Some Aspects of Submerged Arc Welding Process

By H. SRINATH*

Summary

Many of the present day advances in industry would not have been possible without modern welding technology and it is certain that this will continue to be so in future. Among the many advantages offered by fabricated constructions, reduction in weight, possibility of material combinations, flexibility in design and higher resonant frequency are significant. The optimum performance of welded vessels and structures in service necessitates the full exploitation of automatic welding processes. Of all the welding processes, submerged arc welding occupies a prominent place on account of its inherent versatility. It has been employed successfully in the fabrication of boilers, unfired pressure vessels, automobile parts, machinery frames etc. Also, it finds application in hard surfacing aimed at providing greater wear resistance, corrosion resistance etc.

The weld form, which gives an indication of the size and shape of the weld is a measure of the quality of the welded joint. It is characterized by two form factors which are defined as the ratios of the width of weld to re-inforcement of weld (outerweld form factor) and the width of weld to penetration (inner weld form factor). A host of parameters affect the above and an intimate knowledge of the manner of their influence is essential to ensure a sound weldment.

It may be noted that, in general, the welding current has a pronounced effect on the penetration and the reinforcement whereas the arc voltage has no perceptible influence on the penetration. Further, too low a welding speed results in a wider and shallower weld. Whereas the combination of high welding currents and low welding speeds results in the formation of broad and shallow welds, the combination of high welding speeds and low currents results in a narrow and peaky weld. It is apparent from the above that the main concern of the technologist should be to select proper combination of current and speed between the limits of low current—low speed and high current—high speed.

This article highlights the influence of welding current, welding speed, design of groove, type of backing etc. on the weld shape obtained in automatic submerged arc welding of steel plates. Also, the influence of the other mechanical, electrical, positional and physico-chemical factors on the process is reviewed. It is shown that the proper selection of process parameters is essential in order to ensure a sound weldment.

Introduction

Technological advances in the engineering industries have made it imperative to develop automatic welding processes capable of welding plates economically. Automatic welding process is particularly suitable for

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high welding speeds on heavier sections requiring a large volume of weld metal to be deposited.

Submerged arc welding process, which is one of the most widely used automatic welding processes, utilizes the intense heat generated by an electric arc between a copper coated wire electrode and the work, while the welding zone and the arc are shielded by a blanket of granular, fusible material. The characteristic advantages of the process are the smooth deposits and freedom from fumes and spatter. Multi-electrode and multi-power techniques provide for greater deposition rates. Yet another variation of the process is the utilization of flux-cored electrode under a layer of flux.

In this article, the influence of mechanical, electrical, positional and physico-chemical factors on weld form is outlined. Besides, an attempt is made to summarize the current investigations in the field of submerged arc welding.

The weld form which gives an indication of the size and shape of the weld is characterized by two factors viz. inner weld form factor and outer weld form factor. They are defined as—

Inner weld form factor $\psi = \frac{d}{t}$

and Outer weld form factor $\phi - \frac{d}{h}$

where b—width of weld, t—depth of penetration and h—reinforcement of weld.

It has been found that the best values of ψ and ϕ in joining metals should be between 1.3 and 2.0 and 7.0 and 12.0 respectively[1].

There are many factors that affect the weld form and the same may be grouped into the following categories :

(1) Mechanical factors
(2) Electrical factors
(3) Positional factors
and (4) Physico-chemical factors.

Mechanical factors : The movement of the electrode along the groove must be uniform and the electrode must not shift across the groove. Failure to ensure the above requirements would result in the arc being struck with the fusion faces and hence, may lead to irregular weld profile.

The mechanism for straightening the electrode must be placed in the plane of the weld since the effect of "spring back" would then manifest along the groove. This requirement is essential, particularly when narrow and deep grooves are employed.

The length of the electrode projecting beyond the nozzle, referred to as "Electrode extension", has a bearing on the weld form. Specifically, the reinforcement and penetration of the weld decrease with the increase in "electrode extension". The magnitude of "electrode extension" is specially important in circumferential welding. It has been established that the 'electrode extension' should not exceed ten times the electrode diameter and the usual value is 5 to 6 times the electrode diameter[2].

Slippery contact between the wire and the walls of the nozzle results in the wire getting excessively hot and the wire melts non-uniformly with the result that the weld profile becomes irregular.

Electrical factors : The fluctuation in supply voltage has more pronounced effect on weld form in the case of drooping characteristic machine than in the case of self-regulated machine.

Arc voltage : Increase in arc voltage results in a longer arc and the resulting weld is wider and shallower. Periodic fluctuations in arc length will lead to a weld with irregular profile and with slag inclusions. Reinforcement falls off with increase in arc voltage. Besides,

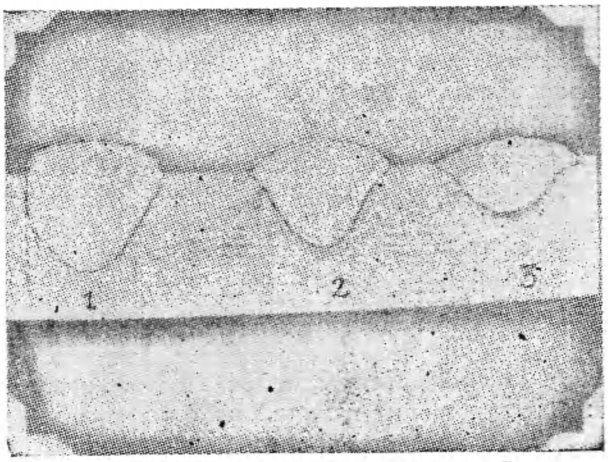


Fig. 1. Effect of current on weld from Dia, of wire-5.0mm, Type of Flux-VUZ 42 mn. Bead 1. 1000A 55mm/hr. 38V ψ=2.85, ϕ=4.17, Bead 2. 850A 55mm/hr. 35V ψ=1.88, ϕ=4.29, Bead 3. 725A 55mm/hr. 35V ψ=2.69, ϕ=5.92.

the consumption of flux increases with arc voltage. The decrease in penetration with the increase in arc voltage is explained by the fact that a portion of current is shunted across the molten flux and hence less current is available for penetrating the base metal.

Welding current : As current density increases the penetration and reinforcement of weld increase (Fig. 1). If current is increased beyond a certain value, there is a tendency for undercutting. Besides, the percentage of base metal in weld metal increases as current density increases and this effect is more pronounced if the current density is higher. As the diameter of electrode increases with the current remaining at the same value, the penetration falls off and the width of weld increases.

With low voltage and high current, the removal of gases generated becomes difficult, and the resulting weld will be porous and will have cracks.

Positional factors : The welding speed has a predominant effect on weld from (Fig. 2). In low speed welding, the cavity in which the arc burns has a big volume and the molten pool is large. This results in a wide and shallow weld. With the increase in speed (upto 12.0 metres/hr), the extent of molten metal under the arc is smaller and the penetration greater. By increasing the welding speed further, the welds will be

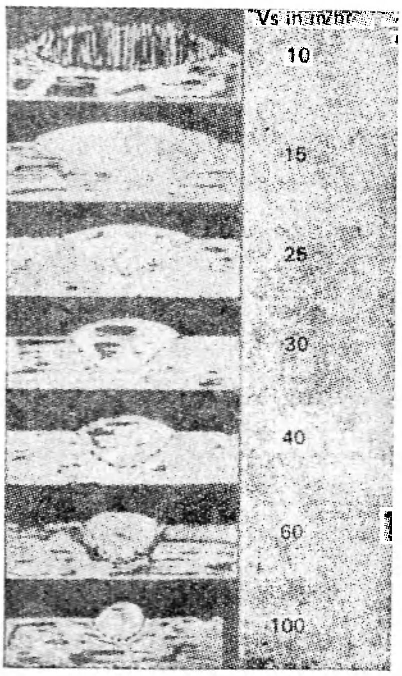


Fig. 2. Influence of welding speed on weld metal.

smaller in width and depth since the duration of arc action is reduced. Between certain values of the welding speed, which depend on the type of the flux, penetration is constant. Too slow a welding speed will cause undercutting, bad shape and irregular appearance of the weld. Combination of low-speed and high current results in shallower bead as the molten pool is excessively large.

Electrode inclination : When welding with the electrode inclined away from the direction of welding (backward), the component of arc blow in the direction perpendicular to the plane of work is directed towards the work. Hence the resulting weld is deeper and narrower and the weld reinforcement higher.

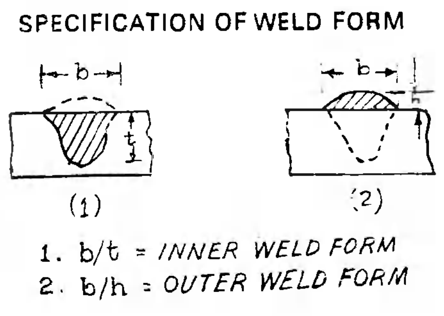
Welding with electrode 'forward' results in wider and shallower weld and this effect is similar to that of increase in arc voltage.

The inclination of the work has a marked effect on the weld form. In the case of 'upwards' welding i.e., welding up an incline, the weld is deeper and narrower. The molten pool flows down in a direction opposite the welding and hence the penetration is high. Besides, the arc below is assisting the motion of molten pool in penetrating the metal deeper. The situation is exactly reversed in the case of 'downwards' welding and hence the resulting weld is wider and shallower.

It may be noted that positioning the electrode ahead of the vertical centre line of work, in case of circumferential welding results in narrower and deeper weld. The directions of arc blow and metal flow are in the direction of rotation of the work piece.

Table 1 summarizes the influence of the welding variables on weld form.

Groove design : Yet another factor which affects the weld shape is the design of the groove. The plate edge preparation for automatic welding must be done with greater care than for manual welding. Also,



INFLUENCE OF THE WELDING VARIABLES ON WELD FORM

Factors influencing the weld form—increasing	*Weld from factors*		
	Penetration *t*	*Width of weld* *b*	*Reinforcement* *h*
1. Welding current A	Intensively increases	Increases	Intensively increases
2. Diameter of electrode or wire	Intensively decreases	Increases	Decreases
3. Arc voltage V	Almost constant	Intensively increases	Intensively decreases
4. Welding speed	Less than 20 cm/min —Increases Between 20 and 60 cm/min —Constant Greater than 60 cm/min —Decreases	Intensively decreases	Intensively increases
5. Inclination of electrode in the direction or welding	Intensively decreases	Intensively increases	Decreases
6. Distance of electrode from nozzle of machine	Slightly decreases	Increases	Decreases

much greater accuracy in alignment of joints and, especially, of edges of root faces is essential to avoid the molten metal running through the joint.

The preparation of grooves is necessitated by the reinforcement desired. The profile of the weld surface should be uniform and there should not be any undercuts. The above requirements are important, specially if the weldment is subjected to fatigue loading[3]. When root gap is not provided there is no room for deposit and hence the reinforcement is more. As groove angle is increased the reinforcement is decreased and the portion of base metal in weld metal is decreased.

With a narrow V-groove, the penetration is smaller if the diameter of the electrode is greater than the width of groove at top. The depth of penetration is increased by increasing the groove angle, or by introducing a gap, or by decreasing the wire diameter. It is found that the penetration is adequate when the radius of curvature of the groove is equal to the diameter of the wire. It may be noted that the groove geometry is determined by the thickness of the base metal, diameter of electrode, number of layers required, arc voltage, arc power and welding speed. A larger groove angle is employed if the base metal contains higher percentage of carbon or alloying elements.

Types of backing : In order to prevent the molten metal running through when welding from one side, weld backing must be provided. The weld backing may be provided by any one of the following :

(1) Closely fitted copper backing bar
(2) Combined flux-copper backing
(3) A strip of the base metal which becomes a part of the joint
(4) Flux
(5) One or two layers of weld metal.

Figure (3) shows the welded 'joint using a copper backing bar. The macro-graph shows the copper pickup clearly. The copper backing bar is unsuitable for weldments exposed to corrosive atmosphere. The combined flux-copper backing is employed when welds are subjected to fatigue loading since the surface finish of the underside of the seam is better in comparison with the welds made by using copper backing bar alone. This method finds wide application for the welding of tubes and vessels.

Fig. 3. Welded joint in 12.0 mm plate made with copper backing. Single V with copper backing. Groove angle 60°, root gap 1.0 mm, root face 3.0 mm, backing bar 50×10 mm, Parameters: 850 A, 35 V, 23.5 m/hr. ψ=1.93, ϕ=10.55 wire Diameter=5.0 mm Flux= VUZ 42 Mn.

Welding of thick plates : X-type and Y-type of groove designs are adopted for the welding of plates whose thickness exceed 15 mm. In X-type of design, the side having smaller 'V' is welded first using smaller current values. The geometry of groove as a function of thickness is shown in Fig. (4). 'Y'-type of grooving is best suited for plate thicknesses between 30 mm and

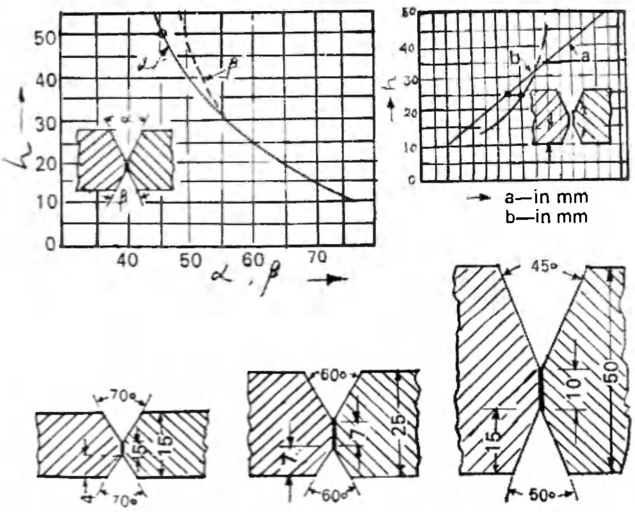


Fig. 4. X joint details for welding from both sides [Extracted from 'Symposium in welding' part II, 1953 (Czechoslavac)].

32 mm. It is uneconomical to adopt 'Y' type of grooving for thicknesses exceeding 40 mm, since it is difficult to get good penetration. It may be noted that for thicknesses greater than 30 mm 'Y' type joint requires more material than X type joint. Figures (5) and (6) show the welded joints obtained with incorrect and correct combination of welding variables.

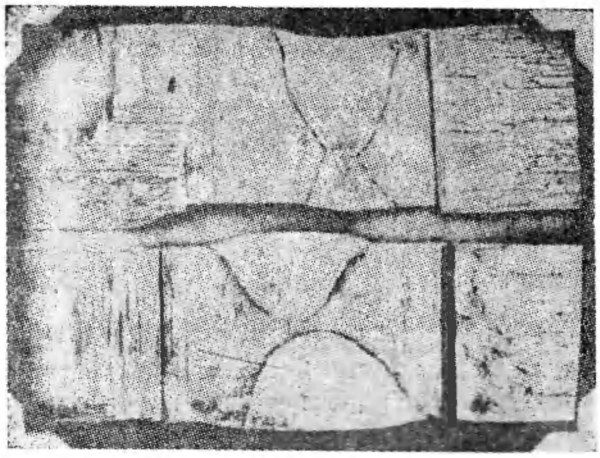


Fig. 5. Y and X joints in 25.0 mm plate. Dia of wire-5.0 mm Flux-VUZ 42Mn. Y-joint-60°, root gap-1 mm, root face 12 mm 800A, 37V, 55.0m/hr, ψ-1.44, ϕ-18.57 950A, 37V, 24.5 m/hr, ψ-1.09, ϕ-No reinforcement X joint-60°, root face 7.3mm, smaller Vee depth 8.0mm 850A, 38V, 32.5m/hr. ψ= 2.10, ϕ=14.6 1000A, 45V, 25.5m/hr. ψ= 2.71, ϕ=20.16.

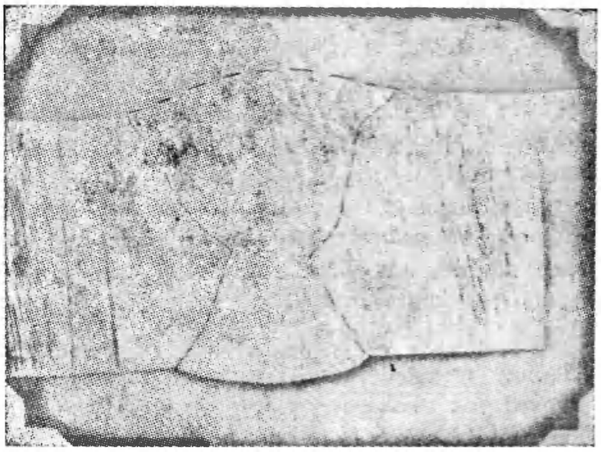


Fig. 6. X joint in 25.0 mm plate 750A, 32V, 29.0m/hr. ψ=1.57, ϕ=9.0 1000A, 37V, 22.5m/hr. ψ=1.6, ϕ=8.0.

It is well known that considerable difficulty is experienced in the welding of thick plates. One of the common defects is the formation of cracks which is due to fairly rapid cooling of the weld metal pool. The design of grooves plays a crucial role in the welding of thick plates. Fig. (7) shows the different types of groove design and the resulting weld form based on the work done in Japan . The advantages of KZ-groove over X-groove are the following :

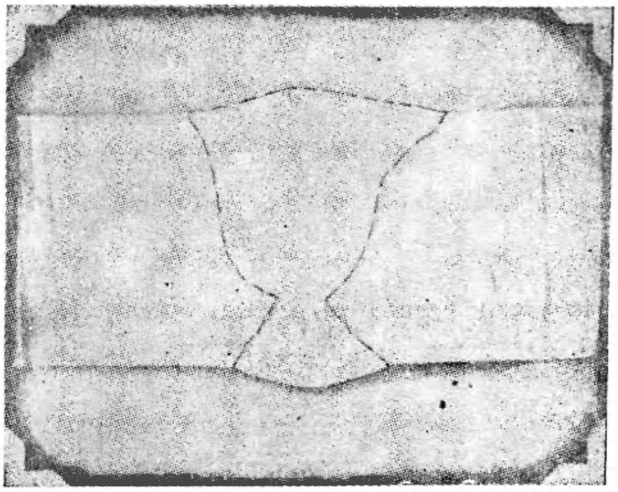


Fig. 6. Y joint in 25.0 mm plate.
800A, 35V, 55mm/hr., $\psi=2.0$, $\phi=6.4$
1000A, 38V, 18.5m/hr., $\psi=1.52$, $\phi=11.20$

(1) The danger of running out of weld metal does not occur since even with very deep penetration the entire base metal acts as a backing. Hence higher currents may be employed.

(2) Machining involved in the preparation of the fusion faces is considerably reduced.

(3) The 'fit-up' of the joint need not be as perfect as in conventional designs. One plate can slide over the other and the root face does not decrease. Besides, the danger of having a gap between plates with consequent running out of weld metal while welding from one side does not occur in KZ design.

It may be noted that KZ-form of grooves may be employed for thicknesses upto 65 mm with current values upto 2000 A.

Physico-chemical factors : The properties of molten metal pool, slag and the gaseous phase under the arc have a pronounced effect on weld form.

The formation ability of the flux, i.e., the ability of the flux in helping to obtain a smooth weld surface with a uniform profile is influenced by the melting point, viscosity and ionising ability of the flux. The formation ability falls off with increasing current. It is to be noted that for circumferential welding and for welding in inclined position fluxes should have higher melting point and higher viscosity in comparison with that for flat position welding.

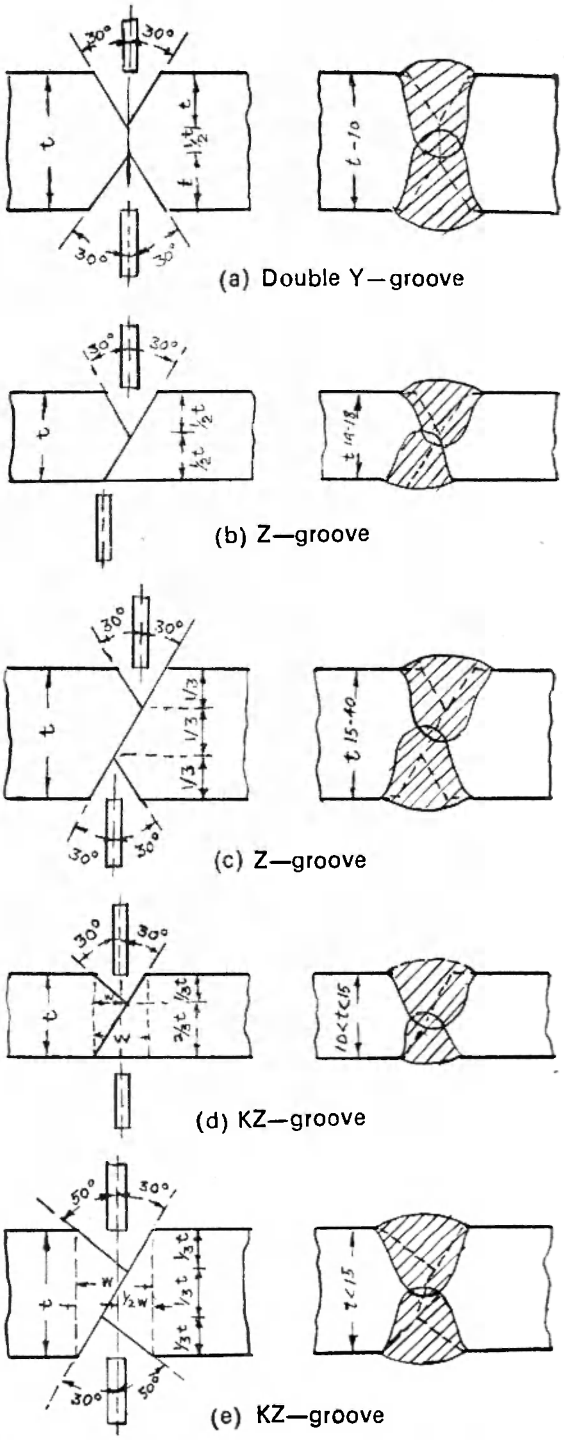


Fig. 7. Different types of Groove form in submerged arc welding.

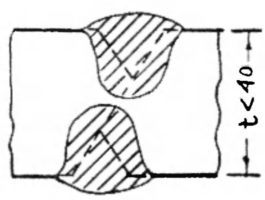


Fig. 7. Disposition of welds of Z-form in thickness exceeding 40.0 mm.

The arc length and stability are influenced by ionisation properties. The application of fluxes with better ionization properties results in broader welds and the conditions for crystallization of weld metal are improved. Besides, the possibility of crack formation is reduced. The resulting weld is liable to be less porous and slag inclusions are avoided.

Fluidity of the molten pool has significant effect. The weld bead will be narrow and peaky when the melt is cooler and less fluid. Combination of high welding currents and low welding speeds leads to broad and shallow welds since the molten pool has higher fluidity. Besides, the penetration is small due to increased volume of melt. The resulting weld may also indicate lack of fusion. The combination of low currents and high welding speeds results in a cooler melt which solidifies more quickly. The deposited bead is narrow and peaky. The weld is likely to be porous since the gases and slag have no time to separate out from the molten pool. It is clear from the above that the chief concern of the technologist is to select the proper combination of current and speed.

The method of granulation of flux and the grain size of the flux affect the weld form. During the manufacture of fused flux, the molten flux is poured into water in the form of jets. If the jet is thick, the resulting flux will be porous and welding with such a flux will lead to a higher content of oxygen and nitrogen in weld metal. Besides, the formation ability of the porous flux is poor.

The use of fine grained flux leads to deeper penetration. Irregularity in weld form and undercutting of the parent metal with unsatisfactory bead formation are the result of using very fine grained flux. It may be noted that width of weld increases as the grain size is increased. The reinforcement and penetration fall off with increase in grain size. Besides, the insulating ability of molten flux increases as the grain size becomes finer. The size of grains determines the surface finish of weld and the current carrying ability. The coarser grained flux melt more slowly and hence gases get released easily. For applications involving higher welding speed and rusty fusion faces, coarser grained flux is recommended. For correct weld profile, the recommended grain size is between 1.0mm and 2.5 mm for electrodes of 5 mm diameter.

Review of some investigations of recent origin :

Based on the investigation of submerged arc weld deposits in Navy Q1 steels using two low alloy steel wires and three fluxes, Smith[5] et. al have concluded that the variation of heat input did not affect significantly the composition, microstructure, tensile and hardness properties of the weld deposits and had only marginal effect on toughness. Besides the toughness of weld deposits depends on the type of flux used.

B. Lindwall[6] has indicated the joint preparations and welding parameters for the submerged arc welding of ferritic-pearlitic steels used for cryogenic purposes. The impact requirement of 41J at —55°C in the weld metal can be met with a wire/flux combination consisting of a $\frac{1}{2}$% Mo wire (DIN S3 MO) and an agglomerated, non-manganese alloying basic flux (DIN 12b45). Besides, by choice of suitable joint preparations and the use of a high current in combination with a low voltage and high travel-speed, welding can be done with a relatively low number of weld passes without exceeding the critical heat input. For example, welding of a 25 mm thick plate with parameters at 725-775 A, 28-30 V, 12-13 mm/sec and 6 layers would involve a heat input of 1.5 to 1.6 KJ/mm.

J. G. Garland[7] has examined the various approaches to the physical control of submerged arc weld pool solidification. It may be noted that the suppression of columnar growth is essential to reduce the solidification crack susceptibility. One of the methods of controlling the weld pool solidification is by the use of a second, relatively low powered trailing arc deliberately situated immediately ahead of the advancing solidification front. The application of large amplitude modulation to this arc would cause marked changes in the rate of advance of the main solidification front in the weld pool and such perturbations to the growth process can act as effective source of solidification nuclei.

Another approach involves the application of high energy vibrations to a consumable wire fed into the rear of the pool immediately ahead of the interface. Owing to the large energy losses associated with transmitting vibration, this approach is not attractive commercially.

Chemical refinement of mild steel submerged arc weld pool solidification by inoculation is basically an attractive approach but the 'defect' is low impact properties obtained to date. The problems to be studied are :

(1) The use of rare earth additions to desulphurise the pool.

(2) The use of TiB_2 instead of TiC. and (3) The effect of inoculating low sulphur weld metals with a Fe-Ti/Coarse TiC.

Garland concludes that the chemical refinement of submerged arc welds using inoculants is more promising and Fe/TiC additions produced marked refinement of the 'as—solidified' grain size in the weld bead.

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