The unabsorbed radiation that passes through the part is recorded on film, fluorescent screens or other radiation monitors. Indications of internal and external conditions will appear as variants of black/white/gray contrasts on exposed film or variants of color on fluorescent screens.

This technique is suitable for the detection of internal defects in ferrous and nonferrous metals, and other materials. Radiography has an advantage over some of the other processes in that the radiography provides a permanent reference for the internal soundness of the object that is radiographed. X-rays and gamma rays are used in the radiographic test.

The x-ray emitted from a source has an ability to penetrate metals as a function of the accelerating voltage in the X-ray emitting tube. If a void present in the object being radiographed, more X-rays will pass in that area and film under the part in turn will have more exposure than non-void areas. Hence, the voids show as darkened areas on a clear background as shown in Figure 5.68.

This test is used to detect the internal defects such as cracks, porosity, blow holes, inclusions. In this test, a film or a photographic plate is placed behind and in contact with weld surface. The portion is exposed to a beam of X-rays. X-rays are produced in an X-ray tube. During exposure, X-rays penetrate through the weldment and then affect the X-ray film. After developing the film, a radiograph is obtained. This radiograph shows the nature of defect.

Blow holes, cracks, cavities and porosity appear higher than the surrounding area. This is a quicker method but the cost of test is high. The radiograph is used as a permanent record. The radiation may affect human beings.

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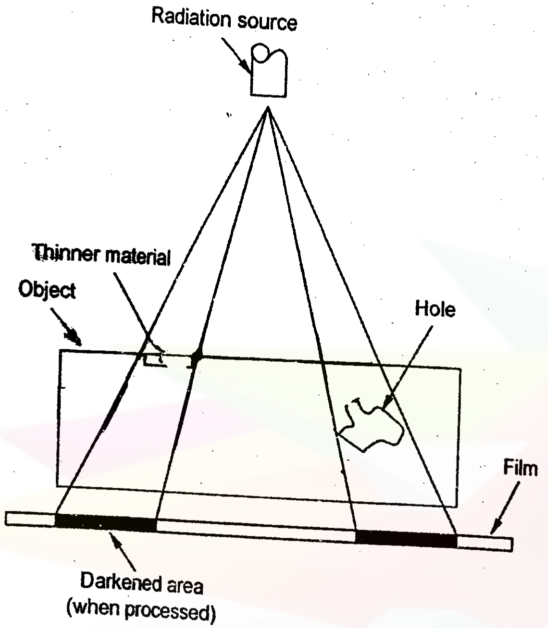

Figure 5.68 Radiography testing

Advantages:

1. It can be used to inspect virtually all materials.
2. Detects both surface and subsurface defects can be identified.
3. It has the ability to inspect complex shapes and multi-layered structures without disassembly.
4. Minimum part preparation is required.
5. Information is presented pictorially.
6. A permanent record is provided which may be viewed at a time and place distant from the test.
7. It can be used for inspecting hidden areas (direct access to surface is not required).

Limitations:

1. Extensive operator training and skill are required.
2. Access to both sides of the structure is usually required.
3. Orientation of the radiation beam to non-volumetric defects is critical.
4. Field inspection of thick section can be time-consuming.

5. Relatively expensive equipment investment is required.
6. Possible radiation hazard for personnel occurs.
7. Depth of discontinuity is not indicated.
8. Film processing and viewing facilities are necessary as is an exposure compound.
9. It is not suitable for automation unless the system incorporates fluoroscopy with an image intensifier or other electronic aids.

5.19.5. Ultrasonic Inspection

This method is used to find internal defects by using ultrasonic sound waves. Very minute defects such as cracks, porosity, blowholes etc. can be accurately detected in castings. Sound waves can pass through solids without any absorption. It can also be reflected from a surface. Hence, ultrasonic waves are used in this test. These ultrasonic waves are produced by a *transducer*. The transducer can change the high frequency electrical energy into ultrasonic sound waves. It is called *transmitter* which can also change the ultrasonic sound waves into electrical energy.

Principle:

High frequency sound waves are sent into a material by the use of a transducer. The sound waves travel through the material and they are received by the same transducer or a second transducer. The amount of energy transmitted or received and time to receive the energy is analyzed to determine the presence of flaws. Changes in material thickness and properties can also be measured.

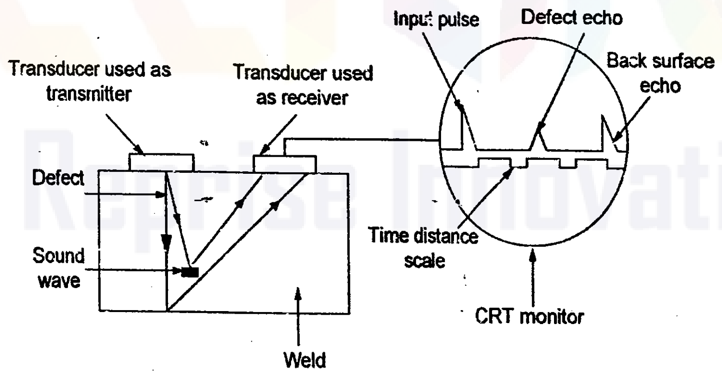

Figure 5.69 Ultrasonic testing

If the work is defect free, the wave will strike the bottom of the work and return to the receiver. The striking of waves at the bottom surface and top surface are indicated in the form of pip (echo) in CRT as 1 and 3 as shown in Figure 5.69. If there is any defect in between top and bottom surfaces, the wave is reflected back from that spot and it is indicated as a pip in CRT as 2.

Ultrasonic inspection techniques:

Two basic ultrasonic inspection techniques are employed such as pulse-echo and through-transmission.

(a) Pulse-Echo inspection:

This process uses a transducer to both transmit and receive the ultrasonic pulse as shown in Figure 5.70(a). The received ultrasonic pulses are separated by the time. It takes the sound to reach the different surfaces from which it is reflected. The size (amplitude) of a reflection is related to the size of the reflecting surface. The pulse-echo ultrasonic response pattern is analyzed on the basis of signal amplitude and separation.

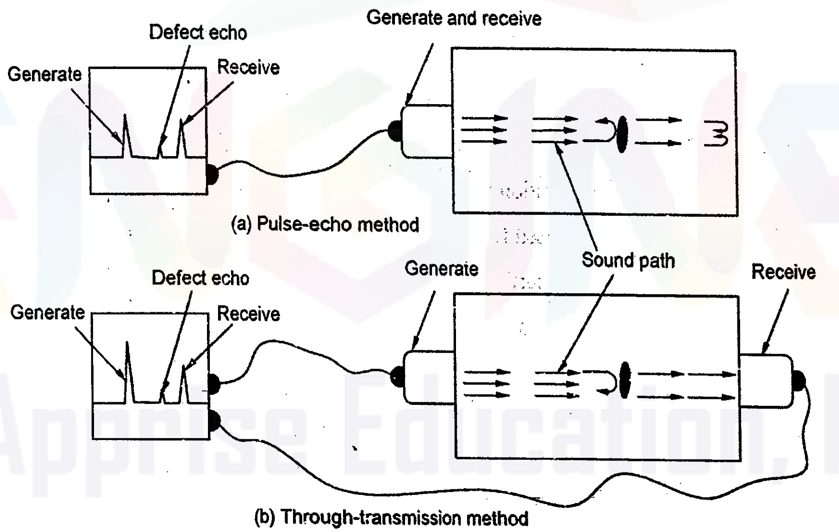

Figure 5.70 Ultrasonic testing techniques

(b) Through-transmission inspection:

This inspection employs two transducers. Among them, one is to generate and the second one is to receive the ultrasound as shown in Figure 5.70(b). A defect in the sound path between two transducers will interrupt the sound transmission. The magnitude (the change in the sound pulse amplitude) of the interruption is used to evaluate test results. Through-transmission inspection is less sensitive to small defects than pulse-echo inspection.

Ultrasonic inspection is used to detect surface and subsurface discontinuities such as cracks, shrinkage cavities, bursts, flakes, pores, delaminations and porosity.

Steps used in the testing:

The following steps should be applied during the inspection:

(a) The couplant should be applied on the inspected area.

(b) For the circular test specimen, the prop will be placed in the corresponding space in the supporting fitting tool. Enough couplant should be used between probe and tool.

(c) For the flat specimen, no tool is needed and couplant is only applied between inspected surface and probe.

(d) Special attention should be paid on the location where the possible cracks exist.

(e) A discontinuity like a crack produces a peak on the screen.

(f) Attention should also be given to the movement of the possible peak caused by the cracks on the specimen.

Advantages:

1. It is a fast and reliable process.
2. Minimum part preparation is required.
3. This method can be used for much more than just flaw detection.
4. It is sensitive to both surface and subsurface discontinuities.
5. The depth of penetration for flaw detection or measurement is superior to other NDT methods.
6. Only single-sided access is needed when the pulse-echo technique is used.
7. It is highly accurate in determining reflector position and estimating size and shape.
8. It provides instantaneous results.
9. Detailed images can be produced with automated systems.
10. It is nonhazardous to operators or nearby personnel and does not affect the material being tested.
11. Its equipment can be highly portable or highly automated.

Limitations:

1. Surface must be accessible to transducer and couplant so that ultrasound can be transmitted.
2. Surface finish and roughness can interfere with inspection.
3. Thin parts may be difficult to inspect.
4. Skill and training are more extensive than with some other methods.
5. It normally requires a coupling medium to promote the transfer of sound energy into the test specimen.
6. Materials that are rough, irregular in shape, very small, exceptionally thin or not homogeneous are difficult to inspect.
7. Linear defects oriented parallel to the sound beam may go undetected.
8. Reference standards are required for both equipment calibration and the characterization of flaws.

5.19.6. Selection of Suitable NDT Method

A good NDT method must recognize the inherent limitations of each process. For example, both radiography and ultrasound have the distinct orientation factors that may guide the choice of which process to use for a particular job. Their strengths and weaknesses tend to complement each other. While radiography is unable to reliably detect lamination such as defects, ultrasound is much better at it. On the other hand, ultrasound is poorly suited to detecting scattered porosity while the radiography is very good.

Whatever inspection techniques are used, paying attention to the "Five P's" of weld quality will help to reduce the subsequent inspection to a routine checking activity. Then, the proper use of NDT methods will serve as a check to keep variables in line and weld quality within standards.

The Five P's are:

1. ***Process selection*** - The process must be right for the job.
2. ***Preparation*** - The joint configuration must be right and compatible with the welding process.
3. ***Procedures*** - The procedures must be spelled out in detail and followed religiously during welding.
4. ***Pretesting*** - Full-scale mockups or simulated specimens should be used to prove that the process and procedures give the desired standard of quality.
5. ***Personnel*** - Qualified people must be assigned to the job.

5.20. TWO MARK QUESTIONS AND ANSWERS

1. ***Sketch at least two types of welded joints.***

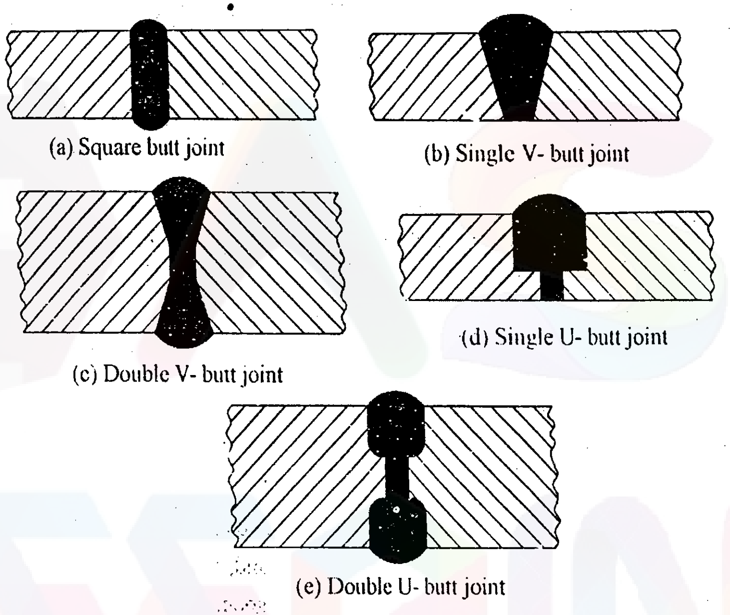

Figure 5.71

2. ***What are the types of welded joints?***
   (i) Butt joint
   (ii) Lap joint
   (iii) T-joint
   (iv) Corner joint
   (v) Edge joint.

3. ***Define butt and lap joint.***

Butt joint:

The joint is made by welding the ends or edges of two plates.

Lap joint:

The two plates are overlapping each other for a certain distance. Then, it is welded. Such welding is called *fillet weld.*

4. ***Define Tee-joint and corner joint.***

T-joint:

The two plates are arranged in 'T' shape which means the plates are located at right angles to each other.

Corner weld:

Two plates are arranged at right angles such that it forms an angle.

5. ***Draw the weld symbols for double U-joint and single V-joint.***

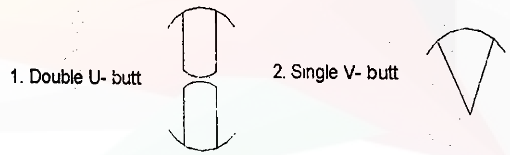

Figure 5.72

6. ***Define edge joint.***

For plates of thickness less than 6*mm*, the ends of the overlapping plates can be directly welded at the edges called *edge weld.*

7. ***When will the edge preparation need?***

If the two plates to be welded have more than 6*mm* thickness, the edge preparation should be carried out.

8. ***Write down the formula for tensile strength of a double V-groove butt joint.***

$$P = (h_1 + h_2)\, l\, \sigma$$

where P - tensile stress

h_1 and h_2 – weld sizes

L - Length of weld

σ - Allowable working stress.

9. ***What are the two types of fillet weld?***

(i) Longitudinal or parallel fillet weld.

(ii) Transverse fillet weld.

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10. ***Write down the expression for strength of parallel fillet weld in terms of permissible shear stress, leg of weld and length of welded joint.***

$$P = 0.707 \times l \times \tau$$

where l is the length of the weld

τ is tensile stress.

11. ***Write down the formula for strength of fillet and double fillet.***

For single fillet, $P = A\tau = 0.707\, h\, l\, \tau$

For double fillet, $P = 2A\tau = 1.414\, h\, l\, \tau$

where h – weld size

L – length of the weld

τ - Tensile stress.

12. ***Write down the formula for the strength of single transverse fillet weld.***

$$P = A\sigma = 0.707\, h\, l\, \sigma$$

where σ - Compressive stress.

13. ***What is the minimum size for fillet weld? If the required weld size from strength consideration is too small how will you fulfill the condition of minimum weld size?***

It is defined as the minimum size of the weld for a given thickness of the thinner part joined or plate to avoid cold cracking by escaping the rapid cooling.

Size of fillet weld, $h = \sqrt{2} \times \text{Throat thickness} (t)$

14. ***Define eccentrically loaded welded joints.***

The external loaded where applied may not pass through the geometric centre in structural joints called *eccentrically loaded joints.*

15. ***What are the two types of stresses are induced in eccentric loading of loaded joint?***

i. Direct shear stress.

ii. Bending or torsional shear stress.

16. ***State the two types of eccentric welded connections.***

1. Welded connections subjected to moment in a plane of the weld.
2. Welded connections subjected to moment in a plane normal to the plane of the weld.

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17. What are the significances of welding specification?

i. To convey the designers idea to the welding operator by placing it to a suitable place of the drawing.

ii. To specify the type of weld.

18. What are the main indications of complete weld symbol?

(i) A basic symbol is to specify the type of weld.

(ii) An arrow and a reference line to indicate the location of the weld.

(iii) Supplementary symbols to indicate special instructions.

(iv) Dimensions of the weld in cross section and length.

19. Define weldability.

Weldability is also known as *joinability* of a material. It refers the ability to weld. It is defined as the capacity of a metal or combination of metals to be welded into a suitable structure, and for the resulting weld joint(s) to possess the required metallurgical properties to perform satisfactorily in intended service.

20. What are the characteristics of good weldability?

(i) Ease with which welding is accomplished,

(ii) Absence of weld defects, and

(iii) Strength, ductility and toughness in welded joint.

21. What are the major factors which depend on the weldability of materials?

(i) Carbon Equivalent Value (CEV)

(ii) Hydrogen-induced cold cracking

(iii) Process factors.

22. How is carbon equivalent value calculated?

A commonly used formula to calculate CEV based on a publication of the International Institute of Welding (IIW) is given by

$$CEV = C + Mn/6 + (Cr + Mo + V)/5 + (Cu + Ni)/15$$

23. Write down the factors effecting weldability and parent metal composition.

If CEV - < 0.35, the steel is weldable using rutile electrode without any pre-heat.

If CEV - 0.35-0.45, either preheat or low hydrogen electrode is required.

If CEV - 0.45-0.55, both preheat and low hydrogen electrode is required.

If CEV - > 0.55, the steel is theoretically not weldable unless special care such as preheat, low hydrogen electrode and post weld heat treatment etc. are taken care of.

24. List down the minor factors which affect the weldability.

(i) Filler metal

(ii) Surface conditions

(iii) Parent metal composition

(iv) Parent metal thickness

(v) Weld metal composition

(vi) Welding process

(vii) Welding procedure.

25. List down the welding processes used to weld copper and its alloys.

1. Shielded metal arc welding (SMAW)
2. Gas-tungsten arc welding (GTAW)
3. Gas-metal arc welding (GMAW)
4. Plasma arc welding (PAW) and
5. Submerged arc welding (SAW).

26. What are the various factors affecting weldability of copper alloys?

These factors are the thermal conductivity of alloy being welded, shielding gas, type of current used during welding, joint design, welding position, surface condition and cleanliness.

27. Name the filler metals used in welding copper alloys.

(i) Copper filler metals

(ii) Copper-zinc filler metals

(iii) Copper-aluminium filler metals

(iv) Copper-nickel filler metals

(v) Copper-silicone filler metals.

28. List down the major defects in welded joint.

1. Lack of fusion
2. Lack of root penetration

3. Cracks
4. Cavity
5. Porosity
6. Undercut
7. Distortion
8. Slag inclusion
9. Lamellar tearing
10. Overlapping.

29. Compare the different welding processes.

Material	*Arc welding*	*Oxy-acetylene welding*	*Electron beam welding*	*Resistance welding*
Aluminium and aluminium alloys	Commonly performed	Commonly performed	Commonly performed	Commonly performed
Copper and copper alloys	Commonly performed	Commonly performed	Commonly performed	Commonly performed
Stainless steel	Recommended	Commonly performed	Commonly performed	Recommended

30. Define undercut in welded joints.

Undercut is a groove gets formed in the parent metal along the sides of the weld.

31. Mention the reasons of occurring distortion after carrying out welding in metal joining process.

1. Arc speed
2. Number of passes
3. Stresses in plates
4. Joint type
5. Order of welding.

32. What is meant by overlap?

Overlap is the protrusion of the weld metal beyond the weld toe or weld root. It may occur because of fusion problem.

33. Mention some common methods of welding inspection based on destructive principles.

(i) Acid etch test
(ii) Tensile test
(iii) Bend test
(iv) Nick break test
(v) Hardness test
(vi) Fatigue test.

34. Define yield stress of the welded joint.

The stress at which the deformation changes from elastic to plastic behaviour below a particular point is called *yield point*. The stress at this point is called *yield stress*.

35. Define hardness of material.

Hardness is defined as resistance to indentation and it is commonly used as a measure of resistance to abrasion or scratching.

36. List down the basic methods which are commonly used to examine finished welds based on nondestructive principle.

- Visual Inspection (VT)
- Dye-penetrant inspection or Liquid penetration inspection (LPI)
- Magnetic particle inspection (MPI)
- Radiographic inspection (RT)
- Ultrasonic inspection (UT).

37. Mention the advantages and disadvantages of visual inspection test.

Advantages:

1. It is simple, easy to apply, quickly carried out and usually low in cost.

Limitations:

1. Only surface defects are detectable.
2. Welding inspector must also decide if additional tests are warranted.

38. What are the steps used in testing the welded joint using magnetic particle test?

(a) The surface of the specimen is roughly cleaned wiping with a piece of textile.
(b) The fluorescent magnetic spray is applied on the surface being inspected.

(c) Magnetic field is applied with a strong magnet to the location of interest. The iron powder is attracted to the crack and the iron powder will be gathered near the cracks.

(d) The spots where the fluorescent magnetic particles accumulated is inspected under UV light.

39. State the advantages of magnetic particle test.

1. Large surface areas of complex parts can be inspected rapidly.
2. The test can detect surface and subsurface flaws.
3. Surface preparation is less critical than it is in penetrant inspection.
4. Magnetic particle indications are produced directly on the surface of the part and form an image of the discontinuity.
5. Equipment costs are relatively low.

40. Write down the limitations of magnetic particle test.

1. Only ferromagnetic materials can be inspected.
2. A proper alignment of magnetic field and defect is critical.
3. Large currents are needed for very large parts.
4. It requires relatively smooth surface.
5. Paint or other nonmagnetic coverings adversely affect sensitivity.
6. Demagnetization and post cleaning are usually necessary.

41. Mention any two advantages and limitations of dye-penetrant test.

Advantages:

1. It is highly sensitivity (small discontinuities can be detected).
2. Few material limitations (metallic and nonmetallic, magnetic and nonmagnetic, and conductive and nonconductive materials may be inspected).

Limitations:

1. Only materials with a relatively nonporous surface can be inspected.
2. Pre-cleaning is critical since contaminants can mask defects.

42. What are the defects that can be inspected in radiographic test?

Cracks, porosity and blow holes.

43. Write down any four advantages of radiographic test.

1. It can be used to inspect virtually all materials.
2. Detects both surface and subsurface defects can be identified.
3. It has the ability to inspect complex shapes and multi-layered structures without disassembly.
4. Minimum part preparation is required.

44. Mention the limitations of radiographic test.

1. Extensive operator training and skill are required.
2. Access to both sides of the structure is usually required.
3. Orientation of the radiation beam to non-volumetric defects is critical.
4. Field inspection of thick section can be time-consuming.

45. Which instrument is used to produce ultrasonic waves? Mention its function.

The transducer is used for producing ultrasonic waves. It changes high frequency electrical energy into ultrasonic sound wave.

46. Name two different ultrasonic inspection techniques.

(a) Pulse-Echo inspection

(b) Through-transmission inspection.

47. Write down the steps used in ultrasonic testing.

(a) The couplant should be applied on the inspected area.

(b) For the circular test specimen, the prop will be placed in the corresponding space in the supporting fitting tool. Enough couplant should be used between probe and tool.

(c) For the flat specimen, no tool is needed and couplant is only applied between inspected surface and probe.

(d) Special attention should be paid on the location where the possible cracks exist.

(e) A discontinuity like a crack produces a peak on the screen.

(f) Attention should also be given to the movement of the possible peak caused by the cracks on the specimen.

48. What are the advantages and limitations of ultrasonic testing?

Advantages:

1. It is a fast and reliable process.

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2. Minimum part preparation is required.
3. This method can be used for much more than just flaw detection.
4. It is sensitive to both surface and subsurface discontinuities.

Limitations:

1. Surface must be accessible to transducer and couplant so that ultrasound can be transmitted.
2. Surface finish and roughness can interfere with inspection.
3. Thin parts may be difficult to inspect.
4. Skill and training are more extensive than with some other methods.
5. It normally requires a coupling medium to promote the transfer of sound energy into the test specimen.

49. *What are five P's in welded joint testing?*

1. ***Process selection*** - The process must be right for the job.
2. ***Preparation*** - The joint configuration must be right and compatible with the welding process.
3. ***Procedures*** - The procedures must be spelled out in detail and followed religiously during welding.
4. ***Pretesting*** - Full-scale mockups or simulated specimens should be used to prove that the process and procedures give the desired standard of quality.
5. ***Personnel*** - Qualified people must be assigned to the job.

5.21. SOLVED QUESTIONS AND ANSWERS

1. Explain the different types welded joints with neat sketches.

   Refer chapter **5.1** in page **5.1**.

2. Write down the design procedure for longitudinal and transverse fillet weld joint design.

   Refer chapter **5.5** in page **5.7**.

3. What is an eccentric loaded welded joint? Describe the procedure for designing such a joint

   Refer chapter **5.8** in page **5.18**.

4. Write short notes on stress concentration factor that affects weld joint design.

   Refer chapter **5.9** in page **5.25**.

5. Discuss briefly about welding specification.

   Refer chapter **5.11** in page **5.26**.

6. Write short notes on weldability.

   Refer chapter **5.13** in page **5.56**.

7. Explain different welding processes for copper and its alloys.

   Refer chapter **5.15.1** in page **5.61**.

8. Describe the factors affecting weldability of copper alloys.

   Refer chapter **5.15.2** in page **5.62**.

9. Write short notes on filler metals used in welding copper alloys.

   Refer chapter **5.15.3** in page **5.62**.

10. Discuss the welability and general guidelines to weld stainless steel parts.

    Refer chapter **5.16** in page **5.62**.

11. Write short notes on various defects in welding with neat sketches.

    Refer chapter **5.17** in page **5.64**.

12. Write down the steps in testing welded joint by acid etch test.

    Refer chapter **5.18.1** in page **5.71**.

13. Explain the tensile test methodology to test the welded joints.

    Refer chapter **5.18.2** in page **5.72**.

14. What is bend test? What are types of bent tests commonly performed? Describe in details how different bend tests are performed on welded joints.

    Refer chapter **5.18.3** in page **5.75**.

15. Write short notes on nick bend test.

    Refer chapter **5.18.4** in page **5.77**.

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16. Describe the destructive testing procedure while testing the hardness of welded joints.

    Refer chapter **5.18.5** in page **5.79**.

17. Explain the fatigue test methodology to test the welded joints.

    Refer chapter **5.18.6** in page **5.82**.

18. Discuss the importance of visual inspection in testing welded joints.

    Refer chapter **5.19.1** in page **5.85**.

19. Enumerate the principle of performing magnetic particle inspection on welded joints. Also, list down the advantages and limitations.

    Refer chapter **5.1**...

20. Explain the steps involved in dye-penetrant inspection while inspecting the welded joints. What are the advantages and limitations of dye-penetrant inspection?

    Refer chapter **5.19.3** in page **5.90**.

21. Elaborately discuss the testing procedure in welded joints using radiographic inspection Also, list down the advantages and limitations.

    Refer chapter **5.19.4** in page **5.93**.

22. Describe the steps involved in inspecting the welded joints by ultrasonic inspection. What are the advantages and limitations of dye-penetrant inspection?

    Refer chapter **5.19.5** in page **5.95**.

23. Write short notes on selection of suitable NDT Method.

    Refer chapter **5.19.6** in page **5.98**.

5.22. Problems for Practice

1. A bracket shown in Figure 5.74 carries a load of 135 *kN*. Calculate the size of the weld if the allowable stress is not to exceed 70 N/mm^2.

2. Figure 5.75 shows a welded connection subjected to a force the member is 12.5 *mm* thick hot rolled steel and welded to the support using two 8 *mm* parallel fillet welds. Estimate the safe force *F* for a factor of safety as 1.8. Assume permissible stress to be 50 *MPa*.

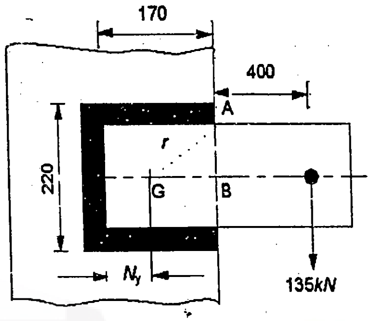

Figure 5.74

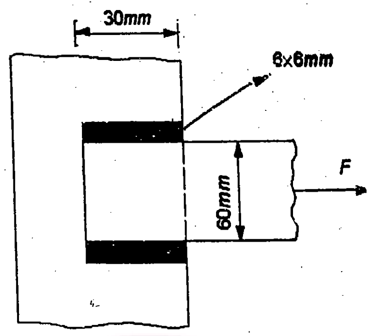

Figure 5.75

3. An eccentrically loaded plate is welded to a frame shown in Figure 5.76. Design the welded joint. If the tensile stress in the plate should not exceed 140N/mm^2 and that in weld is 70 N/mm^2.

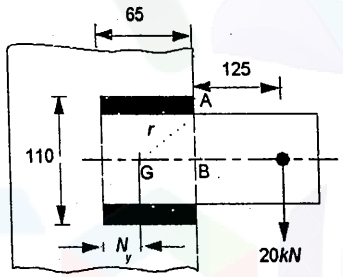

Figure 5.76

4. A plate 120 *mm* wide and 12.5 *mm* thick are to be welded to another plate by means of single transverse and double parallel fillet welds. Determine the length of weld run in each case if the joint is subjected to varying loads. The recommended design stress in tension is not to exceed 90 N/mm^2 and in shear 64 N/mm^2 for static loading.

5. A rectangular steel plate 100 *mm* wide is welded to a vertical plate to form a cantilever with an overlap of 50*mm* and an overhang of 150 *mm*. It carries a vertical downward load of 60 *kN* at free end. Fillet weld is done three sides of the plate for a permissible stress is 140 N/mm^2. Determine the size of the weld.

(Ans:- Size of the weld, $h = 20.23$ *mm*)

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6. Figure 5.77 shows a welded connection subjected to a force the member is 10*mm* thick hot rolled steel and welded to the support using two 6*mm* parallel fillet welds. Estimate the safe force *F* for a factor of safety of 2.8. Assume permissible stress to be 55 *MPa*.

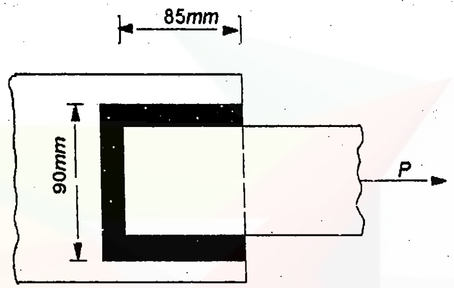

Figure 5.77 **(Ans:- *F* = 5000*N*)**

7. A bracket shown in Figure 5.78 is welded to a plate. The welds have the same size and the permissible force per *mm* of weld length is 1 *kN*. Calculate the lengths l_1 and l_2. The load *P* = 100 *kN*.

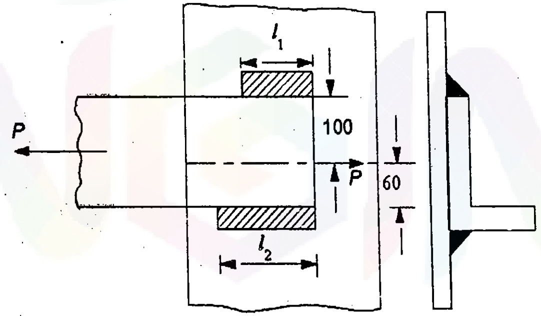

Figure 5.78

(Ans:- l_1 = 70.7*mm* & l_2 = 125.7*mm*)

END of Unit 5

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B.E/B.TECH. DEGREE EXAMINATION, MODEL QUESTION PAPER 1

Seventh Semester

MECHANCIAL ENGINEERING

ME 6008 – WELDING TECHNOLOGY

(Regulation 2013)

Time: Three hours **Maximum marks: 100**

(Use of approved design data book is permitted)

Answer ALL Questions

Part – A (10×2 = 20 marks)

1. ***What is the principle of oxy-acetylene gas welding?***

In oxy-acetylene gas welding, the edges of the metals to be welded are melted by using the heat obtained by burning a mixture of oxygen and acetylene gas. The gases are mixed in the required proportion in a welding torch which provides a control for the welding flame. The flame is produced at the tip of a welding torch. No pressure is applied during welding except pressure gas welding.

2. ***State any two limitations of submerged arc welding.***

   1. It is not suitable for welding works which is inclined and vertical.
   2. The welding zone is not seen. So, it is difficult to guide the electrode movement.
   3. The application is limited to straight seams and pipes and vessels.

3. ***What are the features of resistance welding?***

   (i) No flux such as solder is necessary. So, welded parts can be easily recycled.

   (ii) Easy operation as only pressing buttons facilitates process automation and it does not require trained skills unlike arc welding and gas welding.

   (iii) As this welding is performed efficiently in a short period of time, it is suited for a high-volume production of low-cost products.

   (iv) Since welding is done in short time duration, it gives less heat-affected area on workpieces by resulting a beautiful appearance with less indentation.

4. ***Write any two limitations of spot resistance welding.***

   1. It can create only localized joins which may not be particularly strong.
   2. To achieve small cost of building, the weld manufacture cost is not very high.
   3. The electrodes have to be able to reach both sides of the pieces of metal that are being joined together.

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4. Warping and a loss of fatigue strength can occur around the point where the metal has been spot welded.

5. ***What is meant by cold welding?***

Cold pressure welding is a form of solid phase welding which is unique because it is carried out at ambient temperature.

6. ***Differentiate between friction welding and inertia welding.***

S. No.	*Friction welding*	*Inertia welding*
1.	Power flows from electric motor.	Power flows from flywheel.
2.	Size of the motor limits the power.	Power is independent of the size of the motor.
3.	Heat is produced by sliding motion.	Heat is produced by intermolecular bonding.

7. ***Define atomic hydrogen welding.***

Atomic Hydrogen Welding (AHW) is a combination of electric arc and gas welding technique. It is a thermo-chemical arc welding process in which the workpieces are joined by heat obtained on passing a stream of hydrogen through an electric arc struck between two tungsten electrodes.

8. ***What do you infer about underwater welding?***

Underwater welding usually refers to the *wet welding technique* where there is no mechanical barrier that separates the welding arc from the water. It is also known as *submerged water arc welding*.

9. ***Define weldability.***

Weldability is also known as *joinability* of a material. It refers the ability to weld. It is defined as the capacity of a metal or combination of metals to be welded into a suitable structure, and for the resulting weld joint(s) to possess the required metallurgical properties to perform satisfactorily in intended service.

10. ***Write down any four advantages of radiographic test.***

1. It can be used to inspect virtually all materials.
2. Detects both surface and subsurface defects can be identified.
3. It has the ability to inspect complex shapes and multi-layered structures without disassembly.
4. Minimum part preparation is required.

Part – B (5×16 = 80 marks)

11. ***(a) (i) Discuss the principle involved in carbon arc welding with a neat sketch.***

Refer chapter **1.5** in page **1.15**.

(ii) Compare MIG and TIG welding processes.

Refer chapter **1.9.1** in page **1.40**.

Or

(b) Describe the process of electroslag welding with its advantages, limitations and applications.

Refer chapter **1.11** in page **1.47**.

12. ***(a) What is the working concept of Electric resistance welding? Explain in detail with its advantages and limitations.***

Refer chapter **2.1.2** in page **2.2**.

Or

(b) Write short notes on the following:

(i) Weldability in resistance welding.

Refer chapter **2.1.4** in page **2.7**.

(ii) Seam welding process.

Refer chapter **2.3** in page **2.19**.

(iii) Low-frequency electric resistance welding.

Refer chapter **2.8** in page **2.32**.

13. ***(a) (i) What are the process parameters involved in friction welding and explain in detail.***

Refer chapter **3.3.2** in page **3.10**.

(ii) Describe forge welding process with a neat sketch.

Refer chapter **3.7.2** in page **3.39**.

Or

(b) Discuss the various stages in diffusion welding with their neat sketches. Also mention the advantages and limitations of diffusion welding.

Refer chapter **3.3.1** in page **3.10**.

14. (a) (i) *Explain the method of laser beam welding with appropriate sketches.*

Refer chapter **4.4.4** in page 4.17.

(ii) *Write short notes on welding automation in nuclear sector*

Refer chapter **4.8** in page 4.42.

Or

(b) (i) *Describe the working of atomic hydrogen welding with neat sketches.*

Refer chapter **4.2.1** in page 4.7.

(ii) *Compare underwater welding over normal air welding.*

Refer chapter **4.6.6** in page 4.33.

15. (a) *A bracket shown in Figure Q-1 carries a load of 'P'. Calculate the value of P if the weld size is 15 mm and the allowable stress is not to exceed 80 N/mm².*

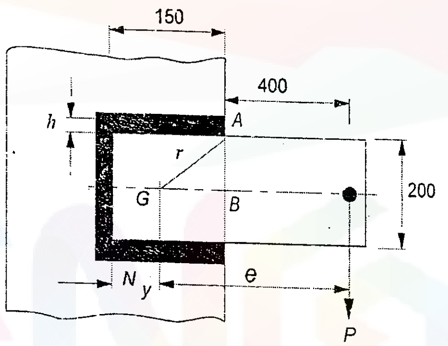

Figure Q-1

Same as **Problem 12** in Page 5.48.

Or

(b) *What is bend test? What are types of bent tests commonly performed? Describe in details how different bend tests are performed on welded joints.*

Refer chapter **5.18.3** in page 5.75.

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B.E/B.TECH. DEGREE EXAMINATION, MODEL QUESTION PAPER 2

Seventh Semester

MECHANCIAL ENGINEERING

ME 6008 – WELDING TECHNOLOGY

(Regulation 2013)

Time: Three hours **Maximum marks: 100**

Use of approved design data book is permitted.

Answer ALL Questions

Part – A (10×2 = 20 marks)

1. *Name the types of flames used in gas welding process.*

(i) Neutral flame,

(ii) Carburising flame, and

(iii) Oxidising flame.

2. *Mention the various functions of the TIG torch.*

- It holds the electrode tungsten.
- It delivers welding current to the tungsten via a welding power cable.
- It delivers shielding gas to TIG torch nozzle. The nozzle then directs the shielding gas to cover the weld pool protecting it from contamination from the surrounding air.
- It often will be the way of getting the welder control circuit to the operation, for example: On / Off power supply and / or amperage control.
- TIG torch can be water-cooled. Hoses in TIG lead will supply cooling water to the TIG torch head assembly.
- TIG torch length will allow a distance from TIG power source and workpiece.

3. *What is the principle involved in resistance welding?*

Resistance welding processes are pressure welding processes in which heavy current is passed for short time through the area of interface of metals to be joined with the application of pressure.

4. *State any two applications of seam welding.*

- It is used to make tin cans, leak proof tanks, automobile mufflers, gasoline tanks, drums, radiators, household utensils, transformers, refrigerators, evaporators and condensers, automobile bodies etc. It is also used for welding thin sheets.

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- Circumference weld is possible in rectangular or square or even in circular shapes.

5. ***Define solid state welding.***

Solid state welding is a group of welding processes which produces coalescence at temperature below the melting point of base materials being welded without the addition of brazing filler metal.

6. ***What do you infer about friction welding?***

Friction welding is a solid state welding process in which coalescence is achieved by frictional heat combined with pressure.

7. ***What is friction stir welding?***

Friction Stir Welding (FSW) is a solid state welding process in which a rotating tool is fed along the joint line between two workpieces. It is used to join two facing surfaces.

8. ***What are the applications of underwater welding?***

(i) Underwater welding is applied in marine applications and installation of offshore oil pipelines.

(ii) It is also used to apply weld repair on massive ships inside the water.

9. ***List down the minor factors which affect the weldability.***

(i) Filler metal
(ii) Surface conditions
(iii) Parent metal composition
(iv) Parent metal thickness
(v) Weld metal composition
(vi) Welding process
(vii) Welding procedure.

10. ***What are the commonly used nondestructive testing methods to examine finished welds?***

- Visual Inspection (VT)
- Dye-penetrant inspection or Liquid penetration inspection (LPI)
- Magnetic particle inspection (MPI)
- Radiographic inspection (RT)
- Ultrasonic inspection (UT).

Part – B (5×16 = 80 marks)

11. ***(a) (i) Describe with a neat sketch the components of oxyacetylene gas welding equipment.***

Refer chapter 1.4.4 in page 1.8.

(ii) Compare AC and DC welding machines.

Refer chapter 1.6.2 in page 1.21.

Or

(b) Describe MIG welding process with a neat sketch. What are the advantages and limitations of MIG welding over TIG welding?

Refer chapter 1.9 in page 1.37.

12. ***(a) (i) Explain the resistance spot welding process with a neat sketch.***

Refer chapter 2.2 in page 2.9.

(ii) Describe the working of flash butt welding process with a neat sketch.

Refer chapter 2.5.2 in page 2.26.

Or

(b) (i) With a neat sketch explain the working of upset welding process.

Refer chapter 2.5.1 in page 2.25.

(ii) Describe the working of high-frequency resistance welding process with its neat sketch.

Refer chapter 2.9 in page 2.32.

13. ***(a) (i) What are the process parameters involved in diffusion welding and explain in detail.***

Refer chapter 3.3.2 in page 3.10.

(ii) Discuss how explosive welding process is carried out.

Refer chapter 3.4 in page 3.16.

Or

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(b) Enumerate the working of ultrasonic welding with a neat sketch. What are the advantages, limitations and applications ultrasonic welding?

Refer chapter **3.9** in page **3.22**.

14. *(a) What is the principle of thermit welding with its advantages, limitations and applications? Explain with a neat sketch of the thermit welding arrangement.*

Refer chapter **4.1.3** in page **4.3**.

Or

(b) (i) Describe the working of wet underwater welding with a neat sketch.

Refer chapter **4.6.4** in page **4.29**.

(ii) Discuss the procedure involved in friction stir welding cycle.

Refer chapter **4.5.6** in page **4.25**.

15. *(a) (i) What is an eccentric loaded welded joint? Describe the procedure for designing such a joint.*

Refer chapter **5.8** in page **5.18**.

(ii) Write short notes on weldability.

Refer chapter **5.13** in page **5.56**.

Or

(b) (i) Explain the tensile test methodology to test the welded joints.

Refer chapter **5.18.2** in page **5.72**.

(ii) Explain the steps involved in dye-penetrant inspection while inspecting the welded joints.

Refer chapter **5.19.3** in page **5.90**.

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B.E/B.TECH. DEGREE EXAMINATION, MODEL QUESTION PAPER 3

Seventh Semester

MECHANCIAL ENGINEERING

ME 6008 – WELDING TECHNOLOGY

(Regulation 2013)

Time: Three hours **Maximum marks: 100**

Use of approved design data book is permitted.

Answer ALL Questions

Part – A (10×2 = 20 marks)

1. *What is the function of fluxes in welding?*

Fluxes are used in welding to prevent atmospheric reaction and to remove impurities.

2. *State any two limitations of submerged arc welding.*

1. It is not suitable for welding works which is inclined and vertical.
2. The welding zone is not seen. So, it is difficult to guide the electrode movement.
3. Operation is limited to some specific metals.
4. The application is limited to straight seams and pipes and vessels.

3. *What is the minimum distance maintained between two successive spot welds made by resistance welding? Why?*

The minimum distance of 150*mm* and maximum distance of 300 *mm* between two successive spot welds or the acceptable distance of 16 times of thickness of metal to be welded because the shunt current flowing through already formed weld spot reduces the efficiency of the welding process.

4. *What are the factors affecting welding energy in percussion welding?*

(i) Cross-sectional area of joint

(ii) Properties of work metal or metals

(iii) Depth to which metal is melted on workpieces.

5. *Define explosive welding.*

Explosive welding (EXW) is a solid state (solid-phase) welding process that uses a controlled application of large pressure generated by the detonation of applied explosives.

6. ***What are the materials welded by forge welding process?***

Many metals can be forge-welded such as high and low-carbon steels. Iron and hypoeutectic cast-irons can be forge-welded. Some aluminum alloys and copper-based alloys can also be forge-welded. Titanium alloys are commonly forge-welded.

7. ***Discuss the principle of Thermit welding.***

Thermit welding is a welding process utilizing heat generated by exothermic chemical reaction between components of the Thermit. The molten metal produced by the reaction acts as a filler material and joins the workpieces after solidification. The welding principle is the heat of the Thermit reaction used for welding in plastic state and mechanical pressure is applied for the joint.

8. ***What is meant by laser beam welding?***

Laser beam welding (LBW) is a welding process which produces coalescence of materials with the heat obtained from the application of a concentrated coherent light beam impinging upon the surfaces to be joined.

9. ***Mention some common methods of welding inspection based on destructive principles.***

1) Acid etch test
2) Tensile test
3) Bend test
4) Nick break test
5) Hardness test
6) Fatigue test.

10. ***Mention any two advantages and limitations of dye-penetrant test.***

Advantages:

1. It is highly sensitivity (small discontinuities can be detected).
2. Few material limitations (metallic and nonmetallic, magnetic and nonmagnetic, and conductive and nonconductive materials may be inspected).

Limitations:

1. Only materials with a relatively nonporous surface can be inspected.
2. Pre-cleaning is critical since contaminants can mask defects.

Part – B (5×16 = 80 marks)

11. ***(a) (i) Sketch the three types of flames in oxy-acetylene welding and state their characteristics.***

Refer chapter **1.4.5** in page **1.10**.

(ii) Compare shielded metal arc welding and gas welding.

Refer chapter **1.6.7** in page **1.27**.

Or

(b) Explain the working principle, types, advantages, limitations and applications of plasma arc welding with appropriate sketches.

Refer chapter **1.10** in page **1.42**.

12. ***(a) Describe the sequence of a resistance spot welding cycles with neat sketches.***

Refer chapter **2.2.2** in page **2.13**.

Or

(b) (i) Enumerate the principle involved in projection welding.

Refer chapter **2.4** in page **2.22**.

(ii) Explain percussion welding process.

Refer chapter **2.6** in page **2.28**.

13. ***(a) (i) Write short notes on welding parameters in ultrasonic welding.***

Refer chapter **3.5.4** in page **3.28**.

(ii) Explain the principle of roll welding with a neat sketch.

Refer chapter **3.8** in page **3.41**.

Or

(b) (i) What is friction welding? Give their advantages and limitations.

Refer chapter **3.6** in page **3.32**.

(ii) Enumerate the principle of hot pressure welding with a neat sketch.

Refer chapter **3.9** in page **3.43**.

14. *(a) Explain the principle of operation, advantages and limitations of electron beam welding.*

Refer chapter **4.3.1** in page **4.9** for operation and chapter **4.3.3** in page **4.79** for advantaged and limitations.

Or

(b) (i) Describe the working of dry underwater welding with a neat sketch.

Refer chapter **4.6.5** in page **4.31**.

(ii) Discuss the welding automation in surface transport vehicles.

Refer chapter **4.9** in page **4.44**.

15. *(a) (i) A plate 100 mm wide and 12.5 mm thick is to be welded to another plate by means of single transverse and double parallel fillet welds. Determine the length of weld run in each case if the joint is subjected to varying loads. The recommended design stress in tension is not to exceed 70 N/mm² and in shear 56 N/mm² for static loading.*

Same as **Problem 4** in page **5.32**.

(ii) Write down the steps in testing welded joint by acid etch test.

Refer chapter **5.18.1** in page **5.71**.

Or

(b) (i) Elaborately discuss the radiographic inspection of welded joints with suitable sketches. Also, list down its advantages and limitations.

Refer chapter **5.19.4** in page **5.93**.

(ii) Enumerate the principle of performing magnetic particle inspection on welded joints.

Refer chapter **5.19.2** in page **5.88**.

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