

Mechanical Engineering Deptt.

4<sup>th</sup> Semester

Production Engineering I.

unit III (welding processes)

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## INTRODUCTION TO WELDING PROCESSES

Welding is a material joining process used in making welds, and a weld is localised coalescence of metals or non-metals produced either by heating the material to suitable temperature with or without application of pressure and with or without the use of filler material. We can classify the various welding processes in number of ways.

Welding is a metallurgical fusion process. Here, the interface of the two parts to be joined is brought to a temperature above the melting point and then, allowed to solidify, so that a permanent joining takes place. Because of the permanent nature of joint, and strength being equal to or something greater than that of parent metal, make welding one of the most extensively used fabrication method. Welding is not only used for making structures but also for repair work such as the joining of broken castings. Products obtained by the process of welding are called weldments.

Welding process consists of a technique of joining metals by heating them locally to semisolid state. In this

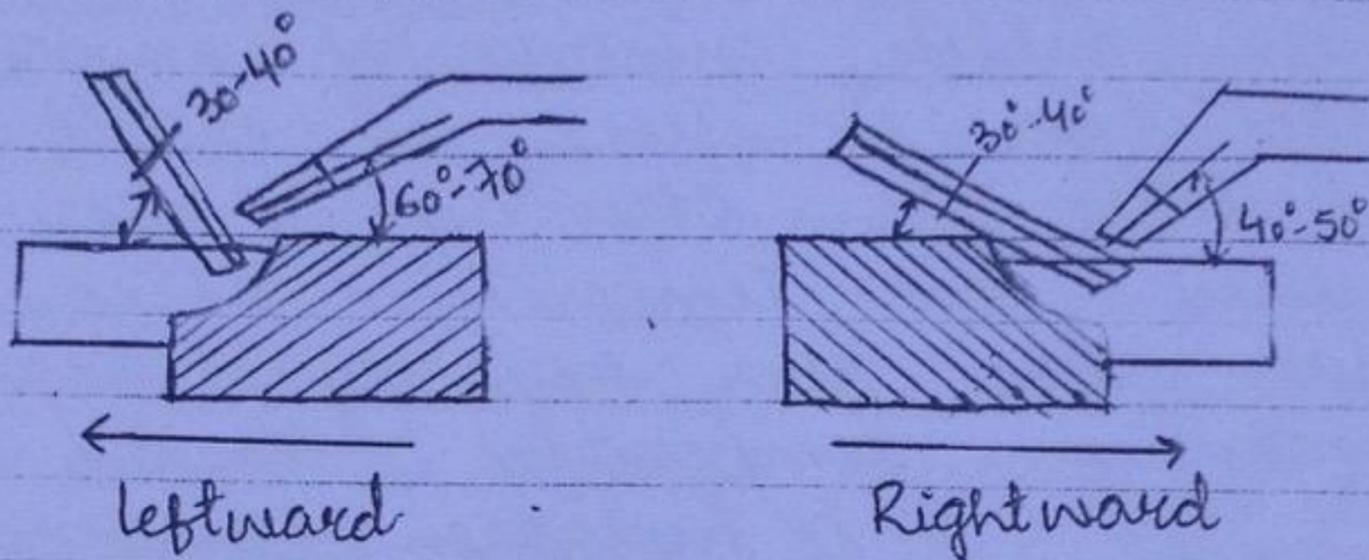
process of joining two metal piece take place resulting in the necessary diffusion of the atoms of the welded pieces take place resulting in the necessary diffusion of the atoms of the welded pieces into the joint (weld) region.

Welding is used abundantly for making permanent joints and is used widely in the manufacturing of automobile bodies, aircraft, frames, railway wagons, machine frames, structural works, tanks, furniture, boilers, general repair work and ship building etc.

## WELDING TECHNIQUES

1. Back-hand welding (Rightward welding): The backhand welding technique means the torch is positioned usually at an angle of 40-50 degrees so that the wire is feeding opposite to the wire direction of arc travel. Filler metal is being fed into the weld metal previously deposited. Generally backhand technique yields a more stable arc and less spatter on the workpiece.
2. Forehand welding (leftward welding): The forehand

Welding technique mean the torch is angled usually at 60-70 degrees so that the electrode wire is fed in the same direction as arc travel. Now the filler metal is being deposited, for the most part directly on the substrate.



### GAS WELDING:-

It is a fusion (non-pressure) welding process. Gas welding (commonly called oxy-fuel welding) is the process that uses fuel gases and oxygen to weld metals, respectively.

It derives the heat from the combustion of a fuel gas such as acetylene in combination with oxygen. The process is a fusion-welding process wherein the joint is completely melted to obtain the fusion. The heat produced by the

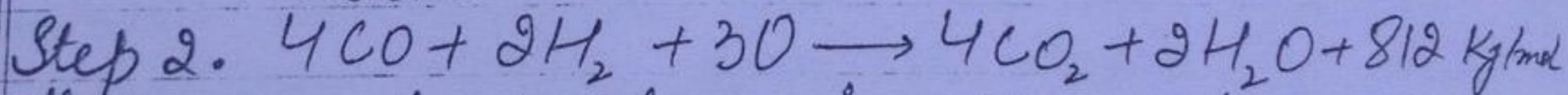
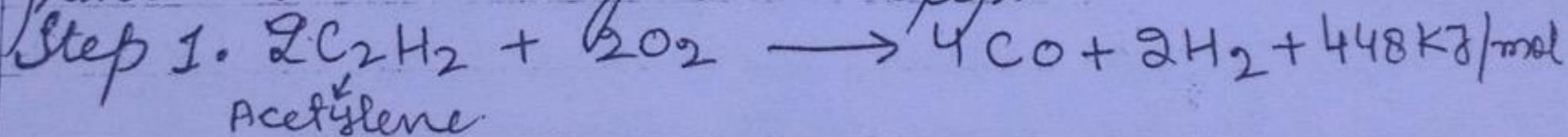
the combustion of gas is sufficient to melt any metal. The highest temperature which can be produced by this flame is  $3100^{\circ}\text{C} - 3200^{\circ}\text{C}$ . The gas welding process in which mixture of oxygen and acetylene is used is called oxyacetylene welding. The other gases may also be used, but temperature obtained is lower than the oxyacetylene flame. The maximum temperature obtained by:

Oxy-hydrogen flame	$2400^{\circ}\text{C}$
Oxy-propane flame	$2200^{\circ}\text{C}$
air-acetylene flame	$2400^{\circ}\text{C}$
air-propane flame	$1750^{\circ}\text{C}$

The oxy-acetylene welding is widely used.

### Principle of operation.

The combustion of gas mixture takes place in mainly two steps

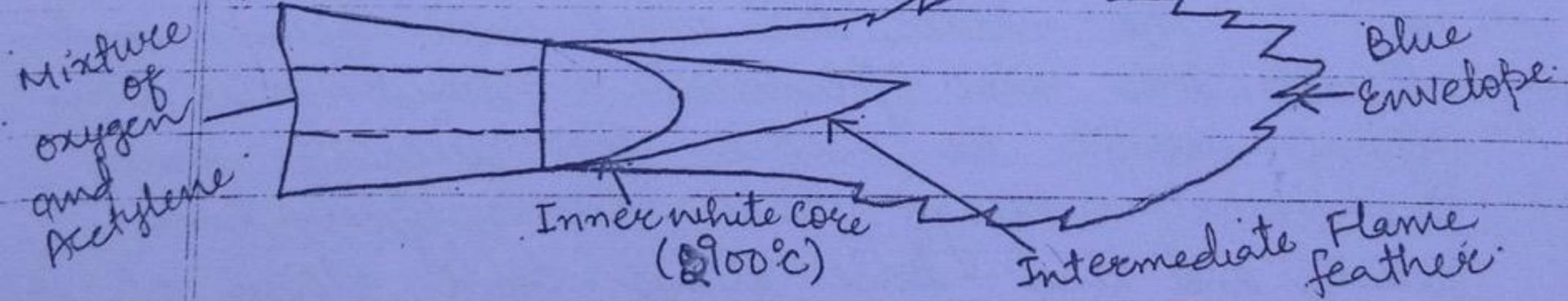


The max temperature is observed near the end of the inner cone, where the first stage of combustion is completed. The outer envelop of the flame serves to preheat the metal. The chemical action

Of the flame is produced oxyacetylene flame can be varied by changing the ratio of the volume of oxygen to acetylene.

### Types of gas welding flames:

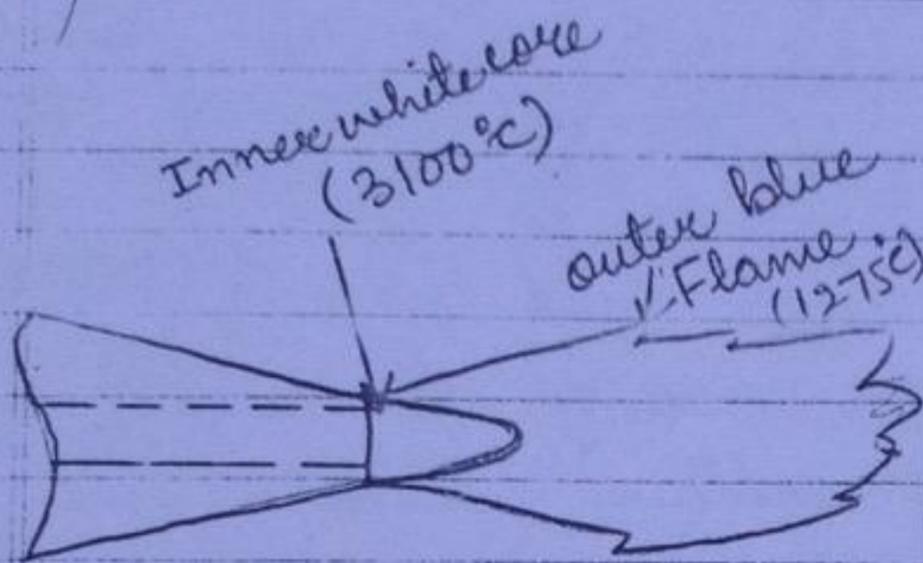
1. Carburizing flame: When acetylene gas is burnt in air, it produces a yellow sooty flame, which is not enough for welding applications. Hence when oxygen is turned on, flame immediately changes into a long white inner area (Feather) surrounded by a transparent blue envelope is called carburizing flame. The carburizing flame is not suggested for general use. However, since this flame produces a strong reduction reducing atmosphere in the welding zone, it is useful for those materials, which are readily oxidised, for example, oxygen-free copper alloys. It is also used for high carbon steels, cast iron and hard surfacing with high-speed steel and cemented carbides. These flames are used for hardening the surfaces of metal.



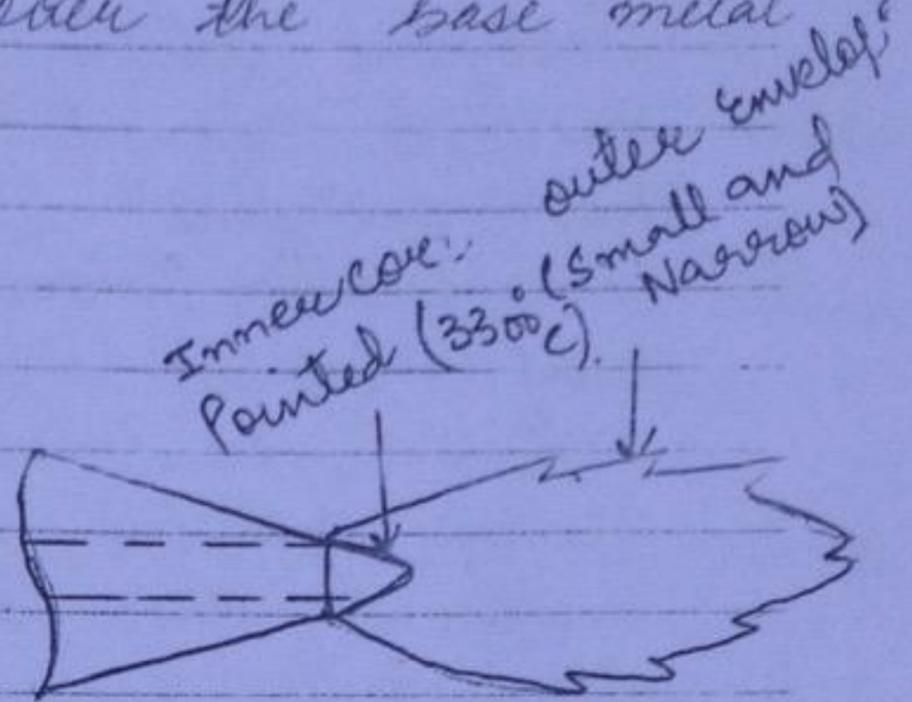
Neutral flame: A certain amount of oxygen is required for complete combustion of fuel gases. When the oxygen supply varies, the flame appearance obtained would also vary. The complete combustion, called neutral flame, all the acetylene present is completely burned and thus all the available heat in the acetylene is released. Thus, this is the most desirable flame to be used in oxy-acetylene welding. These flames are used in general for welding steels, aluminium, copper and cast iron.

Oxidizing flame: When oxygen is in excess, it is called the oxidizing flame. The flame is similar to the neutral flames with the exception that the inner white cone is somewhat small, giving rise to higher tip temperature ( $3300^{\circ}\text{C}$ ). There is an excess amount of oxygen present in the flame, which badly oxidises the weld metal. Because of the burning of the metal, the weld pool foams and spatters. This also produces a loud noise. This flame would be useful for welding some nonferrous alloys such as copper-base alloys and zinc-base alloys. Some alloys of iron such as cast iron and manganese steel are

also better welded by an oxidising flame. The presence of excess oxygen in the oxidising flame causes an oxide film to form quickly which provides a protective cover over the base metal metal.



Neutral Flame



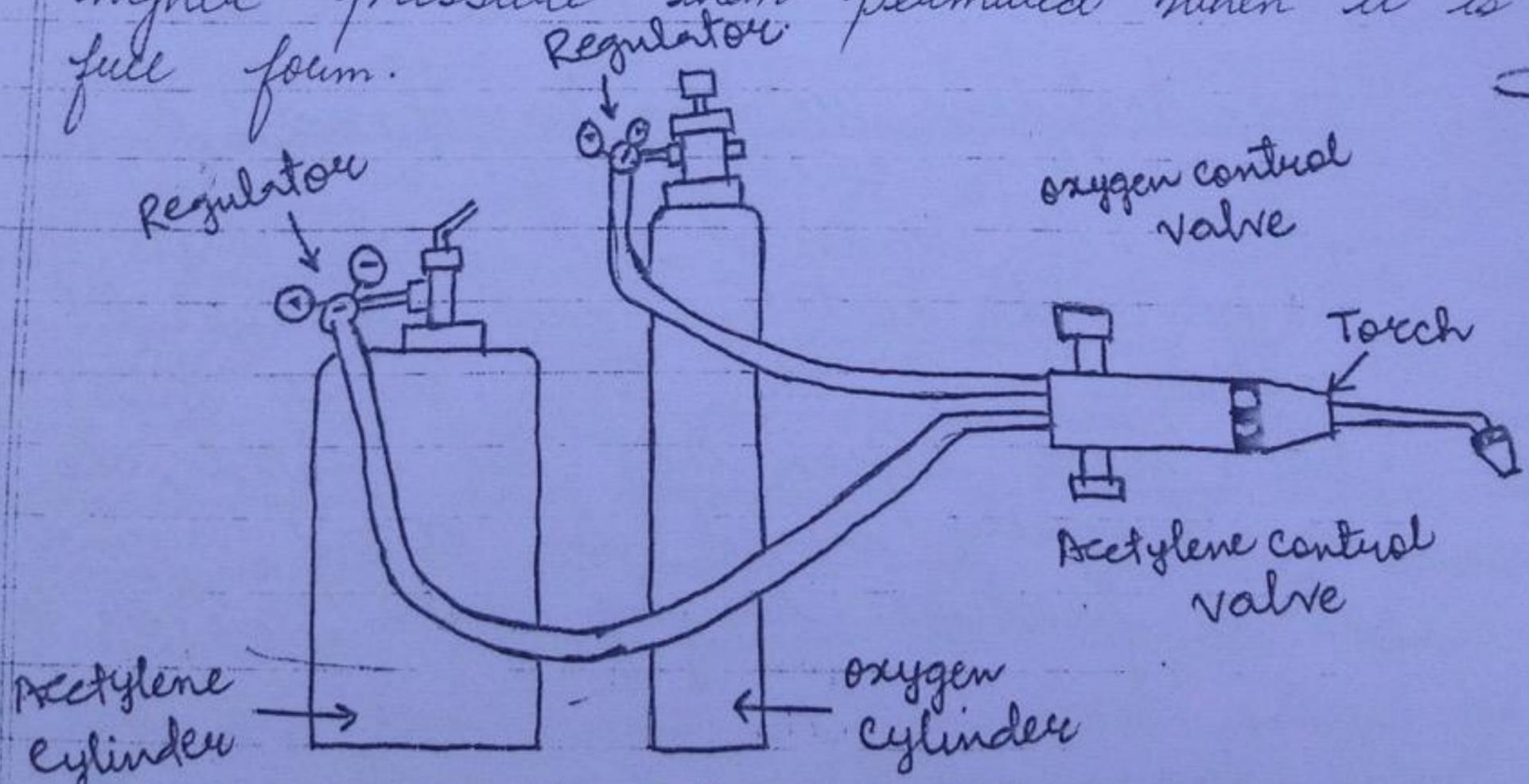
Oxidizing Flame

Oxy-acetylene welding Equipment: A typical oxy-acetylene welding outfit is shown in figure. It contains the supply units for oxygen and acetylene with associated with regulators and the torch, which mixes the two gases before they are ignited. The oxygen is normally stored in strong cylinders at a pressure ranging from 13.8 MPa to 18.2 MPa.

Acetylene is normally made available in the following two forms:

1. Acetylene storage cylinder
2. Acetylene generator

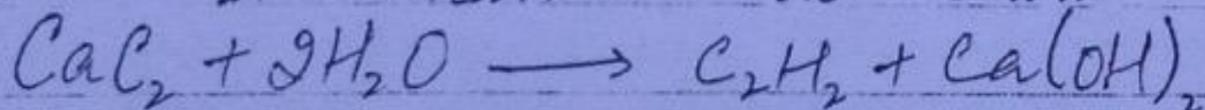
Free acetylene is highly explosive, if stored at a pressure more than 200 KPa, where it becomes very unstable and is likely to explode. Hence, acetylene needs to be carefully stored in a strong cylinder, filled with 80 to 85% porous material such as calcium silicate and then filled with acetone which can absorb upto 420 times its volume of acetylene at a pressure of 1.75 MPa. It is expected that the acetylene molecules fit in b/w the acetone molecules. This helps in storing acetylene at a much higher pressure than permitted when it is in free form.



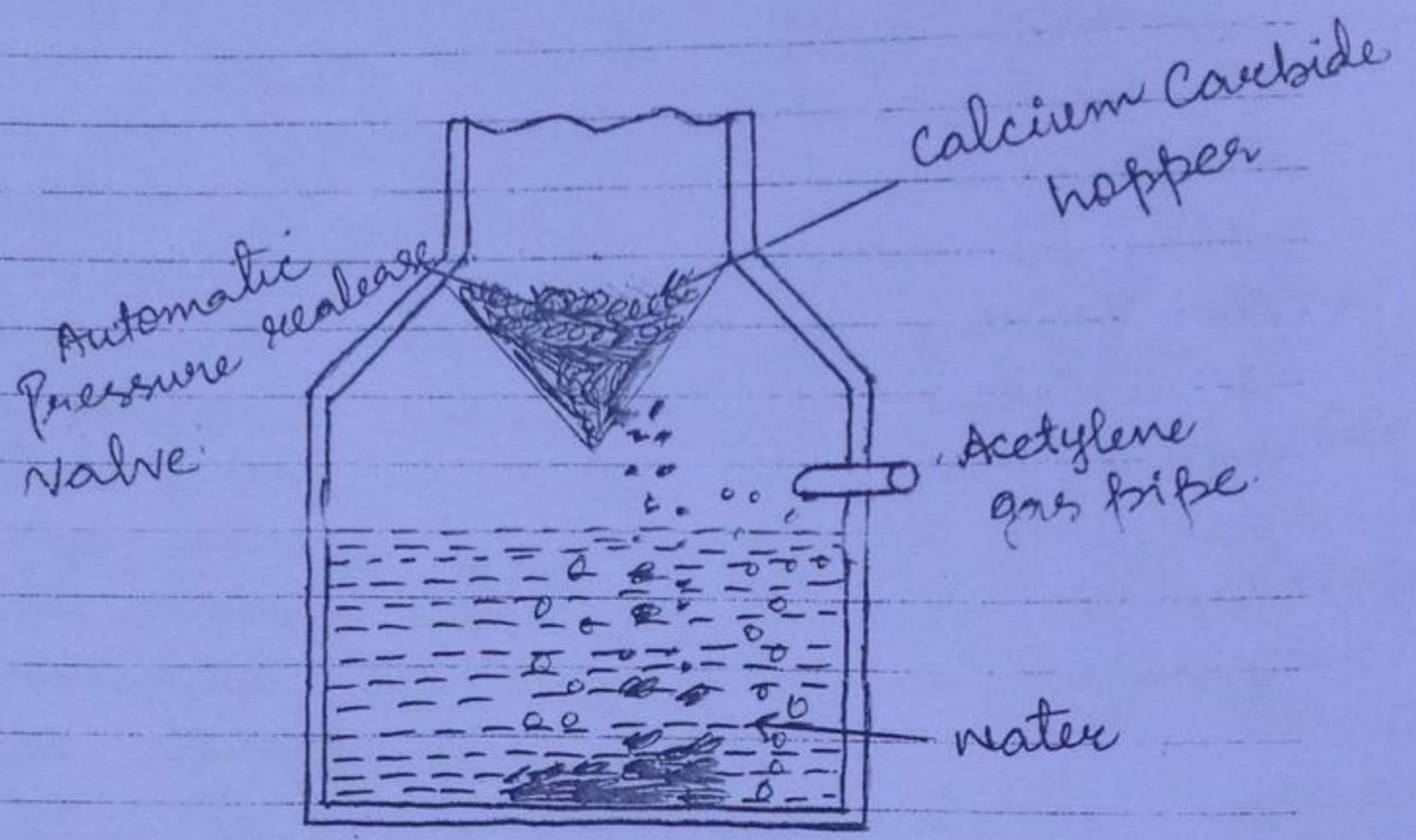
Oxy. Acetylene welding outfit

Acetylene would be released from acetone at a slow rate and thus would not form any pockets of high pressure acetylene. The rate of release depends on the temperature of the gas. Hence, the rate of consumption of acetylene should be under the rate of release which is normally about one-seventh of the capacity of the cylinder per hour. However, if acetylene is drawn at a rapid rate, acetone may also come out along with the acetylene. The presence of acetone in the flame would give it a purple colour. It is not desirable since it reduces the flame temperature.

It is also possible to have an acetylene generator in a place of an acetylene cylinder. Acetylene is normally produced by a reaction between calcium carbide and water which is instantaneous as shown below

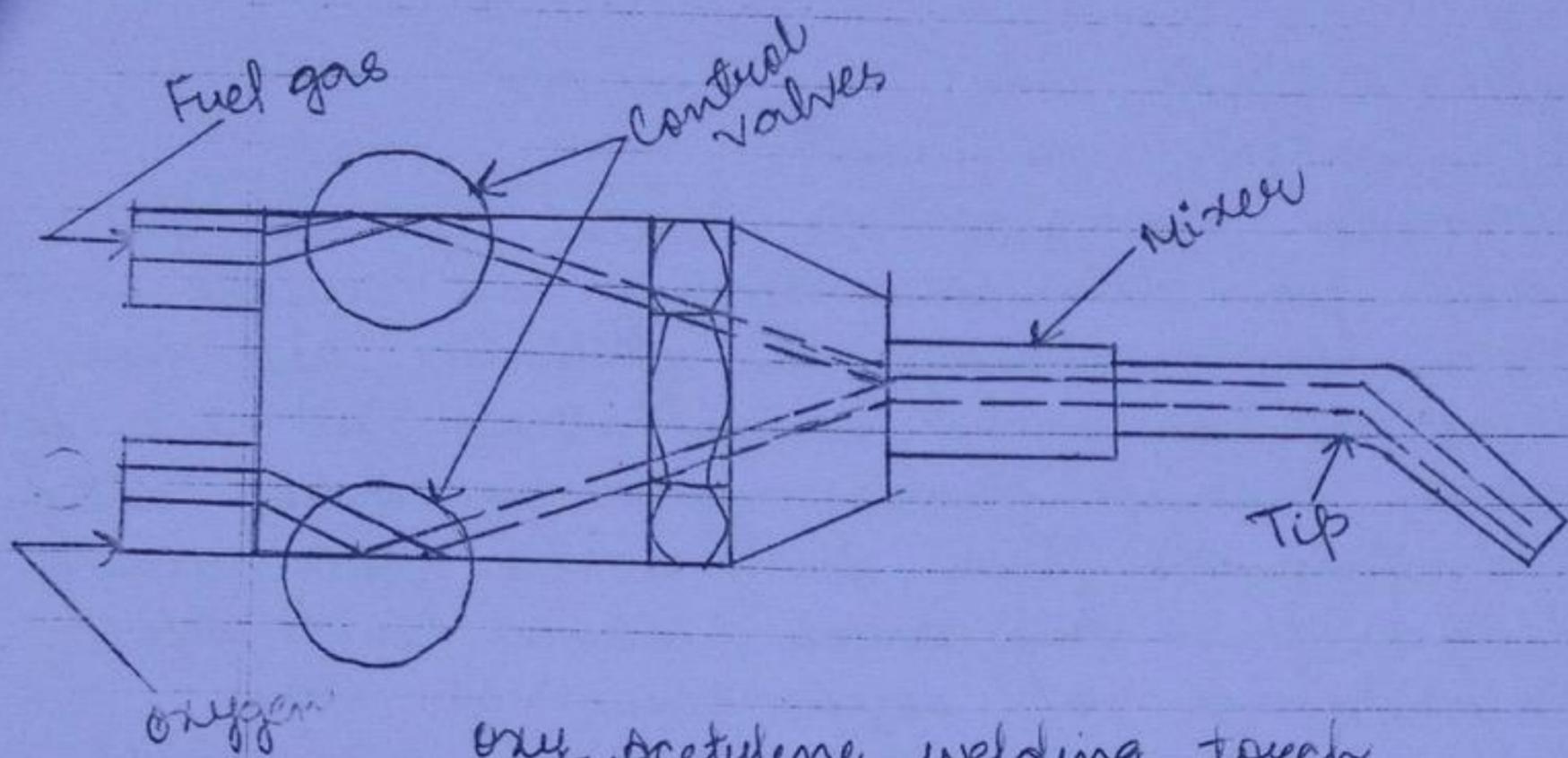


A schematic cutaway view of the acetylene generator is shown in figure. It consists of a cylinder, which is partially filled by water. The calcium carbide is stored in a hopper near the top of the generator. A pressure regulated valve controls the flow of carbide into water, depending on the pressure of the acetylene



Acetylene Generator

in the generator. The acetylene is taken out through a gas pipe as shown in figure. The generator should be permitted to produce acetylene to a safe pressure of 100 KPa. The oxygen and acetylene from the two cylinders are brought through separate pipes to the welding torch as shown in figure. In the torch, the two gases are mixed and then flowed out through the nozzle at the torch tip.



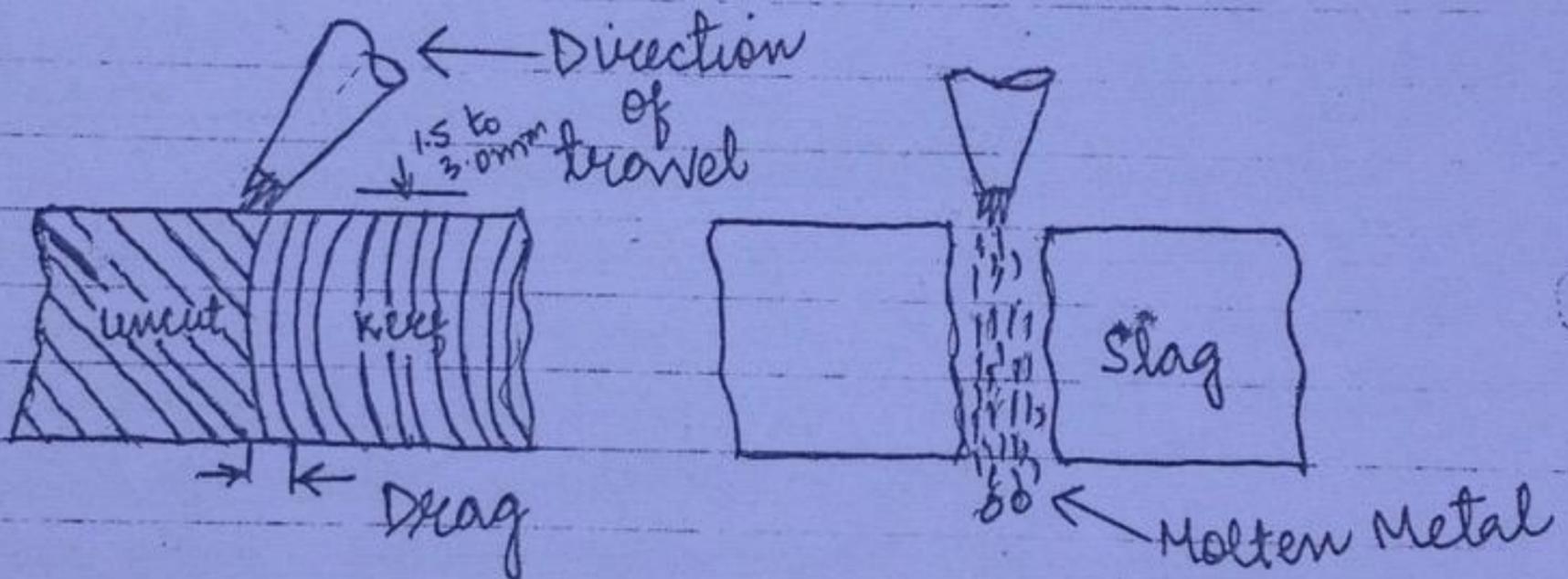
Oxy-acetylene welding torch

Gas cutting: - For cutting metallic plates, the general purpose shears, are used. These are useful only for straight line cuts and also upto a thickness of 40mm. For thicker plates if when the cut is to be made along specified contour, shearing can't be used. To this end oxy-fuel gas cutting is used. plates upto a thickness of 2m can be cut with special precautions or methods.

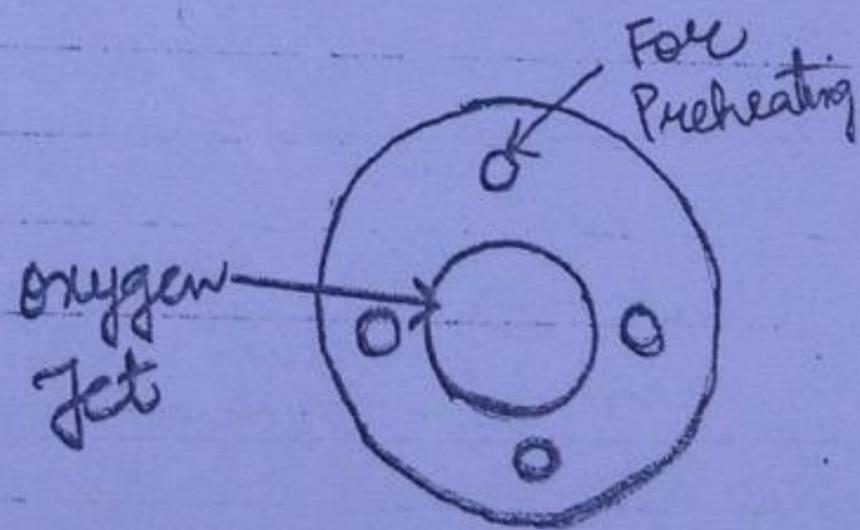
Oxy-acetylene gas cutting method is used to cut the metal nowadays.

Oxygen has a strong affinity for iron & steel at elevated temperature. Oxygen forms iron oxide with iron which has low melting temperature. At high temperature,

It melts out and the metal is cut. The touch for the flame cutting has several small holes for reheating the steel to red heat. There is a main central hole in the touch which carries pure oxygen for cutting action. The preheat flame is just like the welding flame. Thus the touch carries two separate passages of oxygen; one for the supplying oxygen to burn with oxygen to form the preheating flame (through small holes) and the other placed centrally in the nozzle to provide the

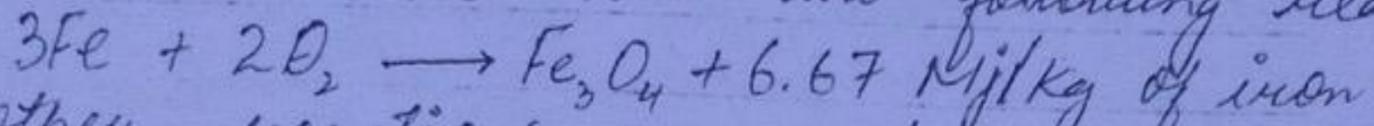


Positioning of cutting torch in oxy-fuel gas cutting

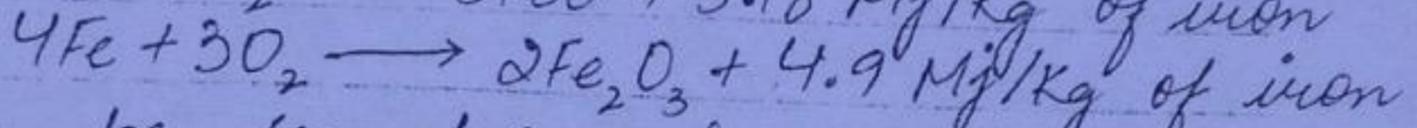
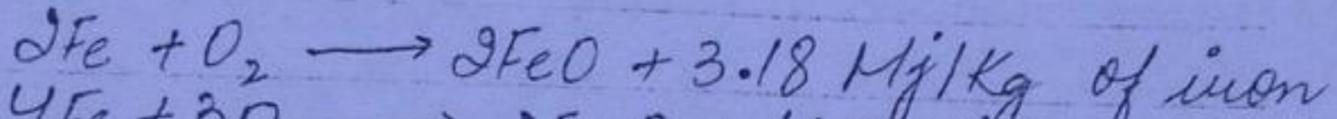


The required jet for oxidation. These passages are known as preheating oxygen passage and cutting oxygen passage.

After the steel is heated to its kindling temperature, which is about  $870^{\circ}\text{C}$  (when it is cherry red colour), it gets readily combined with oxygen giving iron oxide with the following reaction



The other reactions may also take place as follows:



As can be seen from above, all these reactions are exothermic in nature and as such would provide a good amount of heat to preheat the steel. But this heating may not be sufficient to bring the steel to its kindling temperature, & hence preheating flames may have to be continued at somewhat lower rate. The heat generated causes the metal to melt and get blown away by the oxygen pressure. In fact, about 30 to 40% of the metal in the kerf is simply blown away, while the rest is oxidised.

To start the cutting operation, the preheating flames are adjusted properly.

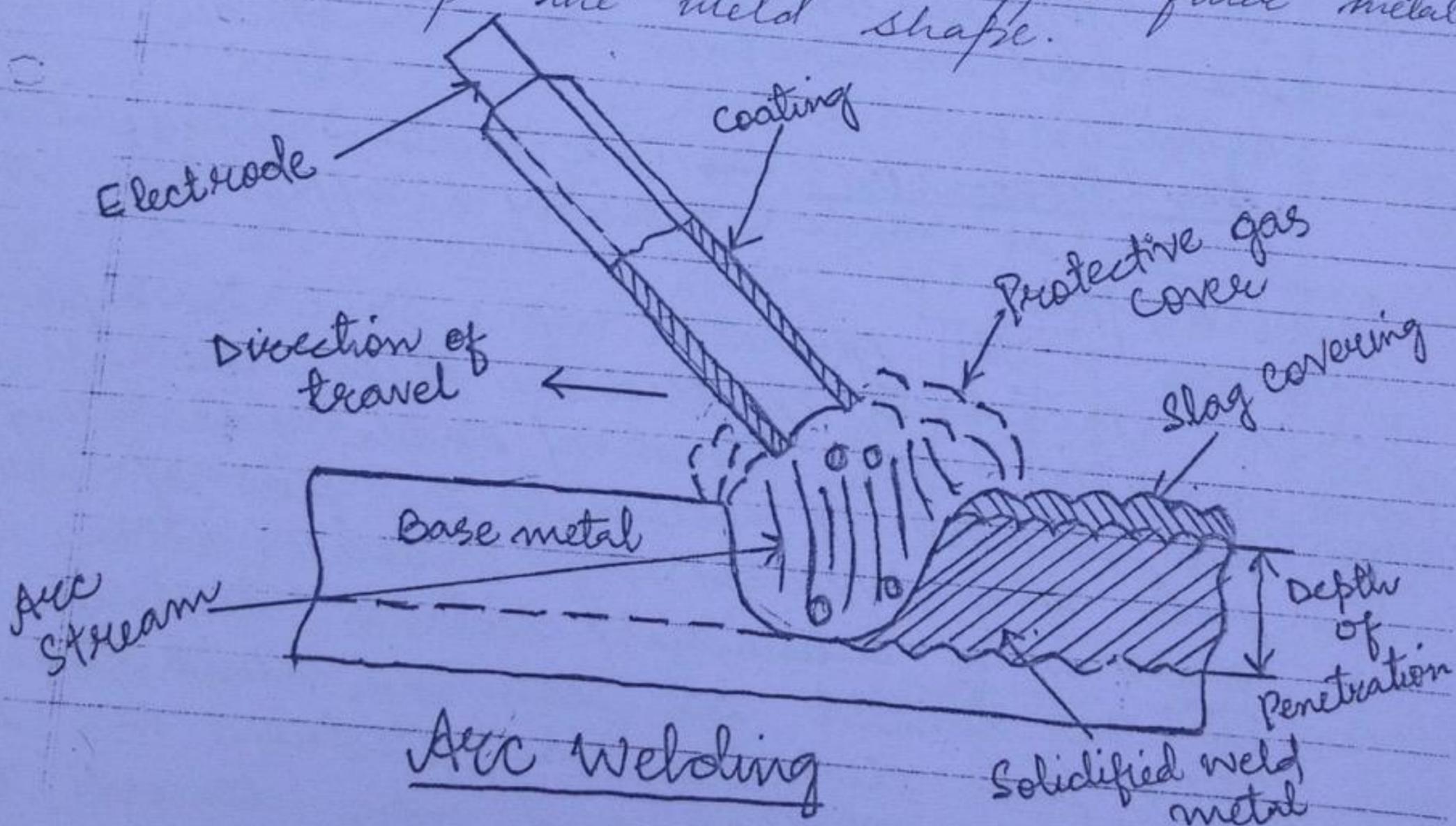
to neutral flame. The torch should be positioned above the metal plate at a distance of about 1.5 to 3.0 mm. After the plate has reached to the red hot temperature, the operator should release the oxygen jet to start the cutting. The high pressure oxygen jet impinge on red hot plate, it form iron oxide and thus remove the metal from there. Since only the metal in the direct path of the oxygen stream is oxidised or melted, therefore a narrow path with fairly smooth and parallel sides (known as kerf) is obtained.

Cutting cast iron is more difficult by this method, since its melting temperature is lower than that of iron oxide. For cutting ~~iron~~ cast iron, a carburising pre-heating flame should be adjusted and the nozzle is kept at a comparatively greater distance. The cast iron needs a relatively longer preheating than steel before actual cutting starts.

Arc Welding: Arc welding is a type of welding that uses a welding power supply to create an electric arc between an electrode and the base material to melt the metal at their welding point. They can

use either direct (DC) or alternating (AC) current, and even consumable or non-consumable electrodes.

Principle of operation: Arc welding provides the consistency of joining two metals by melting them with an arc generated between a coated-metal electrode and the base metal. The temperature produced by the arc can reach as high as  $10000^{\circ}\text{F}$ . The energy produced by the arc is provided by a power source that generates either direct or alternating current. The electrodes that carry the current produce a gas that protects the arc from the outer atmosphere and supplies filler metal to develop the weld shape.



The arc welding is performed with the heat of an electric arc that is maintained between the end of a coated metal electrode and the work piece. The heat produced by the arc melts the base metal, the electrode core rod, and the coating. As the molten metal droplets are transferred across the arc and into the molten weld puddle, they are shielded from the atmosphere by the gases generated from the decomposition of the flux coating. The molten slag floats to the top of the weld puddle where it protects the weld metal from the atmosphere during solidification.

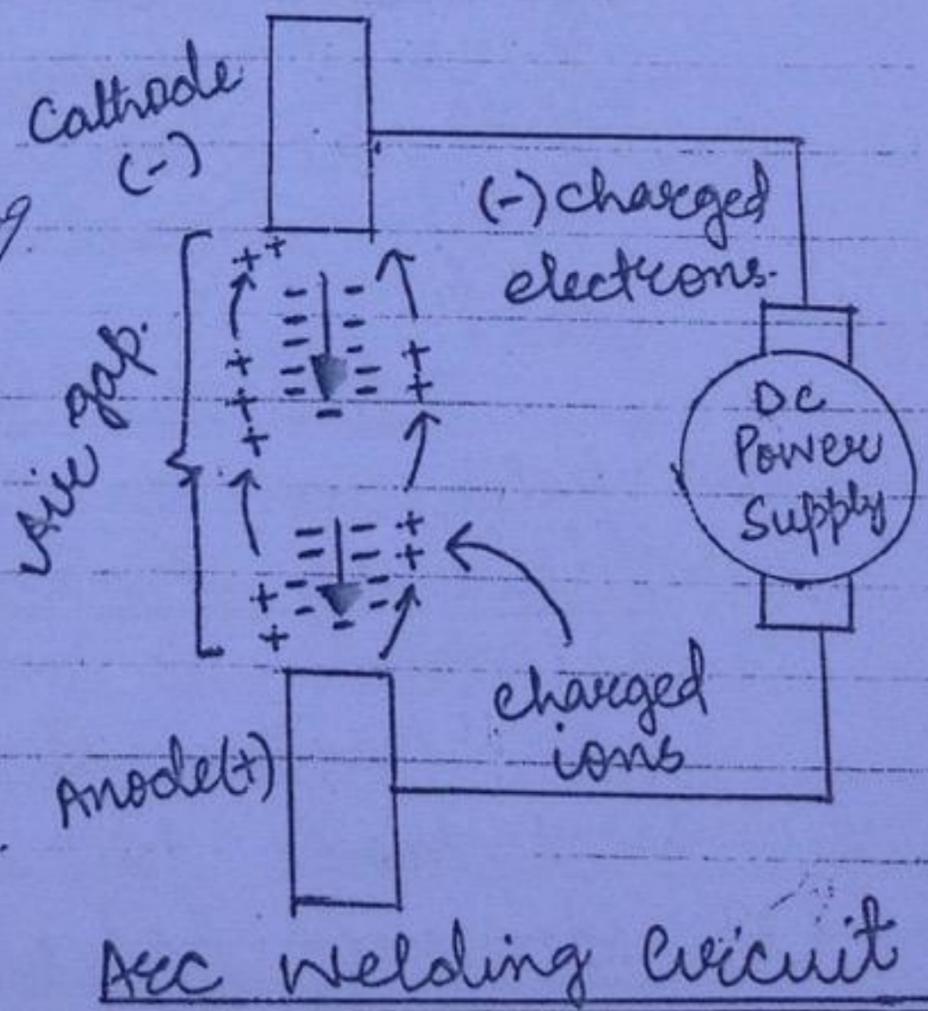
Arc Generation : The arc column is generated between an anode (+ve pole of d.c supply) and cathode (-ve pole)

The generation of arc can be explained on the basis of electrons theory. The arc is generated b/w cathode & anode when they are touched to establish the flow of current and then separated by a small distance. An arc is a substantial electrical discharge through the ionised gas column called plasma b/w two electrodes. The electrons are liberated from the cathode and move towards the anode.

The electrons have small mass. This amount of negatively charged mass is accelerated away from cathode to the positive pole or the anode. When these electrons strike at high velocity at anode, large amount of heat is generated. The path of negatively charged mass is generally in the interior of arc column, which is better portion of arc column. Also when the electrons are moving through the air gap between the electrodes, they collide with the ions in the ionised gas column b/w the electrodes. The positively charged ions, moving from the anode and impinging on the cathode, liberate heat.

There are three ~~streams~~ areas of arc stream,  
 (i) Cathode area (ii) Plasma area (iii) Anode area.

About 65 to 75% of total heat is liberated at the anode by striking electrons, so out of these three, the anode area is the high heat area. The plasma area is heated mainly as a result of atomic collision of few electrons and many ions.



that are passing through the ionised gas column. The cathode or negative pole is subjected mainly to ionic bombardment, which produces medium heat in the arc column. Approximately two third of the energy released in the arc column system is always at the anode or the positive pole in all d.c. systems.

When d.c. power is used, the heat in the arc column is generally equalised between anode and the cathode areas, so the area of medium heat is the plasma area.

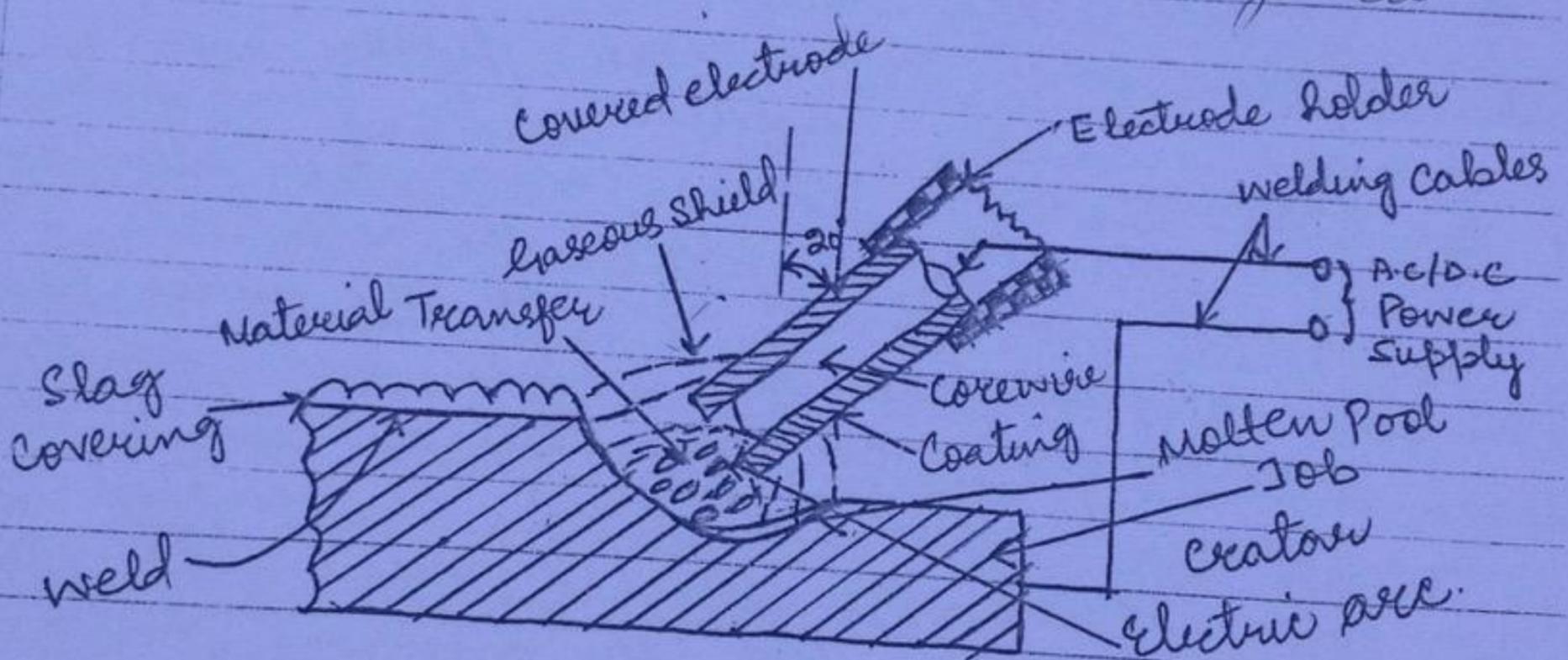
Effect of polarity: Polarity is the direction of flow of current in a circuit. Since current flows in one direction only in a d.c. arc welding, the polarity becomes a very important factor in welding operations.

In case of d.c. welding, two types of polarities are possible:

- (a) Straight polarity: In straight polarity, the electrode is negative and the work piece is positive; the electrons flow from the electrode to the work piece.
- (b) Reversed polarity: In reversed polarity, the electrode is positive and the work piece negative.

The electrons flow from the work piece to the electrode.

Shielded metal arc welding (SMAW) : It is a manual arc welding process that uses a consumable electrode coated in flux to lay the weld. An electric circuit current, in the form of either alternating current or direct current from a welding power supply is used to form an electric arc between the electrode and the metals to be joined.



### Shielded Metal arc welding

In figure, it is clearly shown that in order to strike the electric arc, the electrode is brought into contact with the work piece by a very light touch with the electrode to the base metal then

is pulled back slightly. This initiates the arc and thus the melting point of the work piece and the consumable electrode, and causes droplets of the electrode to be passed from the electrode to the weld pool. As the electrode melts, the flux covering disintegrates, giving off shielding gases that protect the weld area from oxygen and other atmospheric gases.

In addition, the flux provides molten slag which covers the filler metal as it travels from the electrode to the weld pool. Once part of the weld pool, the slag floats to the surface and protects the weld from contamination as it solidifies. Once hardened, it must be chipped away to reveal the finished weld. As welding progresses and the electrode melts, the welder must periodically stop welding to remove the remaining electrode stub and insert a new electrode into the electrode holder. This activity, combined with chipping away the slag, reduces the amount of time that the welder can spend laying the welding, making SMAW one of the least efficient welding processes. In general, the operation factor or the percentage of the

12

operator's time spent laying weld, is approximately 25%.

The actual welding technique utilised depends on the electrode, the composition of the work piece, and the position of the joint being welded. The choice of electrode and welding position also determine the welding speed. Flat welds require the least operator skill, and can be done with electrodes that melt quickly but solidify slowly. This permits higher welding speed. Sloped, vertical or upside-down welding requires more operator skill. It often necessitates the use of an electrode that solidify quickly to permit the molten metal from flowing out of the weld pool. However, this generally means that the electrode melts less quickly, thus increasing the time required to lay the weld.

Gas <sup>Metal</sup> arc welding (GMAW): Metal inert gas (MIG) arc welding, more appropriately called as Gas-Metal Arc Welding (GMAW), utilises a consumable electrode and hence, the term 'metal' appears in the title. There are other gas shielded arc-welding processes utilising the consumable electrodes, such as flux-cored arc-welding (FCAW), all of which can be

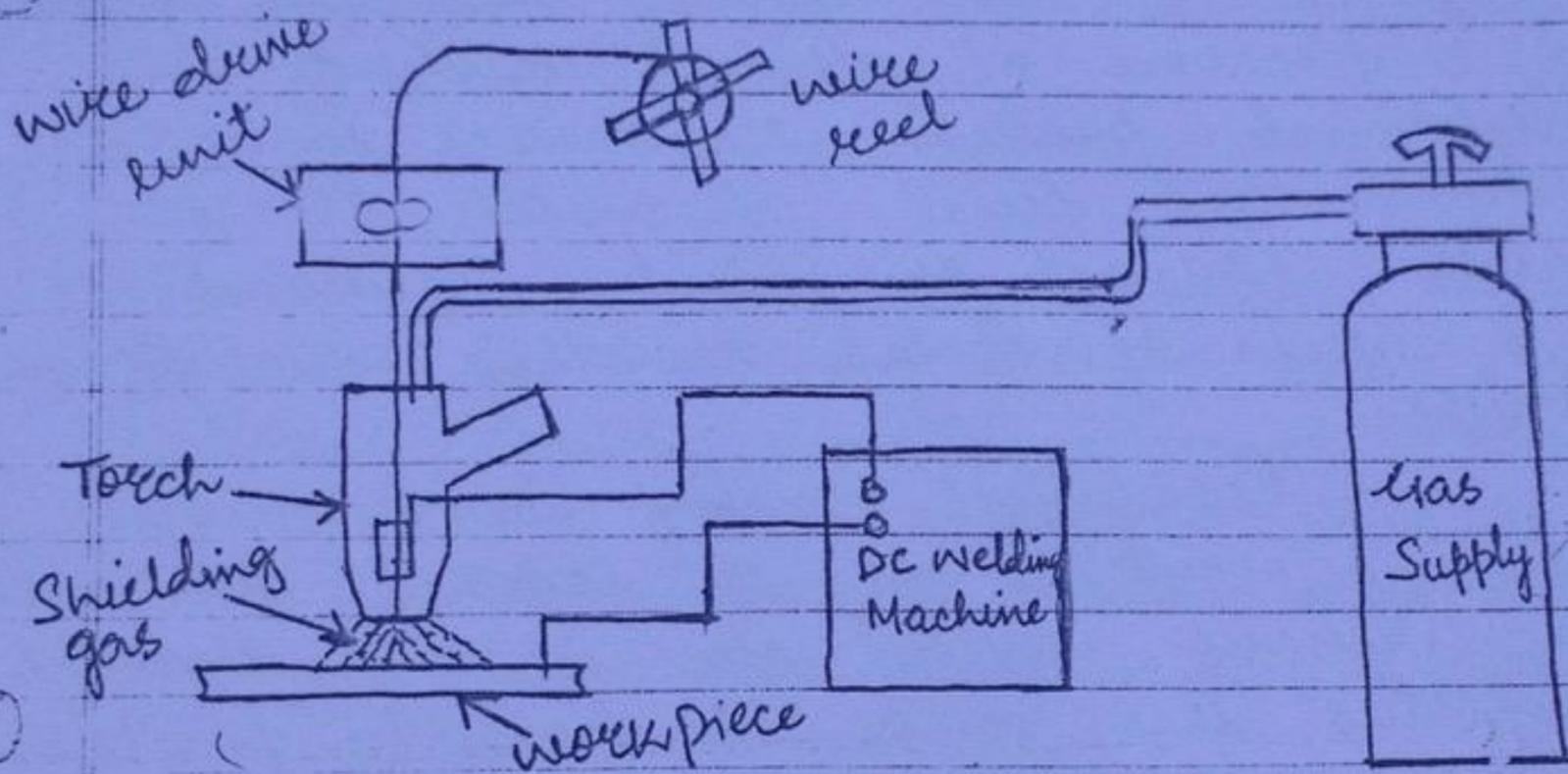
22

termed under MIG. Though gas tungsten arc welding (GTAW or TIG) can be used to weld all types of metals, it is more suitable for thin sheets. When thicker sheet are to be welded, the filler metal requirement makes GTAW difficult to use. In this situation, the GMAW comes handy.

The typical set-up for GMAW (or MIG) process is shown in figure. The consumable electrode is in the form of a wire reel, which is fed at a constant rate, through the feed rollers. The welding torch is connected to the gas supply cylinder, which provides the necessary inert gas. The electrode of the workpiece are connected to the welding power supply. The power supplies are always of the constant-voltage type only. The current from the welding machine is changed by the rate of feeding of the electrode wire.

Normally, dc arc welded machine are used for GMAW with electrode positive (DCEP). The DCEP increases the metal deposition rate and also provide for a stable arc and smooth electrode metal transfer. With DCEN, the arc becomes highly

unstable and also results in a large spatter. But special electrodes metal transfer having calcium or titanium oxide mixture as coating are found to be good for welding steel with DCEM.



### Gas Metal Arc Welding Set-up.

Resistance Welding: The welding processes covered so far, are fusion welding processes where only heat is applied in the joint. In contrast, resistance welding process is a fusion welding process where both heat and pressure are applied on the joint but no filler metal or flux is added. The heat necessary for

the melting of the joint is obtained by the heating effect of the electrical resistance of the joint and hence, the name resistance welding.

Resistance welding uses the principle of application of electric current and mechanical pressure to create a weld between two pieces of metal. The electrodes conduct the electric current to the two pieces of metal as they are forged together.

Resistance welding is a process for fastening metallic objects together. The metallic objects have various electric and thermal properties that make it possible for the resistance welding process to occur.

Resistance welding is accomplished by passing a controlled density of electric current ( $I$ ) through the resistance of the metallic workpiece ( $R$ ) over a specified amount of time ( $t$ ).

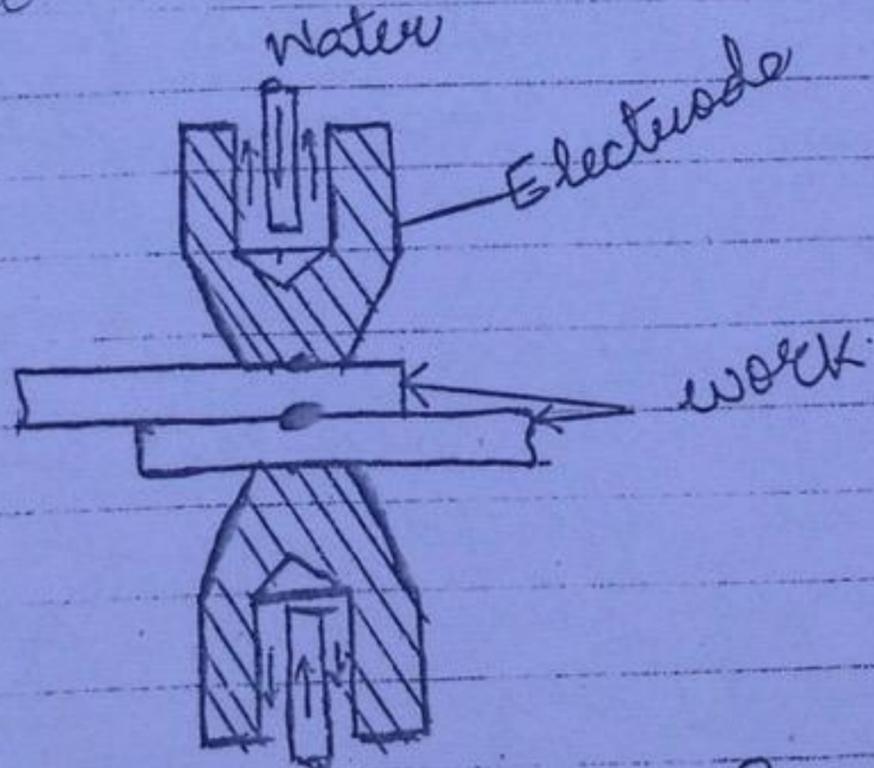
Electrically, metallic objects have some level of resistance to the flow of electric current. The resistance will cause heat energy as electric current pass through the workpiece. The higher the ampacity and duration of current, the higher the heat

energy will be produced. This relationship can be expressed in the simple equation:

$$\text{Energy} = I^2 \times R \times t$$

The "Energy" represents weld energy, the symbol "I" represents current, the symbol "R" represents resistance, and the symbol "t" represents time; as you can see from the equation, energy increases exponentially as current increases.

The schematic representation of the resistance welding process is shown in figure. The main requirement of the process is the low voltage and high current power supply. This is obtained by means of a step down transformer with a provision to have different tapping on the primary side, as required for the different materials.



Electric welding Resistance Process

The secondary winding are connected to the electrodes, which are made of copper to reduce their electrical resistance. The time of the electric supply needs to be closely controlled so that the heat release is just enough to melt the joint and the subsequent fusion takes place due to the force  $\text{C} \times \text{m} \times \text{v}$  (forge welding) on the joint. The force required can be provided either mechanically, hydraulically or pneumatically, as shown in figure. To precisely control the time sophisticated electronic timers are available.

The critical variable in a resistance welding process is a contact resistance between the two workpiece plates and their resistance themselves. The contact resistance is affected by the surface finish on the plate. Since the rougher surface have higher contact resistance. The contact resistance also will be affected by the cleanliness of the surface. Oxides or other contaminants if present, should be removed before attempting resistance welding.

The lower resistance of the joint requires very high current to provide

enough heat to melt it. The average resistance may be of the order of 100 micro ohms, as a result, the current required would be of the order of ten of thousands of amperes. With a 10000 A current passing for 0.1s, the heat liberated,

$$H = (10000)^2 (0.0001) (0.1) = 1000 \text{ J}$$

This is typical for the welding of 1mm thick sheets. The actual heat required for melting (assuming the weld area as a cylinder of 5mm diameter and 1.5mm height) would be of the order of 339J. The rest of the heat is actually utilised in heating the surrounding area and lost at other fronts.

The welding force used has the effect of decreasing the contact resistance and consequently, an increase in the welding current for the proper fusion.

Seam welding: It is the process for producing leak-tight, continuous joints in sheet metals. welds are produced in long continuous seams by rolling the materials sheets between rotating electrode wheels.

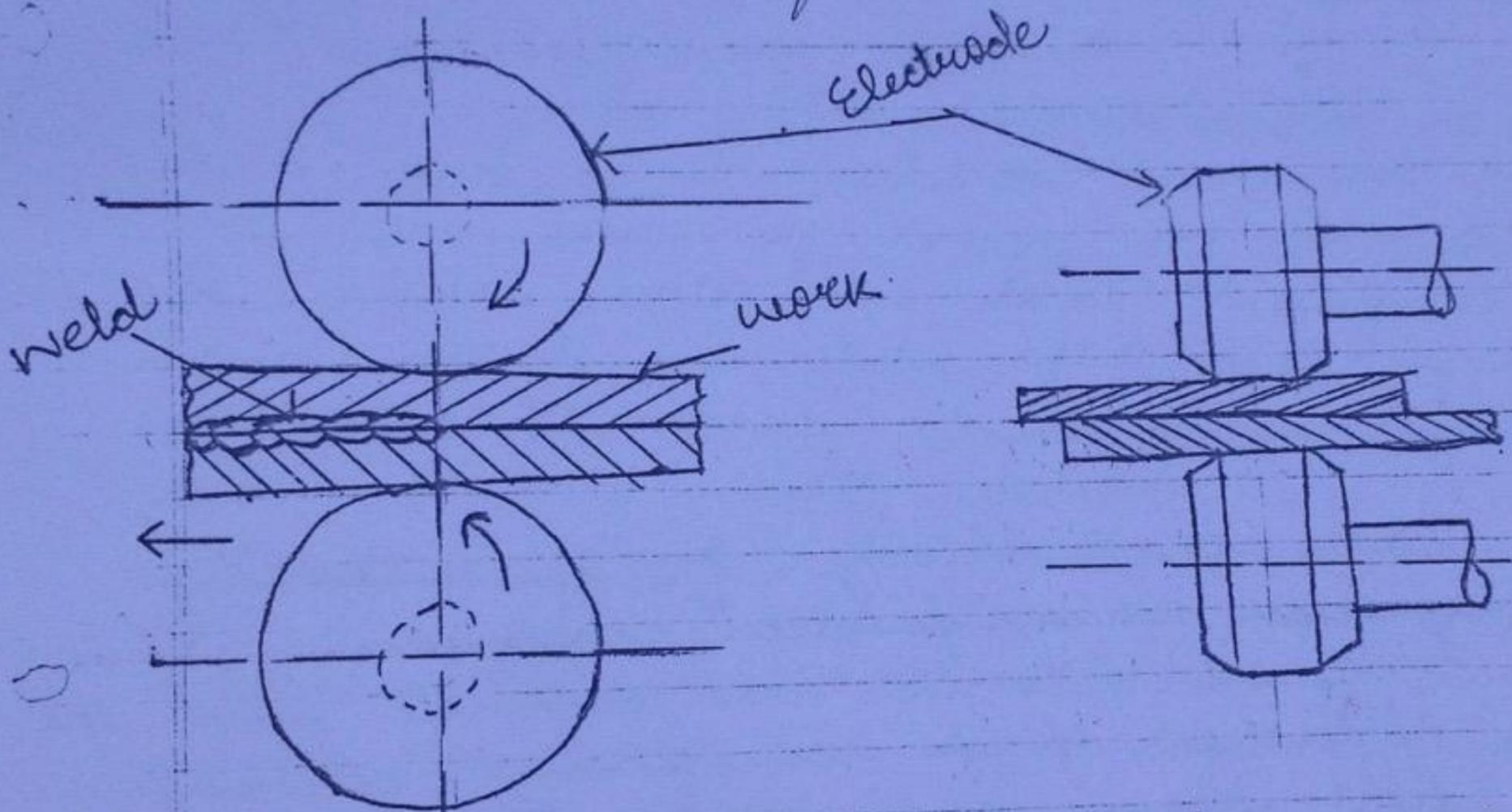
Resistance Seam welding is a process that produces a weld at the surface of two similar metals. The seam is a butt joint or an overlap joint of

is usually an automated process. It differs from butt welding in that butt welding typically welds the entire joint at once and seam welding forms the weld progressively, starting at one end.

A transformer supplies energy to the weld joint in the form of low voltage, high current AC power. The joint of the workpiece has high electric resistance relative to the rest of the circuit and is heated to its melting point by the current. The semi-molten surfaces are pressed together by the welding pressure that creates a fusion bond, resulting in a uniformly welded structure. Most seam welders use water cooling through the electrodes, transformer and controller assemblies due to the heat generated. Seam welding produces an extremely durable weld because the joint is forged due to the heat and pressure applied. A properly welded joint formed by resistance welding is typically stronger than the material from which it is formed.

Like spot welding, seam welding acts on two electrodes, usually made from copper, to apply pressure and current.

The electrodes are disc shaped and rotate as the material passes between them. This allows the electrode to stay in constant contact with the material to make long continuous welds. The electrodes may also move or assist the movement of the material.



Laser beam welding: Laser beam welding (LBW) is a welding technique used to join multiple pieces of metal through the use of laser. The beam provides a concentrated heat source, allowing for narrow, deep welds and high welding rates.

Laser beam welding (LBW) is a welding process which produces coalescence of material with the heat obtained from the application of a concentrated coherent light beam impinging upon the surface to be joined.

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 distances from it to the base metal. The spot can be made as small as 0.003 in (0.076 mm) to large areas of 10 times as big. A sharply

focused spot is used for welding and for cutting. The large spot is used for heat treating.

The laser offers a source of concentrated energy for welding; however there are only a few lasers in actual production use today. The high-powered laser is extremely expensive.

The welding characteristics of the laser and of the electron beam are similar. The concentration of energy by both beams is similar with the laser having a power density in order of  $10^6$  watts per square centimetres. The power density of the electron beam is only slightly greater.

Ultrasonic welding: The process welds metal by the local application of high frequency (between 10,000 and 175,000 Hz) vibratory energy, while the parts are held together under pressure. The pressures vary with the size of the welding machine used. The clamping forces depends on the wattage required to weld the assembly. The wattage can be calculated by use of following equation

$$E = 150 (1.5H) (1.5t)$$

where E equals the energy in watt-seconds  
H is the Vicker microhardness number;

and  $t$  equals the thickness of the sheet in contact with the powered sonotrode, in inches.

Representative applications of ultrasonic welding equipment are to be found in

The electronic industry where it is used to attach fine (0.005 to 0.020 inch-diameter) aluminium or gold lead wires to ~~transformers~~ transistors, diodes and other semiconductor devices or to ceramic or glass substrates. It has also been used successfully to hermetically encapsulated microcircuits and other electronic components such as transistors or diode cans.

The aerospace industry, where it is used for the fabrication of leak-tight joints in bellows.

The metal fabrication industry, helium leak tight bonds in pinch off weld closures used in capillary tube for refrigeration, air conditioning, and similar applications.

Welding problems their cause & remedies.

Problems	Cause	Remedies
Cracking of weld metal	High joint rigidity	Preheat parts, thus reducing the cooling rate. Relieve residual stresses by peening. Increase strength of the weld by building heavier cross section.

- Excessive alloy pickup from the base metal. Change the current level of the travel speed; weld with straight polarity (emissive coating on wires & electrodes). Overlay the base metal at low amperages prior to welding the joint.

Defective electrodes change electrode, grind. This can be from striking ends to moisture, accenting proper dimensions - city, poor striking, bake electrodes.

g, poor wire  
poor fit-up  
~~small~~ broad

Reduce root gap; clad edges

Problems	Causes	Remedies
	Small bead	use larger electrodes; increase cross sectional area of metal.
	High sulphur in the base metal (carbon and low-alloy steel)	use process with high level of sulphur- fixing elements. Use lime-rich fluxes for example the reworking of EXX 18 electrodes.
	Angular distort- ion (weld root in tension)	change to balanced welding on both side. preheat, peen to relieve residual stresses
	Crater cracks	fill in crater prior to withdrawing electrode
Cracking of Hydrogen in base metal welding atmospheres		Use hydrogen free process-gas, melting arc welding, gas tungsten- arc welding, submerged arc welding, etc. use post-weld aging or annealing

Problem

Cause  
Hot Short  
Cracking

Remedies  
Use low-heat input,  
high-speed welding;  
Use thin beads.

High strength  
low ductility  
material.

use annealed or  
stress-relieved material

Hot tensile - weld using an electrode  
cracking in whose melting point  
heat affected matches the base  
zone (Copper alloy) metal.

Excessive  
stresses;

Redesign the joint. Use  
immediate stress-relief  
change welding sequences  
(cladding technique)

High harden-  
-ability

Preheat; change condition  
to slow cool the weld  
beads; weld with  
austenitic electrode.

Brittle phases

Solution heat treat prior  
to welding.

High lead  
content

weld with mini heat  
input. Change material.

Problem	Causes	Remedies.
Porosity	Excessive hydrogen, oxygen or nitrogen in the welding atmosphere	use low-hydrogen process: use filler with high deoxidizers. Check gas flow rate and travel speed
	High rate of weld freezing	Preheat; increase heat input; use lower-melting filler.
	oil, paint or rust on base metal Dirty surface on gas metal arc	Thoroughly clean all joint surfaces. use cleaned wire.
	<del>Welding electrode</del> im proper arc length and current	Control these parameters
Inclusions	Improper joint design oxide inclusions	Increase included angle of joint provide proper shielding.