# Experimental Investigation of Submerged ARC Welding on High Strength Low Alloy Steel (HSLA)

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*Abstract*— Welding is a procedure of changeless joining two materials (normally metals) through confined mixture coming about because of an appropriate blend of temperature, weight and metallurgical conditions. Contingent on the mix of temperature and weight from a high temperature with no weight to a high weight with low temperature, a wide scope of welding forms has been created. There are numerous kinds of welding including Metal Arc, Submerged Arc, Resistance Butt, Flash, Spot, Seam and Projection. While there are numerous techniques for joining metals, welding is a standout amongst the most helpful and fast strategies 1available. SAW is fundamentally a circular segment welding process in which the curve is hidden by a cover of granular and fusible flux. Along these lines, physical properties of flux are critical contemplations in SAW for enhancing welding properties. Three parameters are taken into consideration for performing the welding these are: current(A), voltage(B) and flux(C). From above principle impact plot of dot width it might be inferred that ideal condition for dot width is A3 B1 C1 for example current 320 A, bend voltage 32 V and transition 1.It must be noticed that the above blend of factor levels A3 B1 C1 are not among the nine mixes tried for the investigation. This is normal in light of the multifaceted idea of the test configuration utilized (9 from 33=27 conceivable blends).

***Key words:*** High Strength Low Alloy Steel (HSLA), Submerged ARC Welding

## I. Introduction

SAW is fundamentally a circular segment welding process in which the curve is hidden by a cover of granular and fusible flux. Along these lines, physical properties of flux are critical contemplations in SAW for enhancing welding properties. The wellspring of warmth for SAW is gotten from the circular segment produced between an exposed strong metal (or cored) as a consumable wire terminal and the workpiece. The circular segment is kept up in a cavity of liquid flux or slag that refines the weld metal and shields it from barometrical tainting. Amalgam fixings in flux endeavor to upgrade the mechanical properties and break obstruction of the weld store. Submerged Arc Welding is a combination welding process in which warm is delivered from a circular segment between the work and a persistently encouraged filler metal cathode. The liquid weld pool is shielded from the encompassing climate by thick cover of liquid flux and slag shaped from the granular fluxing material pre-put on the work. Welding isn't new. The most prompt known kind of welding, called assembling welding, returns to the year 2000 B.C. Design welding is an unrefined strategy of joining metals by warming and beating until the point that the metals are consolidated (mixed) together. A champion among the most tremendous welding frames envisioned and comprehensively used all through the world is Submerged Arc welding. Submerged Arc was not the primary modified welding process. Licenses dating in the mid 1920's depict customized welding shapes. It is a multifaceted devise for modified welding with a consistent uncovered wire feed from a reel to the weld zone. The wonderful component portrayed in this patent is the use of faltering of the wire in the joint to be welded. In any case, correspondingly similarly as with different other machine licenses of the time, it was used with an open bend in air. Diverse references observe the welds from this essential method contained porosity and were not sensible for a few applications.

Fig. 1: Submerged Arc Welding

## II. HSLA Steel Properties

Highe-Strenght low-composite (HSLA) steels give extended solidarity to-weight extents over normal low-carbon steels for only an unpretentious esteem premium. Since HSLA composites are more grounded, they can be used in progressively thin regions, making them particularly engaging for transportation-gear sections where weight decline is fundamental. HSLA steels are open in all standard formed structures - sheet, strip, plate, fundamental shapes, bar-measure shapes, and remarkable shapes.

Generally, HSLA steels are low-carbon steels with up to 1.5% manganese, strengthened by little additions of segments, for instance, columbium, copper, vanadium or titanium and a portion of the time by remarkable rolling and cooling techniques. Improved formability HSLA steels contain increases, for instance, zirconium, calcium, or phenomenal earth parts for sulfide-fuse shape control.

| | PARAMETER | UNITS | LEVEL 1 | LEVEL 2 | LEVEL 3 |
|---|---|---|---|---|---|
| A | CURRENT | AMPERE | 280 | 300 | 320 |
| B | VOLTAGE | VOLTS | 32 | 34 | 36 |
| C | FLUX | B.I. | 1 | 2 | 3 |

Table 1: SAW Parameters and Their Levels

 

HSLA steels can have more thin cross portions than proportionate parts created utilizing low-carbon steel; disintegration of HSLA steel would altogether be able to reduce quality by lessening the pile bearing cross section. While growthes of segments, for instance, copper, silicon, nickel, chromium, and phosphorus can improve climatic utilization restriction of these mixes, they furthermore increase cost. Zapping, zinc-rich coatings, and other rust-preventive culminations can help shield HSLA-steel parts from disintegration.

Molding, infiltrating, sawing, and other machining exercises on HSLA steels generally anticipate that 25 should 30% more power than do assistant carbon steels. They are used to manage a ton of weight or a nice solidarity to-weight extent. HSLA steels are ordinarily 20 to 30% lighter than carbon steel with a comparative quality. HSLA steels generally have densities of around 7800 kg/m3.HSLA amalgams have directionally unstable properties. For a couple of assessments, formability and impact quality vary basically depending upon whether the material is attempted longitudinally or transversely to the moved heading. For example, turns parallel to the longitudinal course are logically ready to cause part around the outside, strain bearing surface of the bend. This effect is logically explained in thick sheets. This directional trademark is essentially diminished in HSLA steels that have been treated for sulfide shape control.

| | PARAMETER | UNITS | LEVEL 1 | LEVEL 2 | LEVEL 3 |
|---|---|---|---|---|---|
| A | CURRENT | AMPERE | 280 | 300 | 320 |
| B | VOLTAGE | VOLTS | 32 | 34 | 36 |
| C | FLUX | B.I. | 1 | 2 | 3 |

Table 2: Chemical composition of different Flux

| S.NO | Flux Constituent | Weight of constituent (%) | | |
|---|---|---|---|---|
| | | Flux1 | Flux2 | Flux3 |
| 1 | Silica | 30 | 30 | 25 |
| 2 | TiO2 | 5 | 5 | 10 |
| 3 | CaO | 15 | 15 | 10 |
| 4 | MnO | 2 | 10 | 15 |
| 5 | Al2O3 | 25 | 15 | 15 |
| 6 | CaF2 | 25 | 25 | 25 |
| 7 | Ni based CrC | 3 | 3 | 5 |

Fig. 1: Sieve no.10

Fig. 2: Furnaces for Baking Flux

| C | Si | Mn | P | S | Ni | Cr | Mo |
|---|---|---|---|---|---|---|---|
| 0.4 | 0.32 | 1.97 | 0.02 | 0.3 | 3.01 | 1.07 | 0.15 |

Table 3: Chemical Composition of Base Metal

| C | Mn | P | S | Si | Cr | Ni |
|---|---|---|---|---|---|---|
| 0.13 | 1.97 | 0.011 | 0.012 | 0.07 | 0.08 | 0.08 |

Table 4: Chemical Composition of Electrode

## III. DESIGN OF EXPERIMENT (DOE)

Expanding efficiency and enhancing quality are critical objectives in any business. The techniques for deciding how to build profitability and enhance quality are advancing. They have changed from expensive and tedious experimentation quests to the ground-breaking, exquisite, and financially savvy factual techniques. Plan of Experiments (DOE) or test configuration is the structure of any data gathering practices where variety is available, regardless of whether under the full control of the experimenter or not [4]. Be that as it may, in measurements, these terms are generally utilized for controlled investigations. Different sorts of study, and their structure, are talked about in the articles on supposition surveys and measurable studies (which are kinds of observational examination), characteristic analyses and semi tests (for instance, semi test plan) [5]. In the structure of tests, the experimenter is frequently inspired by the impact of some procedure or mediation (the "treatment") on a few items (the "exploratory units"), which might be individuals, parts of individuals, gatherings of individuals, plants, creatures, materials, and so on. Plan of trials is along these lines an order that has extremely wide application crosswise over [6].

A philosophy for structuring tests was proposed by Ronald A. Fisher, in his imaginative book The Design of Experiments (1935). For instance, he portrayed how to test the speculation that a specific woman could recognize by flavor alone whether the drain or the tea was first put in the container. While this sounds like a pointless application, it enabled him to delineate the most essential thoughts of exploratory structure [7].

DOE is a logical methodology which enables the analysts to pick up learning so as to all the more likely comprehend a procedure and to decide how the effects (property impact the yield reaction). It is typically utilized when it is misty what affect a particular arrangement of sources of info may have either separately or all things considered on process or item. A planned investigation and the concurrent assessment of at least two elements (parameters) for their capacity to influence the resultant normal or fluctuation of a specific item or process trademark. To achieve this in a powerful and statically legitimate mold, the dimension of elements are shifted in a vital way, the aftereffects of specific test blend are watched, and the total arrangement of results is broke down to decide the compelling variables and favored dimensions, and whether increment or decline of those dimensions will possibly prompt further enhancement [8]. Note this is an iterative procedure; the first round through the DOE procedure will ordinarily prompt consequent rounds of experimentation. The start round, regularly alluded to as screenings analyze, is utilized to locate the couple of essential compelling variables out of the numerous conceivable elements required with the procedure or item structure. The examination is commonly a little explore different avenues regarding numerous components at two dimensions. Later adjusts of analyses normally include few variables at multiple dimensions to decide states of further enhancement.

## IV. Development of the Design Matrix

Just three SAW parameters for example current, voltage and flux were examined in this investigation. The scope of the current was chosen to be 280 – 320 An and the voltage was chosen in the range between 32 – 34 V. The flux is of 3 types. The above scopes of the procedure parameters were chosen in light of the information accessible in the writing.

| EXP. NO. | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| | CURRENT (A) | VOLTAGE (V) | FLUX |
| 1 | 280 | 32 | 1 |
| 2 | 280 | 34 | 2 |
| 3 | 280 | 36 | 3 |
| 4 | 300 | 32 | 2 |
| 5 | 300 | 34 | 3 |
| 6 | 300 | 36 | 1 |
| 7 | 320 | 32 | 3 |
| 8 | 320 | 34 | 1 |
| 9 | 320 | 36 | 2 |

Table 5: Design Matrix for Conducting Experiments

## V. Tensile Test

Universal tensile testing machine was used to carry out tensile tests. Ultimate Tensile Load for the base metal is 125.5 KN. Specimen were prepared according to IS 3613-1974 (1993) which indicates acknowledgment tests for wire-flux mixes for submerged circular segment welding of basic steels. Values for stress and elongation are shown in table 6. Then readings for various joints made using different types of flux are taken on UTM.

| Ultimate Tensile Stress | Elongation |
|---|---|
| Not less than 350 N/mm$^2$ | Not less than 22 % |

Table 7: Ultimate Tensile Load Readings

| Flux | Basicity Index | Ultimate Tensile Load(KN) |
|---|---|---|
| 1 | 0.9 | 103.55 |
| 2 | 1.1 | 120.65 |
| 3 | 1.3 | 112 |

Table 8: Ultimate Tensile Stress Readings

| Flux | Basicity Index | Ultimate Tensile Stress(N/mm$^2$) | Displacement (mm) | % elongation |
|---|---|---|---|---|
| 1 | 0.9 | 329 | 9.7 | 19.4 |
| 2 | 1.1 | 408 | 13.2 | 27.38 |
| 3 | 1.3 | 393 | 12.8 | 25.6 |

All specimen tested are within the limits of IS 3613-1974 (1993). So all wire-flux combinations are accepted except for flux1, which is also nearby the BIS values. During welding process there is change in mechanical properties due to change in elemental components of parent metal and the filler electrode cause micro structural changes, from the base metal. The effect of various fluxes on Ultimate Tensile Load and Ultimate Tensile Stress of the welded joints were examined. From Table 7, it appears that maximum ultimate tensile load was observed for specimen no 2 i.e. 120.65KN and the lowest ultimate tensile load for specimen no. 1 is103.55 KN. From Table 5.8 it appears that maximum Ultimate tensile stress observed for specimen no 2 i.e. 408 N/mm2 and the lowest ultimate tensile load for specimen no.1 is 329 N/mm2. So, it is clear that where high tensile strength is the requirement flux 2 is used.

## VI. Impact Toughness Test

The Charpy affect test was performed to assess the sturdiness (J) of weld joints created. Specimens after impact toughness test carried out at room temperature. Impact toughness for base metal is 90 joule.

Fig. 3: Specimens after Impact Testing

| Impact toughness | not less than 35 J |
|---|---|

Table 9: Impact Toughness Readings according to IS 3613-1974 (1993)

| Basicity Index | Impact toughness (joule) | Average(joule) |
|---|---|---|
| 0.9 | 88+90+84 | 87.3 |
| 1.1 | 100+104+98 | 100.6 |
| 1.3 | 85+80+76 | 80.3 |

Table 10: Impact Toughness Values

## VII. ANOVA FOR HARDNESS TESTS

The control factors that may add to diminish variety (enhanced quality) can be immediately recognized by taking a gander at the measure of variety present as a reaction. The dot width, profundity of entrance of the weld bead geometries and weld dot hardness have a place with higher-the-better quality trademark.

$$\frac{S}{N}_{(Bigger)} = -10 \log\left(\frac{\Sigma\left(\frac{1}{y_i^2}\right)}{n}\right)$$

The biggest flag to-clamor proportion is the ideal dimension, in light of the fact that a high estimation of flag to-commotion proportion shows that the flag is a lot higher than the arbitrary impacts of the commotion factors. It is clear from Table 12 that the maximum hardness (HRB) was observed at welded region for flux 3, this is due to the presence of carbides constituents present in the flux due to CrC, hardness value in the weld metal changes with the change in the carbide contents. The increase in hardness at the welding interface is generally due to oxidation processes which took place during welding processes.

| Current | Voltage | Flux | Hardness (HRB) | | | S/N Ratio (Larger the better) | S/N Ratio (Mean) |
|---|---|---|---|---|---|---|---|
| | | | Response 1 | Response 2 | Response 3 | | |
| 280 | 32 | 1 | 85 | 87 | 88 | -19.4448 | 38.5883 |
| 280 | 34 | 2 | 91 | 91 | 94 | -19.7313 | 39.1808 |
| 280 | 36 | 3 | 107 | 109 | 108 | -20.3342 | 40.5876 |
| 300 | 32 | 2 | 91 | 92 | 93 | -19.6848 | 39.1808 |
| 300 | 34 | 3 | 109 | 107 | 108 | -20.3342 | 40.7485 |
| 300 | 36 | 1 | 101 | 100 | 99 | -19.9564 | 40.0864 |
| 320 | 32 | 3 | 110 | 114 | 112 | -20.4922 | 40.8278 |
| 320 | 34 | 1 | 102 | 101 | 99 | -19.9564 | 40.172 |
| 320 | 36 | 2 | 106 | 107 | 101 | -20.0432 | 40.5061 |

Table 11: Pooled ANOVA Table for hardness (Raw data)

| SOURCE | SS | DOF | V | P | F-Ratio |
|---|---|---|---|---|---|
| Current | 1.24554 | 2 | 0.622773 | 26.98922 | 37.69252* |
| Voltage | 0.69662 | 2 | 0.348314 | 15.09496 | 21.08127* |
| Flux | 2.63975 | 2 | 1.319879 | 57.19978 | 79.88389* |
| Travel speed | - | - | - | - | - |
| ERROR | 0.03304 | 2 | 0.016522 | 0.716037 | - |
| T | 4.61497 | 8 | - | 100 | - |

* Significant at 95 % confidence level $F_{critical}$=19
SS –Sum of Squares DOF–Degree of Freedom
V–Variance

Table 12: Pooled ANOVA Table for hardness (S/N ratio)

The guideline of the F-test is that the bigger the F esteem for a specific parameter, the more prominent the impact on the execution trademark because of the adjustment in that procedure parameter. ANOVA Table shows that Flux (F 79.88value), current (F 37.69 value), voltage (F 21.08 value) are the factors that significantly affect the hardness. Flux has highest contribution to hardness. Main effects plot for the S/N ratio of hardness are shown in the Fig.4-6, which shows the variation of hardness with the input parameters. F ratio values greater than F ratio Table values indicate the parameters are significant. Flux having the highest contribution (57%) in increasing hardness followed by current (27%) and voltage (15%)

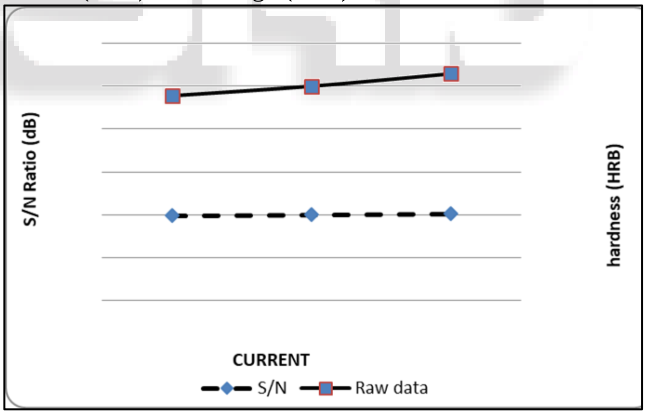


Fig. 4: Effect of Current on Hardness

Hardness of weld metal has been found a function of welding current. Increase in welding current from 280 to 320 A increased the hardness from 96 HRB to 106 HRB.

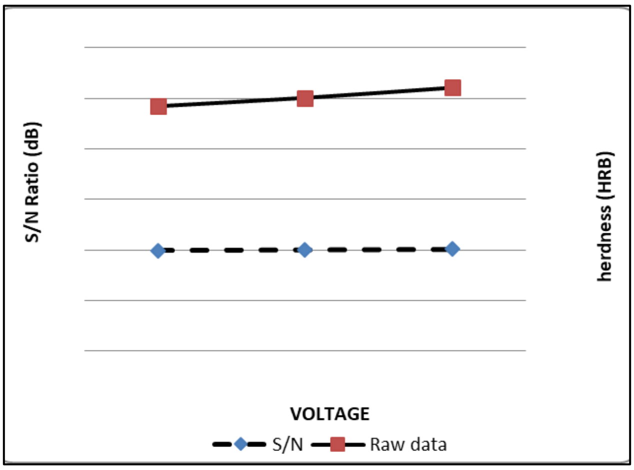


Fig. 5: Effect of Voltage on Hardness

Increase of hardness with an increase of welding voltage is observed. Increase in hardness is mainly due to flux ingredients. Process parameter however affects hardness but mainly it is due to chemical reactions occurred during welding.

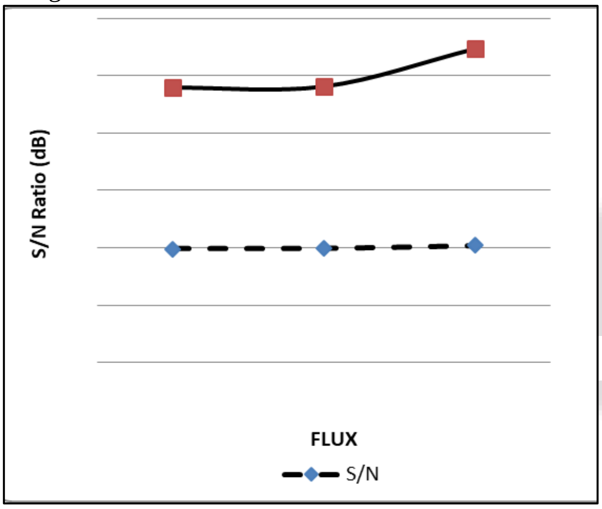


Fig. 6: Effect of Flux on Hardness

From above Figures the optimal hardness is obtained by applying welding current 320 A, arc voltage 36 V and flux 3 for a plate of 7 mm thickness.

## VIII. Conformation Test for Hardness

From mean of each level of every factor response Table for hardness constructed as given in Table 13

| Level | Current (A) | Voltage (B) | Flux (C) |
|---|---|---|---|
| 1 | 39.56493 | 39.67021 | 39.60305 |
| 2 | 39.98053 | 39.99872 | 39.64508 |
| 3 | 40.47503 | 40.35155 | 40.77235 |

Table 13: Response Table for S/N ratio of Hardness (Larger is Better)

The ideal estimation of rigidity is anticipated at the chose dimensions of noteworthy dimensions of huge parameters. The assessed mean of the reaction qualities (hardness) can be registered as

Hardness (H) = C3 + V3 + F3 – 2T

where T is the general mean of hardness C3 is the normal hardness at third dimension of current, 320 A; V3 is the normal hardness at third dimension of voltage 36 V, F3 is the normal hardness at third dimension of motion 1.4 B.I. Substituting the estimations of different terms in Eqn. above, At that point

Hardness = 105.7 + 104.22 + 95.77 - 2 x 100.4 = 104.89 HRB

| Current (A) | Voltage (B) | Flux (C) | Rockwell Hardness (HRB) |
|---|---|---|---|
| 320 | 36 | 3 | 108 |

Table 14: Conformation Experiment for hardness

## IX. Bead width

The weld bead width is the maximum width of the weld metal deposited. It influences the flux consumption rate and chemistry of the weld metal.

The rule of the F-test is that the bigger the F esteems for a specific parameter, the more noteworthy the impact on the execution trademark because of the adjustment in that procedure parameter. ANOVA Table 16 demonstrates that current (F 340.34 esteem), voltage (F 35 esteem) and Flux (F 20.22 esteem), are the elements that altogether influence the dot width. Current has most astounding commitment to dot width.

Fundamental impacts plot for the S/N proportion of globule width are appeared in the Fig. 7-9 which demonstrates the variety of globule width with the info parameters

| SOURCE | SS | DOF | V | P | F-Ratio |
|---|---|---|---|---|---|
| Current | 7.60623 | 2 | 3.803117 | 85.82189 | 340.3473* |
| Voltage | 0.78222 | 2 | 0.391112 | 8.825912 | 35.00127* |
| Flux | 0.45200 | 2 | 0.226004 | 5.10004 | 20.22543* |
| Travel speed | - | - | - | - | - |
| ERROR | 0.02234 | 2 | 0.011174 | 0.25216 | - |
| T | 8.86281 | 8 | - | 100 | - |
| * Significant at 95 % confidence level $F_{critical}$= 19 SS –Sum of Squares DOF–Degree of Freedom V–Variance | | | | | |

Table 15: ANOVA Table for Bead Width

F ratio values greater than F ratio Table values indicate the parameters are significant. Current having the highest contribution (86%) in increasing bead width followed byvoltage (9%) andflux (5%)

| SOURCE | SS | DOF | V | P | F-Ratio |
|---|---|---|---|---|---|
| Voltage | 58.01407 | 2 | 29.00704 | 80.97414 | 119.2433* |
| Current | 5.79629 | 2 | 2.898148 | 8.09028 | 11.91382* |
| Flux | 2.969629 | 2 | 1.484815 | 4.144912 | 6.103837* |

| | | | | | |
|---|---|---|---|---|---|
| Travel speed | - | - | - | - | - |
| ERROR | 4.865185 | 20 | 0.243259 | 6.790666 | - |
| T | 71.64518 | 26 | - | 100 | - |

* Significant at 95 % confidence level $F_{critical}$= 3.4928
SS –Sum of Squares DOF–Degree of Freedom
V–Variance

Table 16 Pooled ANOVA Table for Bead Width (S/N ratio

| SOURCE | SS | DOF | V | P | F-Ratio |
|---|---|---|---|---|---|
| Voltage | 58.01407 | 2 | 29.00704 | 80.97414 | 119.2433* |
| Current | 5.79629 | 2 | 2.898148 | 8.09028 | 11.91382* |
| Flux | 2.969629 | 2 | 1.484815 | 4.144912 | 6.103837* |
| Travel speed | - | - | - | - | - |
| ERROR | 4.865185 | 20 | 0.243259 | 6.790666 | - |
| T | 71.64518 | 26 | - | 100 | - |

* Significant at 95 % confidence level $F_{critical}$= 3.4928
SS –Sum of Squares DOF–Degree of Freedom
V–Variance

Table 17 Pooled ANOVA Table for Bead Width (Raw data)

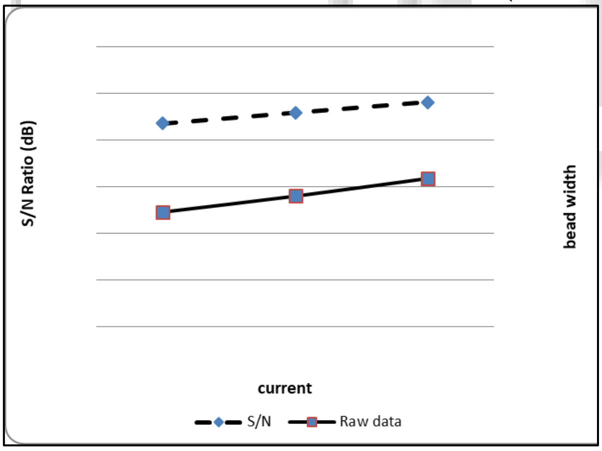


Fig. 7 Effect of Current on Bead Width

Welding current is the most powerful parameter since it influences globule shape,controls the rate at which terminal is softened and therfor e additionally controls the statement rate.

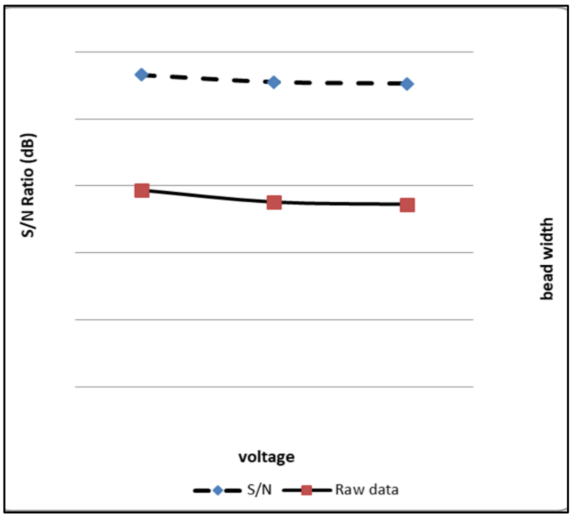


Fig. 8 Effect of voltage on Bead Width

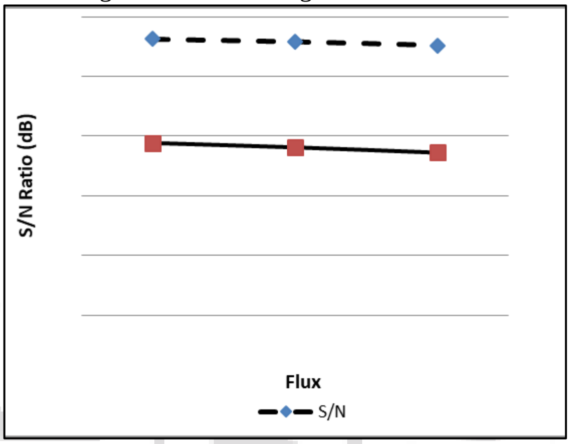


Fig. 9 Effect of Flux on Bead Width

Flux Basicity Index also influences the bead width. In general higher bead width is obtained with the use of low basicity index fluxes due to high viscosity which enhances the tendency of heat concentration in the narrow zone. Wider beads are obtained using flux 1 having lowest basicity index.

## A. *Conformation Test for Bead Width*

From mean of each level of every factor response Table for bead width constructed as given in Table 18

| Level | Current (A) | Voltage (B) | Flux (C) |
|---|---|---|---|
| 1 | 21.74778 | 23.29099 | 23.13653 |
| 2 | 22.89264 | 22.7351 | 22.91288 |
| 3 | 23.99952 | 22.61386 | 22.59055 |

Table 18: Response Table for S/N ratio of Bead Width (Larger is Better)

From above principle impact plot of dot width it might be inferred that ideal condition for dot width is A3 B1 C1 for example current 320 A, bend voltage 32 V and transition 1.It must be noticed that the above blend of factor levels A3 B1 C1 are not among the nine mixes tried for the investigation. This is normal in light of the multifaceted idea of the test configuration utilized (9 from 33=27 conceivable blends).

Globule Width (W) = C3 + V1 + F1– 2T

where T is the general mean of globule width, (Table 21); C3 is the normal dot width at third dimension of current, 320 A; V1 is the normal dab width at first dimension of voltage 32 V, F1 is the normal dab width at first dimension of

transition 0.9 B.I. Substituting the estimations of different terms in Eqn. above,
At that point
Dab Width = 15.76 + 13.97 + 14.43 - 2 x 14.04 = 16.08 mm

The last advance is checking the enhancement in dab width by leading tests utilizing ideal conditions. Three affirmation tests were led at the ideal setting of procedure parameters. The current, voltage and transition were set at level 3,1 and1, the normal dot width of SAW welded HSLA was observed to be 15.8mm, which is inside the certainty interim of the anticipated ideal of dab width.

| Current (A) | Voltage (B) | Flux (C) | Bead Width (mm) |
|---|---|---|---|
| 320 | 32 | 1 | 15.8 |

Table 19: Conformation Experiment for Bead Width

## X. Conclusions

In this work we try to find the optimize process parameters and their effects. The following conclusions were found form the results:

1) Specimen tested are within the limits of IS 3613-1974 (1993). So all wire-flux combinations are accepted except for flux 1.
2) The tensile strength and stress ofsubmerged arc welded HSLA joint welded using Flux 2 having BI 1.1 is maximum.
3) Impact strength increases with the increase in tensile strength. Joint made by welding with flux 2 having highest toughness as 100 joule.
4) Impact strength of all joints is less than base metal except joints made by using flux 2.
5) To optimize hardness ofsubmerged arc welded HSLA joint optimum process parameters are, current (320 A), voltage (36 V) and flux 3.
6) Hardness increases with increase in current, voltage and B.I. of flux.
7) Hardness has major contribution with current, so to get optimize hardness value it should be maximum with optimum voltage.
8) From ANOVA Table for Bead width it may be concluded that optimum condition for bead width is A3 B1 C1 i.e. current 320 A, arc voltage 32 V and flux 1.
9) Current has highest contribution to bead width followed by voltage and flux.

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