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**EFFECT OF PRIMARY WELDING VARIABLES ON
THE MECHANICAL STRENGTH OF MILD STEEL
BUTT WELDED JOINTS USING SUBMERGED ARC
WELDING PROCESS**

A thesis submitted to
**THAPAR INSTITUTE OF ENGINEERING & TECHNOLOGY, PATIALA
(DEEMED UNIVERSITY)**

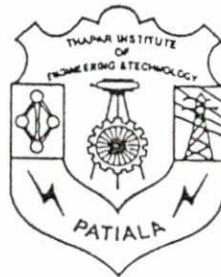
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**Award of the degree of
MASTER OF ENGINEERING
IN
INDUSTRIAL ENGINEERING**

Submitted by
SAHIB SARTAJ SINGH
ME(R) – 8017107

Under the guidance of

Mr. TARUN NANDA
Lecturer
Deptt. of Mechanical Engg.
T. I. E. T. Patiala

Mr AMANDEEP SINGH SHAHI
Sr. Lecturer
Deptt. of Mechanical Engg.
S.L.I.E.T. Longowal



**DEPARTMENT OF MECHANICAL ENGINEERING
THAPAR INSTITUTE OF ENGINEERING AND TECHNOLOGY
(DEEMED UNIVERSITY)**

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Certificate

This is to certify that the thesis entitled, "Effect of primary welding variables on the mechanical strength of mild steel butt welded joints using Submerged Arc Welding process". submitted by Mr. Sahib Sartaj Singh in partial fulfillment of the requirement for the award of degree of **Master Of Engineering (Industrial Engineering)** of Thapar Institute of Engineering And Technology (Deemed University) is an authentic record of student's own work carried out by him under our guidance and supervision.

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(Mr. Tarun Nanda)

Lecturer

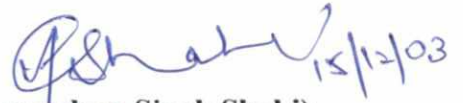
Mechanical Engineering Department

Thapar Institute of Engg. & Tech

(Deemed University)

Patiala-147004

(Supervisor)



(Mr Amandeep Singh Shahi)

Sr. Lecturer

Mechanical Engineering Department

S.L.I.E.T.

Longowal

Distt Sangrur

(Supervisor)

Countersigned



(Dr. R. G. Tathgir)

Professor & Head.

Mechanical Engg. Deptt.

Thapar Institute of Engg. & Tech.

(Deemed University)

Patiala-147004



(Dr. D. S. Bawa)

Dean of Academic Affairs

Thapar Institute of Engg & Tech.

(Deemed University)

Patiala- 147004

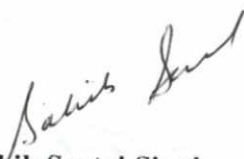
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Abstract

Among the various fabrication processes welding has established itself as one of the leading fabrication processes. Due to its potential competitiveness and versatility it is being used extensively in industries like chemical, fertilizer, agriculture, military, nuclear power, ship-building, aerospace etc. It finds extensive use in the fabrication of structural work like bridges, storage tanks, automobile body shells, pressure vessels etc. Mild steel has become the material of choice due to its good physical and mechanical properties enabling it to withstand various static and dynamic loading conditions. When welding is used as a fabrication process the heat input given to the joint affects the over all strength of the welded joint. This is because the heat input influences the cooling rate which further influences the microstructure and consequently the mechanical properties of the joint. In the present work, an attempt has been made to develop the welding procedure for making butt welded joints possessing adequate mechanical strength using submerged arc welding process. Primary welding variables namely welding current, arc voltage and welding speed, which influence the heat input to the joint, have been identified and their individual effect on the properties namely ultimate tensile strength and hardness has been studied varying one variable at a time approach was used. Correlations have been established between the input and the output variables using Regression analysis (method of least squares) and thus prediction equations have been found out which enable the user to know before hand the output with respect to given input thus saving experimental resources and time which are essential in enhancing the productivity of the welding operation.

Chapter-1

Problem formulation and literature survey

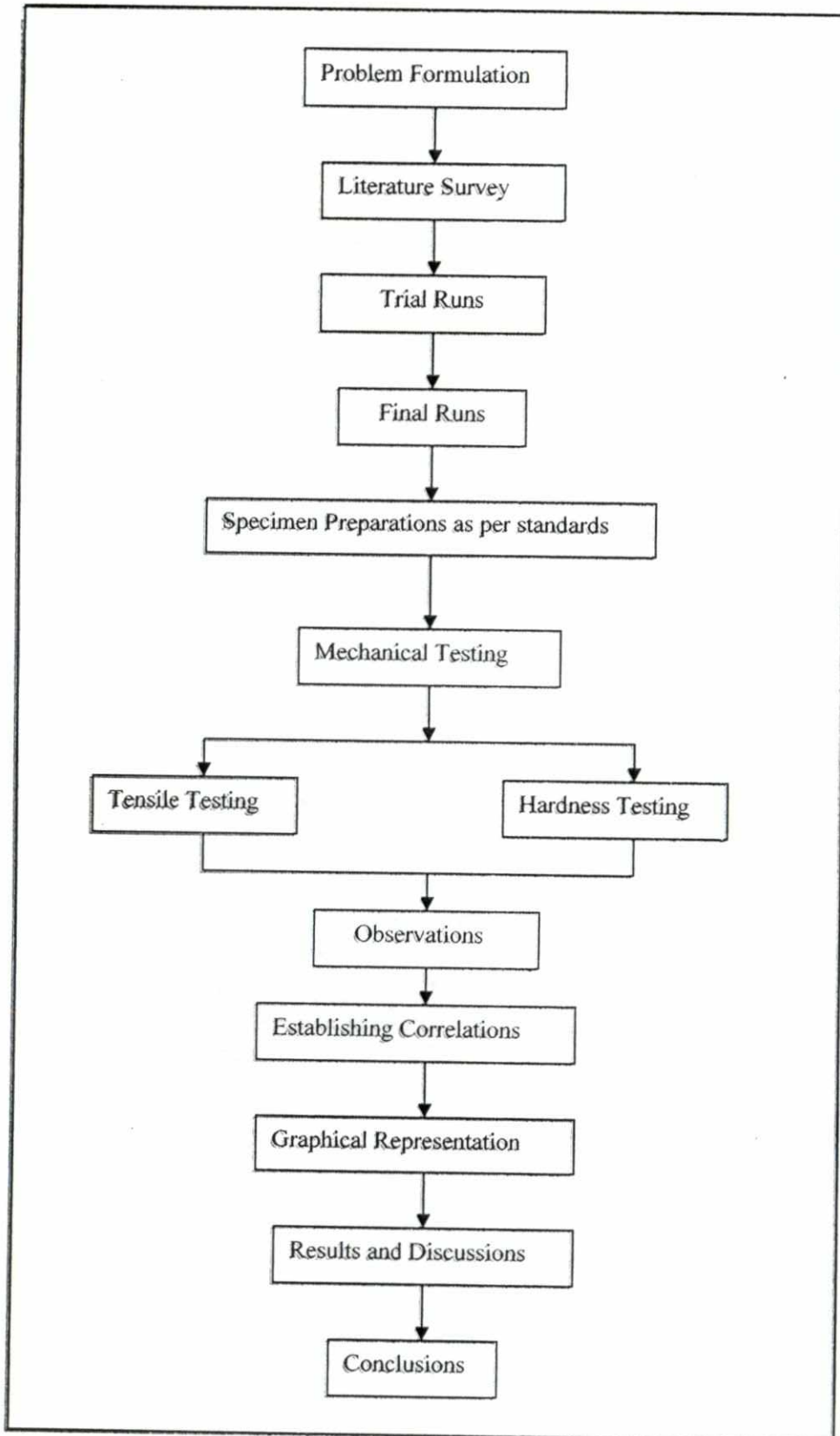
Introduction:

Mild steel butt welded joints are used in number of engineering applications like bridges, pressure vessels, fabrication of automobile body shells, agriculture machinery etc. Although various welding processes are being used but only scanty of information is available regarding the quantitative influence of effect of the heat input on mechanical properties of mild steel butt welded joints. Only qualitative/conceptual information is available in the existing literature. For carrying out the specific job by welding requires a correct welding procedure in order to obtain sound joints of consistent quality. In today's competitive industry which poses very wide and stringent demands on the part of welding procedure and weld quality, automation provides good answer to meet such demands. This further necessitates the availability /generation of data in the form of mathematical models or prediction equations so as to program the welding sequence accordingly. This further enables one, to know before hand that what will be the mechanical properties of butt welded joints using a range of heat input as studied in the specific working envelope of that welding process. Hence it was decided to undertake this problem of establishing a welding procedure to study the effect of heat input on mechanical properties of these joints and supplement this work with establishing correlations between input variables (Welding current, Arc voltage and Welding Speed) and output variables (Ultimate tensile strength and Hardness).

The objectives of the problem so formulated are as given below:

1. To identify the welding variables which influence the mechanical strength of butt welded joints using submerged arc welding process.
2. To establish the working range of the process parameters.
3. To develop correct and cost effective welding procedure for making 12 mm thick mild steel butt welded joints.
4. To establish correlations between input variables viz (Welding Current, Arc Voltage, Welding Speed and Heat input/mm length of weld) and output variables (Ultimate tensile strength and Hardness)

5. To draw meaningful conclusions on the above. For fulfilling these objectives the sequence of investigations are shown as follows.



Miller K Duana and et.al [1] found that increase in voltage effects the addition of alloying elements. With increase of alloying element the tensile strength, hardness increases and impact strength decreases.

Sivaramakrishnan N and et.al [2] found that post weld heat treatment affects the mechanical properties of mild steel. Hardness and tensile strength decrease while impact strength increases after heat treatment.

Smith N.J. et .al [3] Cooling rate affects the mechanical properties.

Thickness of the plate also affects the cooling rate, thick plate produces rapid cooling than thin plate. Rapid cooling rate produces high tensile strength and lower impact strength.

Stoop J. and et.al [4] applied weld simulation techniques to two typical HSLA grades. High yield and tensile strengths were found at high cooling rates with subsequent loss of ductility. Welding of quenched and tempered steels at slow cooling rates or high heat input, caused a considerable loss in base plate yield strength. For fast cooling rates very high yield and tensile strength were found in grain coarsened HAZ with a consequent loss in tensile ductility (Elongation less than 15%). Possible reasons were low martensite content for slow cooling rates. During fast cooling rates ductility reduced due to martensite formation.

1.1 Dependence of bead geometry parameters on welding variables:

When the arc welding is chosen as a method of fabrication, suitable welding procedure must be established. With the increase in mechanization and automation in arc welding, the selection of welding procedure must be more specific to ensure that adequate weld bead quality is obtained. Therefore it should be kept in mind that the selection of input variables (elements of a welding procedure) affects the output variables (weld-bead geometry dimensions). The shape of the weld bead geometry is directly influenced by the process parameters, which further affects the mechanical properties of the welded joints. These parameters are penetration, bead width, reinforcement height, contact angle, dilution, weld penetration shape factor, weld reinforcement form factor. These parameters are further controlled by exploiting welding process variables. These process variables are current, voltage, welding speed, wire feed rate, electrode size, electrode extension, polarity, nozzle to plate distance, type of flux used. [5]

A number of investigators have reported the effects of various welding process variables on the weld bead geometry. The following paragraphs discuss them.

1.1.1. Penetration:

It is the one of the most important characteristics of bead geometry. "Weld bead penetration is the maximum linear distance between the base plate surface on which the bead is laid and the depth to which diffusion has taken place". Also penetration can be defined as the "Depth of the fusion extending into the part of metal being welded". [6] It is influenced by several process variables. Penetration increases continuously with increase in current for all plate thickness as shown in fig 1.1 and 1.7. Arc force is proportional to square of the current. With the increase in current the heat input also increases, which results in rise of weld pool temperature, and wire fusion rate. Due to this the depth of fusion increases hence penetration increases. Arc voltage is directly related to the arc length. As the voltage increases arc length also increases. As shown in fig 1.2 and 1.5, however, increased arc length means more spread of arc column, this leads to increase in weld width and volume of reinforcement while the depth of penetration decreases.

With increase in welding speed, the width of the weld decreases. However, if the increase in speed is small the depth of penetration increases because the layer of molten metal is reduced which leads to higher heat induction towards the bottom of the plate. With further increase in welding speed, the heat input per unit length of weld decreases considerably and the depth of penetration is thus reduced as shown in fig 1.4 and 1.7

In case of SAW, the setting of current is done by controlling the wire feed rate. Thus increasing the wire feed rate results in increase of welding current which leads to higher heat input and metal deposition which increases the weld penetration.

Nozzle to plate distance is the distance from the tip of the contact tube to weld pool. NPD is an indirect measure of electrode extension, which governs the amount of resistance heating which occurs in the electrode. If the electrode extension is small the heating effect is small and penetration is deep. Increase in electrode extension increases the temperature of electrode but decreases the penetration.

The electrode to work angle has an effect on the weld pool motion which in turns has profound effect on the penetration. Depending on the way in which the gun is inclined, the welding technique is known as forehand and backhand welding. When the forehand welding technique is used the weld becomes shallower and wider with less penetration. Back hand technique gives a more stable arc with narrower bead with deep penetration. [7]

Thickness of the base plate also influences penetration. For the same heat input the width and the thickness of the plate has an effect on the weld penetration. If the weld width and the thickness of the plate are small it means more heat concentrated on the small area and result in larger heat effected zone. As the current density increases the penetration also increases as shown in fig 1.3. Current density is the ratio welding amperage and cross-sectional area of the electrode. As the electrode extension increases without changing other variables, penetration decreases .Current is the most important welding variable because it influences deposition rates, penetration, and over all welds size. It is the single most important variable in controlling submerged arc weld penetration. An increase in current results in increase in penetration proportionately, but increases the weld width only slightly.

Gunnert [8] evaluated the effects of weld current, voltage and travel speed on the weld penetration and

$$P = K (I/SE^2)^{1/3} \quad (1.1)$$

Where,

P = arc penetration [inch]

I = welding current [amp]

S = speed of travel [inch/min]

E = Arc Voltage [volt]

K = constant which depends upon the process and consumables.

From the above relation it is clear that with the increase in current there is an increase in current density in the conductor, the amount of wire fused per unit time also increases. Due to this when the size of the weld pool increases, there is an increase in penetration. Arc voltage has lesser influence on penetration. The above relationship shows that there is an optimum voltage at which penetration is maximum. Further increase in voltage decreases the penetration.

In the above equation effect of arc voltage was not considered, and equation (1.1) was modified by Jackson and Shrubbsall [9] as follows:

$$P = K^3 I^4 /SV^4 \quad (1.2)$$

Where

V = Arc voltage

Another attempt was made by McGlone and Chadwick [10] to establish the following relation:

$$P = \frac{0.0035 [I]^{0.07} (V)^{0.09} (1 + \tan A / 2)^{1.08}}{(S)^{0.21} (D)^{0.46}} \quad (1.3)$$

Where,

A = Groove angle in radians.

D = Electrode diameter in mm.

The above equation did not consider the effect of polarity and electrode extension R.S. Chandel [11] investigated the effect of polarity and electrode extension for submerged arc welding and proposed the following relation:

$$P \text{ (for DCEN)} = \frac{(L)^{0.099} (A)^{0.41} (I)^{1.19} (S)^{0.209}}{(V)^{1.089} (D)^{0.844} \times 76} \quad (1.4)$$

$$P \text{ (for DCEP)} = \frac{(L)^{0.15} (A)^{0.824} (I)^{2.075} (S)^{0.168}}{(D)^{0.695} (V)^{0.695} \times 933254} \quad (1.5)$$

Where L = Electrode extension

Rosenthal [12] has given a theoretical relationship between the weld dimensions and welding conditions by using dimensionless parameters D and N which are related to each other as shown the following equation.

$$N = \frac{Q.p.v}{4\pi\alpha^2\rho c(T_m - T_0)} \quad (1.6)$$

Penetration can be calculated as

$$p = 2\alpha D/v \quad (1.7)$$

Where

v = Weld speed (m/sec)

p = Weld penetration

D = Dimensionless depth

T_m = Melting point of work material

T₀ = Ambient temperature

α = Thermal diffusivity mm²/sec

N = Operating parameter

Q = Heat-input

Gupta [13] proposed the following equation for penetration

$$P = A \frac{1}{\sqrt{V}} + B(E - 30) + C, \text{ where,} \quad (1.8)$$

I = Welding current

V = Travel speed (cm/min)

E = Arc Voltage

A, B, C = constants

Table 1.1: The effects of above described parameters are also shown by the table below.

Parameters	Parameter variation	Depth of penetration	Width of bead	Reinforcement
Arc voltage	+	-	++	---
Welding speed	+	-	----	++
Current density	+	++	-	++
Wire electrode diameter	+	---	+	---
Nozzle to pate distance	+	-	+	+

+ A little greater

++ greater

+++ very much greater

- A little less

-- much less

---- very much less

1.1.2. Bead width:

Bead width is an important characteristics of a weld particularly when using an automatic equipment to fill up the weld groove. As shown in fig 1.2, with increase in welding voltage bead width also increases. In welding, the main function of the voltage is to control the arc length and distribution of energy. Higher voltage means longer arc and larger area over which molten metal is deposited. Gurev and Stout [14] reported that in MIG welding the bead width increased with increasing heat input into the work i.e. with increase in current or decrease in welding speed. The bead width increases with increase in current up to some optimum value, further increase in current produces decrease in bead width. Welding speed has a nearly linear relationship with welding bead width as shown in fig 1.5. As welding speed is

decreased, heat input per unit length of joint increases, and the penetration and bead width increase and vice versa.

Joint geometry and flux have very little effect on bead width.

The direction of current flow will also affect the weld bead profile. The current may be direct with the electrode positive (reverse polarity), electrode negative (straight polarity), or alternating. Reverse polarity produces wider beads with more penetration at a lower deposition rate than straight polarity. Straight polarity welding will contribute to narrower bead with less penetration and more build up because straight polarity reduces base plate dilution. The bead shape, penetration, and deposition rate for alternating current fall between those of straight and reverse polarity. Alternating current is used when welding current exceeds 1000A and on multi-wire application to reduce arc blow and arc interactions.

Shrapov [15] proposed the following equation for calculation of bead width

$$B = \frac{0.2qi \sqrt{a}}{\lambda T_m} / st, \text{ Where} \quad (1.9)$$

s = travel speed cm/sec

t = plate thickness, cm

q = heat input, cal/sec

$T_m = 1539^\circ\text{C}$

a = constant (0.0859 cm/sec)

$\lambda = \text{Constant (0.01 cal/cm sec / }^\circ\text{C)}$

i = welding current in amps

Lutsenko [16] studied the effect of welding parameters on bead geometry by submerged arc welding process and proposed the following equation.

$$P = I^2 / d.S.10^{-4}, \quad (1.10)$$

where,

P = Characteristics the arc pressure i.e arc force

I = Welding current

d = Plate thickness, cm

S = Travel speed, cm/sec

1.1.3. Reinforcement height:

The reinforcement height should be roughly 20% of the plate thickness. The arc current has nearly linear relationship with reinforcement height as shown in fig 1.6.

Excessive reinforcement not only increases the electrode consumption but also sharp changes in plate thickness which leads to the failure of weld joints due to notch effect i.e. stress concentration.

If the welding speed is increased, power or heat input per unit length of the weld is decreased, less welding wire is used up per unit length of weld, consequently, there is less weld reinforcement. If welding speed is decreased, power or heat input per length of weld is increased, more welding wire is used up per unit of length of weld, consequently, there is more weld reinforcement.

Excessively high voltage will produce a hat-shaped concave weld, which will have low resistance to cracking and a tendency to undercut. Excessively low voltage will produce an unstable arc and a crowned bead, which have uneven contour where it meets the plate. In case of SAW, reinforcement remains constant with the increase in voltage. But Drayton has observed that reinforcement height decreases with increasing the voltage. As shown in fig1.6

Lutsenko [16] proposed the following equation for reinforcement

$$R = F_d / \mu B \text{ (cm)} \quad (1.11)$$

$$F_d = \alpha_d I / 3600$$

$$Y_s = \text{Deposition area (cm}^2\text{)}$$

$$\alpha_d = \text{Coefficient of deposition}$$

$$Y_s = \text{Specific density (7.8gm/cm}^3\text{)}$$

$$\mu = \text{Weld shape coefficient (0.67)}$$

$$B = \text{Bead width}$$

$$I = \text{Welding current}$$

1.1.4. Contact angle:

Contact angle is the angle included between the base metal line and the tangent to the weld metal at the point where weld metal and the base metal meet. The contact angle influences the bead shape, undercuts and overlapping. Consol reported that the angle between the base metal and weld face i.e. contact angle decreases by decreasing the current, increasing the voltage and travel speed and decreasing electrode stickout. He also reported that parameters increase reinforcement height also increase the contact angle. No significant effect of plate thickness was observed. [17, 18]

1.1.5. Dilution:

Dilution is a measure of diluted base metal with the weld metal or we can say dilution is the ratio of area of penetration to sum of areas of penetration and reinforcement. As the increase in area of penetration and reinforcement height is almost proportional for same change in current, dilution almost remains constant for all plate thickness. With the increase in thickness there is not much change in dilution and it remains almost same for all thickness.

Dilution of the weld metal by the base metal increases with increase in ratio of current to speed of travel. An increase in voltage may increase the amount of dilution, as a consequence of the slightly lower electrode melting rate that results with the higher voltage conditions. The study of dilution helps in evaluating not only the proportion of the weld metal deposited but also in ascertaining to some extent the stress concentration due to excessive complexity of the bead shape. It is reported that dilution increases with increase in wire feed rate, arc voltage, nozzle to plate distance, and decreases with increase in electrode to work angle, from back hand to fore hand. [17, 18]

1.1.6. Weld penetration shape factor (WPSF):

It is the ratio of weld width to penetration. It is also known as coefficient of internal shape.

$$\Psi = D/P$$

Ψ = coefficient of internal shape

P = arc penetration (inch)

D = weld width (inch)

It indicates the type of bead geometry.

Greater is ψ , greater is the proportion of deposited metal in the weld bead and vice versa.

Shrihari reported that WPSF increased with increase in welding current as well as increase in arc voltage. He also reported that WPSF improved when the nozzle angle was changed from trailing to leading position. The limits of WPSF have been reported to be different for each welding process. [19] In case of assembly welding operation, the range is 0.5 to 5.0 with the nominal values in the range 1.2 to 3.5 while for repair welding operations the range is 2 to 10 with the nominal values varying in the range 4 to 8. A good sound weld is obtained by choosing nominal values as shown in table 1.2 and 1.3.

Table 1.2: Weld Penetration Shape-Factor

COEFFICIENT	TYPE OF WELDING OPERATION	
	ASSEMBLY	REPAIR
OF INTERNAL SHAPE	0.5 – 5	2 – 10
NOMINAL VALUE	1.2 – 3.5	4 – 8

Table 1.3: Weld Reinforcement Form-Factor

COEFFICIENT	TYPE OF WELDING OPERATION	
	ASSEMBLY	REPAIR
OF EXTERNAL SHAPE	2 – 8	2 – 10
NOMINAL VALUE	4 – 6	2 – 4

1.1.7. Weld reinforcement form factor:

It is the ratio of weld width to reinforcement height and is also known as WRFF or coefficient of external shape.

$$\phi = D/S$$

ϕ = coefficient of external shape

D = weld width (inch)

S = excess weld metal (inch) or reinforcement height.

This factor also indicates the type of bead geometry and is a requirement to obtain weld as smooth as possible, Also high values of coefficient of external shape are necessary to minimize the excess of weld metal deposited.

Shrihari reported that the limits of WRFF are different for each welding process. He shows that in the case of repair welding, we take lower value of ϕ in comparison of assembly welding (automatic arc welding). A good sound weld is obtained by choosing nominal values. [19]. The weld bead geometry and associated shape relationship have been shown as follows.

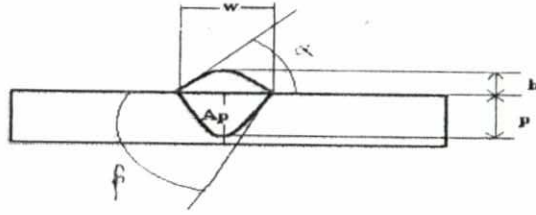


Fig 1.9 Bead geometry and shape relationship (BG&SR)

W = Bead width

P = Bead penetration or depth of penetration

h = Bead height or crown height or height of reinforcement

α = Angle of convexity

β = Angle of entry [23]

The various shape relationships are as follows

(1) WPSF (w/p) = weld penetration shape factor

(2) WRFF (w/h) = weld reinforcement form factor

$A_t = A_r + A_p$

A_r = Area of reinforcement

A_p = Area of penetration

(3) %D = $(A_p/A_t) 100$ = percentage dilution

(4) Rate of heat input per unit length (RHI)

$RHI = \eta(VI/S)\cos\phi$ J/mm

η = Arc efficiency in %age = Heat developed at anode / Total heat developed

V = Arc voltage, volts

I = welding current, amps

S = welding speed, mm/sec

$\cos\phi$ = power factor [20]

1.2 PROCESS PARAMETERS

In SAW, metal deposition rate is the highest [20]. The deposit quality is determined by the type of flux, grade of wire and the following parameters.

2.2.1. Welding current

2.2.2. Arc voltage

2.2.3. Size of electrode

2.2.4. Electrode extension

2.2.5. Type of electrode

2.2.6. Polarity

2.2.7. Welding speed

1.2.1. Welding Current:

It controls the melting rate of the electrode and thereby the weld deposition rate. It also controls the depth of penetration and thereby the extent of dilution of the weld metal by the base metal [20]. Too high a current causes excessive weld reinforcement, which is wasteful, and causes burn through, in case of thinner plates or in badly fitted joints. Excessively decreased current gives an unstable arc and over lapping.

Metal deposition rate increases with increase in current [16]. Melting of electrode is caused by generation of high heat due to resistance in the passage of current. With the increase in current, the resistance heating increases so the deposition also increases as:

Heat generated (H) or = $I^2 R.t$

Resistance heating

I = Welding current

R = Resistance

t = Time

With the increase in heat input per unit length the deposition rate increases [16].

Heat Input / length of weld = $V.I / S$ (KJ/mm)

V = arc voltage

I = current

S = Travel speed

With the increase in travel speed heat input per unit length decreases so does the deposition rate. Deposition rate is not much influenced by arc voltage. In general melting rate of filler wire is given by:-

$MR = A.I + B.L.I^2$

MR = Melting rate

A and B are constants whose values depends upon the filler wire and base metal composition [7]

According to Hossfield, A.M. [14] the wire protruding beyond the contact tip is heated according to the relationship.

$$H = \frac{I^2 L \sigma}{D^2}, \text{ Where}$$

I = welding current

L = electrode extension

σ = resistivity of the wire

D = Diameter of wire

Thus this preheating of the wire increases with increase in current and length of electrode extension and decreases with wire diameter.

Wilson, Claussen and Jackson have shown that the total melting rate is as follows [14]

$$MR = \frac{1}{1000} \left[0.35 + \frac{d^2}{645} + 2.08 \times 10^{-7} \left(\frac{1 \times L \times 25.4}{d^2} \right)^{0.22} \right], \text{ where}$$

d = wire diameter in mm

L = electrode extension in mm

I = current in amperes.

Howard B.Cary reported that the deposition rate is the highest for direct current electrode negative (DCEN). The deposition rate for alternating current is between DCEP and DCEN [21].

1.2.2. Welding voltage

S.B. John [22] reported in his study that there is no effect of arc voltage upon metal deposition rate. No arc instabilities were encountered except at the extreme of current/voltage range. Welding voltage is the difference in electrical potential between the tip of the welding wire and the surface of the molten weld metal. The welding voltage varies in length of the arc between the welding wire and the molten weld metal. If the arc voltage increases, the arc length also increases, if the voltage decreases, the arc length also decreases. Gupta [13] states that the arc voltage has little effect on the electrode deposition rate, which is determined mainly by the welding current. The voltage principally determines the shape of the weld bead cross-section and its external appearance. Lowering the arc voltage produces a stiffer arc, which improves penetration in a deep weld groove and resist arc blow on high speed work. An excessively low voltage produces a high, narrow bead with poor slag removal.

work. An excessively low voltage produces a high, narrow bead with poor slag removal.

1.2.3. Electrode Size:

Electrode size influences the deposition rate. At any given amperage setting, a small diameter electrode will have a higher current density and a higher deposition rate than with a larger diameter electrode. However, a larger diameter electrode can carry more current than a smaller electrode, so the larger electrode can ultimately produce a higher deposition at higher amperage.

Electrode size also affects the weld bead shape and depth of penetration at fixed amperage. At a given welding current, large electrode diameter results in wider and less penetrating bead. Small electrodes are used with semiautomatic equipment to provide flexibility of the movement. They are also used for multiple electrodes, Where a poor fit up is encountered a larger electrode is better than smaller one. Arc ignition is easier with smaller electrode due to high current density [7].

1.2.4. Type of Electrodes:

Submerged arc electrodes are available to produce almost all types of weld metal including mild steel, low alloy steel, high carbon steel, special alloy steel, stainless steel, nonferrous alloys and special alloys for surfacing applications. The electrodes commonly used are bare rods or wires with a clean bright surface to facilitate the introduction of the welding current. They are normally in the form of coils, although straight lengths are also sometimes used. Except when welding corrosion-resistant materials, the electrodes are usually copper coated to improve contact surface and avoid rusting [23].

1.2.5. Polarity

Deposition rate is higher for direct current reverse polarity (DCEP) because maximum heat i.e. 2/3 of total heat is generated at positive electrode. Deposition rate for alternating current is between DCEP and DCEN.

1.2.6. Electrode Extension

It is also termed as stick-out or nozzle to plate distance. It refers to the length of the electrode between the end of contact tube and the arc, which is subjected to resistance heating (also called I^2R heating). The longer the stick-out, the greater the amount of heating and the higher the deposition rate and lower is the penetration. [22]

Deposition rates can be increased by about 25 to 50 percent by using long electrode extensions with no change in welding amperage. With single electrode, automatic

SAW, the deposition rate might approach that of the two-wire method with two power sources. When the electrode extension is increased to take advantage of the high electrode melting rate, the voltage setting on the machine should be increased to maintain proper arc length. However as electrode extension increases, it may become difficult to maintain the electrode tip in the correct position with respect to the joint. In developing a procedure, an electrode extension of approximately eight times the electrode diameter is a good starting point. As the procedure is developed, the length is modified to achieve the optimum electrode melting rate with fixed amperage.

1.2.7. Welding speed

With the increase in welding speed, the width of the weld decreases. However, if the increase in speed is small the depth of penetration increases because the layer of the molten metal is reduced which leads to higher heat conduction towards the bottom of the plate. With the further increase in welding speed the heat input per unit length decreases which results in decrease in penetration. As in case of submerged arc welding, increase in welding speed, above 40m/hr the heat input per unit of length of the weld decreases considerably and the depth of penetration thus reduced, shown in fig 1.4, 1.5, 1.6, 1.7. Speed above 80m/hr, lack of fusion may result.

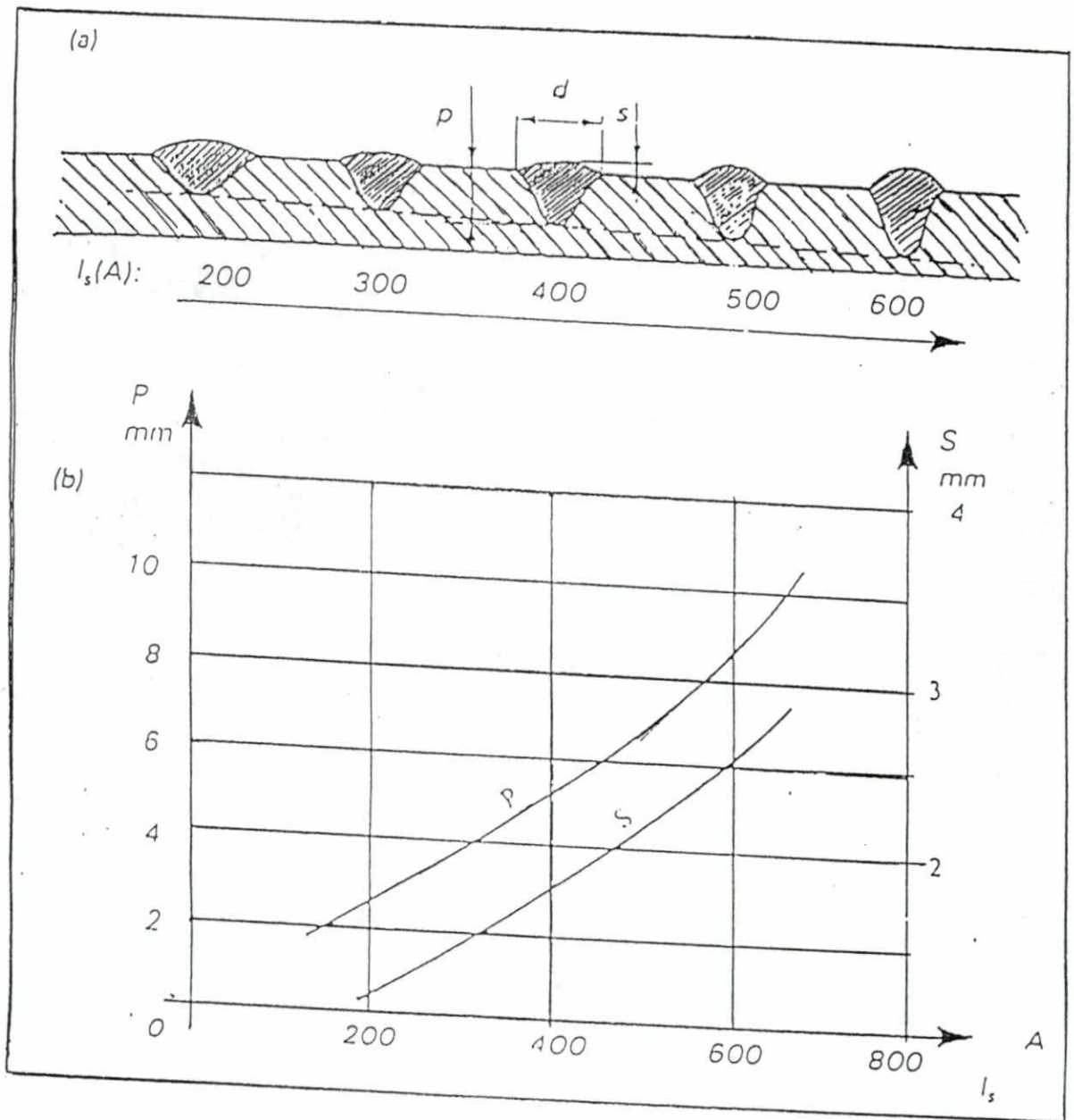


Fig 1.1 Influence of current on weld bead shape

S = Reinforcement height in mm

P = Penetration in mm

I_s = Welding current

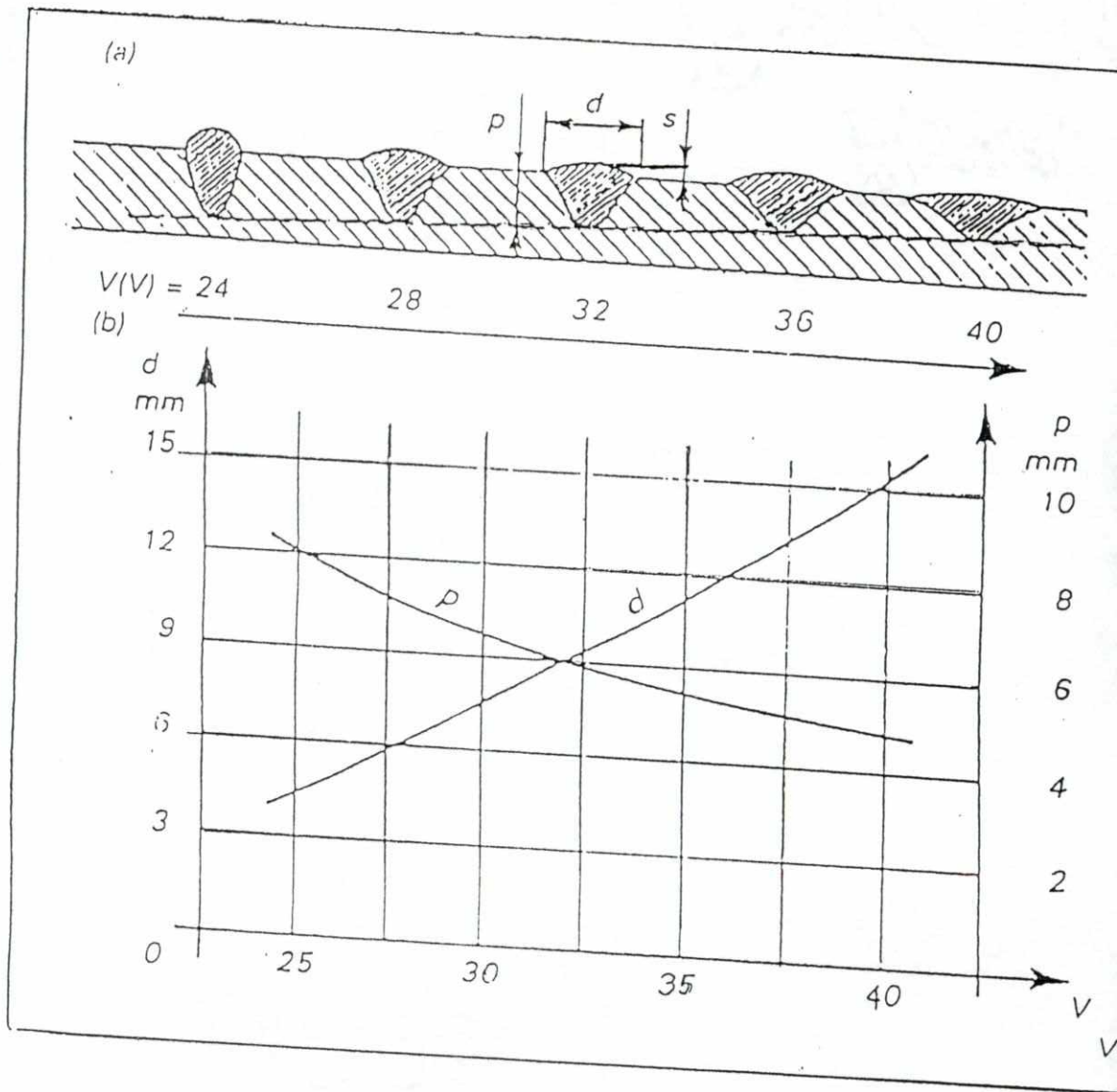


Fig 1.2 Influence of Arc voltage on weld bead shape

S = Reinforcement height in mm

P = Penetration in mm

d = Weld width

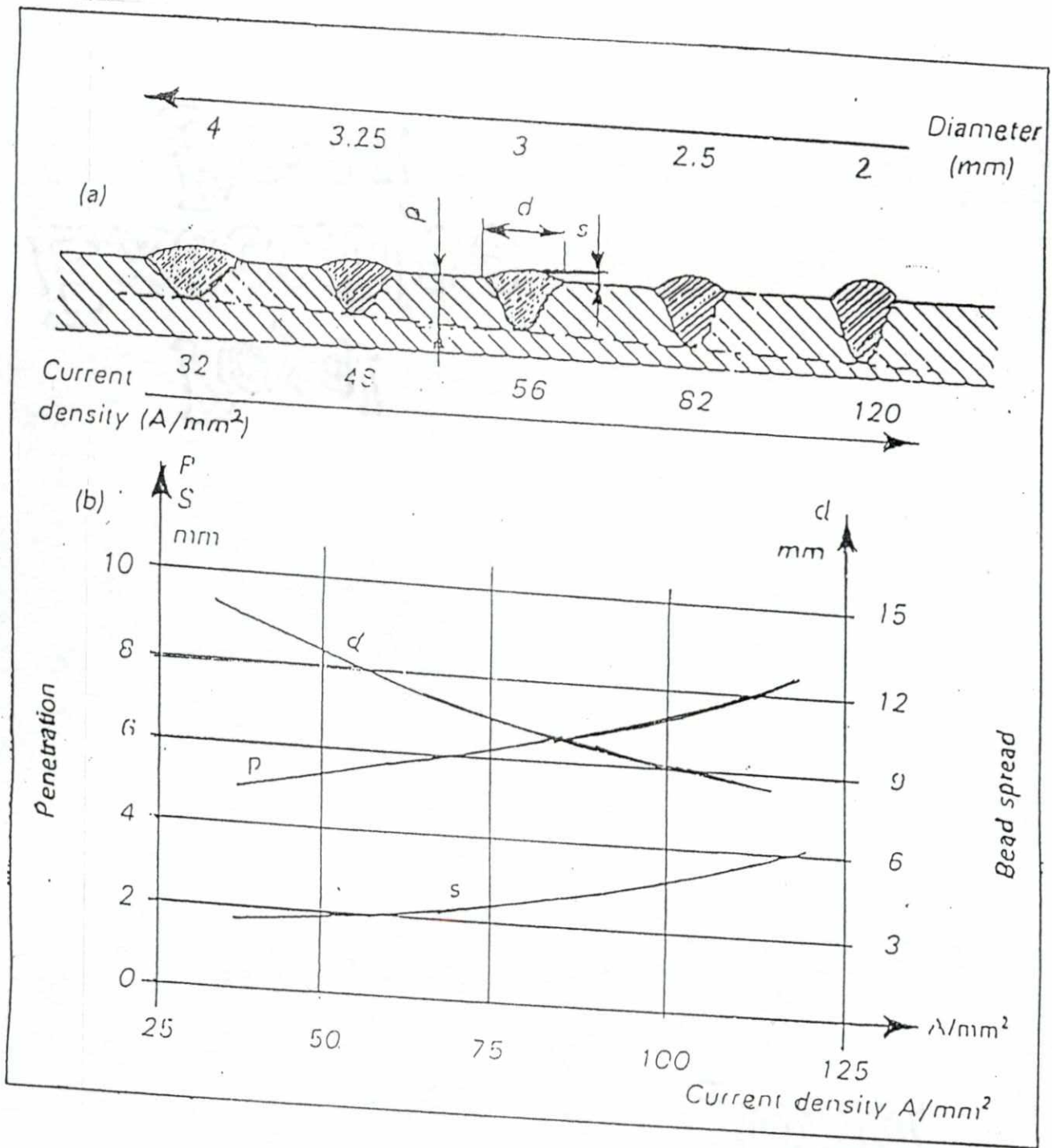


Fig 1.3 Influence of Current Density on weld bead shape

S = Reinforcement height in mm

P = Penetration in mm

d = Weld width

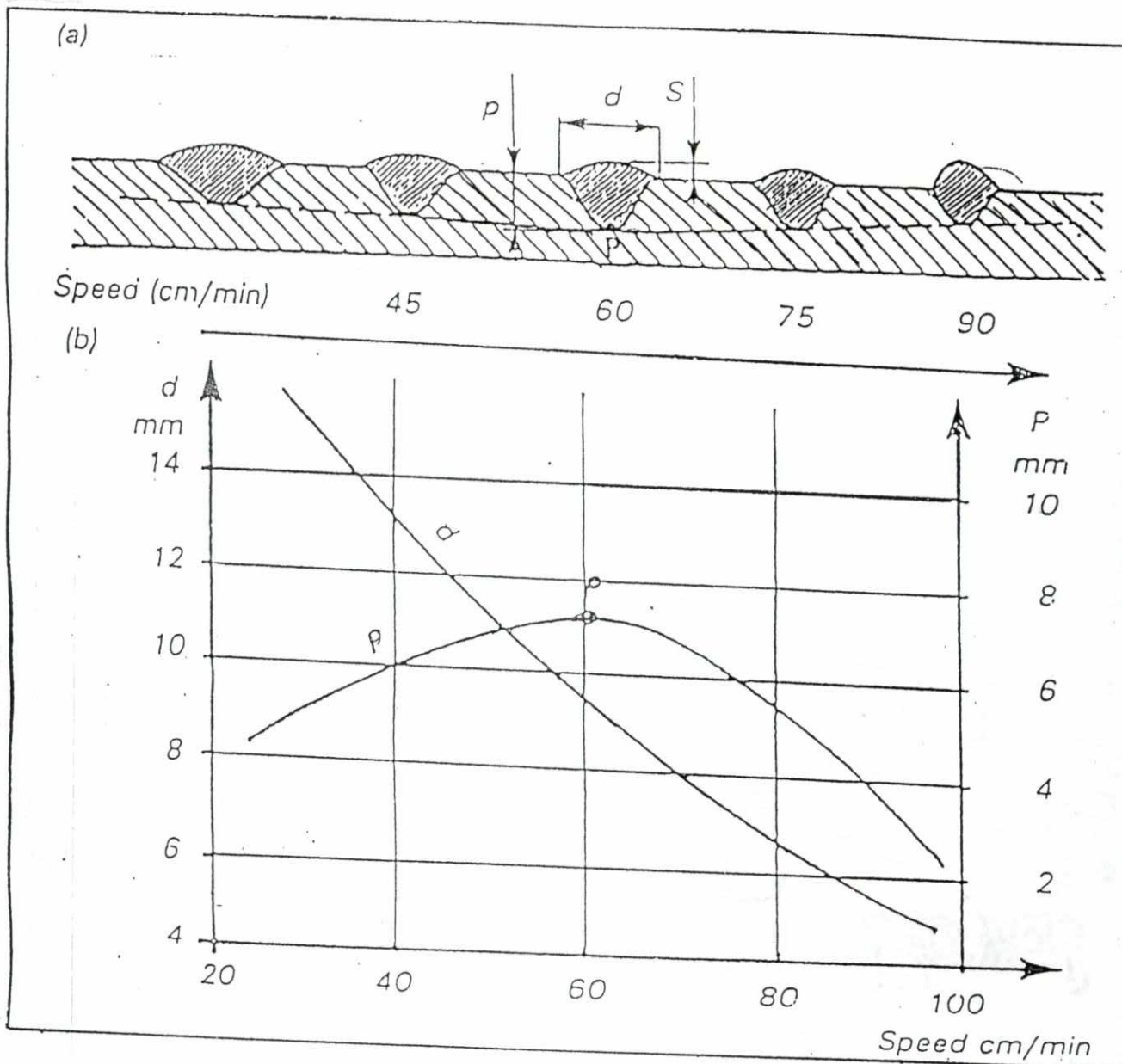


Fig 1.4 Influence of Welding speed on weld bead shape

S = Reinforcement height in mm

P = Penetration in mm

d = Weld width

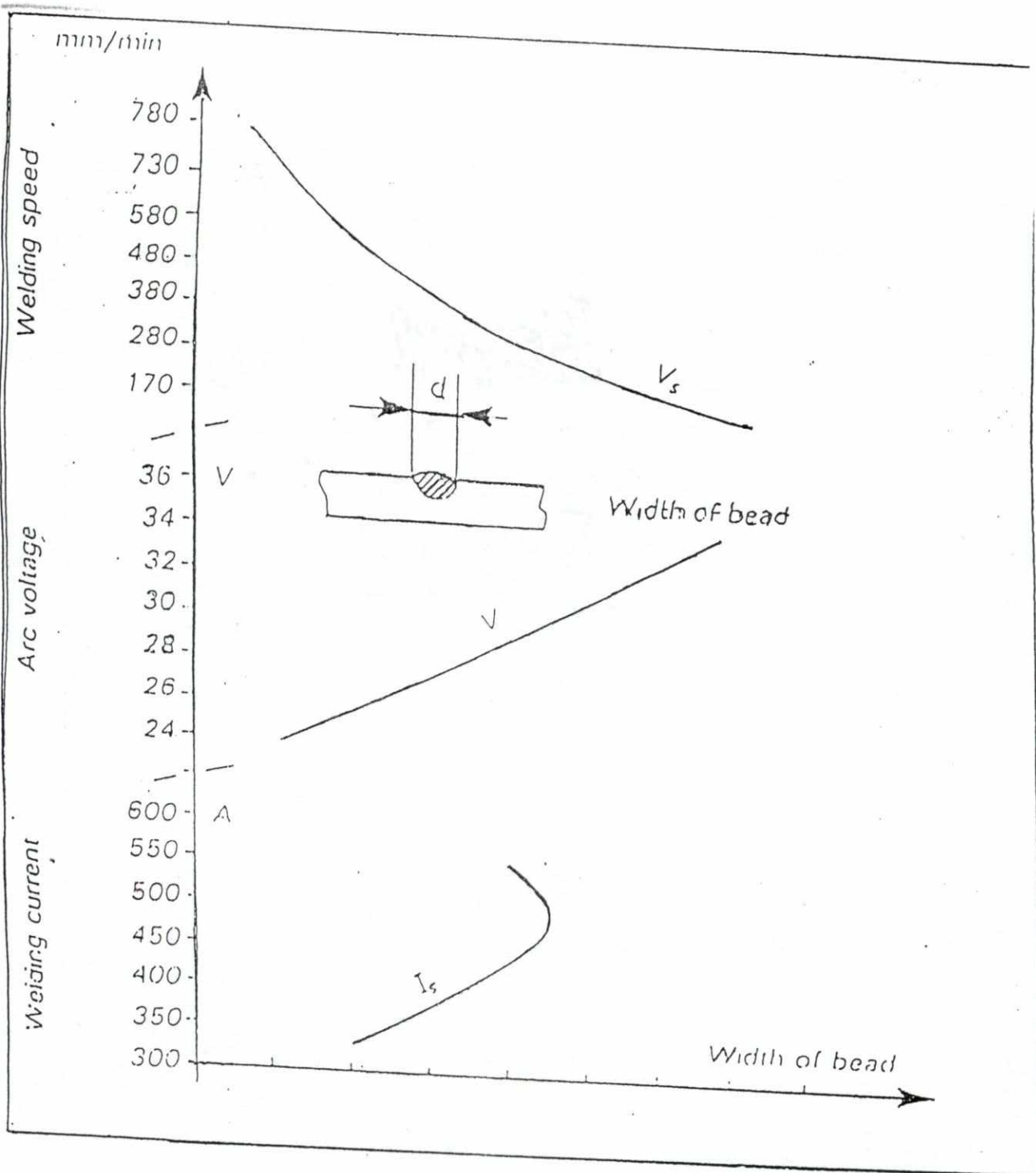


Fig 1.5 Influence of the principle parameters on the weld width

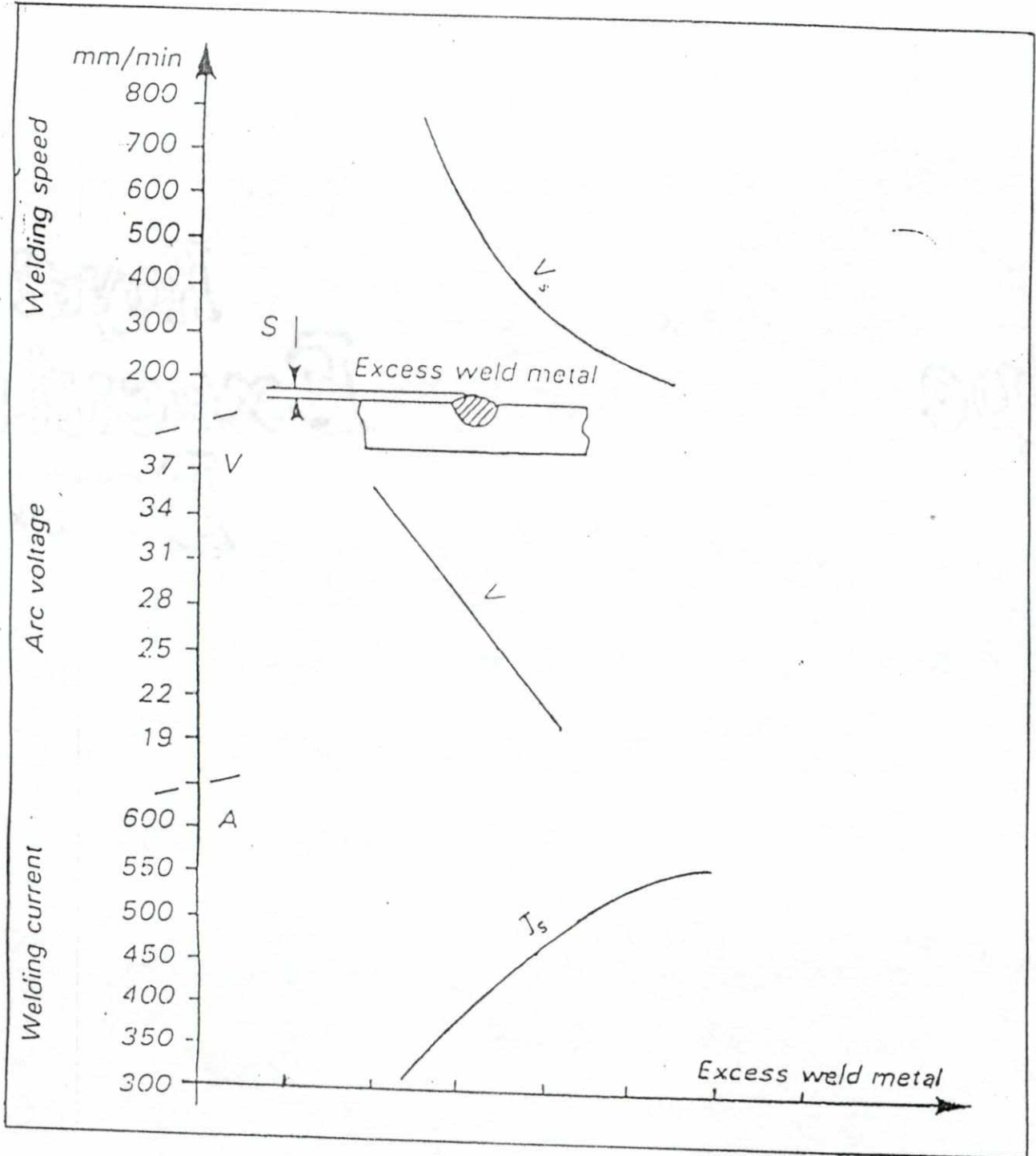


Fig 1.6 Influence of the principle parameters on the Reinforcement height

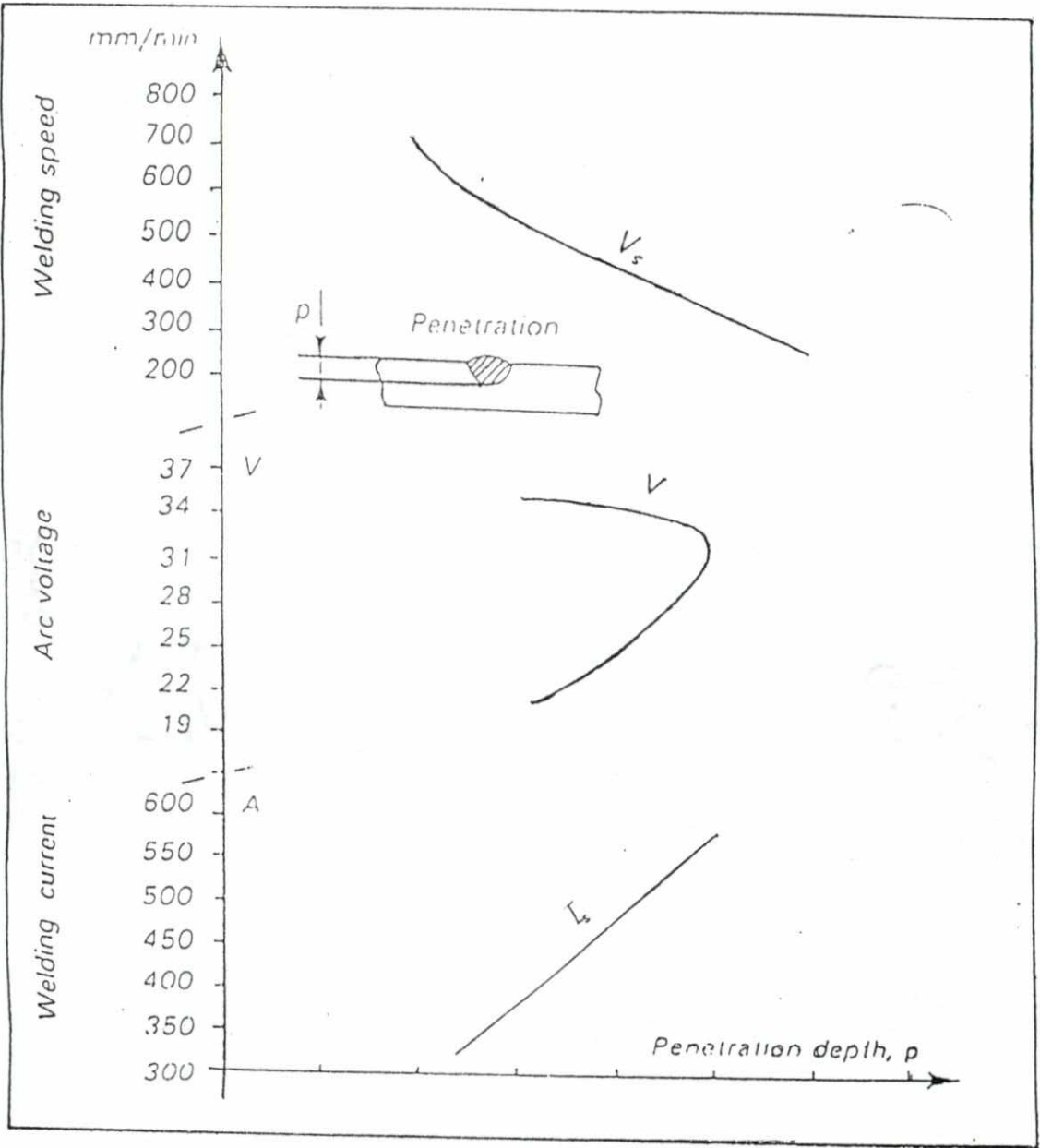
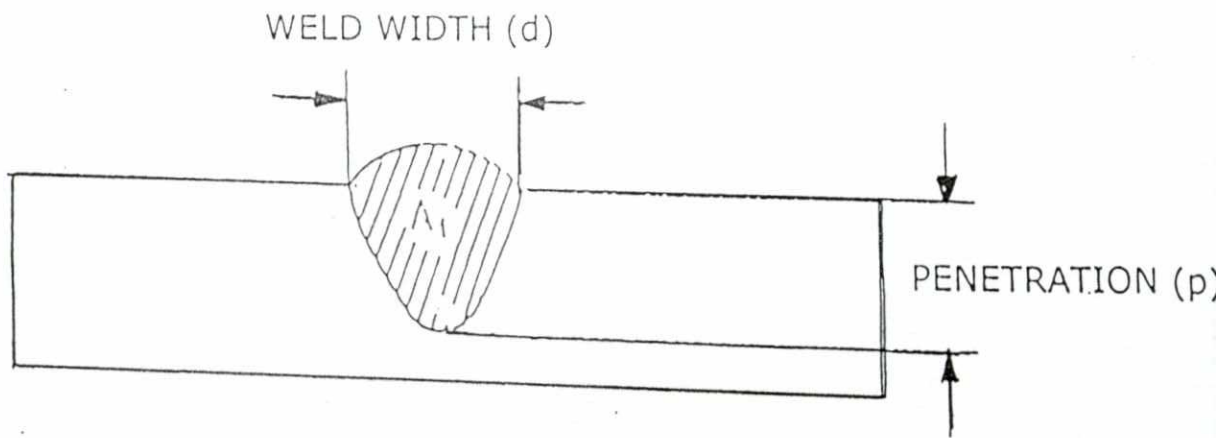


Fig 1.7 Influence of the principle parameters on the Penetration

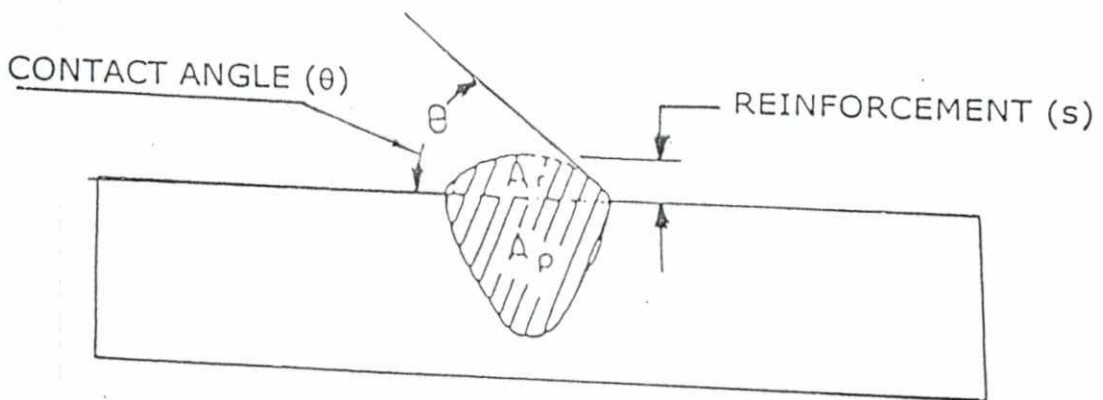


$$\text{WELD PENETRATION SHAPE FACTOR (WPSF)} = \frac{\text{WELD WIDTH}}{\text{PENETRATION}}$$

$$\text{OR } \text{WPSF} = d / p$$

$$\text{WELD REINFORCEMENT FORM FACTOR (WRF)} = \frac{\text{WELD WIDTH}}{\text{REINFORCEMENT HEIGHT}}$$

$$\text{OR } \text{WRF} = d / s$$



$$\% \text{ DILUTION (D)} = (A_p / A_t) \times 100$$

$$A_p + A_r = A_t$$

Fig 1.8 Weld bead geometry shape relationship

Chapter-2

Introduction

2.1 GENERAL

Welding is playing an important role in engineering and other industries today. It has become one of the principal means of fabrication and repairing metal products. Welding has proved as a fast, dependable and flexible means of fabrication. It reduces products cost by simplifying designs and eliminates costly patterns and machining operations Jefferson defines welding as follows. [23]

“Welding is the process of joining two similar or different metals by bringing the junction to fusion point by the use of intense heat with or without the application of pressure and addition of filler material.”

As per AWS “The permanent joining of two materials, usually metals, through a localized coalescence, resulting from suitable combination of temperature, pressure, and metallurgical conditions is known as welding”. [24]

Welding is a process which ensures continuity of material. According to service requirements the choice of condition under which assembly is carried out will take account of one or other or even several of different aspects of continuity. The means of obtaining this continuity are: [13]

Fusion: These are used particularly for joining base metals or applying metal, electron beam and laser beam welding and in brazing and braze welding.

Pressure: This is usually used with an increase in the temperature of the parts. Pressure welding is the technique associated with friction, explosive, diffusion, ultrasonic and resistance welding processes.

To obtain the required temperature and/or pressure for welding several types of energy sources are available, which have been listed as follows:

Thermo chemical energy, obtained either by gaseous combustion or by action of aluminum powder on metallic oxides.

Electro thermal energy produced either by the application of an electric arc (by ionization of gas) or electrical resistance (by passing currents through parts).

Mechanical energy obtained by percussion, explosion, friction, emission of ultrasonic waves etc.

Focused energy, electric (electron bombardment), or luminous (LASER).

One can say that, all possible sources of energy are used to produce welds. However they do not yield identical concentration of available heat. Such a variety of heating methods should in principle allow the most diverse welding problems to be resolved. This in fact is what actually happens, each process having its own areas of strength and none of them being completely interchangeable.

2.2 Historical development of submerged arc welding:

During 1930s, having recognized the potential advantages of mechanized welding; several attempts were made to mechanize the arc welding process. Developing a continuous electrode as an extension of the manual arc welding electrode was ruled out for the following reasons:

1. Since the coating is non-conducting, arranging electrical contact with the electrode is not practicable.
2. The coating is likely to peel off when the electrode is coiled
3. The coating is also likely to crush when fed through the feed rolls and
4. Further in attempts to mechanize the SMAW process, magazines were prepared which could carry several flux coated electrodes with arrangement that when one electrode got consumed, the next would automatically come into position. But this attempt also failed because of arc initiation in the fresh electrode.

In one of the methods attempted, the work piece was painted with a thin flux, while feeding of bare wire and arc travel were mechanized. In another case, automatic carbon arc welding was tried out, in which paper impregnated with flux was delivered to the arc as it traveled.

All such methods proved unsuccessful, because they failed to provide adequate shielding to the arc. Then in 1932 the idea of placing a thick layer of dry granular flux on the joint ahead of the carbon electrode was conceived and successfully developed in the USA and later applied to the welding of penstocks water conduits in California. This process was later called, "SUBMERGED ARC WELDING" process. SAW was the logical step and the process became a commercial success both in USA and USSR by the middle and late 1930s. The modern SAW is an arc welding process in which one or more arcs are formed between one or more than one bare electrodes and the work piece. The arc is completely submerged under a blanket of granular flux which adequately shields the arc from atmospheric contamination.

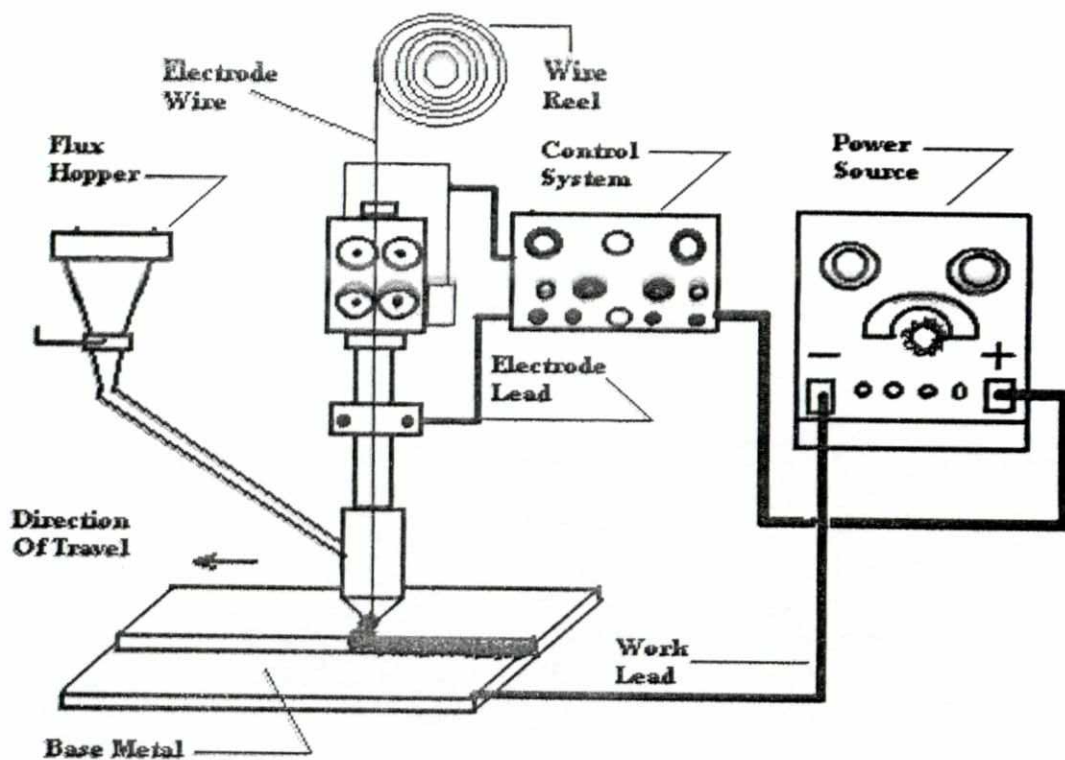


Fig 2.1 SAW Process

2.2.2 Definition Submerged Arc Welding:

Sub Merged Arc welding produces coalescence of metals by heating them in an arc (or arcs) maintained between a bare metal electrode or electrodes and the work. The arc is shielded by a layer of granular and fusible flux, which covers the molten metal and the base metal near the joint and protects the molten weld metal from atmospheric contamination. Filler metal is obtained from the electrode and sometimes from a supplementary welding rod. [24]

2.3 Methods of applications:

There are three general methods by which the process can be applied:

1. Automatic welding
2. Semi-automatic welding
3. Machine welding

1. Automatic welding: in this case self regulating equipment is used, no operator is required. The cost and production rate of equipment is high.

2. Semi-automatic welding: in this case equipment performs the complete operations. Operator only monitors and adjusts controls of the process.

3. Manual welding: welder utilizes hand welding gun, through which the nozzle provides electrode wire and flux. A wire feeder drives electrode and flux is supplied with hopper by gravity mounted on the gun or it may be forced fed. This method of welding offers flexibility of manual guidance using small electrodes and moderate travel speed.

The following conditions should be evaluated while deciding the use of semiautomatic, machine and automatic submerged arc welding.

1. Production volume
2. Length of the weld
3. Joint thickness
4. Weld accessibility
5. Weld quality
6. Weld appearance
7. Fixture need

2.4 Power source:

Welding with DC power source provides more versatile control over the bead shape, penetration and speed in addition starting is much easier hence direct current is proffered:-

- (a). where fast, accurate arc striking is essential.
- (b). where close arc control is needed.
- (c). where difficult contours are to be followed at maximum speed.

Control of the bead shape is the best with DCEP because of more regular condition at the toe of the weld and because there is less molten metal. Minimum penetration is obtained with DC straight polarity and maximum with DC reverse polarity and a degree of penetration between both is provided by alternating current.

Higher deposition rate are obtained with direct current reverse polarity. Alternating current minimizes arc blow. This assumes importance at high welding current. AC is usually preferred for the trail arcs or arcs for multi wire multi-power welding. Two arcs in close proximity are affected by each other's magnetic field.

Two DC arcs of like polarity flare together where as arcs of unlike polarity flare apart. If one AC and one DC arc are employed this action can be controlled .alternating

current may be used where arc below cannot otherwise be eliminated or on short weld where grounding is a problem.

2.5 Wire feeding system:

The electrode is stored in coil or a drum, which may be mounted on the welding head or remotely for semiautomatic welding. The electrode is driven through the welding gun to the arc by electric motor driven rolls.

There are two methods used for controlling electrode feed speed. With constant voltage power source, the drive motor speed is set to furnish the electrode at the required constant speed. With a constant current power source, the electrode feed speed varies as to maintain constant arc length. The speed control drive motor senses arc voltage and changes automatically according to arc voltage as to compensate arc length variations. If the arc length decreases, the electrode speed decreases to allow the electrode to melt off to the set length (voltage). Then speed increases again. If the arc length increases the electrode speed increases momentarily to decrease the arc length.

2.6 Flux feed:

The welding flux is deposited just ahead of or concentric with the arc from a flux delivery tube as the welding progresses along the joint. The granular flux is stored in a hopper mounted on the welding head and gravity fed through the tube.

2.7 Fluxes:

The flux shields the molten weld pool from the atmosphere by covering the molten metal with molten slag. It cleans the molten weld pool; it modifies the chemical composition of the weld metal and influences the shape of the weld bead and its mechanical properties. Fluxes are granular mineral compound mixed according to various formulations. They are produced by several different methods.

1. Fused flux
2. Bonded flux
3. Agglomerated flux
4. Mechanically mixed flux

2.7.1 Fused flux:

To manufacture a fused flux the raw material are dry mixed and then melted in an electric furnace. After melting and any final additions, the furnace charge is poured and cooled, and then the crushed screened for sizing and packed.

2.7.2 Bonded flux:

To manufacture a bonded flux the raw material is powdered, dry mixed and bonded with potassium silicate, sodium silicate or a mixture of two. After blending the wet mixture is palletized and baked. The pellets are then broken up, screened to size and then packed.

2.7.3 Agglomerated fluxes:

The agglomerated fluxes are manufactured in the same manner as bonded fluxes except that a ceramic binder is used instead of silicate binder. The ceramic binder requires drying relatively at high temperatures.

2.7.4 Mechanically mixed fluxes:

These are produced by mixing two or more fused, boded or agglomerated fluxes in any ratio to yield desired results.

2.8 Basicity index:

Basicity index is a quantitative measure of the basicity of the flux or slag oxide system and it is used as a parameter with which the chemical behavior of flux and slag can be correlated. Slag metal reactions in elements transfer depends upon this chemical behavior. Basicity index also influences the oxygen content in the weld pool, which further affects the porosity, inclusion level and oxidation of alloys. The different researchers have given different definitions of basicity index. But according to IIW Basicity index can be given by

Basicity Index - B.I. = Basic Oxides / Acidic Oxides

$$\text{Basicity index} = \frac{\text{CaO} + \text{BaO} + \text{SrO} + \text{Na}_2\text{O} + \text{K}_2\text{O} + \text{Li}_2\text{O} + \text{CaF}_2 + 0.5(\text{MnO} + \text{FeO})}{\text{SiO}_2 + 0.5(\text{Al}_2\text{O}_3 + \text{TiO}_2 + \text{ZrO}_2)}$$

- (a) Acidic fluxes – B.I. < 1
- (b) Neutral fluxes – 1.5 > B.I. > 1
- (C) Basic fluxes – 2.5 > B.I. > 1.5
- (d) Highly Basic fluxes – B.I. > 2.5

Acidic flux provide lowest flux consumption, deep penetration, smooth weld bead and non-hygroscopic in nature, but also responsible for inferior mechanical properties, poor stability.

Neutral fluxes having Al₂O₃ up to 50%, which increases the notch toughness. It is having properties between acidic and basic flux.

Basic fluxes provide good arc stability, mechanical properties and fluidity but also having undesired properties like, higher flux consumption, distorted bead, very hygroscopic in nature, least penetration, less tolerant to rust and scaling.

2.9 Process variables:

The various operating parameters in sub merged arc welding which are essential for obtaining good quality of welds at high production rate are given in approximate order of their importance.

1. Welding current
2. Type flux
3. Welding voltage
4. Welding speed
5. Electrode size
6. Type of electrodes
7. Joint geometry

2.10 Advantages:

1. The process can be used at high welding speed and deposition rate.
2. No visible arc with little fumes or spatters.
3. Heat losses are almost negligible, providing maximum heat transfer from 80 – 90 %
4. Lesser distortion and sound weld quality with slow cooling rate.
5. Having deep penetration characteristics also can be used for hard facing.
6. Flux provides protection to molten weld pool from atmospheric contamination and good mechanical properties to weld joint.
7. Continuous welding process that can be used for welding in exposed area with relatively high winds.

2.11 Limitations:

1. Generally used for flat position only because of control of flux, sometimes in horizontal positions.
2. Slag is to be removed after each pass.
3. Only that metals can be welded for which fluxes have been produced.
4. Process is not suitable for thin metal (less than 4.7 mm) because burn through is likely.
5. Flux may subject to contamination that may cause weld porosity.

2.12 Applications:

1. Ship and barrage building.
2. Rail road car fabrication.
3. Pipe and pressure vessels manufacturing.
4. Fabrication structure member where long welds are required .
5. Chemical reactors.
6. Storage tanks.
7. Cladding and narrow gap welding.

Chapter-3

Experimentation

3.1 Base metal:

The material used as base metal obtained was obtained from flats of 75mm wide, 12mm thick and 20 feet length. The material was cut down to size of 75×12×200 mm plate so that it suited to the testing equipment. Two pieces of size 75×12×200 mm were cut for making the tensile specimen and testing the ultimate tensile strength, percentage elongation and hardness of the welded joint. Total 72 pieces were cut so as to have 12 specimens per parameter varied thus necessitating the use of 36 specimens so as to give an average value of each output variables. Chemical composition of base metal used for experimentation is given in Table 3.1

Table 3.1 Base metal composition

C	Si	Mn	Cr	S	P	Ni,M,V	Fe
0.26%	0.17%	0.45%	0.12%	.048%	0.034%	.034%	Rest

3.2. Consumables:

The consumable used for experimentation i.e. filler wire and flux are discussed as follows.

3.2.1 Filler wire

Auto-melt grade SA-1, 4 mm diameter, copper coated mild steel solid wire manufactured by (ESAB, India Ltd) was used. Specifications of filler wire used were (AWS-A 5.17EL-8). The chemical composition of the wire is given in the following table.

Table 3.2 Composition of filler wire

C	Mn	Si	P	S	Fe
0.10%	0.45%	0.02%	.03	.03	rest

3.2.2. Flux

Agglomerated-basic type flux was used. The specification of flux used is (AWS 5.17 OK FLUX 10.71LF6A4EL-8). The chemical composition of flux is as shown in table 3.3

Table 3.3 Composition of flux

C	Mn	Si
0.08%	1.00%	0.25%

Basicity Index of the flux is 1.6

3.3 Equipment used:

For this study “KEARC” sub merged arc welding equipment, type ASA-I has been used with power source WR-1200-H whose specification is as given below[29] :-

Manufacturer: M/s Kanubhai Electrical Pvt. Ltd., New Delhi

Maximum welding Current at 60% Duty cycle: 1200 amp

Maximum Welding Current at 100% Duty cycle: 900 amps

Operating voltage : 20-44 V

Electric Supply : 415 V

3.4 Procedure of experimentation

3.4.1 Cutting: The raw material was obtained in the form of flats which were cut into suitable sizes of 75×12 ×200 mm with the help of power hacksaw.

3.4.2 Cleaning:

The test pieces were thoroughly cleaned with the help of hand grinder and emery paper thoroughly to make them free from rust, dirt, grease and oil. Which generally act as source of hydrogen.

3.4.3 Edge preparation:

In order to achieve good side wall fusion it was necessary to prepare the edges by providing single V-groove on the edges of the base plates, the details of which are as given in fig 3.1

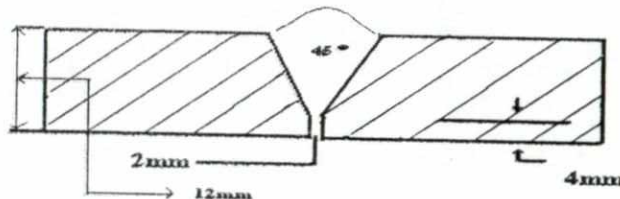


Fig 3.1 Edge Preparation

3.4.4 Tacking: In order to maintain constant root gap throughout the welded length and to avoid any misalignment between the work piece/base-plate tacking was done as shown in fig 3.2

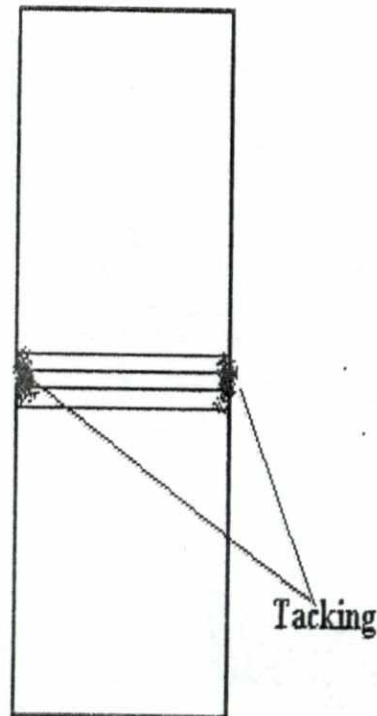


Fig 3.2 Tacking

3.4.5 Conducting trial runs:

Trial runs were conducted for establishing the working range of the process parameters. Bead on plate technique was used to find out the range of process parameters and the acceptance criterion for the same was as follows:-

1. Good bead appearance i.e. even rippled bead with proper curvature/crown height and uniform width.
2. Spatter less and smoke less operation, during welding.
3. Visual inspecting the joint for any visible defect like porosity, undercuts, lack of fusion, cracks, flaws etc.
4. Proper metal deposition without excessive crown height.

Based upon the above observations the range of the process parameters finally established is given in table 3.4.

Table 3.4: Range of process parameters

S No	Parameters	Min	Max
1	Current I (Amps)	400	525
2	Voltage V (Volts)	30	40
3	Speed S (mm/sec)	5.33	7.33

3.4.6 Final runs:

The specimens were categorized as A, B and C and the welding conditions used for each category are briefly as given in the following table 3.5.

Table 3.5 Welding conditions for different category samples

Sample Name	Welding conditions
Sample A	Welding current varied, welding voltage and welding speed constant.
Sample B	Welding voltage varied, welding current and welding speed constant.
Sample C	Welding speed varied, welding current and welding voltage constant.

3.4.7 Preparations of sample A category specimens

Six specimens belonging to category A samples were prepared by varying the welding current in the steps of 25 Amps keeping arc voltage and welding speed as fixed. The range of welding current was varied from 400 to 525 Amps where as arc voltage and welding speed used were 35 volts and 7.08 mm/sec respectively. The other welding conditions used were as follows. [23]

1. NPD = 25mm
2. Electrode to work angle $\theta = 90^0$
3. Polarity = reverse
4. Welding position = flat
5. Flux type = agglomerated
6. No of runs = 2

3.4.8 Preparation of sample B category specimens

In this category of sample, specimens were prepared by varying arc voltage from 30 to 40 volts in steps of 2 volts keeping welding current and speed as 425 Amps and 7.08mm/sec respectively.

The reason for selecting welding current and welding speed at their fixed levels was to give heat input as low as possible to the joint (ensuring adequate fusion) so as to avoid problems like distortion etc.[23]

3.4.9 Preparation of sample C category specimens

For preparing samples belonging to category C welding speed was varied from 5.33 to 7.33 mm/sec while keeping the welding current and arc voltage as fixed at 425 Amps and 35 volts respectively. Other welding conditions were similar as in sample A and B. Six samples were prepared for each category thus making a total of eighteen samples which were subjected to various mechanical tests as discussed in the next chapter.[23]

3.5 Welding procedure

In the first set, arc voltage and welding speed were kept constant; welding current was varied to six levels in the steps of 25 amperes i.e. 400,425,450,475,500 and 525 amps. Same combination of parameters was used while giving the second run. Similarly welding voltage was varied through six levels i.e. 30, 32,34,36,38, and 40 volts by keeping current and welding speed constant. Similarly welding speed was varied through six levels i.e. 5.33, 5.66, 6.00, 6.66, 7.00 and 7.33 by keeping arc voltage and welding current constant. The welding was done using SAW process. The work pieces were tacked with starting and ending tab so that the welding started on starting tab then on work piece with stable arc followed by ending tab to avoid any crater as shown in fig 3.3

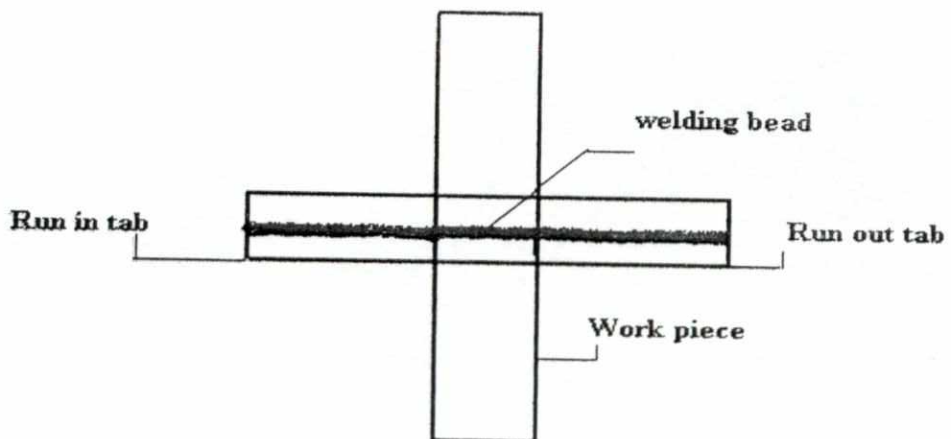


Fig 3.3 Welding Procedure

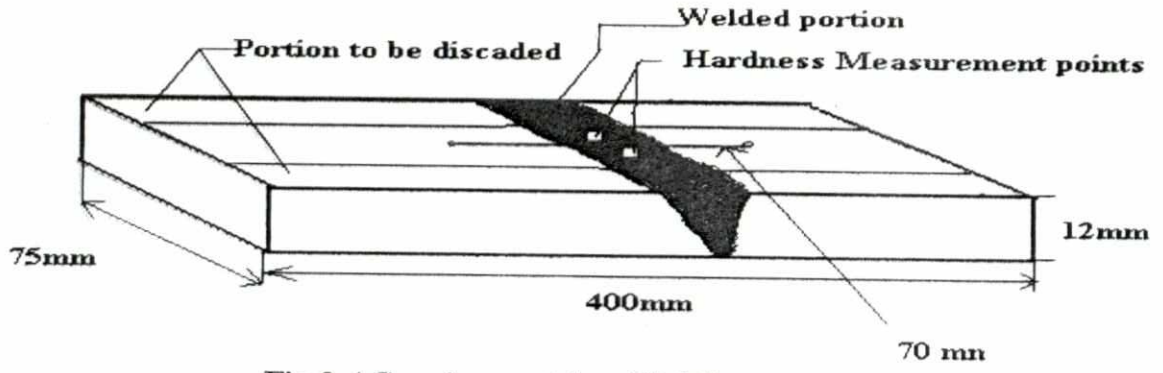


Fig 3.4 Specimens After Welding

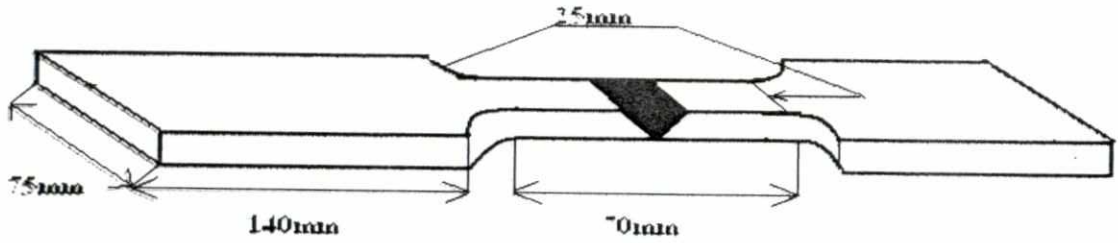


Fig 3.5 Specimen to be used for Testing

3.6 Impact testing:

For the sake of completeness of mechanical properties of the butt welded joints, it was considered important to have fair assessment of the toughness values of these joints made under different heat input conditions. Standard specimens of Charpy-Vnotch impact test were prepared for each of the samples belonging to category A, B and C. Impact strength testing was performed on the impact testing machine using the standard procedure. After testing at the room temperature, it was found that toughness values were in the range of 80 to 100 Joules which indicated that the specimen possessed adequate toughness. [28]

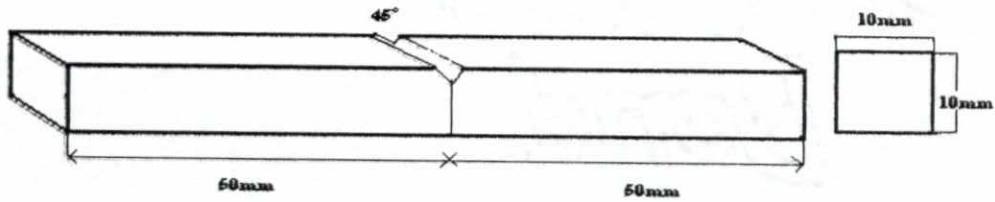
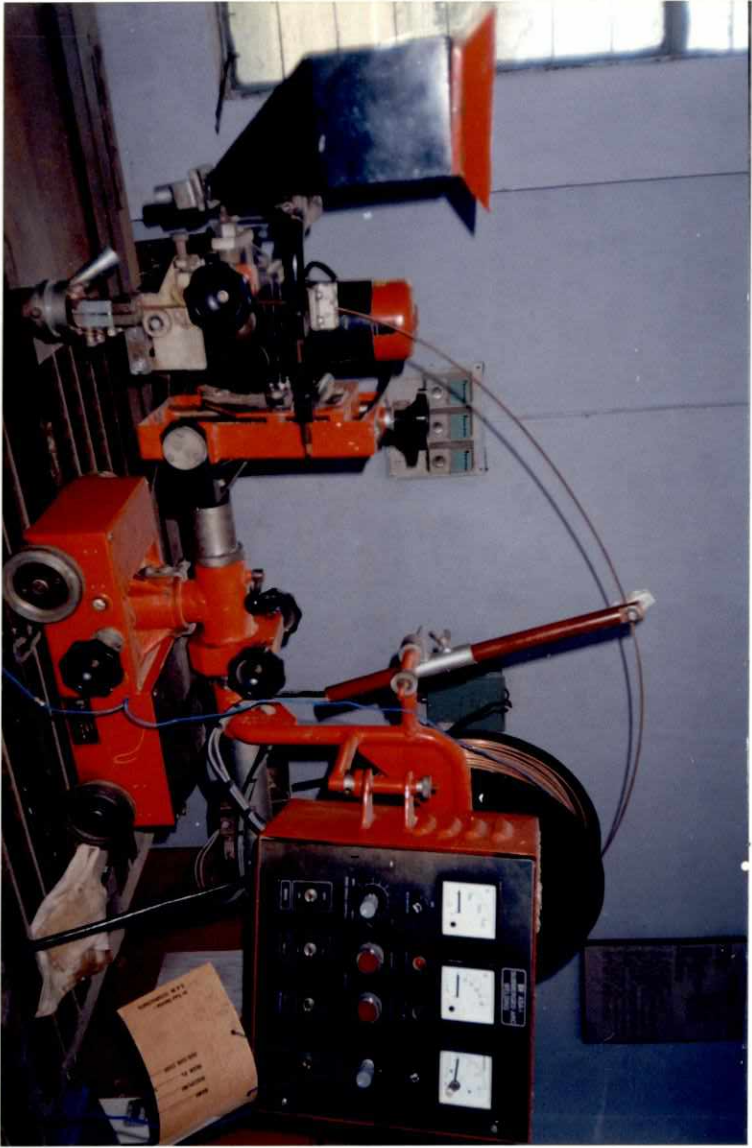


Fig 3.6 Specimen to be used for impact testing



SAW equipment used for welding

Chapter-4

Mechanical Testing

4.1 Introduction:

All types of welded structures, from steel bridges to high temperature components of jet engines serve a function. Likewise the welded joints in these structures or components are designed for service related capabilities or properties. To ensure that they will fulfill their intended function, a test of some type is usually performed. The ideal test of course is the observance of the structure in the actual service but actual service tests are expensive, time consuming and some time not feasible. Therefore standardized tests and testing procedures are used that give results which can be related to metals and structures that have performed satisfactorily in service. Performance of welded joints references are frequently AWS B 4.0 standard methods for mechanical testing of welds and ASTM A370 standard methods and definitions for mechanical testing of steel products.

Welded structures are subjected to a number of standard tests to determine their suitability for the anticipated service conditions. These tests are designed to check chemical, mechanical, and metallurgical properties and to locate defects such as incomplete fusion, slag inclusion, porosity, cracks, etc. These tests are also used for the qualification of welding procedures and welders, and some of them are suitable for checking the quality of consumables and base metals [25].

4.2 Tensile test:

This test is used to determine the yield strength, the ultimate tensile strength and percentage of elongation of a welded metal. In this case tensile specimens of standard dimensions were machined from the weld metal, inserted one by one in tensile testing machine and reading was noted one by one. Tensile testing machine is a pulling device fitted with an arrangement of measuring and registering load on the dial. A gradual load was applied on the specimen and resultant strain was observed on the specimen. The ultimate tensile load was observed from the machine. Ultimate tensile strength was calculated by dividing load over area of cross-section. The elongation was observed by change in gauge length. In the present study transverse butt weld test was choose. The traverse weld test standard accepted test by various codes to determine the joint efficiency. In this case tensile test on these butt weld have been

carried out according to Indian standards (IS:3600 / part-3) method of testing fusion welding joints and weld metal in steel, the details of which are shown in fig 4.1

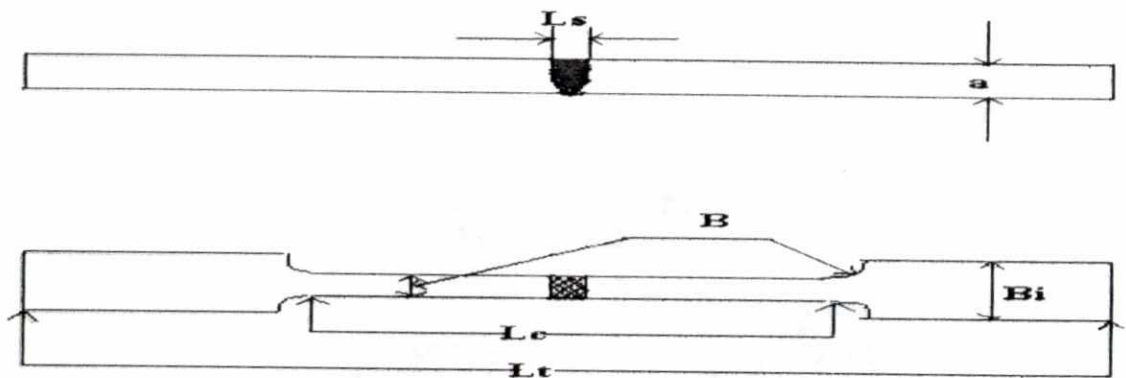


Fig 4.1 Tensile Test Specimens

Total length----- Lt -----To suit particular machine

Width of the shoulder -Bi----- Bi + 12mm

Width of the gauge length—B----- ≥ 25 mm

Gauge length -----Lc----- Ls + 60 mm

Radius of the shoulder—B----- ≥ 25 mm

Thickness of the plate-----a

Ls is the maximum width of the weld after machining

4.3 Directions of Indian standards for testing butt welded joints in transverse direction [26]

1. Field of application: this type of testing is applied to ferrous materials with butt joints made by any fusion welding process.
2. Principle: Breaking of the test specimen, taken transversely from welded joint, by applying tensile load.
3. Unless specified, the test should be carried out at ambient temperature.
4. Test piece: The test piece is taken from a part of welded test assembly transversely to the welded joint in such a way that after machining the weld axis will remain in the middle of the parallel length of the test piece.
5. Each test piece is marked in such a way that after its removal it is possible to identify its exact position in fabrication or on the test assembly from which it has been taken. No heat treatment is applied to the test assemblies unless it is specified or allowed by the application standard regarding welded joint to be tested.

6. The test piece can be taken from appropriate means. Shearing is excluded for thickness of more than 12 mm if thermal cutting or other methods, which should effect the cut surfaces, are used, the cuts are made at a distance from the surfaces of the final parallel length of the test piece greater than or equal to 12 mm.

7. Machining of the test piece: The test piece is finished by machining or grinding, suitable care should taken to avoid superficial strain- hardening or excessive heating of the material. The surfaces should be free from scratches or notches transverse to the test piece direction.

8. Only the weld reinforcement on the face and root side should be removed, unless otherwise specified in the application standard.

9. Generally the test piece thickness should be equal to the thickness of the parent metal near the welded joint .It is permissible , however to take several test pieces from the welded joint to cover the full thickness of the joint , instead of single test piece in the welded joint thickness has been identified.

10. Method of testing:

The test piece should be loaded gradually and continuously in a direction to the weld axis until rupture. The speed of loading should be uniform as possible, in any case, possible variation of loading speed during testing should be progressive and without abrupt changes.

Procedure used for tensile testing the specimens fabricated as details in previous chapter on experimentations were subjected to tensile testing following the directions and procedures as mentioned in section 4.3 of this chapter.

This test has been performed on a universal testing machine, the specification of which is given below:

Make: ENKAY Industries, New Delhi

Capacity: 50 Tonnes

Loading and Unloading mechanism: Hydraulic operated

Results:

The tensile strength is calculated as the ratio of maximum load sustained by the test piece during testing to the original cross-sectional area of the test piece in the parallel length, expressed in MPa. These results are as shown in tables 4.3, 4.4 and 4.5.

After breaking the test piece, the fracture surfaces should be examined and the existence of any defect should be recoded. The test was performed on all the specimens and the observations so made were entered in to the tables.

4.4 Hardness test:

Hardness is the ability of a material to resist indentation or penetration, to resist abrasive wear. Hardness of a material increases with an increase in tensile strength. Hardness of the base metal weld metal of a welded joint is affected by chemical composition, the metallurgical effects of welding, cold working of the metal, heat treatment and several other factors.

In this investigation the method used for hardness testing is Rockwell. Correlation between hardness and tensile strength would be developed which would help in predicting tensile strength, process parameters and heat input from the hardness value for 12mm thick mild steel flat before welding.

4.5.1 Computational procedure to establish correlations

The best fit equations to correlate the mechanical parameters and the welding parameters have been obtained using standard statistical techniques of regression analysis. The experimental data has been analyzed by the least squares regression technique.

4.5.2 Principle of least squares

The principle of least square provides an elegant procedure for fitting a unique curve to a given data.[27]

Let the curve

$$y = a + bx + cx^2 + \dots + kx^{m-1}$$

Be fitted to the set of n data points.

$$(x_1, y_1), (x_2, y_2), \dots, (x_n, y_n).$$

Now we have to determine the constants a, b, c, \dots, k such that it represents the curve of best fit. In case $n=m$ on substituting the values (x_i, y_i) in (1), we get n equations from which a unique set of n constants can be found. But when $n > m$, we obtain n equations which are more than the m constants. So we try to determine those values of a, b, c, \dots, k which satisfy all the equations as nearly as possible and thus may give the best fit. In such cases, we apply the principle of least squares.

At $x = x_i$, the observed (or experimental) value of the ordinate is $y_i = P_i L_i$ and the corresponding value on the fitting curve (1) is

$$a + bx_i + cx_i^2 + \dots + kx_i^m = M_i L_i (= n_i, \text{ say})$$

Which is the expected (or calculated) value. The difference of the observed and expected values i.e. $y_i - n_i (= e_i)$ is called the error (or residual) at $x = x_i$. Clearly some

of the errors e_1, e_2, \dots, e_n will be positive and others negative. Thus to give equal weight age to each error, we square each of these and form their sum i.e.

$$E = e_1^2 + e_2^2 + \dots + e_n^2.$$

The curve of best fit is that for which e 's are as small as possible i.e. E , the sum of the squares of the errors is a minimum. This is known as the principle of least squares and was suggested by Legendre in 1806.

The prediction equations obtained between mechanical properties i.e. ultimate tensile strength (T) and hardness (H) and welding parameters current (I), voltage (V), welding speed (S) and heat input per mm length of weld (K) using method of least squares are shown in the table 4.1

Table 4.1 Prediction equations

Mechanical properties v/s welding parameters	Prediction equations	Fig no
Samples A		
I v/s U	$U = 0.0222 I^2 - 20.955 I + 5389.1$	5.1
I v/s K	$K = -0.0008 I^2 + 0.6807 I - 125.82$	5.2
I v/s E	$E = 0.0008 I^2 - 0.7459 I + 195.53$	5.3
H v/s U	$U = 979.55H^2 - 4492.3H + 5586.8$	5.4
H v/s K	$K = -4.4524H + 34.599$	5.5
H v/s E	$E = 31.088H^2 - 144.84H + 188.49$	5.6
Samples B		
V v/s U	$U = -0.8802 V^2 + 60.39 V - 558.19$	5.7
V v/s K	$K = -0.0459V^2 + 2.746V - 15.597$	5.8
V v/s E	$E = -0.0308V^2 + 2.122V - 15.875$	5.9
H v/s U	$U = -244.51H^2 + 1006.5H - 558.19$	5.10
H v/s K	$K = -10.869H^2 + 37.651H - 6.9637$	5.11
H v/s E	$E = -8.4945H^2 + 35.118H - 15.627$	5.12
Samples C		
S v/s U	$U = 72.211S^2 - 928.47S + 3392.1$	5.13
S v/s K	$K = -4.8896S^2 + 63.548S - 180.09$	5.14
S v/s E	$E = 0.4827S^2 - 6.1877S + 39.777$	5.15
H v/s U	$U = 333.07H^2 - 1556.5H + 2239$	5.16
H v/s K	$K = -31.814H^2 + 147.97H - 145.91$	5.17
H v/s E	$E = 1.33H^2 - 6.2052H + 27.319$	5.18

Where

I = Current in Amps

V = Voltage in volts

S = Welding speed in mm/min

U = Ultimate tensile strength in MPa

H = Heat input /length of weld (KJ/mm)

K = Hardness in HRC

E = Percentage elongation

Table 4.2 Welding Conditions

Sample Category	Welding conditions
Sample A	Welding current varied, welding voltage and welding speed fixed.
Sample B	Welding voltage varied, welding current and welding speed fixed.
Sample C	Welding speed varied, welding current and welding voltage fixed.

Apart from the welding conditions stated in the above mentioned table the following welding conditions were used for each specimen.

Table 4.3 Observations for sample A

Sr No	Current (I) Amps	Voltage (V) Volts	Speed (S) mm/sec	Heat input (H) KJ/mm H=VI/S	UTL (L) Kg	Area of cross-sections at the gauge length (A) mm ²	UTS (U) Mpa	Hardness of weld (K) HRC	Percentage elongation (E) mm
A1	400	35	7.08	1.97	17500	300	572.25	25.33	24
A2	425	35	7.08	2.10	14992	300	490.25	25.13	21.1
A3	450	35	7.08	2.22	14200	300	464.34	27.4	20.2
A4	475	35	7.08	2.34	13924	300	455.34	21.66	19.8
A5	500	35	7.08	2.47	14700	300	480.69	23.66	20.7
A6	525	35	7.08	2.6	15700	300	513.39	23.415	21.9

Welding conditions:

1. Welding Current (varied) = 400 A to 525 A
2. Arc voltage (fixed) = 35 volts
3. Welding speed (fixed) = 7.08 mm / sec
4. NPD = 25mm
5. Electrode to work angle $\theta = 90^{\circ}$
6. Polarity = reverse
7. Welding position = flat
8. Flux type = agglomerated
9. No of runs = 2

Table 4.4 Observations for sample B

Sr No	Current (I) Amps	Voltage (V) Volts	Speed (S) mm/sec	Heat input (H) KJ/mm H=VI/S	UTL (L) Kg	Area of cross-sections at the gauge length (A) mm ²	UTS (U) Mpa	Hardness of weld (K) HRC	Percent age elongation (E) mm
B1	425	30	7.08	1.80	13900	300	454.53	25.745	19.8
B2	425	32	7.08	1.92	14690	300	480.22	25.33	20.8
B3	425	34	7.08	2.04	15000	300	490.3	23.8	21.1
B4	425	36	7.08	2.16	14100	300	461.07	24.165	20
B5	425	38	7.08	2.28	14250	300	460.22	22.75	20.2
B6	425	40	7.08	2.40	13950	300	455.22	20.495	19.9

Welding conditions:

1. Welding Current (fixed) = 425 A
2. Arc voltage (varied) = 30 volts to 40 volts
3. Welding speed (fixed) = 7.08 mm / sec
4. NPD = 25mm
5. Electrode to work angle $\theta = 90^0$
6. Polarity = reverse
7. Welding position = flat
8. Flux type = agglomerated
9. No of runs = 2

Table 4.5 Observations for sample C

Sr No	Current (I) Amps	Voltage (V) Volts	Speed (S) mm/sec	Heat input (H) KJ/mm H=VI/S	UTL (L) Kg	Area of cross-sections at the gauge length (A) mm ²	UTS (U) Mpa	Hardness of weld (K) HRC	Percent age elongation (E) mm
C1	425	35	5.33	2.79	14000	300	457.8	18.58	19.9
C2	425	35	5.66	2.62	15000	300	490.5	25.83	21.1
C3	425	35	6.00	2.47	14000	300	457.8	23.16	19.9
C4	425	35	6.66	2.23	10500	300	343.3	26.16	20
C5	425	35	7.00	2.12	13500	300	441.45	25.66	19.3
C6	425	35	7.33	2.029	14800	300	483.96	22.83	20.9

Welding conditions:

1. Welding Current (fixed) = 425 A
2. Arc voltage (fixed) = 35 volts
3. Welding speed (varied) = 5.33 mm / sec to 7.33 mm / sec
4. NPD = 25mm
5. Electrode to work angle $\theta = 90^0$
6. Polarity = reverse
7. Welding position = flat
8. Flux type = agglomerated
9. No of runs = 2

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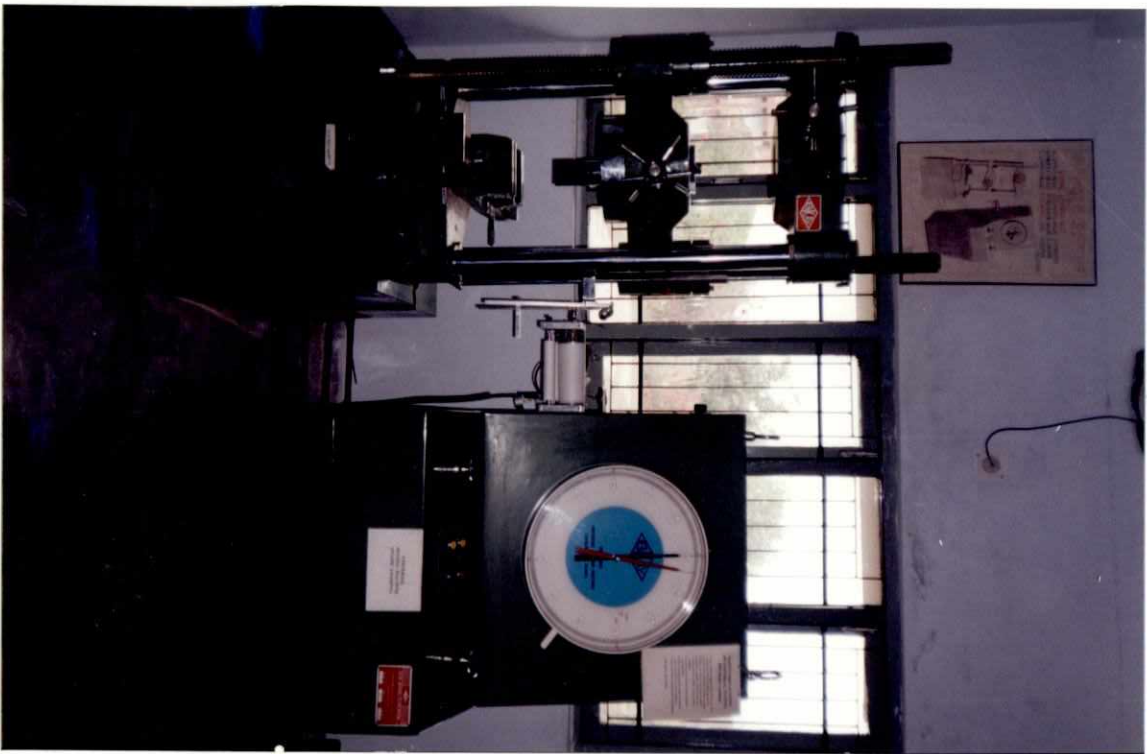
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Specimens used for tensile testing



**Equipment used for hardness testing
(Rockwell hardness tester)**



Equipment used for tensile testing

Chapter 5

Results and discussions

After carrying out the experimentation thoroughly as detailed in the previous chapter the data has been presented in the graphical form for easy and quick analysis. In the forgoing paragraph is discussed the trend of each of the output variables viz UTS, hardness and percentage elongation corresponding to each input variables namely welding current, arc voltage, welding speed and heat input per unit length of the weld i.e. the primary welding variable.

5.1 Effect of Welding Current on UTS (Sample A):

Corresponding to six different values of welding current varied in the steps of 25 amperes, is shown six different values of UTS possessed by each of the six specimens. Using the method of least squares, a best fit curve was fitted into this scattered data and the trend was obtained i.e. parabola is shown in fig 5.1. As is evident from the fig that is the maximum UTS possessed by the specimen was 572 MPa which occurred at 500 amperes. The minimum UTS is 455 MPa corresponding to 475 amperes. The average UTS of sample category A were found to be 495 MPa. The trend so obtained can be explained on the basis of the fact that as welding current increases, for a given set of other welding conditions, heat input also increases. This increased heat input results in decreasing the cooling rate of the weldment or in other words the thermal gradient established during the solidification is not so steep. These further result in coarse grained micro structure. Since the mechanical properties depend upon the microstructure. This coarse grain micro structure results in relatively lower hardness and hence lowers UTS.

The reverse happens when welding current is low which means low heat input to the weldment and hence higher cooling rate due to relatively steeper thermal gradient during solidification. Higher cooling rate results in fine grain structure, giving high hardness and high UTS. This is what is actually depicted from the trend as shown in fig 5.1.

5.2 Effect of Welding Current on Hardness (Sample A):

As discussed in section 5.1 any change in welding current will result in change in the heat input to the weldment. The same reasoning can be used to explain the trend between welding current and hardness which shows gradual decrease in hardness

values as welding current increases. Corresponding to six values of welding current, varied in steps of 25 Amps, six values of hardness were obtained. Using method of least squares the curve was fitted between the scattered data. The trend obtained was a parabola as shown in fig 5.2. As is evident from the fig that the maximum hardness was 27.4 HRC corresponding to 450 Amps when welding speed and welding voltage were kept constant at 7.08mm/sec and 35volts respectively and minimum hardness was 21.66 HRC corresponding to 475 Amps, keeping other welding conditions constant. The average Hardness of sample A category was found to be 24.42 HRC. The trend so obtained can be explained on the basis that with an increase in welding current, heat input increases, resulting in decreased cooling rate of weldment. This results in coarse grained structure. This large size grain structure results in lower hardness.

5.3 Effect of Welding Current on Percentage Elongation (Sample A):

The percentage elongation of each specimen corresponding to respective value of welding current used was calculated using the following formula.

$$\text{Percentage Elongation} = \frac{(\text{Original Area} - \text{Final Area})}{\text{Original Area}}$$

The importance of this calculation was that it gives an indication regarding the ductility of the joint and thus enables to have an idea that whether the given joint will be able to with stand service conditions / loadings as per the specification of the codes. The trend of the graph between welding current and percentage elongation is as depicted in fig no 5.3. It shows that with an increase in welding current, percentage elongation decreases up to certain extent, there after showing a slight increase. This behavior can be attributed to the fact that as welding current increases, heat input increases which further decreases the cooling rate thus giving a coarser microstructure, which results in decreased value of percentage elongation. Slight deviations from the conceptual behavior may be due to the chemical heterogeneity in the fusion zone.

5.4 Effect of Heat input / length of weld on UTS (Sample A):

Heat Input to a weldment given by following relation.

$$H = \eta VI \cos\phi / S$$

where η is the heat transfer coefficient, V is the arc voltage, I is the welding current and $\cos\phi$ is the power factor. In case of SAW value of η is generally closer to unity and same has been taken for the all calculations for heat input. The heat input calculations carried out are those as taken from the variations in welding current, arc voltage and welding speed. The trend between heat input and UTS is shown in fig 5.4 which depicts

a parabola fitted using method of least squares. As is evident and discussed in the proceeding paragraphs, any change in the primary variables namely welding current, welding voltage and welding speed will change heat input per unit length, which will, correspondingly affect the cooling rate of the weldment, which will further affect the microstructure and hence the mechanical properties / strength of the joint . The quantitative information obtained from this graph as given below.

The heat input was varied between 1.97 to 2.6 kJ/mm by changing current from 400 Amps to 525Amps in the steps of 25 Amps keeping welding voltage and welding speed constant i.e. 35 volts and 7.08mm/sec. The UTS was maximum i.e. 572 MPa corresponding to heat input 1.97 KJ/mm and UTS was minimum i.e. 455 Mpa corresponding to a heat input of 2.34 KJ/mm. It is evident from above, that with the increase in heat input UTS decreases. The reason behind this is that with an increase in heat input / mm length of weld the temperature gradient developed is not so steep. That is why cooling rate decreases giving coarser microstructure and hence lower values of UTS.

5.5 Effect of Heat Input/ length of weld on Hardness (Sample A):

For a given set of readings of voltage current and speed, heat input was calculated for each specimen belonging to category of sample A and the scatter between heat input and hardness measured at the weldment is shown in fig 5.5. Best fit curve which suited to this scattered plot was a linear one. The explanation of this curve, based upon the fitted curve is that as heat input increases, the thermal gradients established are less steeper which result in slow heat dissipation from the joint or in other words cooling rate decreases resulting in coarse grain microstructures and thus low hardness. In this case heat input was varied 1.97 to 2.6 kJ/mm by changing current from 400 Amps to 525Amps in the steps of 25 Amps keeping welding voltage and welding speed constant i.e. 35 volts and 7.08mm/sec. the maximum Hardness was calculated 27.4 HRC corresponding to Heat Input 2.22 kJ/mm and minimum Hardness was 21.66 HRC corresponding to Heat Input 2.34 KJ/mm. The average Hardness was 24.42 HRC.

5.6 Effect of Heat Input/ length of weld on Percentage Elongation (Sample A):

As discussed in section 5.5, with the increase in heat input, hardness decreases and hence the resistance to plastic deformation also decreases. As is evident from the graph between percentage elongation and heat input, as heat input increases percentage elongation of the samples decreases parabolically for the first four samples and then there is a slight increase in the percentage elongation for the remaining two samples

which may be attributed to chemical heterogeneity in the fusion zone. In this case heat input was varied 1.97 to 2.6 kJ/mm by changing current from 400 Amps to 525Amps in steps of 25 Amps keeping welding voltage and welding speed constant i.e. 35 volts and 7.08mm/sec respectively. The maximum Percentage Elongation was found to be 24 % corresponding to heat input of 1.9KJ/mm and minimum Percentage Elongation was 19.8% corresponding to heat input 2.34KJ/mm. The average % Elongation was 21.2%.

5.7 Effect of Arc Voltage and UTS (Sample B):

The second primary welding variable was arc voltage and the trend between arc voltage, varied in steps of 2volts, and the corresponding values of UTS in MPa has been shown in fig no 5.7. This behavior of the graph as depicted by best fit curve arc voltage and UTS can be explained on the basis that arc voltage affects the penetration in two ways, firstly as arc length increases arc voltage also increases correspondingly, thus resulting in the spread of arc cone. In other words arc heat due to the increased arc cone spreads over the larger surface of the base plate thus resulting in increased in bead width. Secondly it is an electrical parameter which is directly related to heat input thus resulting in increased penetration therefore it is the cumulative effect of these two points which decides the final out come of the trend between arc voltage and UTS. The first half of the curve that is up to 34 volts UTS increases and during second half 36 to 40 volts shows decrease in UTS values. Maximum value UTS was 490MPa corresponding to 34 volts and minimum value of UTS 454 MPa was corresponding to 30 volts. The average value of UTS was 466MPa.

5.8 Effect of Arc Voltage on Hardness (Sample B):

The graph between Arc voltages varied in steps of 2 volts. The hardness of the joints as measured on the weldment of the specimen has been shown in fig 5.8. As indicated by the best fit curve, as the arc voltage increases hardness correspondingly decreases. The reason for this decrease is that as arc voltage increases heat input increases, which lowers the cooling rate of the fusion zone of the joint, consequently giving coarser microstructure, thus giving lower hardness values. The maximum value of Hardness was 25.745 HRC corresponding to 30 volts and minimum value of hardness was 20.495HRC corresponding to 40 volts. The average value of hardness was 23.71 HRC.

5.9 Effect of Arc Voltage on Percentage Elongation (Sample B):

The graph was plotted between arc voltage and percentage elongation by varying arc voltage in steps of 2 volts. The trend was depicted by the best fit curve shows that with an increase in arc voltage, percentage elongation an increases initially, thereafter

second half of the arc voltage varied 36 to 40 volts the percentage elongation decreases. In this graph maximum elongation 21.1% corresponds to 34 volts and minimum elongation 19.8 % corresponding to 30 volts. The average percentage Elongation was 20.2 %.

5.10 Effect of Heat input/ length of weld on UTS (Sample B):

The graph between heat input and UTS for the sample category B is shown in fig 5.10. The heat input / mm length of weld calculated in this case is made by varying voltage and keeping welding current and welding speed constant. A polynomial equation was fitted into the scattered plot. In this the more dominating trend is that of decreased UTS as heat input increases. This fact is again in line with the discussion mentioned in the previous section. In this case heat input was varied from 1.80KJ/mm to 2.40KJ/mm by varying voltage from 30 volts to 40 volts in six steps of 2 volts each keeping welding current and welding speed constant at 425 Amps and 7.08mm/sec respectively. During this variation of heat input the maximum UTS was found 490.3MPa at 2.04KJ/mm and minimum UTS 454.3MPa at 1.80KJ/mm. The average UTS were 466.92 MPa.

5.11 Effect of Heat Input/ length of weld on Hardness (Sample B):

The graph between heat input and hardness for sample category B is shown in fig 5.11. The reasoning for this trend i.e. with an increase in heat input the hardness of the weldment decreases is again as per the discussion given in section 5.5. In this case heat input was varied from 1.80KJ/mm to 2.40KJ/mm by varying voltage 30 volts to 40 volts in six steps of 2 volts each keeping welding current and welding speed as constant at 425 Amps and 7.08mm/sec respectively. Maximum Hardness was found to be 25.745HRC corresponding to heat input 1.80 KJ/mm and minimum Hardness 20.495HRC corresponding to heat input 2.40KJ/mm. The average hardness was found to be 23.71HRC.

5.12 Effect of Heat Input/ length of weld on Percentage Elongation (Sample B):

Heat input in this case was calculated by keeping welding current and welding speed as constant and varying voltage in steps of 2 volts each. Although a parabola has been fitted in the scattered plot, but over all trend of this curve states that as heat input increases percentage elongation also decreases. . In this case heat input was varied from 1.80KJ/mm to 2.40KJ/mm by varying voltage 30 volts to 40 volts in six steps of 2 volts each keeping current and speed constant at 425 Amps and 7.08mm/sec respectively. In this graph the heat input was varied 1.80KJ/mm to 2.40KJ/mm, the maximum percentage elongation was found to be 21.1% corresponding to 2.04 KJ/mm

and minimum percentage elongation was 19.8 % corresponding to heat input 1.80 KJ/mm. In this case heat input was varied from 1.80KJ/mm to 2.40KJ/mm by varying voltage 30 volts to 40 volts in six steps of 2 volts each keeping current and speed constant at 425 Amps and 7.08mm/sec respectively. The average percentage elongation was 20.2 %.

5.13 Effect of Welding Speed on UTS (Sample C):

The trend as shown by the best fit curve between welding speed and UTS states that as welding speed increases UTS also decreases to a certain extent, there after showing a linear increase in UTS values during the last one third of the graph. Since welding speed affects the heat input inversely so increase in welding speed means decreased heat input per unit length of the weld and consequently higher cooling rate resulting in fine microstructures. Another aspect of this trend can be viewed from the fact that at slower welding speed, dilution is low where as at high welding speed it is high. Since fresh base metal surface is exposed to the incoming heat of the arc which increases the dilution. This means that more penetration and hence more side wall fusion. This result is slower cooling rates and hence lowers UTS value. In this case maximum UTS was 490.5 MPA corresponding to welding speed 6 mm/sec and minimum UTS 343 MPa corresponding to 6.66 mm/sec. The average UTS was 445.88 MPa

5.14 Effect of Welding Speed on Hardness (Sample C):

The graph between welding speed and hardness as measured on weldment of each specimen is shown in fig 5.14. The trend as stated by the best fit curve in to the data shows that as welding speed increases hardness value also shows an increase for the first four specimens, that is up to welding speed of 6.66 mm/sec. This can be explained on basis of fact as stated in the previous section 5.13. The maximum hardness was 25.83 HRC corresponding to welding speed 5.66 mm/sec and minimum hardness 22.83 HRC corresponding to 7.33 mm/sec. The average hardness was 23.70 HRC.

5.15 Effect of Welding Speed on Percentage Elongation (Sample C):

The graph between welding speed and percentage elongation is shown in fig 5.15. The trend as depicted by the best fit curve shows that as welding speed increases percentage elongation decreases for the first four specimens i.e. for the range of welding speed from 5.33 to 6.66 mm/sec, there after showing slight increase for the next portion of the graph. Reason for the same can be attributed to the fact as discussed in previous sections. The maximum elongation was 21.1 % corresponding to welding speed 5.66

mm/sec and minimum Elongation 19.3 % corresponding to welding 7.00mm/sec. The average percentage elongation was found to be 20.2 %.

5.16 Effect of Heat input/ length of weld on UTS (Sample C):

As mentioned previously sample C category samples were prepared by varying welding speed and keeping welding current and arc voltage as constant and accordingly calculation of heat input per unit length were made. As indicated in this graph 5.16 decrease in heat input per unit length of weld results in increase in cooling rate which results in fine microstructures which accounts for the increase in UTS. In this case the heat input was varied 2.029KJ/mm to 2.79KJ/mm length change of UTS was found to be in the range of 343Mpa to 490.5Mpa.

5.17 Effect of Heat Input/ length of weld on Hardness (Sample C):

The graph between heat input and hardness is shown in fig 5.17 which shows that as heat input increases hardness correspondingly decreases which is due to the fact that increases, in heat input results in decrease in cooling rate thus giving coarser micro structures resulting in lower hardness values. The heat input was varied by changing welding speed from 5.33mm/sec to 7.33mm/sec in six steps. Maximum hardness was found to be 26.16HRC corresponding to heat input 2.23KJ/mm and minimum hardness 18.58 HRC corresponding to 2.77. The average hardness was 23.70HRC.

5.18 Effect of Heat Input/ length of weld on Percentage Elongation (Sample C):

As mentioned previously sample C category samples were prepared by varying welding speed and keeping welding current and arc voltage as constant and accordingly calculations of heat input per unit length were made. As indicated by this graph decrease in heat input per unit length of weld results in increase in cooling rate which results in fine microstructures which accounts for the increase in UTS values. The heat input was varied by changing welding speed from 5.33mm/sec to 7.33mm/sec in six steps. The maximum percentage elongation was 21.1 % corresponding to heat input 2.62KJ/mm and minimum percentage elongation was 19.3 % corresponding to heat input 2.12KJ/mm. The average percentage elongation was found to be 20.2 %.

Fig 5.1 Sample A, Welding Current v/s UTS

$$U = 0.0222 I^2 - 20.955 I + 5389.1$$

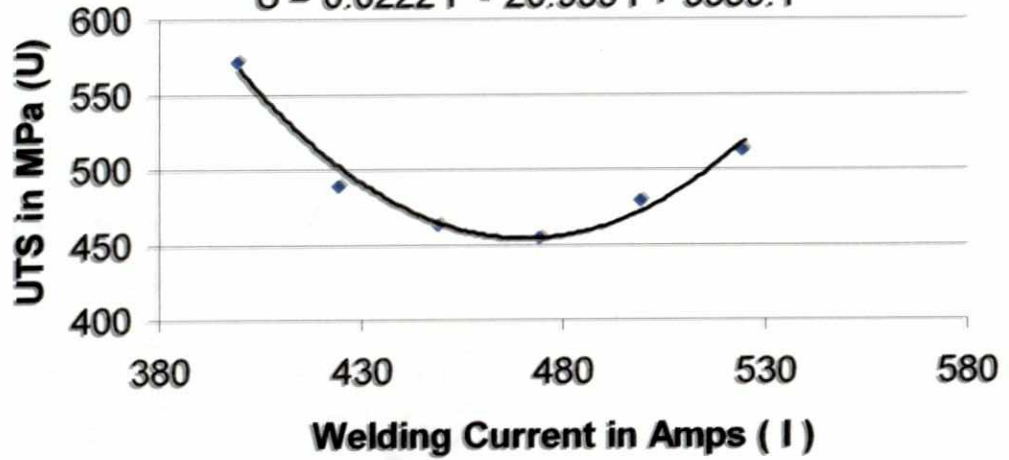


Fig 5.2 Sample A, Current v/s Hardness

$$K = -0.0008 I^2 + 0.6807 I - 125.82$$

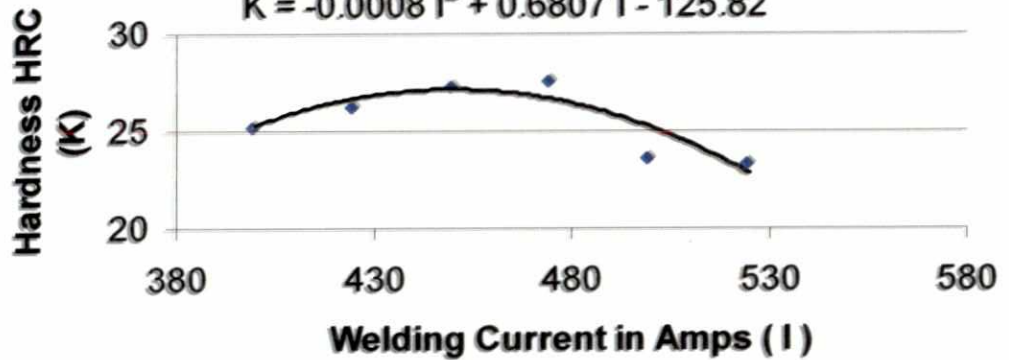


Fig 5.3 Sample A, Welding current v/s Percentage Elongation

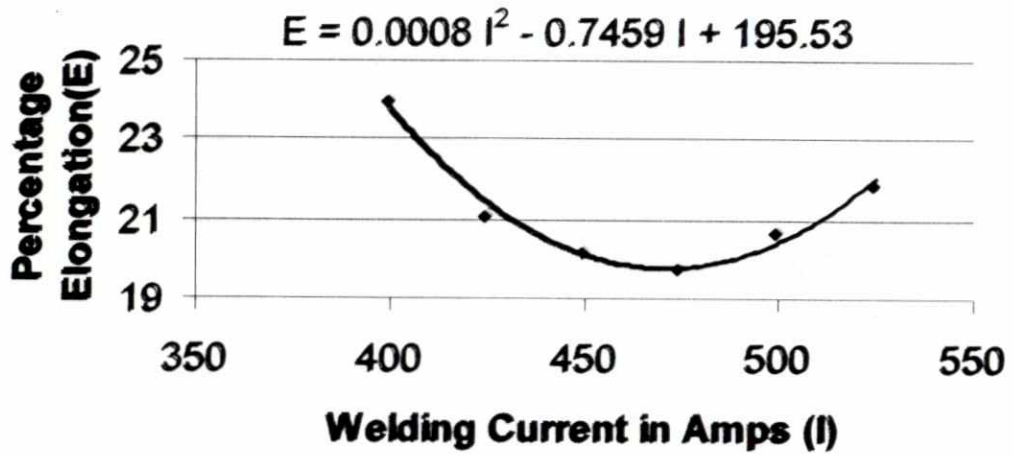


Fig 5.4 Sample A, Heat Input / mm length of weld v/s UTS

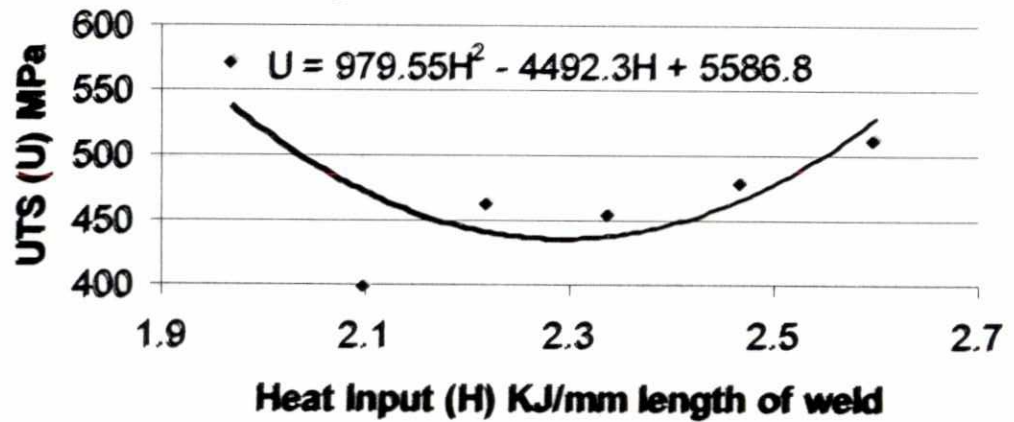


Fig 5.5 Sample A, Heat Input / mm length of weld v/s Hardness

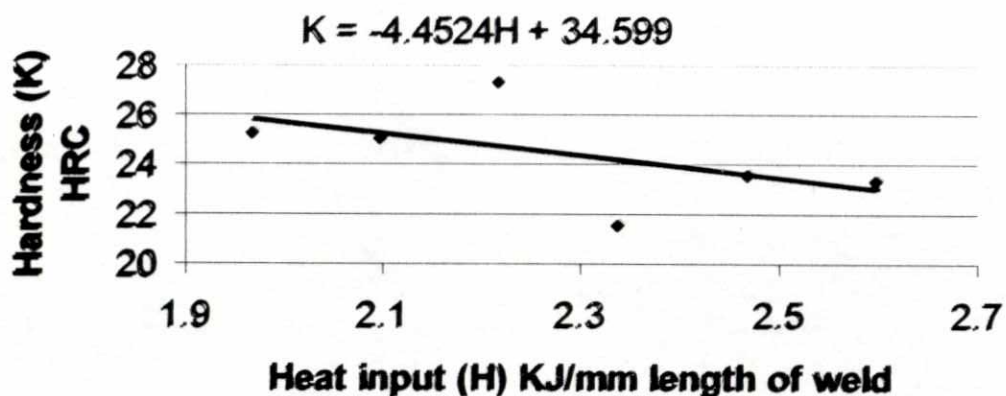


Fig5.6 Sample A, Heat Input / mm length of weld v/s Percentage Elongation

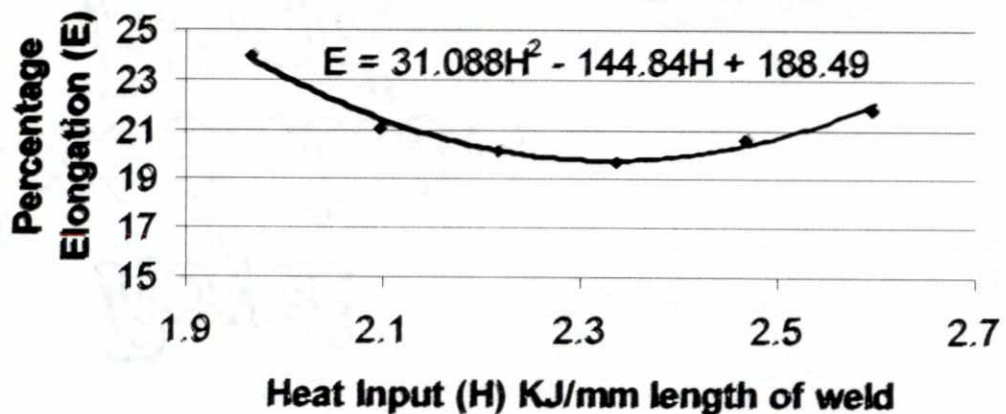


Fig 5.7 Sample B, Arc voltage v/s UTS

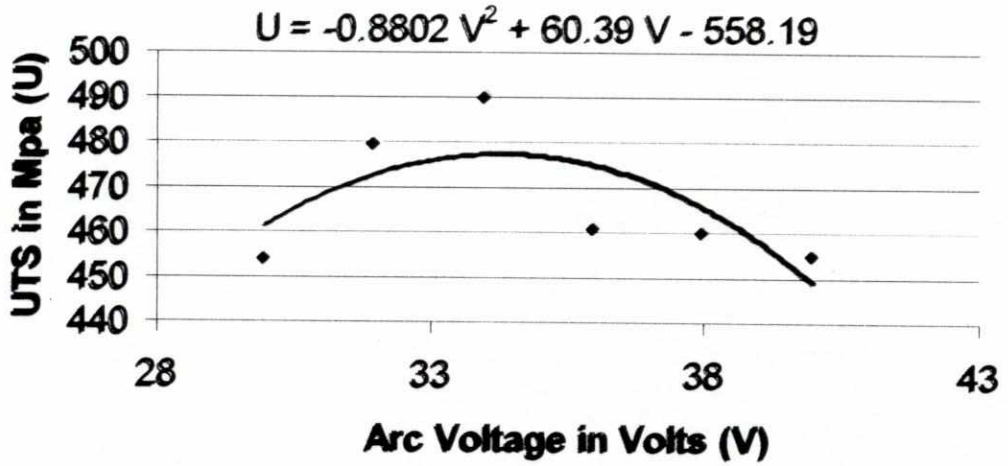


Fig 5.8 Sample B, Arc voltage v/s hardness

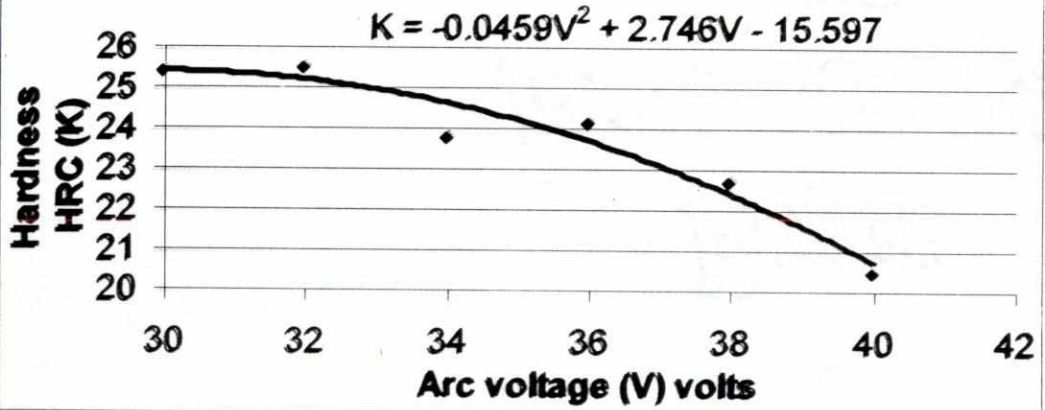


Fig 5.9 Sample B Arc voltage v/s Percentage Elongation

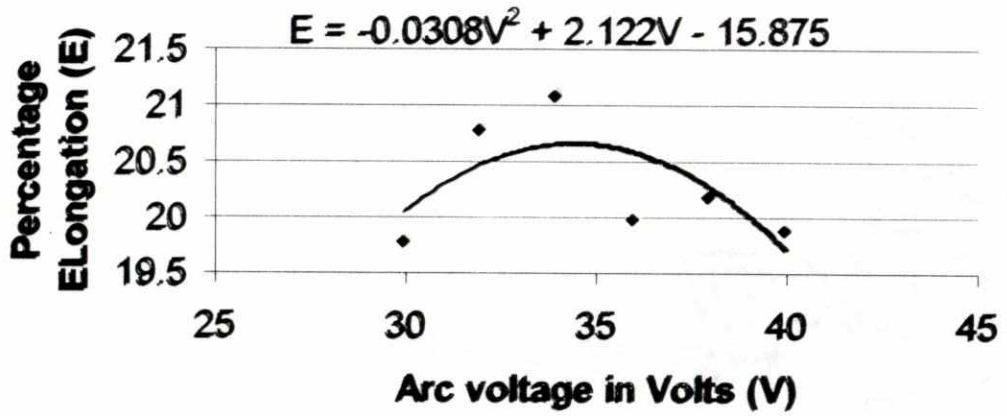


Fig 5.10 Sample B, Heat Input /mm length of weld v/s UTS

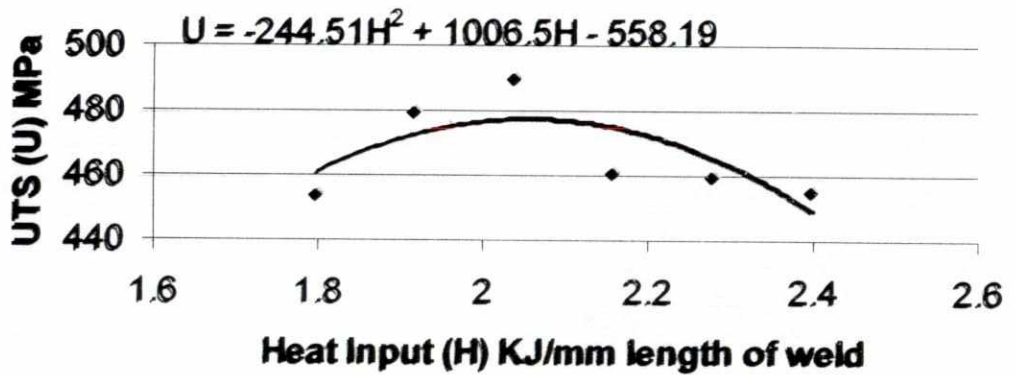


Fig 5.11 Sample B, Heat Input / mm length of weld v/s Hardness

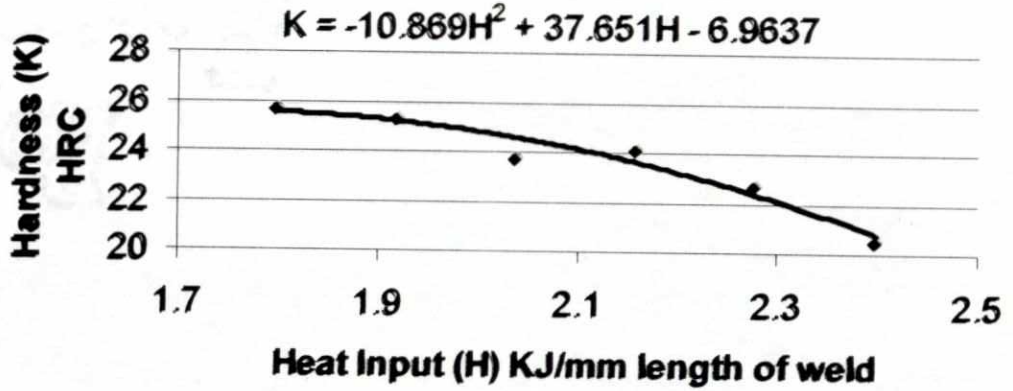


Fig 5.12 Sample B, Heat Input /mm length of weld v/s Percentage Elongation

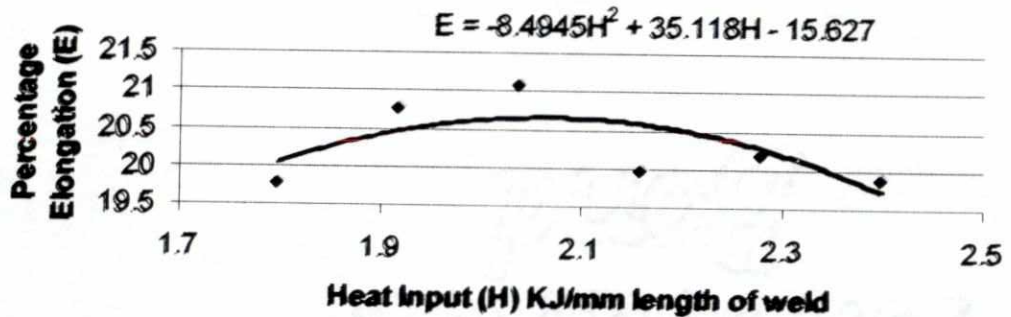


Fig 5.13 Sample C, Welding speed v/s UTS

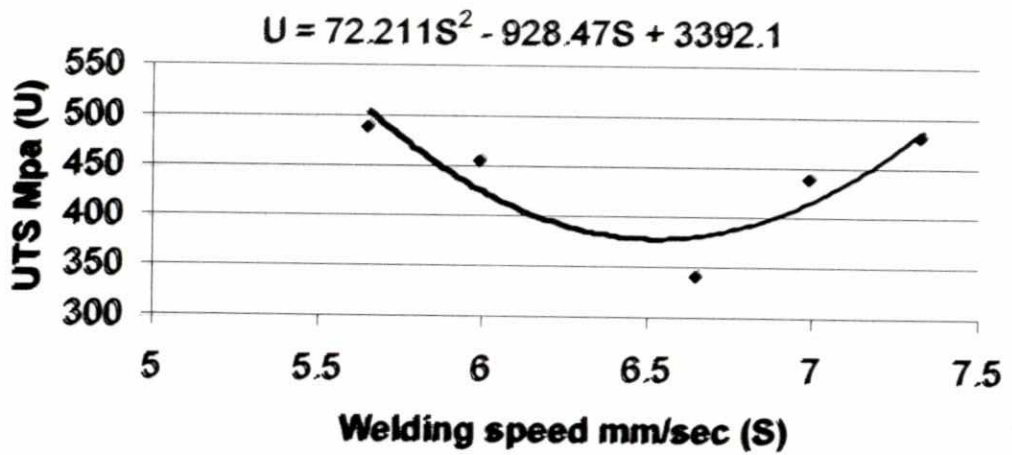


Fig 5.14 Sample C, Welding Speed v/s Hardness

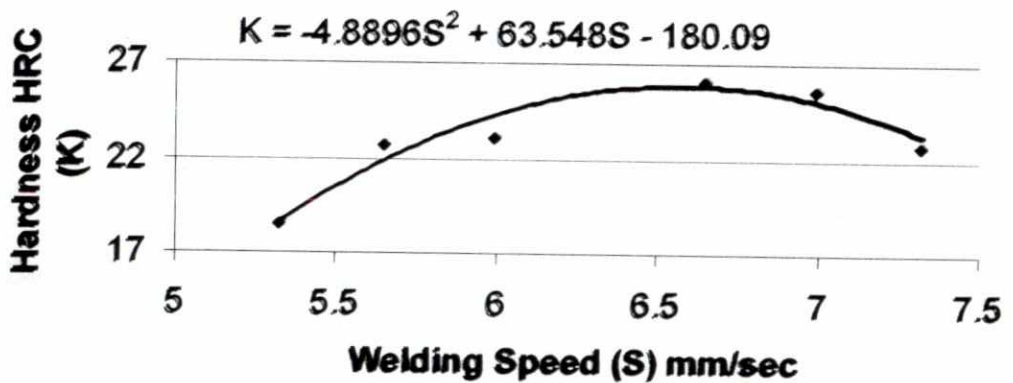


Fig 5.15 Sample C, Welding Speed v/s Percentage Elongation

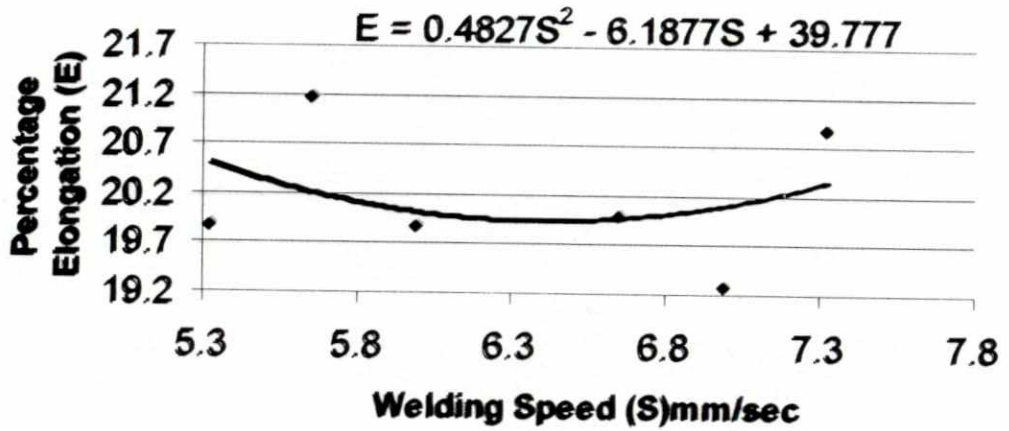


Fig 5.16 Sample C, Heat Input / mm length of weld v/s UTS

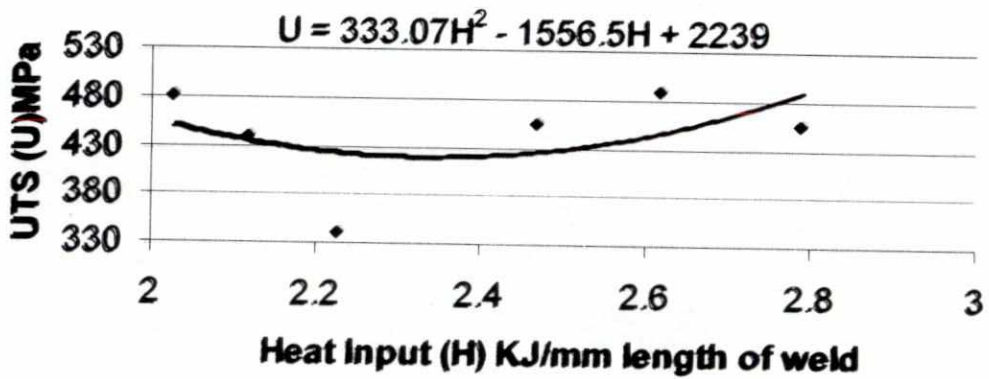


Fig 5.17 Sample C, Heat Input / mm length of weld v/s Hardness

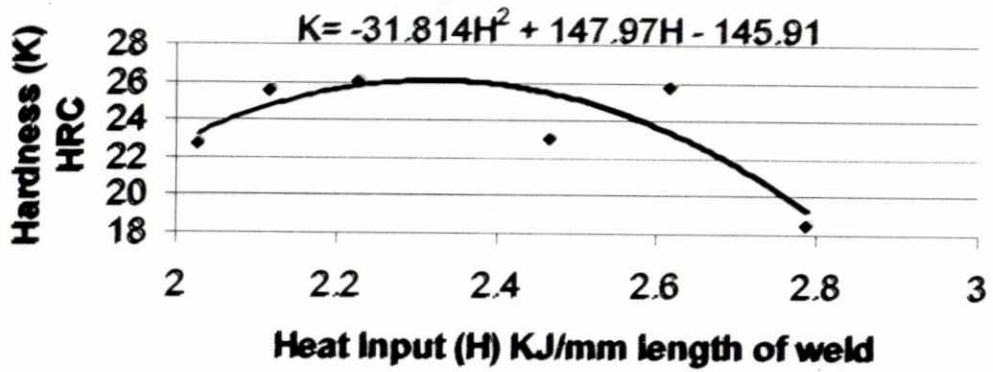
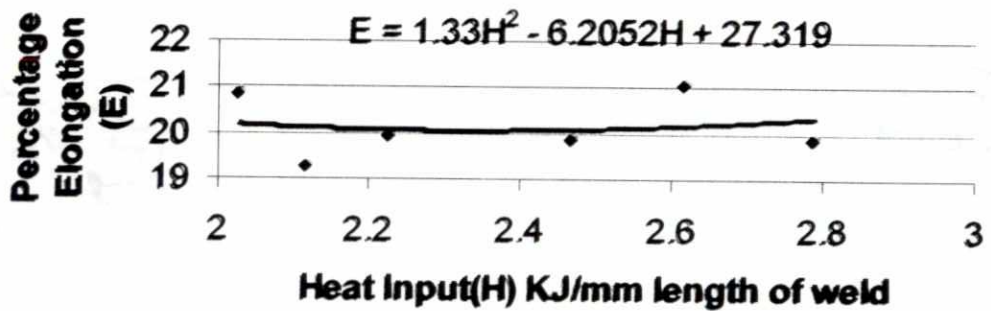


Fig 5.18 Sample C, Heat Input / mm length of weld v/s Percentage Elongation



Chapter-6

Conclusions

The findings of the present study can be summed up in the form of conclusions which are as given below:

1. Various primary welding variables which effect mechanical strength of butt welded joint were identified and the process range of these parameters namely welding current, arc voltage and welding speed was found out.
2. Various correlations were established between input variables (Welding Current, Arc Voltage, Welding Speed and Heat input) and output variables (UTS, Hardness and Percentage Elongation) using method of least squares. These correlations help in forming the basis for automation.
3. It was found that welding current was most influential variable since it effects penetration to a significant extent, thus affecting the side wall fusion, dilution and consequent the mechanical strength of the joint.
4. The present study has established a detailed welding procedure for welding of 12mm thick M S plate using SAW process and giving consistent weld quality.
5. While performing UTS test it was found fracture took place in the base metal instead of weld metal. This indicated that the joints possessed strength greater than the base metal.
- 6 One variable at a time approach gives a good indication of the trends between input and output variables.
7. The observation were inline with the fact that welding variables affect the heat input which further affects the cooling rate, which consequently affects the microstructure and hence mechanical properties of the butt welded joints.

Chapter - 7

Scope for future work

1. The effect of secondary variables like nozzle to plate distance, electrode to work angle, type of other fluxes on the mechanical strength of butt welded joint using SAW process can be investigated.
2. The same study can be undertaken for establishing suitable welding procedure of other materials like stainless steel, high strength low alloy steel etc of different thicknesses.
3. One variable at a time approach can be further supplemented by factorial design approach so as to yield suitable information on the interaction present between the input variable, which affect the out put variables i.e. mechanical strength of the joints in this case.
4. Micro structural studies can be included so as to give an indication of microstructure v/s properties relationships.
5. The data generated on the similar lines can be applied to other welding processes also.

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