Influence of Flux Basicity on Weld Bead Geometry and HAZ in Submerged Arc Welding

by S.R.Gupta* & Navneet Arora**

Weld bead geometry and heat affected zone which are generally dependent on the welding parameters may also be influenced by the chemical composition of flux i.e. the flux base and its basicity in submerged arc welding. The different flux constituents which impart different physical/chemical properties to the flux may also affect the weld bead geometry and heat affected zone.

Investigation have been carried out to study the combined effect of welding parameters and flux basicity which is one of the measure for chemical nature of the flux on weld bead geometry and heat affected zone in the case of mild steel.

It has been found that the welding parameters and flux basicity appreciably influence the depth of penetration and the weld bead width. The reinforcement is also influenced by the welding parameters, however, flux basicity does not seem to affect reinforcement appreciably.

The widths of heat affected zones at the centre line of the weld bead and at the toe of the weld are appreciably influenced by the welding parameters. Higher basicity fluxes generally give rise to lower width of heat affected zones as compared to low basicity fluxes.

INTRODUCTION

The weld bead geometry and heat affected zone are affected by a number of variables such as welding current,welding voltage,welding speed, electrode size and extension, width and depth of flux and the nature of flux in the case of Submerged Arc Welding. In addition to above the heat affected zone is also influenced by the thickness of the base material, thermal conductivity of the base material, as well as the initial temperature of the base material.

From the available literature it has been found that the influence of the chemical nature of the flux i.e. flux basicity as well as welding parameters on weld bead geometry and heat affected zone have not been systematically investigated. Therefore, experimental investigations have been carried out to evaluate the influence of welding parameters and flux basicity on weld bead geometry and the width of heat affected zones at the centre line of the weld and toe of the weld in submerged arc welding in case of mild steel over a selected range of welding parameters with different fluxes having different basicity.

BRIEF LITERATURE REVIEW

The influence of various welding parameters which affect the weld bead geometry, have been studied by various investigators. It has been reported that the welding current controls the rate at which electrode melts, dimensions of the weld bead, flux consumed and the amount of base metal melted. Increased welding current increases the penetration, the reinforcement and the melting rate. Weld bead width also increases with the welding current, reaches a maximum and then remains constant or decreases [1,2].

Increases in the welding voltage produces a flatter and wider bead, increases flux consumption and tends to reduce porosity. Excessively high or low welding voltages may produce undesirable bead and slag removal may be difficult [1,2].

Increase in the welding speed reduces the heat input per unit length of the weld, consequently, the weld reinforcement, penetration and weld width decrease.

A smaller diameter electrode has high current density and higher deposition rate than a large diameter electrode at any given current level. Penetration decreases with the increase in electrode diameter at constant current because of reduced current density. Further, the increase in electrode extension leads to decrease in bead width and penetration and increase in the bead convexity [1-3].

Flux constituents affect the flux properties which in turn affect weld bead geometry and shape. Influence of some major constituents of the submerged arc welding fluxes is given below:

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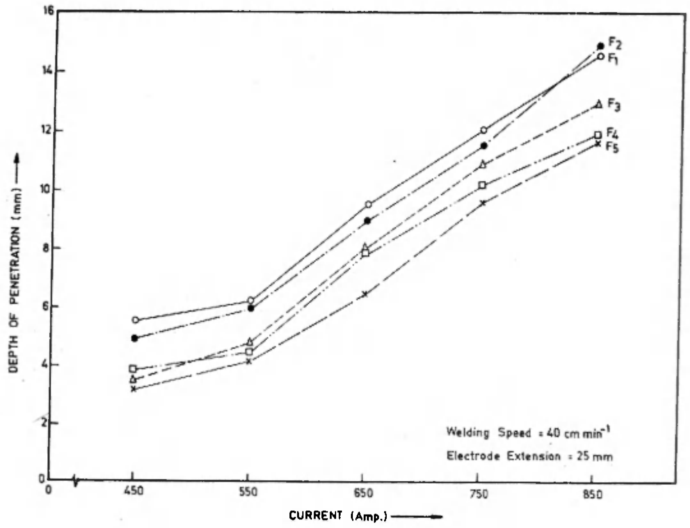

Fig. 1. *Influence of welding current on depth of penetration at welding voltage 26V.*

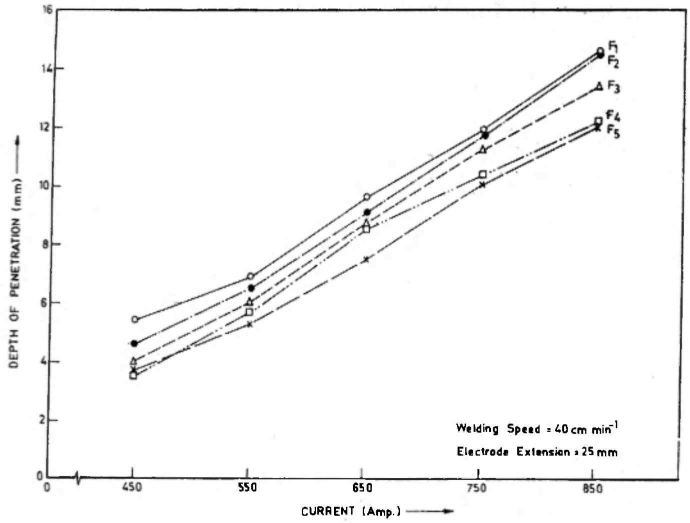

Fig. 2. *Influence of welding current on depth of penetration at welding voltage 30V.*

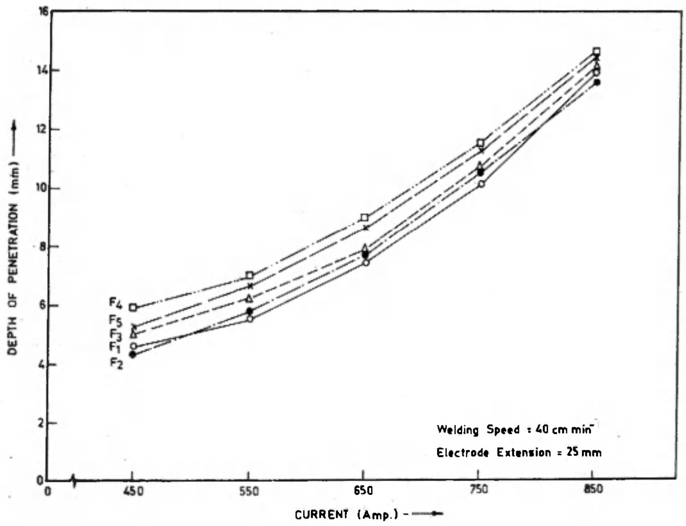

Fig. 3. *Influence of welding current on depth of penetration at welding voltage 34V.*

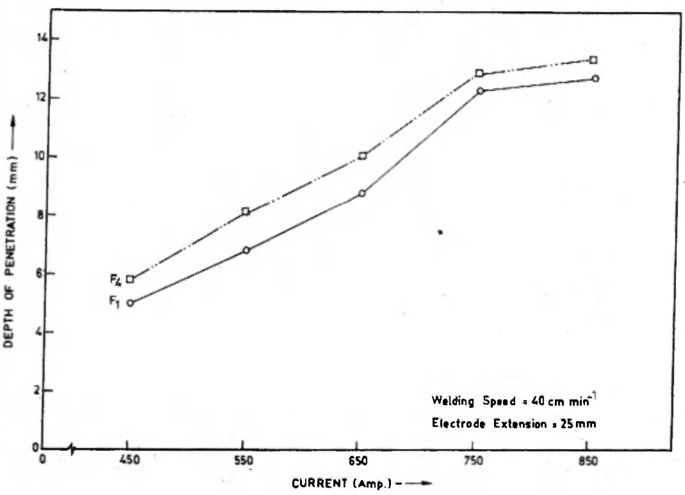

Fig. 4. *Influence of welding current on depth of penetration at welding voltage 38V.*

Table 1. Fluxes with their Chemical Composition and Basicity Index

Flux	Type of Manufacture	% Chemical SiO_2+TiO_2	Comosition $CaO+MgO$	Al_2O_3+MnO	CaF_2	Basicity Index
F1	FUSED	35	35	25	-	1.2
F2	FUSED	30	25	35	10	1.4
F3	FUSED	20	30	20	20	2.5
F4	AGGLOMERATED	15	35	20	25	3.1
F5	AGGLOMERATED	SiO_2=10%	30	20	35	3.5

Silica (SiO_2) which is one of the important ingredient of submerged arc welding fluxes, decreases the width depth ratio i.e. higher penetration [4,5].

MnO leads to alloying of Mn into the weld metal by reduction reaction and favours higher welding speeds and deeper penetration [5-7]. Basic constituents like CaO, $CaCO_3$, CaF_2 produce shallow penetration, however, MgO leads to deep penetration [5,8].

Sodium, potassium salts and other elements which improve arc stability and reduce cathode spot wandering, generally increase penetration [4].

In addition to chemical properties of the flux, physical properties also affect weld bead geometry e.g. larger grain size of flux can give rise to lumped peaky weld bead with increased penetration, lower the surface tension of the molten flux better the weld appearance. Further, a flux with a high viscosity will tend to confine the molten weld pool, thus increasing the heat input for a given area and resulting into deeper penetration [4,9].

Due to severe thermal cycle during welding, original microstructure and properties of the metal in region close to the weld are changed. This volume of the metal or zone is usually referred as heat affected zone (HAZ) and is influenced by heat input, thickness, initial temperature and thermal conductivity of the base material [10].

Heat input and cooling rate which depend on welding parameters and type of flux i.e. its properties, play major role in deciding the extent of HAZ, microstructure and hardness. HAZ width is increased when preheating is offered. Higher cooling rate leads to smaller HAZ width, while slow cooling rate leads to larger HAZ widths [10, 11].

EXPERIMENTAL PROCEDURE

For carrying out the investigations five commercial fluxes of different basicity indices were selected. The approximate composition, basicity indices and manufacturing type are given in the Table I.

Beads on plates were deposited using different fluxes on mild steel plates containing 0.22% carbon, and 1.0% manganese at different setting of welding parameters, the details of which are given below:

Welding current 450-850A in steps of 100
Welding voltage 26-34 V in steps of 4
Welding speed 40 cm min^{-1}
Electrode extension 25 mm
Flux height 50 mm

Welding was carried out with 4 mm diameter eletrode wire containing 0.12% C, 1.8% Si. The transverse sections of the weld bead were taken from the portions where stable beads were obtained i.e. neglecting the cold start length and crater portion. The depth of penetration, weld bead width and reinforcement were measured with the help of microscope. The width of HAZ were measured at two different regions i.e. along the central line and at the toe of the weld.

RESULT AND DISCUSSIONS

Weld Bead Geometry

Fig. 1-4 show the influence of welding current on the depth of penetration for different fluxes. From the figures it can be observed that:

(1) The depth of penetration increases with the increase in welding current over entire investigated range.

(2) Fluxes with lower basicity lead to higher depth of penetration upto 30 V as compared to the fluxes having higher basicity. However, for 34 V the penetration is lower with fluxes having lower basicity.

(3) Gap between the curves corresponding to different fluxes decreases with the increase in the welding voltage.

The increase in penetration with the increase in welding current is an established fact. With the increase in welding current the energy input per unit length of weld seam increases if other welding parameters are not changed. Though large part of energy may be consumed in the melting of more flux and electrodes wire, still a part may be available for melting large amount of parent metal thus leading towards increased penetration.

For flux F1 (Basicity index (B.I.-1.2) the penetration is almost highest over the entire range of welding current for 26 and 30 V welding voltage, while for fluxes F4(B.I -3.1) and F5 (B.I. -3.5) it is lower over the entire range of the welding current . However, this trend is reversed with 34 V welding voltage. To get further clarification about this phenomenon, welding was carried out at 38 V with two fluxes F1 & F4 and results are shown in Fig.4, where the penetration is also lower with flux F1. This indicates that the phenomenon has changed somewhere between 30 & 34V. It is very difficult to assign any specific reason for this changed behaviour of fluxes F1,F4 & F5. However, on the basis of previous work (12) the

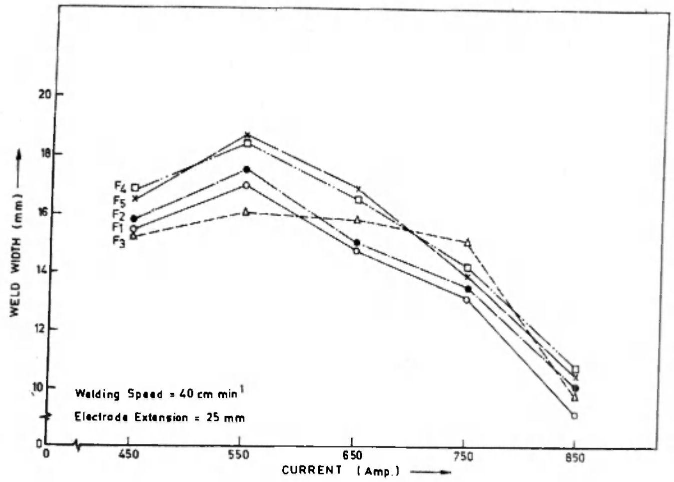

Fig. 5. *Influence of welding current on weld width at welding voltage 26V.*

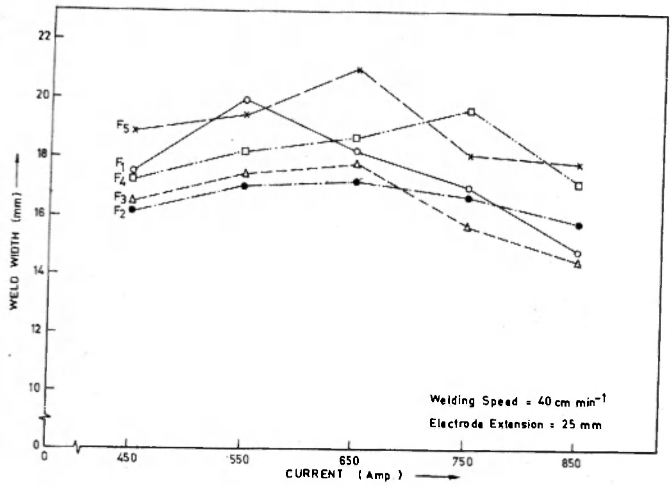

Fig. 6. *Influence of welding current on weld width at welding voltage 30V.*

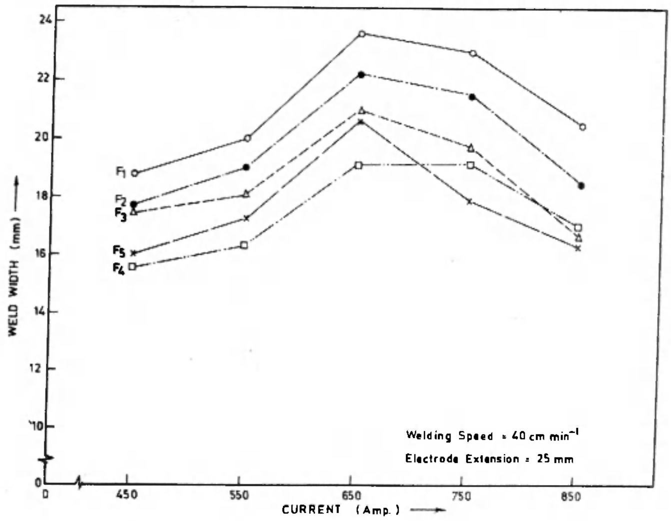

Fig. 7. *Influence of welding current on weld width at welding voltage 34V.*

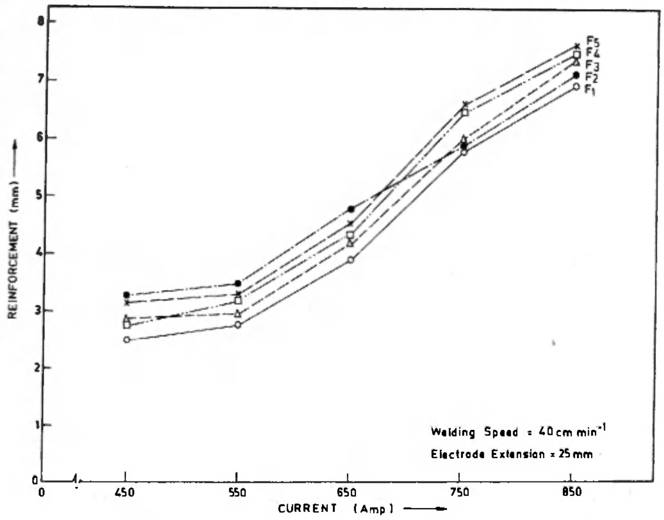

Fig. 8. *Influence of welding current on reinforcement at welding voltage 26V.*

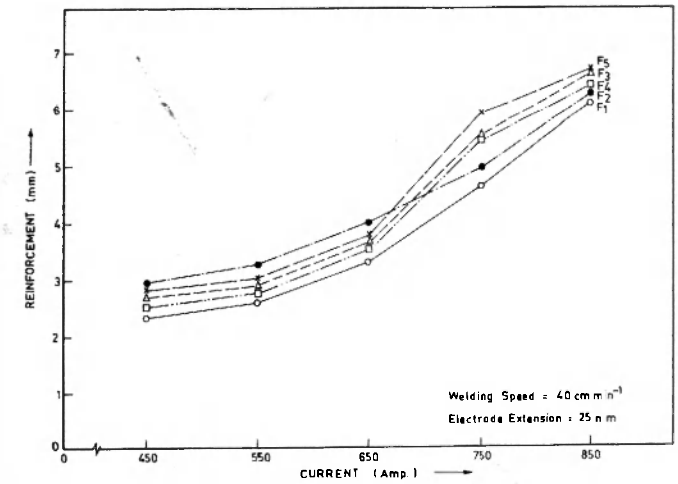

Fig. 9. *Influence of welding current on reinforcement at welding voltage 30V.*

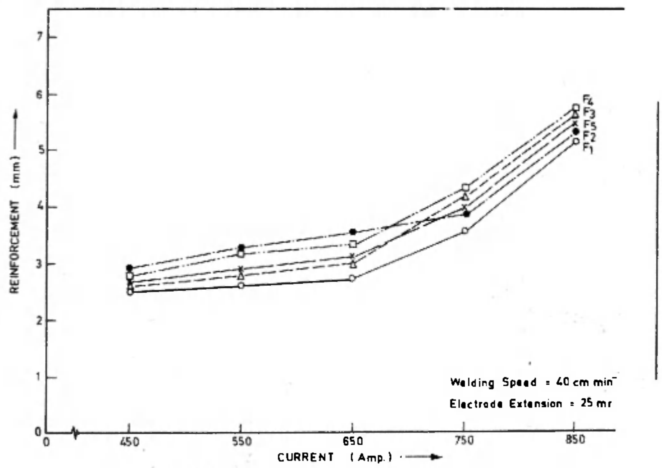

Fig. 10. *Influence of welding current on reinforcement at welding voltage 34V.*

possible reason may be the amount of flux consumed per Kg of weld metal. It has been reported that with the increase in welding voltage the flux consumption for both fluxes F4 & F5 does not increase appreciably with the increase by about 0.045 Kg/Kg of weld metal per volt, while for flux F1 it increases appreciably and is 0.155 Kg/Kg of weld metal per volt. This indicates that the heat consumed for the melting of flux increases appreciably for flux F1 as compared to F4 & F5 with increase in the welding voltage. This results into lesser heat available for the melting of parent metal when welding with the flux F1 at higher voltages and thus the reduced depth of penetration.

At lower voltage, it seems that the influence of heat consumption for melting of fluxes is not dominating but the influence of flux constituents is a dominating factor. That is why the fluxes with lower basicity give higher penetration and the larger gap between the curves at lower welding voltages. With the increased welding voltage, flux consumption increases, and because of higher rate of consumption with flux of lower basicity, the depth of penetration reduces relatively which leads to reduction in the gaps between the curves. With further increase in the welding voltage, the gap further reduces and ultimately reverse trend is obtained.

Figs. 5-7 show the influence of welding current and voltage on the weld bead width for different fluxes. From the figures it can be observed that:

1. The bead width increases with the increases with the increase in the welding current upto a certain current level and then decreases for all values of welding voltages.

2. The bead widths obtained are lower for fluxes of lower basicity at lower welding voltages, while the trend changes for higher welding voltage i.e. 34V. The trend for flux F3 is not very clear and it is difficult to give any comment at this stage.

3. The bead width increases with increase with increase in the welding voltage over the entire range of investigation for fluxes F1, F2 & F3. However, for highly basic fluxes F4 & F5, the width first increases with increase in the welding voltage and then decreases.

4. The difference between the width of weld beads for different fluxes at a particular current level increases with increase in the welding voltage.

5. The current level at which maximum width is obtained,invariably increases with increase in the welding voltage for all the fluxes.

The increase in the weld width with increase in the welding current for a particular voltage may be due to the heat supplied by arc. However, with further increase in the current, the arc may become shorter and too penetrating leading to the increased depth of penetration but the reduction in the weld width. Further,the increased amount of molten flux around the arc shall try to constrict the arc specially at the surface of the plate where molten flux tries to get accumulated. This may also reduce the width of weld bead.

The amount of above mentioned arc constriction shall depend on the fluidity and amount of the molten flux as less viscous flux shall flow down in larger amount,leading to larger constriction of the arc and more viscous molten flux shall lead to lesser constriction of the arc. This phenomenon is more dominating at higher welding voltage as compared to lower voltage.

Figures 8-10 show the values of reinforcement of weld beads for different welding currents and voltages for different fluxes. From the figures it can be observed:

1. The reinforcement increases with increase in the welding current for all the fluxes.

2. The reinforcement decreases with increase in the welding current for all the fluxes.

3. No significant increase in reinforcement is observed upto welding currents 550A, 650A & 750A for welding voltages 26V, 30V & 34V respectively. Beyond the above mentioned current levels for a particular welding voltage reinforcement increases appreciably.

4. No definite trend of reinforcement with respect to basicity is found within the range of investigations.

The increasing trend of reinforcement with increase in the welding current and decreasing trend with increase in the welding voltage are well established facts which have been observed. However, the occurance of appreciable change in reinforcement beyond a particular welding current level for a particular welding voltage is due to gradual increase in the weld width upto that level. Beyond the above mentioned current levels the appreciable change in reinforcement may be caused due to appreciable decrease in the weld width as well as increased amount of electrode melting in most of the cases as discussed earlier.

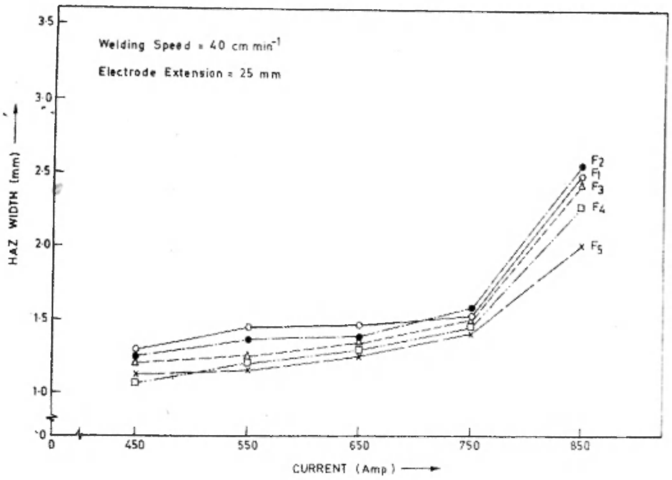

Fig. 11. *Influence of welding current on width of HAZ (at centre line of weld bead) at welding voltage 26V.*

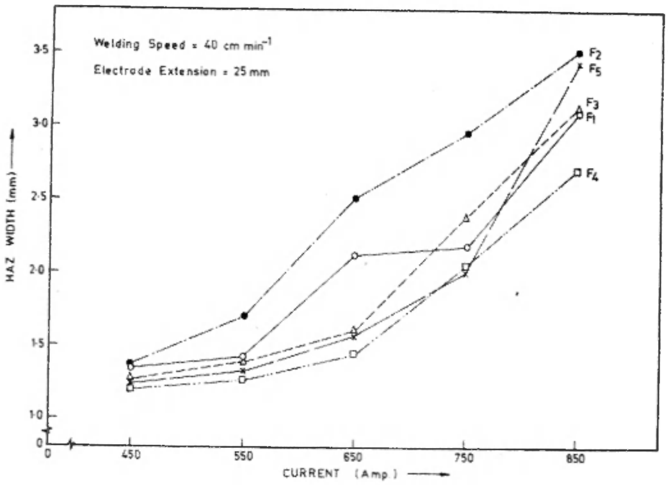

Fig. 12. *Influence of welding current on width of HAZ (at toe of weld) at welding voltage 26V.*

Width of HAZ at Centre Line and at Toe Of Weld:

Figures 11 & 12 (which are representative figures) give the influence of welding current on width of HAZ at the centre line of weld bead and at the toe of the weld respectively at 26, 30 and 34 V welding voltages. It has been observed that the HAZ width at centre line:

1. Increases with increase in the welding current for all fluxes at different welding voltages.
2. Decreases with increase in the welding voltage for low basicity fluxes for lower current range i.e. upto 550A, and beyond 550A first increases then decreases with increase in the welding voltage and increases for the high basiciy fluxes in most of the cases.
3. Decreases invariably with the increase in the basicity of the flux for particular setting of the welding current at 26V and 30V welding voltages, however,trend changes for 34V welding voltage.

The width of HAZ at the centre line seems to be directly influenced by the depth of penetration i.e. higher the depth of penetration more is the width of HAZ. This seems to be reasonable because higher depth of penetration, normally means larger melting of the parent metal by higher rate of heat input, which should increase the width of HAZ at the centre line unless some fast cooling is provided by the weld backing. In our case we have not provided any weld backing like Cu-plate etc. and the thickness of the used plate is also reasonably large i.e. 20mm, so the higher heat seems to increase the width of HAZ.

Further, with the fluxes with higher basicity indices where we have observed that the depth of penetration increases with increase in the welding voltage, the width of HAZ also invariably increases. Also, for fluxes with low basicity indices where the depth of penetration increases with increase in the welding voltage 26 to 30 V and then decreases for 34 V, the HAZ width follows the same trend beyond the level of 550A. However, in the low current range i.e. upto 550A, the HAZ width invariably decreases with the increase in the welding voltage. It is difficult to assign any specific reason for such behaviour of the fluxes F1 & F2.

Further, it is also observed that the HAZ width at toe of the weld:

1. Increases with increase in the welding current for all the fluxes.
2. Increases invariably with increase in the welding voltage for low basicity fluxes. However, for high basicity fluxes in most of the cases it first increases with increase in the welding voltage and then decreases with increase in the welding voltage and then decreases with the further increase in the welding voltage to 34 V.
3. Is having no definite trend w.r.t flux basicity except that lower values of HAZ are observed with highly basic fluxes in many cases as compared to low basicity fluxes in lower welding current range.
4. Increases appreciably at 850A welding current for all welding voltage for all fluxes. Under these conditions it has also been found that the weld width appreciably decreases as discussed earlier.

The increase in the width of HAZ with increase in the welding current can be attributed to the fact that the rate of heat input increases with increase in the welding current. The different widths of HAZ obtained with different fluxes at the same welding parameters may be due to different proportions of heat shared by the molten flux and weld metal.

CONCLUSIONS

On the basis of the results of experimental investigations the following conclusions can be drawn:

1. The depth of penetration increases with increase in the welding current and the fluxes with lower basicity give rise to higher depth of penetration upto 30V. However, if welding voltage is increased the depth of penetration is reduced with fluxes of low basicity as compared to the high basicity fluxes.

2. The weld bead width increases with increase in the welding current upto a certain current level. This current level is dependent on the type of flux and welding voltage. With the further increase in welding current the weld bead width decrease for all fluxes at different welding voltages.

3. The current level at which maximum weld width is obtained increases invariably with increase in the welding voltage for all fluxes.

4. Smaller bead widths are obtained with fluxes of lower basicity upto 30V. However,at 34 V welding voltage this trend changes i.e. smaller bead widths are associated with fluxes of higher basicity indices.

5. The reinforcement increases with increase in the welding current and decreases in the welding voltage. However, flux basicity does not seem to affect reinforcement appreciably.

6. The widths of HAZ at the centre line of the weld bead as well as at toe the weld increase with increase in the welding current. Further, these invariably decrease with the increase in the basicity of the flux for similar welding conditions.

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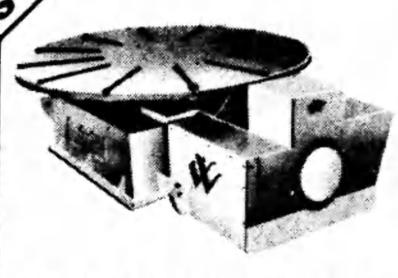

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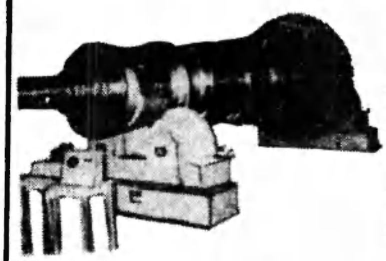

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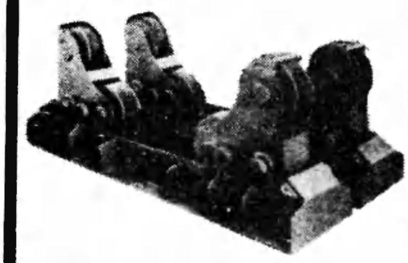

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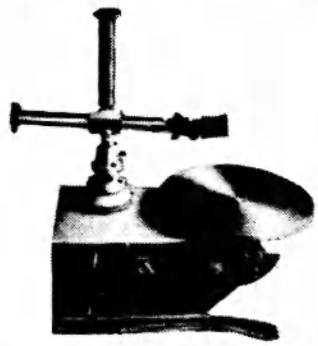

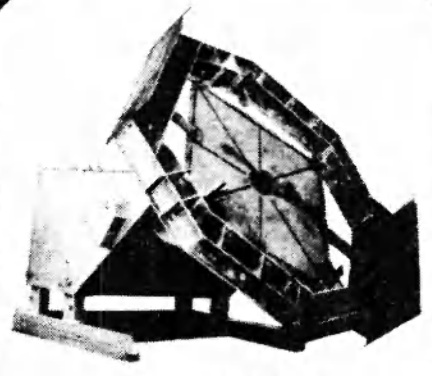

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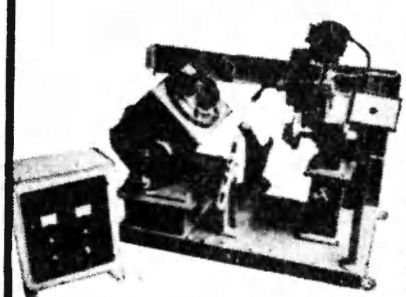

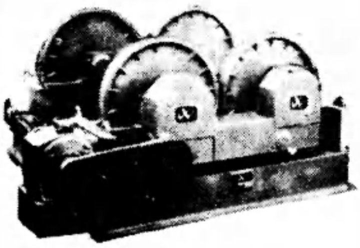

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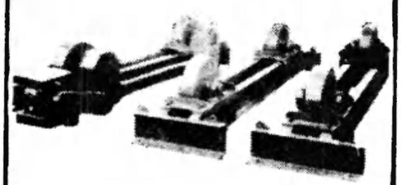

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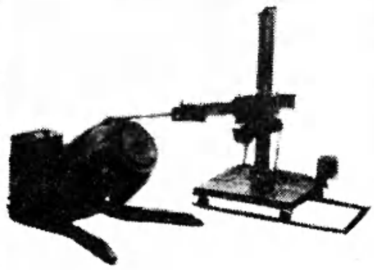

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