Electroslag Welding Process

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As the thickness of the welded metal increases, multirun techniques of welding become uneconomical. The use of automatic welding with high currents give a weld-pool so large that it runs ahead of the electrode, out of control, resulting in inadequate fusion. This has led to the development of a new process—'Electroslag welding'. The plates to be welded are kept vertical instead of in the flat position and the welding process is rather like continuous casting. The process was developed in the Soviet Union at Paton Institute in the year 1950[1], from the principles of submerged arc welding.

The distinction between electroslag and submerged arc as media for welding will serve to clarify the fundamentals of the process. In submerged arc process, the depth of the flux is not sufficient to permit slag conductivity—the arc is struck at 25—32 volts. If, in submerged arc welding, the slag is allowed to collect so as to form a molten pool of 1—1½″ depth, the arc would disappear and the voltage would rise to 45 to 55 volts. The current would then be carried by conductive slag. This is Electroslag welding[2].

Principle of Electroslag Welding

Fig. 1 shows the basic arrangement for electroslag welding process. A pool of slag is maintained in a moulding device—usually water cooled copper plates —and the plates to be welded. The molten bath is kept at the correct temperature to melt the edges of the base metal and electrode (i.e. filler metal) by the electric resistance offered to the current during its passage from electrode wire through the slag into the weld pool. The molten slag pool acts both as heat source and shielding agent. Most fused salts used as flux become increasingly conducting (electrically) as their temperature is raised. Once the molten slag is established over the weld, the process proceeds by resistance heating. The depth of the slag is critical and has a bearing on the quality of the weld. Too little slag results in a recurrence of arcing and too much slag can cause lack of fusion. Once the process has started, the current carrying plasma streams set the slag in motion (*Fig. 2*) causing turbulence in the slag bath and a shallow crater

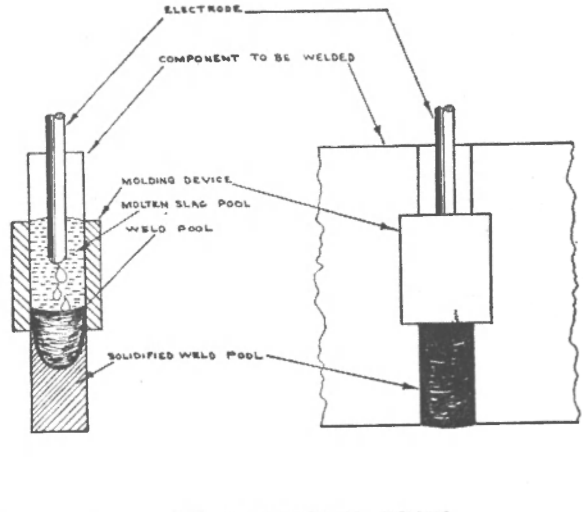

FIG. 1 BASIC ARRANGMENT FOR ELECTROSLAG WELDING.

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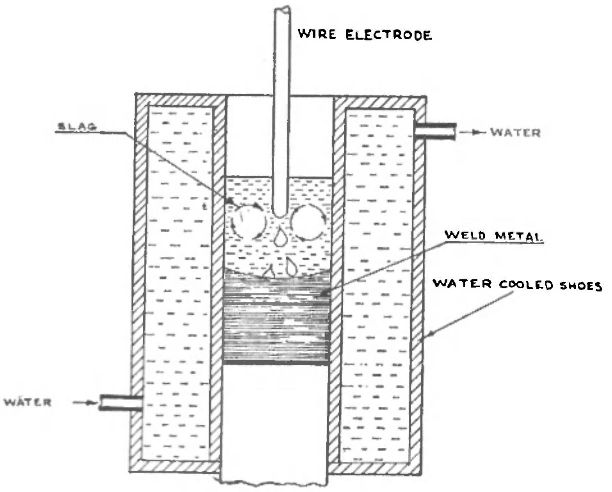

FIG 2 CIRCULATION OF SLAG RESULTING FROM THE FLOW OF WELDING CURRENT

under the electrode. The molten slag at a temperature of upto 2000°C, washes the joint edges, melting into them to produce a weld with a dilution—high by arc welding standards—of upto about 50 per cent. It is an advantage in that plate edge preparation is cheapened. A rough flame cut edge is fully suitable and there is no need for expensive machining.

Heat Generation and Distribution

Heat is evolved as the result of the passage of current through the slag pool. The quantity of heat Q evolved is given by

$$Q = 0.24\ V \times I \text{ Calories.}$$

where V is the voltage and I the current. A negligible amount of heat may be produced by the thermochemical reaction between the metal and the slag. It has been shown that the slag conductivity and current flowing are the function of pool depth, and slag resistance is in inverse proportion. Properties of slag affect the process greatly. Increased conductivity of the slag tends to stabilize the electroslag process; however, if the conductivity is too high, the energy generated in the slag pool may prove inadequate to maintain the welding process. The heat balance of the process is affected by the following factors :

1. Heat expended in melting the electrode.
2. Heat expended in melting the base metal.
3. Heat expended in melting the flux.
4. Heat losses to the water cooled mould, radiation losses from slag pool surface and heat carried away by the metal being welded.

Out of the above heat losses, the major heat loss is the heat carried away by the mass of the work piece. Heat concentration is lower in this process reducing risk of cracks developing in the weld zone when air hardening steels are being welded.

Structure of the Weld Metal

The structure of the weld metal determines the mechanical properties, resistance to intergranular cracking, resistance to corrosion and other properties. Weld metal has the following structural characteristics :

1. Large amount of liquid metal cools slowly like cast metal resulting in large crystals.
2. Uniform removal of heat over the whole weld periphery resulting in columnar type of crystals.
3. Presence of considerable amount of liquid metal and slag above the growing crystals facilitating degasification of the pool.

The size of the crystals produced is determined by temperature and holding time of the melt at this temperature, direction and intensity of heat removal, intensity of agitation of liquid metal, composition of liquid metal and the amount of impurities present. If the cooling rate is lowered (welding with preheat or welding metals of low conductivity) the width of coarse crystal zone decreases. The coarse and fine columnar crystals normally grow towards the surface with a certain additional deflection towards the heat centre of the weld pool (*Fig. 3*)[3]. All the conditions for the formation of columnar crystals with markedly elongated dendrites are favourable in Electroslag welding. The primary crystals formed are seldom larger than 1 mm[4]. Then an area of columnar crystals follows; these crystals give very unfavourable configuration in the centre of the weld metal. Certain impurities can be entrained in the weld metal from the melted base metal. These are conditions of segregation processes causing deterioration of the mechanical properties in the weld metal zone. The growth of dendrites in the centre of weld metal can be reduced by keeping the welding rate within certain limits or using extremely pure base and filler metal and slag with excellent refining capacity.

Due to coarse grain structure of the weld metal, a post-weld normalizing treatment is beneficial, particularly in improving the rather low impact properties

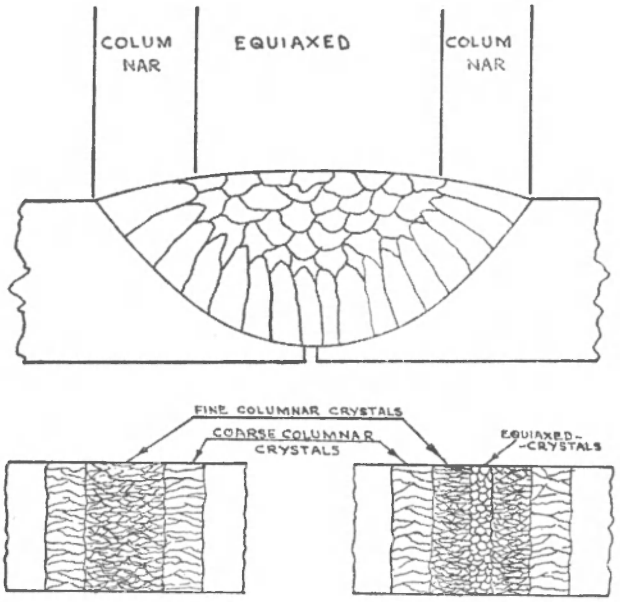

FIG. 3. STRUCTURE OF THE WELD IN ELECTROSLAG WELDING DEPENDING ON COOLING RATE

resulting from the columnar structure. Attempts have been made to produce as welded structure which would be sufficiently fine grained to possess satisfactory impact properties eliminating post-weld treatment, which is expensive, inconvenient and some times impossible. The main lines of approach have been[5]

(a) To introduce grain refiners in the weld metal

(b) Promoting nucleation and breaking of columnar structure by ultrasonic vibrations.

(c) By control of welding technique in such a manner that a satisfactory grain structure is obtained on solidification.

Changes in Heat Affected Zone (HAZ)

In electroslag welding, the cooling rates are low during the transformation $\gamma \rightarrow \alpha$, whereas the duration of thermal effect is sufficiently long to cause an undesirable growth of grains in the HAZ above approximately 1100°C. Because of large slowly moving weld pool, electroslag welds are characterised by protracted thermal cycles unlike multipass submerged arc welding (*Fig. 4*) where reheating effect of subsequent welds is utilized to produce a refined grain size although approximately same maximum temperatures are encountered in both the processes. The unfavourable properties in the weld area, however, are not the only consequence of the thermal cycle during electroslag welding. Other factors affecting the properties are the high thickness of the material being welded, the intensive thermal influence, and the fact that the weld area is subjected to an intense deformation cycle. The compression stresses occurring on heating relax by the dilation of the contact faces in to the weld metal. The effect of tensile stresses is felt after the solidification of the weld, and as a consequence there is a marked plastic deformation of a large part of HAZ.

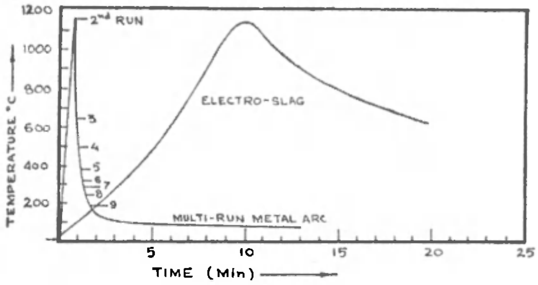

FIG. 4. THERMAL CYCLE EXPERIENCED IN THE HEAT-AFFECTED ZONE OF A 3" THICK ELECTROSLAG WELDED PLATE, CAMPARED WITH MULTIRUN METAL ARC. FIG. INDICATE PEAK TEMP. AT ROOT FOR SUCCESSIVE RUN

The changes of the properties in the electroslag weld area cannot, therefore, be explained by the effect of the thermal cycle alone, but by the superimposition of thermal and deformation cycles. The changes taking place in the HAZ can thus be summarised as :

1. Changes connected with transformations (such as formation of martensite).

2. Changes connected with heating above 1100°C—growth of grains resulting in coarse grained pearlite or bainite structure with marked widmanstatten texture. This structure as such is disadvantageous, mainly on cyclic stressing. Besides it always contains a certain amount of residual austenite or martensite.

3. The structure has an influence of alloying elements nitrides (e.g. Ti X, NbX, VX, etc.) which should not be neglected. These elements give fine grained structure, harden the ferrite and plasticity is improved by combining the interstitial nitrogen in the stable nitride or carbo-nitride phase. In electroslag welding nitride particles dissolve in the superheated zone and can not fulfil their original purpose.

4. The parent metal influences the weld metal structure and properties by transferring P & S to the weld metal (if these impurities are in excess) with negative consequence and because the weld metal crystallises epitaxially in the superheated zone,

it inherits its coarse grained structure. Hence Electroslag welding steel should contain a low amount of impurities such as sulphur, with a high melting temperature of MnS inclusions and should resist the growth of the grains in the superheated zone.

Operation of Electroslag Process

The electroslag welding process is only stable when a weld pool of adequate size and heat content has been established. Once the process has been established it should continue without any interruption because it is impossible to restart welding without introducing severe defects. The maximum time for which welding may be stopped is one minute[5]. At the beginning of each weld, a U shaped run-on plate is provided at the bottom. Welding is started by striking an arc from the electrode wire to the root of the run-on plate with a small quantity of flux. As the temperature builds up, more flux is added and the molten slag periodically quenches the arc which is reignited as the wire short circuits the plate. After a series of such flashes, current conduction begins through the slag and the process is under way. An adequate depth of molten slag ensures that arc is quenched and that current conduction is by electric resistance.

The equipment for Electroslag welding consists of a wire feed mechanism mounted on a vertical column which pulls electrode wire from coils and pushes it through a wire guide into the bath of molten slag. Oscillation of wire in the horizontal plane ensures uniform distribution of heat and weld metal. The molten metal and slag is supported by copper shoes. The copper shoes are water cooled and supported against the metal surface by springs or similar means. Adjustment of the shoes consequent upon a leak requires a certain amount of care and experience.

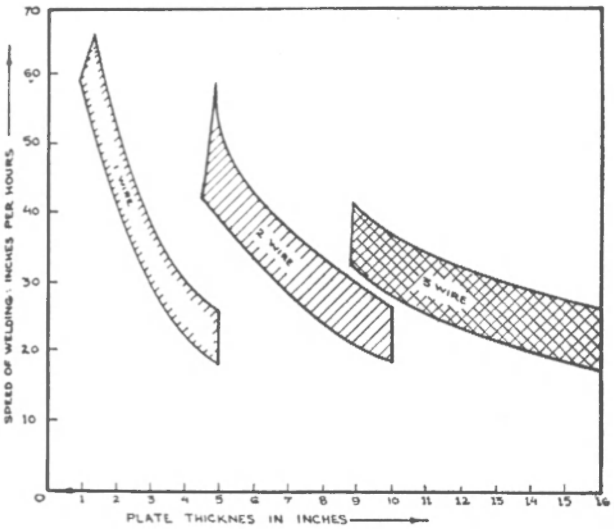

FIG 5 WELDING SPEED RATE FOR PLAT THICKNESS UPTO 16",
USING 1, 2, & 3 WIRE OPERATION

A separate welding power unit provides required current. One terminal of the power unit is connected to the wire guide and the other terminal is connected to the work. A flux hopper is provided for use in maintaining the desired height of the slag bath. For heavy plates more than one electrode can be used and deposits of 105—135 lbs/hr.[2] of weld metal can be obtained. Using a joint spacing of 1⅛", the rate of welding is shown in *Fig. 5*[2]. Heavy plates ranging from 3" to 12" in thickness are completely welded at a speed of 2 to 4 ft. per hour.

Special Features of Electroslag Welding

The technological features of Electroslag welding, which distinguish it from all other welding processes and have made it the preferred method for jointing heavy plates in a number of countries are discussed below :

1. Increase in efficiency compared to arc welding and other methods of multilayer welding processes.

2. There is little trouble due to porosity because gases have ample time to escape due to slow speed of solidification of the molten weld pool.

3. There is no hot cracking with proper thermal cycle which gives pre and post-heating to the weld.

4. The risk of cold cracking in the parent metal is greatly reduced because of slower rate of heating and cooling.

5. Distortion is eliminated due to symmetrical edge preparation and simultaneous welding of the entire metal thickness.

6. Gas content, slag entrapment and non-metallic inclusions are sharply reduced.

7. High homogeneity of the weld deposits.

Applications

Electroslag welding is a basic method for heavy sections of different metals and alloys in repairing and fabrication. Electroslag welding is most often employed for the production of pressure, reactor or other vessels with wall thickness of more than approximately 50 mm. The process may be mechanised for the welding of sections varying in thickness between ½ in. and 6⅓ ft.[7], these being the limits which have so far been achieved in production. It is most economical in joining metals greater than 2 in. thick. In structural work any high speed of welding can be chosen without causing hot cracking but in pressure vessels and similar works the speed is adjusted to suit the condition which yields optimum mechanical properties with particular reference to grain size and notch ductility. The process is very well adopted for carbon and structural steels, titanium alloys and cast irons. Medium alloy steels may be welded satisfactorily with proper post-heat treatment, the high rate of dilution being an advantage. High alloy steels are welded successfully without edge preparation and with the help of proper fluxes to minimise oxidation. Thick sections of titanium are welded with special flux of higher melting point and flushing the slag bath surface with argon.

The process is widely used for welding boiler drum and downcomers, press frames, large shafts, open hearth furnace frames, parallel side valves, ship hull structures and many other similar applications.

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