ELECTRIC HEATING & WELDING

Electric heating: Advantages and methods of electric heating - resistance heating, design of heating element, problems - induction heating, Induction cooking and dielectric heating.
Electric welding: Resistance, arc welding - electric welding equipment – comp. between A.C. and D.C. Welding.

History of Fire

The Stone Age was a broad prehistoric period during which stone was widely used to make implements with an edge, a point, or a percussion surface. The period lasted roughly 3.4 million years and ended between 8700 BCE and 2000 BCE with the advent of metalworking. In Stone Age, the fires were produced based on friction in number of ways. Among those methods they produced fire by rubbing two pieces of wood together then dry grass and leaves are added as the wood began to smoke (see Fig.1), in another way they produced the fire by drilling the wooden devices. Other early humans discovered that a certain stone (called Iron Pyrites), when struck against a hard rock, gave off a spark that could also create fire (see Fig.2).

Fig.1 Creation of fire using two woods(Friction)

Fig.2 Creation of fire through using stones

In 1879, Thomas Edison invented the electrical bulb which led to the invention of the first portable electric heating system. In 1905, Albert Marsh discovered *chromel* (an alloy of nickel and chromium) that was 300 times stronger than other heating elements.

Electric heating and Applications

It is a process in which electrical energy is converted to heat energy. Electric heating is extensively used both for domestic and industrial applications.

Domestic applications like room heaters, immersion heaters for water heating, hot plates for cooking, electric kettles, electric irons, pop-corn plants, electric ovens for bakeries, electric toasters etc.

Industrial applications of electric heating include melting of metals, moulding of glass, enamelling of copper wires, heat treatment of metals like annealing, tempering, soldering etc.

Electric heater

An electric heater is device that converts an electric current into heat. The heating element of electric heater has resistance property. The electrical heater mainly works on the principle of Joule heating i.e an electric current passing through a resistor will convert that electrical energy into heat energy. The commonly used materials for design of heating elements are

(i) Nichrome – It is the alloy of 80% of Nickel and 20% of Chromium.

(ii) Euraka or Constantan – It is the alloy of 45% of Nickel and 55% of Copper.

(iii) Nickel Chromium Iron – It is the alloy of 60% of Nickel, 16% of Chromium and 24% of Ferrous.

Most modern electric heating devices use *nichrome* wire as the active element.

Requirement of good heating material or Properties of heating element

The following are the requirement of good heating material or properties of heating element.

(i) The heating element should have high melting point.
(ii) It should be free from oxidation, corrosion and rust.
(iii) It should have low temperature coefficient of resistance.
(iv) High mechanical strength.
(v) It should have positive temperature coefficient of resistance
(vi) Lower in cost.

Advantages of Electrical Heating:

The electrical heating is required for both industrial and domestic purposes. In industries, heating is required for the melting of metals, moulding of glass, enamelling of copper, baking of insulator and welding etc. In domestic purposes the heating is required for cooking, water heating, room heating in winter, pressing clothes and many more.

The electric heating has the following advantages over conventional methods.

1. Electric heating is free from dirt hence minimum effort for cleaning is required.
2. Electric heating is free from flue gases hence no need of exhaust system for heat generation.
3. Temperature control can be done very easily.
4. An electric heating system is economical compared to other conventional heating systems available in the industry. Both the installation cost and running costs are quite low.
5. Automatic protection against any abnormality in the heating system can easily be provided in electrical heating.
6. The efficiency of the system is quite high compared to other equivalent heating systems.
7. The electric heating system is noise free.
8. Starting of the system is quite faster than other heating systems.

Different Methods of Heat Transfer

The different methods by which heat is transferred from a hot body to a cold body are as under:

Conduction: In this mode of heat transfer, one molecule of the body gets heated and transfers some of the heat to the adjacent molecule and so on.

Consider a solid material of cross-section A, *x is* thickness in metre. If T_1 and T_2 are the temperatures of the two sides of the slab in °*K*, then heat conducted between the two opposite faces in time *t* seconds is given by $H = K\dfrac{A(T_1 - T_2)t}{x}$.

Convection: In this process, heat is transferred by the flow of hot and cold air currents. This process is applied in the heating of water by immersion heater or heating of buildings. The quantity of heat absorbed by the body by convection process depends mainly on the temperature of the heating element above the surroundings and upon the size of the surface of the heater.

If T_1 and T_2 are the temperatures of the heating surface and the fluid in °*K*, a and b are the constants.

Heat dissipated $H = 3.875(T_1 - T_2)$.

Radiation: It is the transfer of heat from a hot body to a cold body in a straight line without affecting the intervening medium. The rate of heat emission is given by Stefan's law according to which Heat dissipated,

$$H = 5.72eK\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right] \text{w/m}^2$$

Where T_1 is the temperature of hot body in °*K* and T_2 is the cold body (or cold surroundings) in °*K*.

If d is the diameter of the heating wire and l its total length, then the electrical power input to the heating element, $P = \pi\, dl\, H$.

Design of Heating Element:

Practically, two types of heating elements are used for heating purpose. Those are

i) A wires of circular cross-section

ii) Strip or Ribbon type heating element

Under steady-state conditions, a heating element dissipates as much heat from its surface as it receives the power from the electric supply *i.e* if P is the power input and H is the heat dissipated by radiation, then $P = H$ under steady-state conditions.

i) A wires of circular cross-section:

As per Stefan's law of radiation, heat radiated by a hot body per unit area is

$$H = 5.72eK\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right] \text{w/m}^2$$

Where T_1 is the temperature of hot body in °*K* and T_2 is the cold body (or cold surroundings) in °*K*.

Input power $P = VI = \frac{V^2}{R} = \frac{V^2}{\left(\frac{\rho l}{a}\right)}$, but area $a = \pi d^2/4$

$$\text{Power } P = \frac{\pi d^2 V^2}{4\rho l} \rightarrow \frac{d^2}{l} = \frac{4\rho P}{\pi V^2} \quad \text{------- (1)}$$

If H is the heat dissipated by radiation per unit surface area of the wire, then total heat radiated is $(\pi d) \times l \times H$

At steady state, the input power (P) = Total Heat dissipated i.e $P = (\pi d)\, l\, H$

$$\frac{\cancel{\pi} d^{\cancel{2}} V^2}{4\rho l} = \cancel{\pi}\cancel{d}\, l\, H$$

$$\frac{l^2}{d} = \frac{V^2}{4\rho H} \quad \text{------- (2)}$$

By solving equations (1) and (2), the heating element can be designed.

***ii) Strip or Ribbon type heating element*:**

As per Stefan's law of radiation, heat radiated by a hot body per unit area is

$$H = 5.72eK\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right] \text{w/m}^2$$

Where T_1 is the temperature of hot body in °*K* and T_2 is the cold body (or cold surroundings) in °*K*.

Input power $P = VI = \frac{V^2}{R} = \frac{V^2}{\left(\frac{\rho l}{a}\right)}$, but area a = wt where width is 'w' and thickness is 't'

$$\text{Power } P = \frac{wtV^2}{\rho l} \Rightarrow \frac{wt}{l} = \frac{V^2}{\rho P} \quad \text{------- (1)}$$

If H is the heat dissipated by radiation per unit surface area of the wire, then total heat radiated is H(2wl)
At steady state, the input power (P) = Total Heat dissipated i.e P = H(2wl)

$$\frac{\cancel{w}tV^2}{\rho l} = 2\cancel{w}l\,H$$

$$\frac{t}{l^2} = \frac{2\rho H}{V^2} \quad \text{------- (2)}$$

By solving equations (1) and (2), the heating element can be designed.

Methods of Electrical Heating:

Basically, heat is produced due to the circulation of current through a resistance. The current may circulate directly due to the application of potential difference or it may be due to induced eddy currents. Similarly, in magnetic materials, hysteresis losses are used to create heat. In dielectric heating, molecular friction is employed for heating the substance. An arc established between an electrode and the material to be heated can be made a source of heat. Bombarding the surface of material by high energy particles can be used to heat the body. Different methods of producing heat for general industrial and domestic purposes are classified as:

Electrical Heating

- Power Frequency Heating
  - Resistance heating
    - Direct
    - Indirect
  - Arc heating
    - Direct
    - Indirect
- High Frequency Heating
  - Induction heating
    - Core type induction heating
    - Core less type induction heating
  - Dielectric Heating

Resistance Heating

It is based on the I^2R effect. When current is passed through a resistance element I^2R loss takes place which produces heat. There are two methods of resistance heating.

Direct Resistance Heating:

In this method the charge (material to be heated) is treated as a resistance and current is passed through it. The charge may be in the form of powder, pieces or liquid. The two electrodes are inserted in the charge and connected to either 1-Ph AC or DC supply as shown in Fig. (a). Two electrodes will be used in the case of d.c. or 1-ph a.c. supply but there would be three electrodes in the case of 3-ph supply.

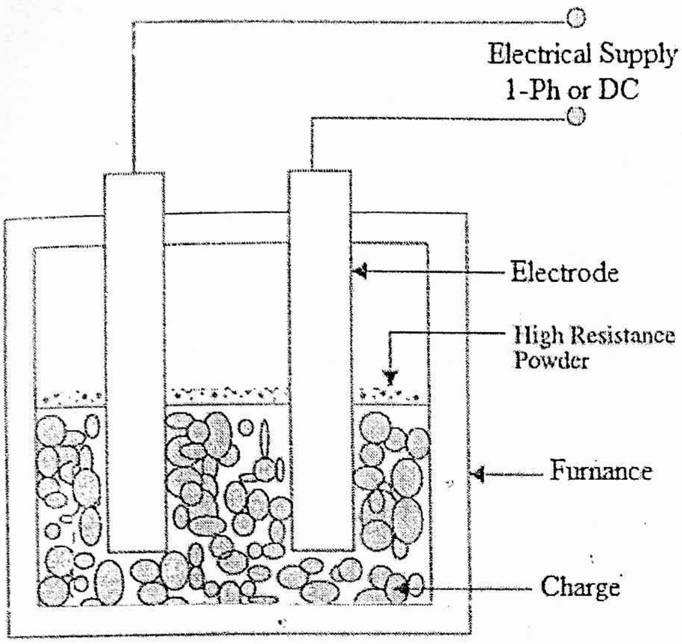


Fig. a : Direct Resistanace heating

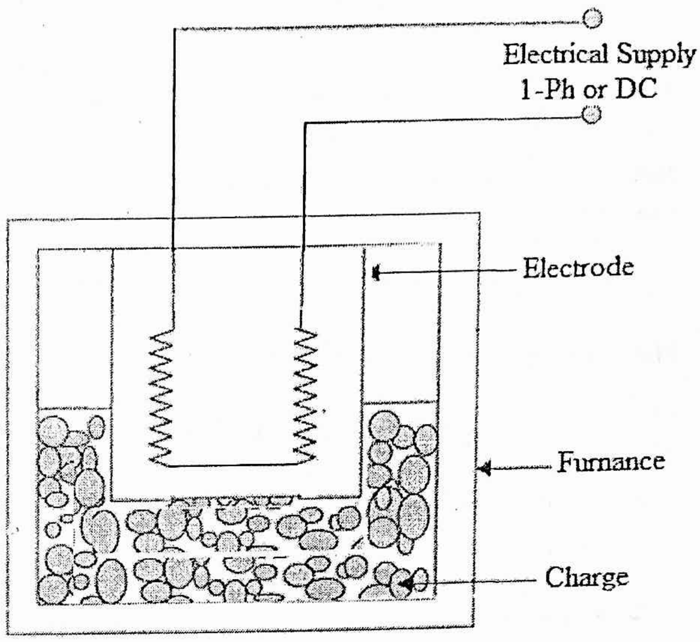


Fig. b : In-direct Resistanace heating

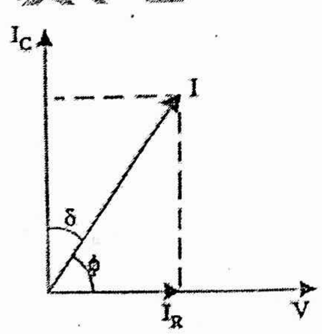
When the charge is in the form of small pieces, a powder of high resistivity material is sprinkled over the surface of the charge to avoid direct short circuit. Heat is produced when current passes through it. The main advantage of this method is high efficiency because the heat is produced in the charge itself. This method is used for resistance welding, boilers for heating the water etc.

Indirect Resistance Heating.

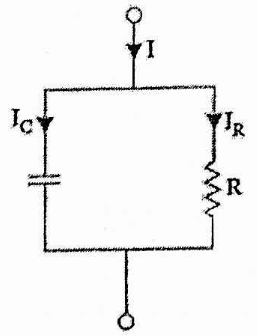
In this method of heating, electric current is passed through a resistance element which is placed in an electric oven. Heat produced is proportional to I^2R losses in the heating element. The heat so produced is delivered to the charge either by radiation or convection or by a combination of the two. Sometimes, resistance is placed in a cylinder which is surrounded by the charge placed in the jacket as shown in the Fig.b.

Dielectric Heating:

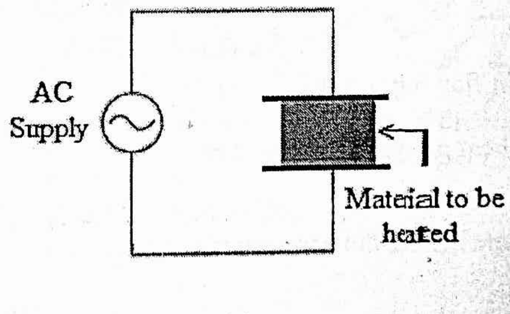
When a practical capacitor is connected across an a.c. supply, it draws a current (I) which leads the voltage (V) by an angle ϕ as shown in Fig.(a). It means that there is a certain component of the current which is in phase with the voltage and hence produces some loss called dielectric loss. At the normal supply frequency of 50 Hz, this loss is small and negligible. But at higher frequencies this loss becomes so large that it is sufficient to heat the material. The insulating material to be heated is placed between two conducting plates (form a parallel-plate capacitor) as shown in Fig.(c). Fig.(*b*) shows the equivalent circuit of the capacitor.



(*a*)



(*b*)



(c)

Power drawn from supply = VI Cos ϕ but $I_c = I = V/X_c = 2\pi f\, CV = \omega CV$

$\therefore$ $P = V(\omega CV)\text{Cos}\,\phi = \omega CV^2 \text{Cos}\phi$

But, $\phi = (90 - \delta)$, so $\text{Cos}\phi = \text{Cos}\,(90 - \delta) = \text{Sin}\delta$

For small value of δ (in radians), $\text{Sin}\delta = \delta$

$$\boxed{\text{Power drawn from supply } P = \omega CV^2\delta \text{ watts}}$$

Here capacitance $C = \epsilon_0\, \epsilon_r\, \frac{A}{t}$, where t is the thickness and A is the surface area of the dielectric slab.

Generally, a.c. voltage of 20 kV at a frequency of 10 - 30 MHz is used.

This method of heating is used

- For gluing of multilayer plywood boards
- For preheating of plastic compounds before sending them to the moulding section
- For drying of tobacco
- For baking of biscuits and cakes etc. in bakeries
- For electronic sewing of plastic garments like raincoats etc
- For dehydration of food which is then sealed in air-tight containers
- For removal of moistures from oils
- For quick drying of glue used for book binding purposes etc.

Advantages of Dielectric Heating

1. Uniform heating is possible because the heat is generated within the dielectric medium.
2. With increasing the frequency, the heating becomes faster.
3. Since no flame appears in the process, so the materials like plastics and wooden products etc., can be heated safely.
4. Heating can be stopped immediately as and when desired.

Prob. An insulating material 2 cm thick and 200 cm^2 in area is to be heated by dielectric heating. The material has relative permitivity of 5 and power factor of 0.05. Power required is 400 W and frequency of 40 MHz is to be used. Determine the necessary voltage and the current that will flow through the material. If the voltage were to be limited to 700 V, what will be the frequency to get the same loss?

Solution.

Capacitance $C = \epsilon_0\, \epsilon_r\, \frac{A}{t} = 8.854\times10^{-12} \times5\times200\times10^{-4}/2 \times10^{-2} = 44.27\times10^{-12}$ F

Power $P = 2\pi\, fC\, V^2\text{Cos}\phi \rightarrow V^2 = \dfrac{P}{2\pi fC\, \text{Cos}\phi} = \dfrac{400}{2\pi\times40\times10^6\times44.27\times10^{-12}\times 0.05}$

$\therefore$ Voltage **V = 848 V**

Current flowing through the material, $I = P/V\text{Cos}\phi = 400/848 \times 0.05 =$ **9.48 A**

Since heat produced $H \;\alpha\; V^2 f \rightarrow \dfrac{H_2}{H_1} = \dfrac{V_2^2 f_2}{V_1^2 f_1}$

For same losses, the heat generated also same, $\therefore$ Frequency $f_2 = f_1 \dfrac{V_1^2}{V_2^2}$

$= 40\times10^6\, (848/700)^2 =$ **58.7 MHz**

Resistance welding:

This method is used to join two plain metal work pieces together by running an electrical current through them. The necessary welding heat is generated by the electrical resistance of the metals, by the contact resistance in between them and by the electrical current.

The working principle of resistance welding is the generation of heat because of electric resistance. The resistance welding such as seam, spot, protection works on the same principle. Whenever the current flows through electric resistance, then heat will be generated. This heat generation takes place because of the energy conversion from electric to thermal. The heat generation **$H = I^2Rt$.**

Resistance Welding Applications

- This type of welding can be widely used in automotive industries for making nuts as and bolts.
- The leak prove joint in tanks, boilers, etc, the Seam welding is used.
- For welding metal tubes and pipes Flash welding is proffered.

Resistance Welding Advantages

- This method is simple and does not require high expert labor.
- The rate of production is high
- Both same and different metals can be weld.
- This type of welding is faster in operation
- It does not need any flux, filler metal & protecting gases.

Resistance Welding Disadvantages

- The work section thickness is limited because of the current requirement.
- It consumes high electric-power.
- This type of weld joints has small tensile & fatigue power.

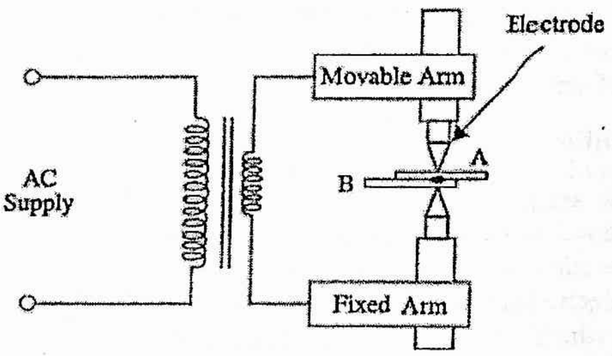
Types of Resistance Welding

Different **types of resistance welding** are discussed below.

Spot welding:

It is used for joining two or more metal sheets. The sheets to be welded are held between the two electrodes as shown in figure. One electrode is movable and the other is fixed. Pressure is applied from the top electrode by moving it downward.

The fusion of material takes place at the spot. Then the sheet is moved to have another spot weld at the desired place. The time period for each weld may be 100^{th} of a second or more. The current may be of the order of 5KA or more. The voltage between electrodes is about 2 volts.



For the sheets, the time required is about 1/50 sec. for each 0.25 mm of the total thickness of the two sheets to be welded. Wires, rods and small pieces of a sheet can also be welded by this method.

Advantages of Spot Welding:

- It has low initial cost.
- A less skilled worker can also operate this welding.
- The operation can be made fully automatic or semi automatic.

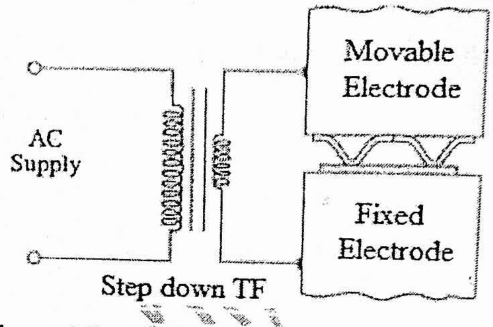
Disadvantages of Spot Welding

- High thickness metals cannot be welded.
- Skilled workers are required for maintenance purpose.

The Spot Welding is commonly used in automobile and aircraft industries, for making containers, used in the fabrication of steel furniture.

Projection welding:

It is a modified form of spot welding. In this process, large-diameter flat electrodes (also called platens) are used. Here the upper and lower platens are connected across the secondary of a step-down transformer and are large enough to cover all the projections to be welded at one stroke of the machine. When movable electrode touches the work piece, welding current flows *through each projection.* The welding process is started by first lowering the upper electrode on to the work-piece and then applying mechanical pressure to ensure correctly-forged welds. After this, welding current is switched on as in spot welding. As projection areas heat up, they collapse and union takes place at all projections simultaneously.



Advantages of Projection Welding

- More than one spot can be welded at one time.
- Proper heat balance can be obtained easily.
- Welds can be placed closer than spot welding.
- Electrode life is much longer than the life of electrode used in spot welding.
- Appearance and uniformity of this weld are better than spot welding.
- With the projection welding, it is easy to weld certain jobs which cannot be welded by spot welding.

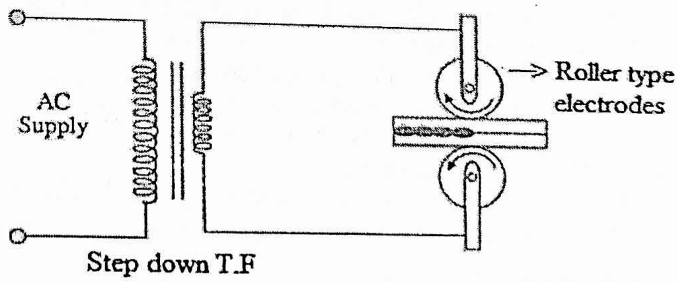
Disadvantages of Projection Welding

- Metals, which cannot support projections, cannot be welded satisfactorily.
- To make projection is an extra operation.
- The initial cost of equipment required for projection welding is high.

This type of welding is usually employed on punched jobs, where the projection automatically exists, Welding of stainless steel parts etc.

Seam welding:

The seam welding is done in order to obtain a continuous joint. In this case, roller type electrodes are used and the pressure between electrodes remains constant. The two sheets on which seam welding is required are placed overlapping each other. The current is passed between the two moving electrodes and sheets get welded.



Advantages of Seam Welding

- Less overlap required of two parts than spot or projection welding.
- Several parallel seams can be produced.
- Gas tight or liquid tight welds can be produced.

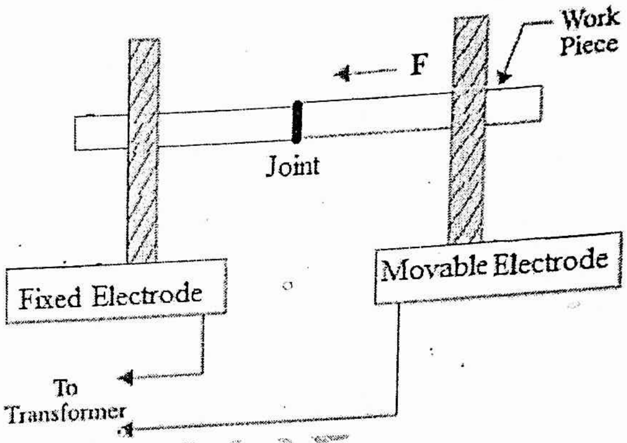
Disadvantages of Seam Welding

- Seam welding sets are more costly than spot welding sets.
- It is difficult to weld thickness greater than 3mm.
- Welding can be done only along a straight line.

It is used for making containers, heat exchangers, pressure vessels, motor cases etc.

Butt Welding

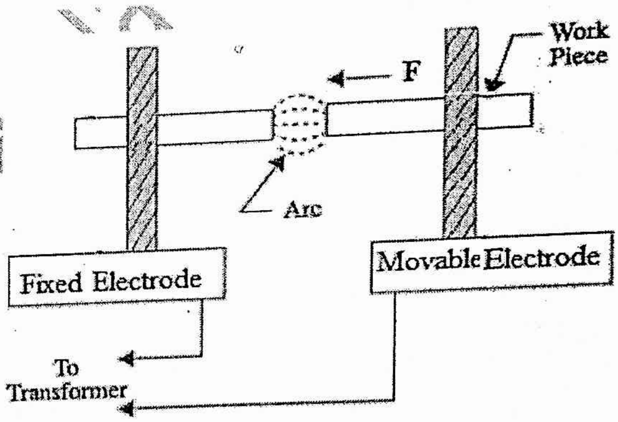
To form a butt joint, work pieces are placed touching each other end to end as in figure. A pressure is also applied in the axial direction of the job. The jobs are securely clamped and heavy current is passed through them. The heat is produced to raise the temperature of material and fusion takes place at the points of contact.



This method is used for welding pipes, wires and rods etc. The voltage required for welding is 2 to 12 volts and current varies from 50 A to several hundred amperes, depending upon the kind of material and the area to be welded at a time.

Flash Butt or Flash Welding

It is similar to butt welding except that the parts to be welded are joined together under light pressure and heavy current is passed through the joint. Due to poor contact, arcing takes place at the joint. When sufficient heat has been produced the two parts are suddenly pressed together and current is stopped simultaneously.



Advantages of Flash Butt Welding

- It is a fast and cheap process.
- Preparation of weld surface is not required.
- Many dissimilar metals with different melting temperatures can be welded.
- It offers 100% strength factor.

Disadvantages of Flash Butt Welding

- More chances of fire hazards, Metal is lost during welding.
- Concentricity and straightness of work pieces are often difficult to maintain during the welding process.

It is used for welding rail ends, shaft axles, chain etc.

Comparison between AC and DC Welding:

AC Welding	DC Welding