Determination of SAW process parameters using Design of Experiments and Regression Analysis

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CERTIFICATE

This is to certify that report entitled **“Determination of SAW process parameters using Design of experiment and Regression Analysis”** by **Mr. Nipun Ahuja** is the requirement of the partial fulfilment for the award of Degree of **Master of Technology (M. Tech.)** in **Production Engineering** at **Delhi Technological University**. This work was completed under my supervision and guidance. He has completed his work with utmost sincerity and diligence. The work embodied in this project has not been submitted for the award of any other degree to the best of my knowledge.

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Abstract

This project report details the prediction of submerged arc welding using design of experiment and regression analysis. SUBMERGED ARC WELDING (SAW) produces coalescence of metals by heating them with an arc between a bare metal electrode and the work. The process has been adapted to a wide range of materials and thicknesses. Various multiple arc configurations may be used to control the weld profile and increase the deposition rates over single arc operation. High weld quality, high deposition rates, dcep penetration, and adaptability to automatic operation make the process suitable for fabrication of large weldments. It is used extensively in pressure vessel fabrication, ship and barge building, railroad car fabrication, pipe manufacturing, and the fabrication of structural members where long welds are required. Automatic SAW installations manufacture mass produced assemblies joined with repetitive short welds. The process is used to weld materials ranging from 0.06 in. (1.5 mm) sheet to thick, heavy weldments. Submerged arc welding is not suitable for all metals and alloys. It is widely used on carbon steels, low alloy structural steels, and stainless steels. It joins some high-strength structural steels, high-carbon steels, and nickel alloys. However, better joint properties are obtained with these metals by using a process with lower heat input to the base metal, such as gas metal arc welding.

Design of experiments (DOE) or experimental design is the design of any information-gathering exercises where variation is present, whether under the full control of the experimenter or not. Formal planned experimentation is often used in evaluating physical objects, chemical formulations, structures, components, and materials. Other types of study, and their design, are discussed in the articles on opinion polls and statistical surveys (which are types of observational study), natural experiments and quasi-experiments (for example, quasi-experimental design). In the design of experiments, the experimenter is often interested in the effect of some process or intervention (the "treatment") on some objects (the "experimental units"), which may be people, parts of people, groups of people, plants, animals, etc. Design of experiments is thus a discipline that has very broad application across all the natural and social sciences and engineering.

Five levels of the four process parameters i.e. arc voltage, welding current, welding speed and electrode stick out for submerged arc welding (SAW) were considered. An orthogonal array was prepared. Using software XLSTAT 2012, linear and non- linear regression mathematical modelling were done and equations for width, Reinforcement and penetrations were prepared. These equations were dependent on arc voltage; welding current, welding speed and electrode stick out. For different samples and observations, values of voltage, current, welding speed and electrode stick out were put in the equations of width, reinforcement and penetration and their values (width, reinforcement, penetration) were predicted. Regression modelling is good tool for predicting parameters of submerged Arc Welding (SAW).

CHAPTER 1
INTRODUCTION

Fig. 1- Submerged Arc Welding

SUBMERGED ARC WELDING (SAW) produces coalescence of metals by heating them with an arc between a bare metal electrode and the work. The arc and molten metal are “submerged” in a blanket of granular fusible flux on the work. Pressure is not used, and filler metal is obtained from the electrode and sometimes from a supplemental source such as welding rod or metal granules. In submerged arc welding, the arc is covered by a flux.

SUBMERGED ARC WELDING (SAW) is an arc welding process in which the arc is concealed by a blanket of granular and fusible flux. Heat for SAW is generated by an arc between a bare, solid-metal (or cored) consumable wire or strip electrode and the work piece. The arc is maintained in a cavity of molten flux or slag, which refines the weld metal and protects it from atmospheric contamination. Alloy ingredients in the flux may be present to enhance the mechanical properties and crack resistance of the weld deposit.

This flux plays a main role in that

(1) The stability of the arc is dependent on the flux,

(2) Mechanical and chemical properties of the final weld deposit can be controlled by flux, and

(3) The quality of the weld may be affected by the care and handling of the flux.

A continuous electrode is being fed into the joint by mechanically powered drive rolls. A layer of granular flux, just deep enough to prevent flash through, is being deposited in front of the arc. Electrical current, which produces the arc, is supplied to the electrode through the contact tube. The current can be direct current (dc) with electrode positive (reverse polarity), with electrode negative (straight polarity), or alternating current (ac). After welding is completed and the weld metal has solidified, the unfused flux and slag are removed. The unfused flux may be screened and reused. The solidified slag may be collected, crushed, resized, and blended back into new flux. Recrushed slag and blends of recrushed slag with unused (virgin) flux are chemically different from new flux. Blends of recrushed slag may be classified as a welding flux, but cannot be considered the same as the original virgin flux. [1]

SUBMERGED ARC WELDING can be applied in three different modes: semiautomatic, automatic, and machine.

SEMIAUTOMATIC WELDING IS done with a hand-held welding gun, which delivers both flux and the electrode. The electrode is driven by a wire feeder. Flux may be supplied by a gravity hopper mounted on the gun or pressure fed through a hose. This method features manual guidance using relatively small diameter electrodes and moderate travel speeds. The travel may be manual or driven by a small gun-mounted driving motor.

AUTOMATIC WELDING IS done with equipment that performs the welding operation without requiring a welding operator to continually monitor and adjust the controls. Expensive self-regulating equipment can be justified in order to achieve high-production rates.

MACHINE WELDING employs equipment that performs the complete welding operation. However, it must be monitored by a welding operator to position the work, start and stop welding, adjust the controls, and set the speed of each weld.
SUBMERGED ARC WELDING is used for making groove, fillet, plug, and surfacing welds. Groove welds are usually made in the flat position and fillet welds are usually made in the flat and horizontal positions. This is because the molten weld pool and the flux are most easily contained in these positions. However, simple techniques are available for producing groove welds in the horizontal welding position. Good submerged arc welds can be made downhill at angles up to 15 degrees from the horizontal. Surfacing and plug welding are done in the flat position. Welds made by this process may be classified with respect to the following:
(1) Type of joint
(2) Type of groove
(3) Welding method (semiautomatic or machine)
(4) Welding position (flat or horizontal)
(5) Single or multiple pass deposition
(6) Single or multiple electrode operation
(7) Single or multiple power supply (series, parallel, or separate connections).

Advantages of submerged arc welding include the following:

- THE ARC IS UNDER A BLANKET OF FLUX, WHICH VIRTUALLY ELIMINATES ARC FLASH, SPATTER, AND FUME (THUS MAKING THE PROCESS ATTRACTIVE FROM AN ENVIRONMENTAL STANDPOINT).
- HIGH CURRENT DENSITIES INCREASE PENETRATION AND DECREASE THE NEED FOR EDGE PREPARATION.
- HIGH DEPOSITION RATES AND WELDING SPEEDS ARE POSSIBLE.
- COST PER UNIT LENGTH OF JOINT IS RELATIVELY LOW.
- THE FLUX ACTS AS A SCAVENGER AND DEOXIDIZER TO REMOVE CONTAMINANTS

- SUCH AS OXYGEN, NITROGEN, AND SULFUR FROM THE MOLTEN WELD POOL. THIS HELPS TO PRODUCE SOUND WELDS WITH EXCELLENT MECHANICAL PROPERTIES.
- LOW-HYDROGEN WELD DEPOSITS CAN BE PRODUCED.
- THE SHIELDING PROVIDED BY THE FLUX IS SUBSTANTIAL AND IS NOT SENSITIVE TO WIND AS IN SHIELDED METAL ARC WELDING AND GAS METAL ARC WELDING.
- MINIMAL WELDER TRAINING IS REQUIRED (THUS, RELATIVELY UNSKILLED WELDERS CAN BE EMPLOYED).
- THE SLAG CAN BE COLLECTED, REGROUND, AND SIZED FOR MIXING BACK INTO NEW FLUX AS PRESCRIBED BY MANUFACTURERS AND QUALIFIED PROCEDURES.

Limitations of submerged arc welding include the following:

- THE INITIAL COST OF WIRE FEEDER, POWER SUPPLY, CONTROLS, AND FLUXHANDLING EQUIPMENT IS HIGH.
- THE WELD JOINT NEEDS TO BE PLACED IN THE FLAT OR HORIZONTAL POSITION TO
- KEEP THE FLUX POSITIONED IN THE JOINT.
- THE SLAG MUST BE REMOVED BEFORE SUBSEQUENT PASSES CAN BE DEPOSITED.
- BECAUSE OF THE HIGH HEAT INPUT, SAW IS MOST COMMONLY USED TO JOIN STEELS MORE THAN 6.4 MM THICK.

Submerged arc welding is most commonly used to join plain carbon steels. Alloy steels can be readily welded with SAW if care is taken to limit the heat input as required to prevent damage to the heat-affected zone (HAZ). Low-heat-input procedures are available for welding alloy steels and heat-treated steels to prevent grain coarsening and cracking in the HAZ. Maintaining proper preheat and inter pass temperature is also important when welding alloy steels to prevent weld metal and HAZ cracking and to develop the required mechanical properties in the weld deposit. Submerged arc welding can be used to join stainless steels and nonferrous alloys. It is also commonly used to produce a stainless or nonferrous overlay on top of a base metal.

To produce a submerged arc weld, both flux and electrode are consumed. Each flux and electrode combination, along with the variation of base material and process parameters, will produce a unique weld deposit. Because the integrity of the weld deposit depends on these parameters, specific fluxes and electrodes must be used in combination to optimize the weld metal properties.

Power Sources

A constant-voltage power supply is self-regulating, so it can be used with a constant-speed wire feeder. No voltage or current sensing is required. The current is controlled by the wire diameter, the electrical stick out, and the wire-feed speed, while the voltage is controlled by the power supply. Constant-voltage dc power is the best choice for the high-speed welding of thin steel. Unlike constant voltage, constant-current power supplies are not self-regulating, so they must be used with voltage sensing variable-wire-feed speed controls. A constant-current wire feeder monitors arc voltage and adjusts the wire-feed speed in response to changes in the arc voltage. The wire-feed speed control attempts to maintain a constant arc length, while the power supply controls the arc current.

The constant-current output of a conventional ac machine varies with time like a sine wave dropping through zero with each polarity reversal. The voltage associated with the current is approximately a square wave. Because the power output is zero with each polarity change, an open-circuit voltage greater than 80 V may be required to ensure arc initiation. The constant-current ac machine requires voltage-sensing variable-wire-feed speed controls. On newer, solid-state power
Supplies, the current and voltage output both approximate square waves, with the instantaneous polarity reversal reducing arc initiation problems. The solid-state power supplies have constant-voltage characteristics that may be used with constant-speed wire-feed controls.

Flux Classification

Fluxes can be categorized depending on the method of manufacture, the extent to which they can affect the alloy content of the weld deposit, and the effect on weld deposit properties.

Classification Relative to Production Method.

Based on the manufacturing process, there are two different types of fluxes: fused and bonded.

Fused Fluxes. The raw materials for a fused flux are dry mixed and melted in a furnace. The molten mixture is then rapidly solidified, crushed, screened, and packaged. Because of their method of manufacture, fused fluxes typically do not contain ferroalloys and deoxidizers.
Bonded Fluxes. The powdered ingredients of a bonded flux are dry blended, and then mixed with a binder, usually potassium or sodium silicate. After pelletizing, the wet flux is dried in an oven or kiln, sized appropriately, and then packaged. The relatively low baking temperatures allow bonded fluxes to contain deoxidizers and ferroalloys.[5]

Classification Relative to Effect on Alloy Content of Weld Deposit.

Independent of manufacturing method, a given flux may be described as an active, neutral, or alloy flux, depending on its ability to change the alloy content of the weld deposit. With all submerged arc fluxes, variations in arc voltage and other welding variables will change the ratio of flux consumed to electrode or weld metal deposited. This ratio is often referred to as the flux-to-wire ratio. Normal flux-to wire ratios for SAW are 0.7 to 0.9. An increase in the flux-to-wire ratio may be caused by either an increase in arc voltage or a decrease in the welding current. Likewise, a decrease in the flux-to-wire ratio may be caused by a decrease in arc voltage or an increase in the welding current. How the weld deposit composition changes with voltage (flux-to-wire ratio) provides an additional means of describing a flux. [5]
While SAW is the most inexpensive and efficient process for making large, long, and repetitive welds, much time and energy are required to prepare the joint. Care must be taken to line up all joints to have a consistent gap in groove welds and to provide backing plates and flux dams to prevent spillage of flux and molten metal. Once all the pieces are clamped or tacked in place, welding procedures and specifications should be consulted before welding begins.
Procedural variations in SAW include current, voltage, electrical stick out (distance from last electrical contact to plate), travel speed, and flux depth. Variation in any of these parameters will affect the shape and penetration of the weld, as well as the integrity of the weld deposit.
Weld Current. Because the welding current controls such parameters as deposition rate, penetration, and dilution, it is the most important welding variable. An increase in welding current at a constant voltage will decrease the flux-to-wire ratio, while a decrease in current will increase the flux-to-wire ratio. Welds made at excessively low current will tend to have little penetration and higher width-to-depth ratios. Welds made at an excessively high current will have deep penetration; high dilution, more shrinkage, and excess build up. Low current will also produce a less stable arc than higher currents.
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 is

most commonly used. For a given set of welding conditions, reverse polarity will produce wider beads with more penetration at a lower deposition rate than straight polarity. Straight-polarity welding will contribute to narrower beads with less penetration and more build up. Because straight polarity reduces base plate dilution, it is frequently used in surfacing applications. For the same welding current, the deposition rate with straight polarity is higher than with reverse polarity. Straight polarity is preferred for poor fit up. 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 1000 A and on multiple-wire applications to reduce arc blow and arc interaction. In SAW, the current density in the electrode also plays a role in bead shape and penetration. Smaller-diameter electrodes with a high current density will produce narrower beads with deeper penetration than larger-diameter electrodes. Larger diameter electrodes are able to bridge larger root openings. In cases where a given current can be achieved with two different electrode diameters, the smaller electrode will produce the higher deposition rate.

Weld Voltage. Like current, welding voltage will affect the bead shape and the weld deposit composition. Increasing the arc voltage at a constant current will increase the flux-to-wire electrode ratio, while decreasing the voltage will reduce the flux-to-electrode ratio. The effect of the magnitude of arc voltage on bead shape increasing the arc voltage will produce a longer arc length and a correspondingly wider, flatter bead with less penetration. Higher voltage will increase flux consumption, which could then change deposit composition and properties. Slightly increasing the arc voltage will help the weld to bridge gaps when welding in grooves. Excessively high voltage will produce a hat-shaped concave weld, which has low resistance to cracking and a tendency to undercut. Lower voltages will shorten the arc length and increase penetration. Excessively low voltage will produce an unstable arc and a crowned bead, which has an uneven contour where it meets the plate. [2]

Electrical Stick out. In SAW, the current flowing in the electrode between the contact tube and the arc (electrode extension) will cause some I2R heating, resulting in a voltage drop across that length of electrode. This resistance heating and subsequent voltage drop can be used to obtain higher deposition rates. Normal electrode extension for solid SAW wire is approximately 8 to 12 times the electrode diameter. As this length increases at a constant current, so does the resistance heating and the melt-off rate. To compensate for the voltage drop and the increase in wire-feed speed, the voltage must be increased to obtain a properly shaped bead. Extending the electrode 20 to 40 times the diameter can increase deposition rates by more than 50%. Although higher deposition rates can be achieved by extending the electrode, keeping the electrode aligned with the joint becomes increasingly difficult as the extension increases. [2]

Travel Speed. Variations in travel speed at a set current and voltage also affect bead shape. As welding speed is decreased, heat input per length of joint increases, and the penetration and bead width increase. The penetration will increase until molten metal begins to flow under the arc and interfere with heat flow at excessively slow speeds. Excessively high travel speeds will promote a crowned bead as well as the tendency for undercut and porosity. [2]

Flux layer depth is another variable that will alter the appearance, penetration, and quality of a submerged arc weld. If the flux layer is too deep, a greater-than-normal amount of flux will be melted, resulting in weld beads that are narrower than normal. Some surface imperfections may also appear because gases may be trapped by the deep flux layer. If the flux layer is too shallow, the arc will flash through, and the bead will have a rough appearance or porosity due to lack of shielding from the atmosphere. The correct depth of flux is just enough to prevent flash through. This will allow welding gases to escape while providing adequate protection.

PRINCIPLES OF OPERATION

IN SUBMERGED ARC welding, the end of a continuous bare wire electrode is inserted into a mound of flux that covers the area or joint to be welded. A wire-feeding mechanism then begins to feed the electrode wire towards the joint at a controlled rate, and the feeder is moved manually or automatically along the weld seam. For machine or automatic welding, the work may be moved beneath a stationary wire feeder.

Additional flux is continually fed in front of and around the electrode, and continuously distributed over the joint. Heat evolved by the electric arc progressively melts some of the flux, the end of the wire, and the adjacent edges of the base metal, creating a pool of molten metal beneath a layer of liquid slag. The melted bath near the arc is in a highly turbulent state. Gas bubbles are quickly swept to the surface of the pool. The flux floats on the molten metal and completely shields the welding zone from the atmosphere.

The flux blanket on the top surface of the weld pool prevents atmospheric gases from contaminating the weld metal, and dissolves impurities in the base metal and electrode and floats them to the surface. The flux can also add or remove certain alloying elements to or from the weld metal.

Factors that determine whether to use submerged arc welding include:

(1) The chemical composition and mechanical properties required of the final deposit
(2) Thickness of base metal to be welded
(3) Joint accessibility
(4) Position in which the weld is to be made
(5) Frequency or volume of welding to be performed

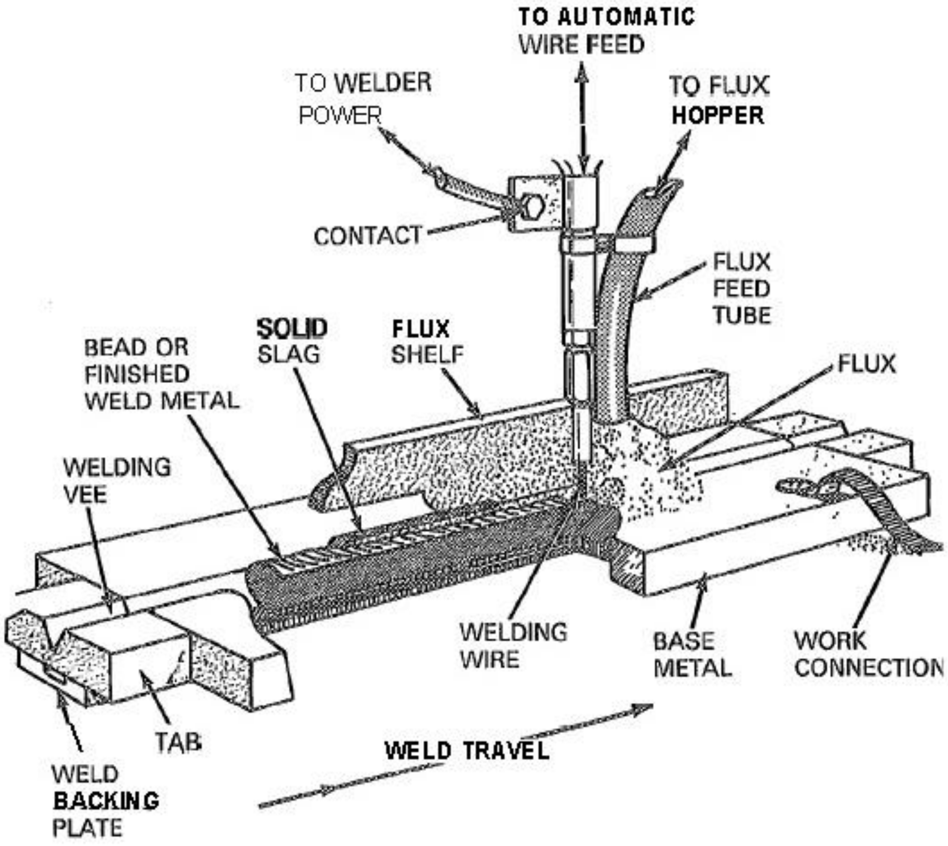


Fig. 2 SAW principle

GENERAL METHODS

SUBMERGED ARC WELDING can be applied in three different modes: semiautomatic, automatic, and machine.

SEMIAUTOMATIC WELDING IS done with a hand-held welding gun, which delivers both flux and the electrode. The electrode is driven by a wire feeder. Flux may be supplied by a gravity hopper mounted on the gun or pressure fed through a hose. This method features manual guidance using relatively shall diameter electrodes and moderate travel speeds. The travel may be manual or driven by a small gun-mounted driving motor.

AUTOMATIC WELDING IS done with equipment that performs the welding operation without requiring a welding operator to continually monitor and adjust the controls. Expensive self-regulating equipment can be justified in order to achieve high-production rates.

MACHINE WELDING employs equipment that performs the complete welding operation. However, it must be monitored by a welding operator to position the work, start and stop welding, adjust the controls, and set the speed of each weld. [1]

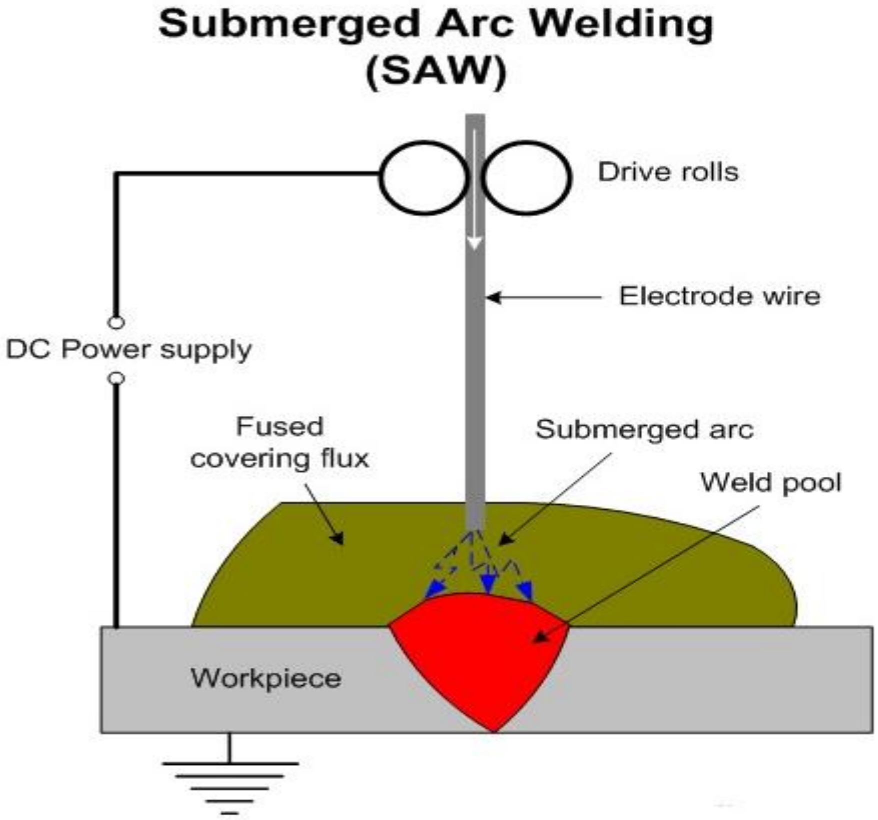


Fig. 3 SAW method

PROCESS VARIATIONS

SUBMERGED ARC WELDING lends itself to a wide variety of wire and flux combinations, single and multiple electrode arrangements, and use of ac or dc welding power sources. The process has been adapted to a wide range of materials and thicknesses. Various multiple arc configurations may be used to control the weld profile and increase the deposition rates over single arc operation. Weld deposits may range from wide beads with shallow penetration for surfacing, to narrow beads with deep penetration for thick joints. Part of this versatility is derived from the use of ac arcs.

Various types of power sources and related equipment are designed and manufactured especially for multiple arc welding. These relatively sophisticated machines are intended for high production on long runs of repetitive type applications.

EQUIPMENT

THE EQUIPMENT REQUIRED for submerged arc welding consists of
(1) a power supply,
(2) an electrode delivery system,
(3) a flux distribution system,

(4) a travel arrangement,
(5) a process control system.

Optional equipment includes flux recovery systems and positioning or manipulating equipment.

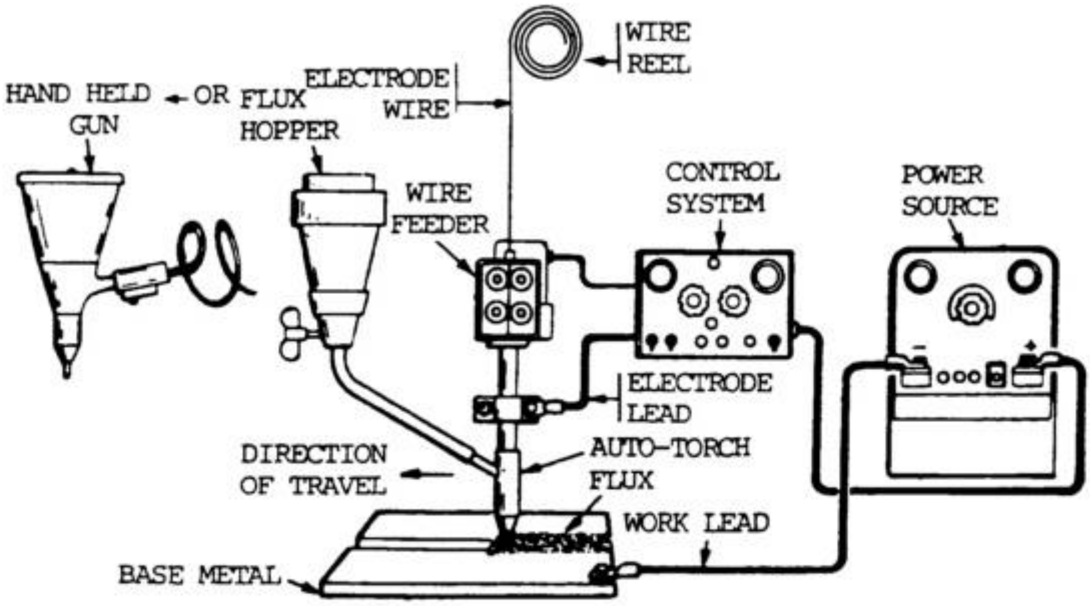


Fig. 4: SAW Equipment

POWER SOURCE

THE POWER SOURCE chosen for a submerged arc welding system plays a major operating role. Several types of power supply are suitable for submerged arc welding. A dc power supply may be a transformer-rectifier or a motor or engine generator, which will provide a constant voltage (CV), constant current (CC), or a selectable CV/CC output. AC power supplies are generally transformer types, and may provide either a CC output or a CV square wave output. Because SAW is generally a high-current process with high-duty cycle, a power supply capable of providing high amperage at 100 % duty cycle is recommended.

DC CONSTANT-VOLTAGE POWER supplies are available in both transformer-rectifier and motor-generator models. They range in size from 400 A to 1500 A models. A constant-voltage power supply is self-regulating, so it can be used with a constant-speed wire feeder. No voltage or current sensing is required to maintain a stable arc, so very simple wire feed speed controls may be used. The wire feed speed and wire diameter control the arc current, and the power supply controls the arc voltage. Constant-voltage dc power supplies are the most commonly used supplies for submerged arc welding.

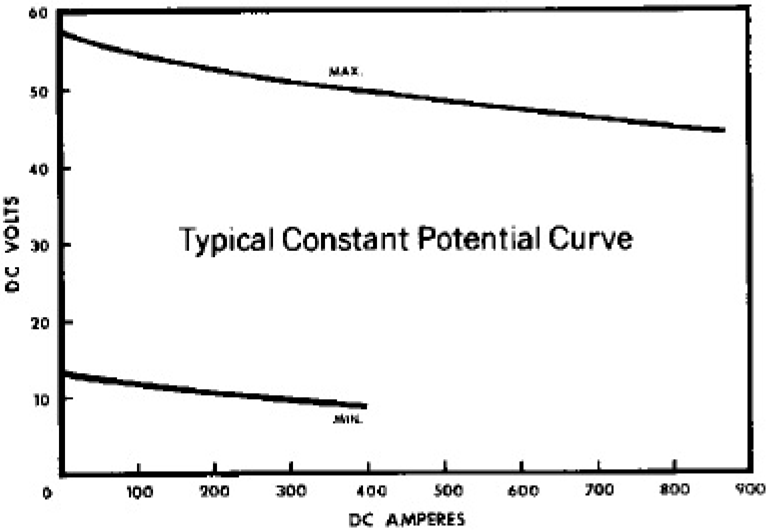


Fig. 5: Potential curve

CONSTANT-CURRENT DC POWER sources are available in both transformer-rectifier and motor-generator models, with rated outputs up to 1500 A. Constant-current sources are not self-regulating, so they must be used with a voltage-sensing variable wire feed speed control. This type of control adjusts the wire feed speed in response to changes in arc voltage. The voltage is monitored to maintain a constant arc length. With this system, the arc voltage is dependent upon the wire feed speed and the wire diameter. The power source controls the arc current. Because voltage-sensing variable wire feed speed controls are more complex, they are also more expensive than the simple, constant wire feed speed controls that may be used with CV systems.

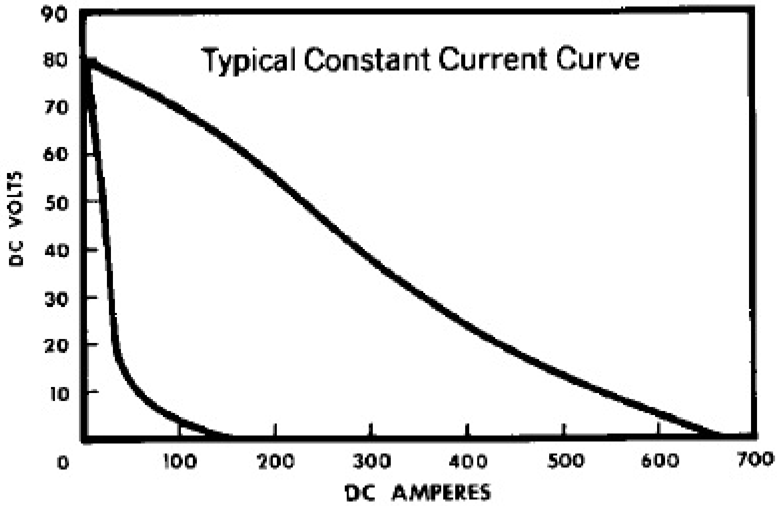


Fig. 6: Current curve

Alternating Current Power Sources

POWER SOURCES for AC welding are most commonly transformers. Sources rated for 800 to 1500 A at 100 % duty cycle are available. If higher amperages are required, these machines can be connected in parallel.
Conventional ac power sources are the constant-current type. The output voltage of these machines approximates a square wave, and the output current approximates a sine wave.

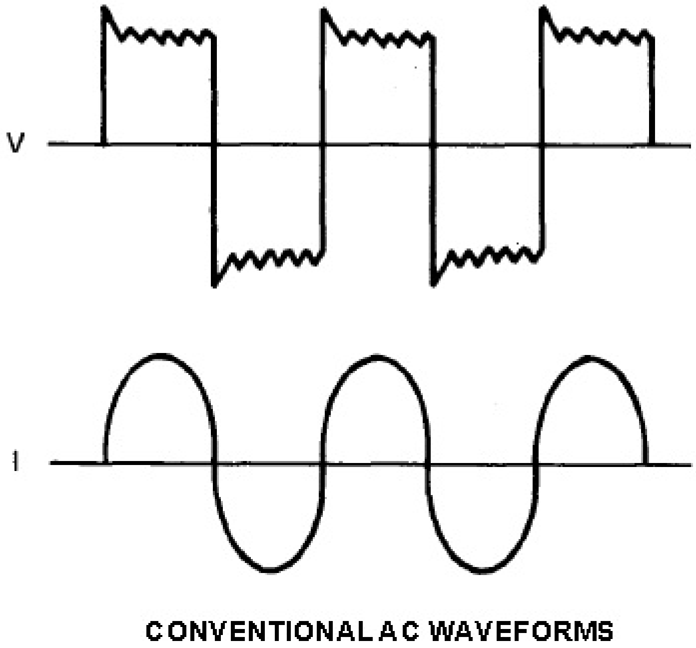


Fig. 7: AC waveforms

CONTROLS

THE CONTROL SYSTEMS used for semiautomatic submerged arc welding are simple wire feed speed controls. Controls used with constant-voltage power supplies maintain a constant wire feed speed. Controls used with constant-current power supplies monitor the arc voltage and adjust the wire feed speed to maintain a constant voltage. The simplest wire feeders have one-knob analog controls that maintain constant wire feed speed.
Digital controls are currently available only for use with constant voltage power supplies. These controls provide for wire feed speed adjustment (current control), power supply adjustment (voltage control), weld start-stop, automatic and manual travel on-off, cold wire feed up-down, run-in and crater fill control, burn back, and flux feed on off. Digital current, voltage, and wire feed speed meters are standard on digital controls. Analog controls are available for use with both constant-voltage and constant-current power supplies. Basic controls consist of a wire feed speed control (adjusts current in CV systems; controls voltage in CC systems), a power supply control (adjusts voltage in CV systems; adjusts current in CC systems), a weld start-stop switch, automatic or manual travel on-off, and cold wire feed up-down.

WELD HEADS AND TORCHES

A SUBMERGED ARC welding head comprises the wire feed motor and feed roll assembly, the torch assembly and contact tip, and accessories for mounting and positioning the head. A flux nozzle is usually mounted on the weld head, to deposit the flux either slightly ahead of or concentric with the welding wire. Wire feed motors are typically heavy duty, permanent magnet-type motors with an integral reducing gearbox, feeding wire at speeds in the range of 20 to 550 in./min. (8 to 235 mm/sec). The feed roll assembly may have one drive and one idler roll, two drive rolls, or four drive rolls. Four-roll drive assemblies are reported to provide positive feeding with the least wire slippage. Feed rolls may be knurled-V or smooth-V type; hurled-V rolls are the most common. In some cases, where the wire is being pushed through a conduit, smoother feeding will result if smooth V- groove rolls are used. Torch assembly designs are numerous, but their purpose is always the same. The torch assembly guides the wire through the contact tip to the weld zone, and also delivers welding power to the wire at the contact tip.

Special equipment is needed for standard submerged arc welding, narrow groove (SAW-NG), and strip electrode SAM. Parallel wire SAW uses special feed roll and torch assemblies that provide positive feeding of two wires through one torch body. Strip electrode SAW also requires a special feed roll and torch assembly. Torches that feed strip are generally adjustable to accommodate several sizes of strip, typically 1.2,1.8,2.4,3.5 in. wide, and up to 0.04 in. thick (30,45,60,90 mm wide; up to 1 mm thick). The

assemblies for parallel wire and strip electrode SAW are generally designed for mounting on standard welding heads with little or no modification.

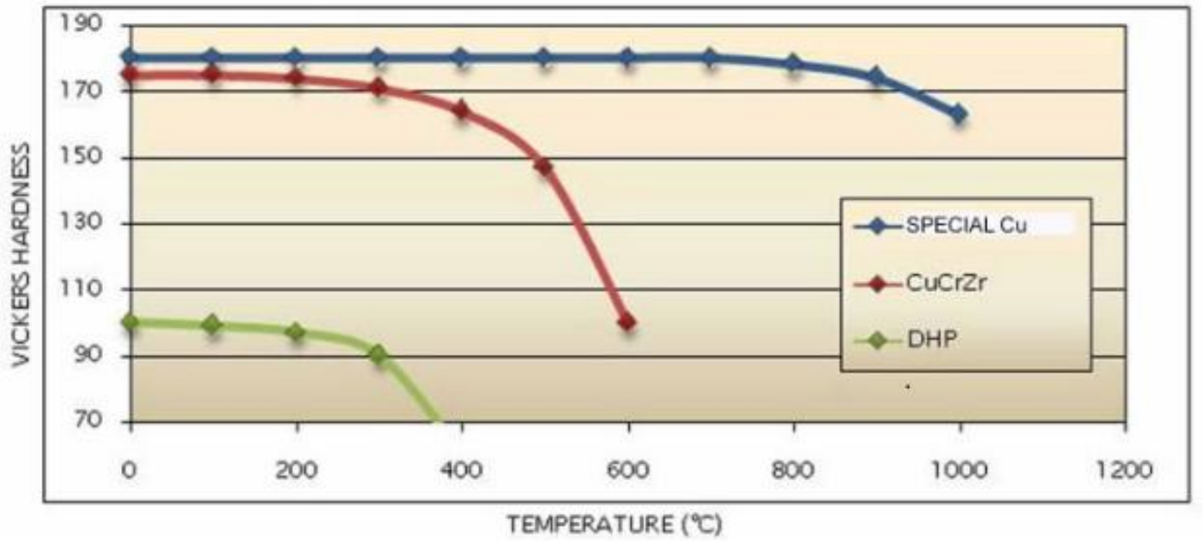


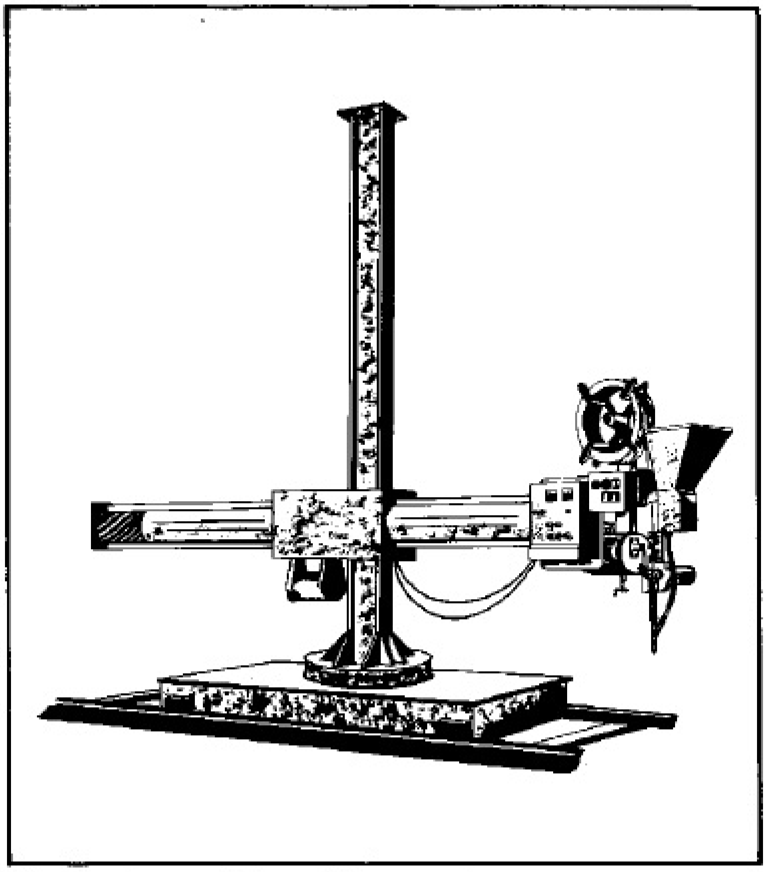
Fig. 8: ELECTRODE TIP HARDNESS

ACCESSORY EQUIPMENT

ACCESSORY EQUIPMENT commonly used commonly with SAW include travel equipment, flux recovery units, fixturing equipment, and positioning equipment.

TRAVEL EQUIPMENT

WELD HEAD TRAVEL in SAW is generally provided by a tractor-type carriage, a side beam carriage, or a manipulator. The weld head, control, wire supply, and flux hopper are generally mounted on the tractor. Manipulators are similar to side beams, in that they are fixed and the work piece must be brought to the welder. Manipulators are more versatile than side beams in that they are capable of linear motion in three axes. The weld head, wire, flux hopper, and often the control and operator ride on the manipulator.



Manipulator with welding equipment

Fig. 9:Manipulator

FLUX RECOVERY UNITS

FLUX RECOVERY UNITS are frequently used to maximize flux utilization and minimize manual clean-up. Flux recovery units may do any combination of the following:

(1) Remove unfused flux and fused slag behind the weld
(2) Screen out fused slag and other oversized material.
(3) Remove magnetic particles.
(4) Remove fines.
(5) Recirculate flux back to a hopper for reuse.
(6) Heat flux in a hopper to keep it dry.

MATERIALS

1. **BASE METALS**

The following are general classes of base metals welded:

a) Carbon steels up to 0.29 % C.
b) Low alloy Steels
c) Chromium- molybdenum steels
d) Stainless steel
e) Nickel based alloys

2. **ELECTORDES**

Electrodes are supplied in bare solid wire as well as composite metal cored electrodes. Electrode manufacturers prepare composite electrodes that duplicate complex alloys by enclosing required alloying elements in a tube of more available composition (stainless steel or other metals).

Electrodes are normally packaged as coils or drums ranging in weight from 25 to 1000 lb (11 to 454 kg). Large electrode packages are economical. They increase operating efficiency and eliminate end-of-coil waste. Steel electrodes are usually copper coated, except those for welding corrosion resisting materials or for certain nuclear applications. The copper coating provides good shelf life, decreases contact tube wear, and improves electrical conductivity. Electrodes are packaged to ensure long shelf life when stored indoors under normal conditions. Submerged arc welding electrodes vary in size from 1/16 to 1/4 in. (1.6 to 6.4 mm) in diameter. [3]

3. **FLUXES**

FLUXES SHIELD THE molten weld pool from the atmosphere by covering the metal with molten slag (fused flux). Fluxes clean the molten weld pool, modify the chemical composition of the weld metal, and influence the shape of the weld bead and its mechanical properties. Fluxes are granular mineral compounds mixed according to various formulations. Based on the choice of several manufacturing methods, the different types of fluxes are fused, bonded (also known as agglomerated), and mechanically mixed. [8]

Fused Fluxes

To MANUFACTURE A fused flux, the raw materials are dry mixed and melted in an electric furnace. After melting and any final additions, the furnace charge is poured and cooled. Cooling may be accomplished by shooting the melt through a stream of water or by pouring it onto large chill blocks. The result is a product with a glassy appearance which is then crushed, screened for size, and packaged.

Fused fluxes have the following advantages:

(1) Good chemical homogeneity
(2) Easy removal of the fines without affecting the flux composition
(3) Not hygroscopic normally, which simplifies handling, storage, and welding problems
(4) Readily recycled through feeding and recovery systems without significant change in particle size or composition

Their main disadvantage is the difficulty of adding deoxidizers and ferro-alloys to them during manufacture without segregation or extremely high losses. The high temperatures needed to melt the raw ingredients limit the range of flux compositions. [8]

Bonded Fluxes

To MANUFACTURE A bonded flux, the raw materials are powdered, dry mixed, and bonded with either potassium silicate, sodium silicate, or a mixture of the two. After bonding, the wet mix is pelletized and baked at a temperature lower than that used for fused fluxes. The pellets are then broken up, screened to size, and packaged.

The advantages of bonded fluxes include the following:

(1) Easy addition of deoxidizers and alloying elements; alloying elements are added as Ferro-alloys or as elemental metals to produce alloys not readily available as electrodes, or to adjust weld metal compositions.

(2) Usable with thicker layer of flux when welding

(3) Colour identification

The disadvantages are the following:

(1)' Tendency for some fluxes to absorb moisture in a manner similar to coatings on some shielded metal arc electrodes

(2) Possible gas evolution from the molten slag

(3) Possible change in flux composition due to segregation or removal of fine mesh particles [8]

Mechanically Mixed Fluxes

To PRODUCE A mechanically mixed flux, two or more fused or bonded fluxes are mixed in any ratio necessary to yield the desired results.

The following are disadvantages of mechanically mixed fluxes:

(1) Segregation of the combined fluxes during shipment, storage, and handling

(2) Segregation occurring combined flux from mix to mix systems during the welding operation

(3) Inconsistency in the advantage of mechanically mixed fluxes is that several commercial fluxes may be mixed for highly critical or proprietary welding operations. [8]

Particle Size and Distribution

FLUX PARTICLE SIZES and their uniform distribution within the bulk flux are important because that influences feeding and recovery, amperage level, and weld bead smoothness and shape. As amperage increases, the average particle size for fused fluxes should be decreased and the percentage of small particles should be increased. If the amperage is too high with a given particle size, the arc may be unstable and leave ragged, uneven bead edges. When rusty steel is welded, coarse particle fluxes are preferable, because they allow gases to escape more easily. Some flux manufacturers may mark their packages with sizing information presented in the form of two mesh numbers. The numbers represent the largest and smallest particle sizes present when standardized screens are used to measure them. The first number identifies the mesh (screen) through which essentially all of the particles will pass, and the second number identifies the mesh through which most or all of the particles will not pass. Those particle sizes do not provide all the information that may be needed. For instance, designating fluxes having a mesh size 20 x 200 does not indicate whether the flux is coarse with some fines, or is fine with some coarse particles. All that is known is the range, Some flux manufacturers offer each of their fluxes in only one particle size range, customized for a general area of flux application. [8]

Flux Usage

IF THE FLUX is too fine, it will pack and not feed properly. If a fine flux or a flux with small amounts of fine particles is recovered by a vacuum system, the fine particles may be trapped by the system. Only the coarser particles will be returned to the feeding system for reuse, which may cause welding problems.

In applications where low hydrogen considerations are important, fluxes must be kept dry. Fused fluxes do not contain chemically bonded H20, but the particles hold surface moisture. Bonded fluxes contain chemically bonded H20, and may hold surface moisture as well. Bonded fluxes need to be protected in the same manner as low-hydrogen shielded metal arc electrodes. The user should follow the directions of the flux manufacturer for specific baking procedures. When alloy-bearing fluxes are used, it is necessary to maintain a fixed ratio between the quantities of flux and electrode melted, to obtain a consistent weld metal composition.

This ratio is actually determined by the variables of the welding procedure. For example, deviation from an established volt-ampere relation will change the alloy content of the weld metal by changing the flux-electrode melting ratio. Fluxes are also identified as chemically basic, chemically acid, or chemically neutral. The basicity or acidity of a flux is related to the ease with which the component oxides of the flux ingredients dissociate into a metallic cation and an oxygen anion. Chemically basic fluxes are normally high in MgO or CaO, while chemically acid fluxes are normally high. The basicity or acidity of a flux is often referred to as the ratio of CaO or MgO to Si02. Fluxes having ratios greater than one are called chemically basic. Ratios near unity are chemically neutral. Those less than unity is chemically acidic. Basic fluxes have recently become the prime fluxes for welding in critical applications where close controls on deposit properties and chemistry are required. Most of the basic group are formulated for specific wire deposits, i.e., fluxes that stabilize chromium or carbon loss. They limit transfers of silicon/manganese/oxygen from the slag to the weld metal. Basic fluxes are available to suit any material weld able by submerged arc. [8]

Fig. 10: SAW flux and wire

CARBON STEEL ELECTRODES AND FLUXES

AWS SPECIFICATION A5.17 prescribes the requirements for electrodes and fluxes for submerged arc welding of carbon steels. Solid electrodes are classified on the basis of chemical composition (as manufactured), while composite electrodes are based on deposit chemistry. Fluxes are classified on the basis of weld metal properties obtained when used with specific electrodes. Carbon steels are defined as those steels having additions of carbon up to 0.29 percent, manganese up to 1.65 percent, silicon up to 0.60 percent, and copper up to 0.60 percent, with no specified range of other alloying elements.

Fluxes are classified on the basis of the chemical composition and mechanical properties of the deposited weld metal with some particular classification of electrode. Selection of SAW consumables will depend on the chemical and mechanical properties required for the component being fabricated, the welding position (lG, 2G, 2F), and any required surface preparation of the steel to be welded. SAW consumable manufacturers produce electrode/flux combinations which are formulated to meet specific chemical and mechanical property requirements and weld ability conditions. Purchasing consumables always from the same manufacturer is recommended when composite electrodes are used, whereas with solid electrodes the fabricator can pick and choose among available fluxes to be used with a given AWS electrode classification. It should be noted that the electrode chosen has the greatest influence on the resulting deposited weld metal chemistry, while the flux chosen has a great effect on the Charpy V-notch (CVN) impact properties and the overall weld ability of the electrode/flux combination. The following items must be considered when selecting SAW consumables:

(1) Whether to choose a “neutral” or “active” flux. A neutral flux adds little or no alloying elements to the weld deposit, whereas an active flux adds alloying elements to the deposited weld metal, Active fluxes are usually chosen for single pass welding operations; their application for multiple pass use may be limited by engineering specifications because of concern that excessive alloy build-up will take place in the deposited weld metal.

(2) Whether the fluxes being considered are correctly balanced in chemical composition, for use with a given electrode classification.

(3) The mechanical property requirements required. This includes CVN impact properties as well as the strength and ductility of the resulting deposit.

(4) Usability of a given electrode/flux combination, including wetting of side walls without undercut or cold lap, ability to weld over rust and scale, and ease of slag removal. [8]

WELDING OF LOW ALLOY STEEL MATERIALS

Low ALLOY STEEL materials are welded with electrode and flux combinations classified under ANSI/AWS A5.23. Low alloy steels are divided into many subgroups, using the chemical composition and tensile strength of the steels as the factor which determines which SAW consumables should be chosen to weld the joints. This is particularly true for components that will be used at temperatures greater than 650°F (345”C), where oxidation resistance and elevated tensile properties are important. [1]

Higher Strength low Alloy Steels

HIGHER STRENGTH LOW alloy steels are steels with relatively low chemical additions, usually less than 1 percent of the chemical composition, of Cry Cu, Ni, Cb, and V. These steels are usually supplied in the as-rolled, normalized, or quenched and tempered condition from the manufacturer, depending on the material specification requirements.

High Yield Strength, Quenched and Tempered low Alloy Steel

HIGH YIELD STRENGTH quenched and tempered low alloy steels are similar to the higher strength low alloys steels mentioned above, except that they have higher amounts of alloy additions, up to approximately 2 percent each of Cr, Cu, Ni, Cb, and V. These steels are always supplied in the heat-treated condition. Typical steels that are welded with SAW consumables in ANSI/AWS AS.23 include ASTM A514 and A517. There are many different grades of these steels with varying chemical composition. When welding these steels, the manufacturer of the steel should be consulted to determine which consumables are recommended. Selection of the electrode/flux combination depends on the thickness of the steels and the mechanical properties required, including notch toughness properties. [1]

Carbon-Molybdenum Steels

CARBON-MOLYBDENUMS TEELS ARE similar to carbon steels except they have an addition of approximately 0.5 percent of molybdenum. These steels are used in pressure vessels or pipe lines operating at elevated temperature. Carbon-molybdenum steels are produced in the as rolled or normalized conditions.

Chromium-Molybdenum Steels

CHROMIUM-MOLYBDENUM STEELS ARE steels containing varying amounts of chromium, up to a nominal 9 percent chemical composition, and molybdenum up to a nominal 1 percent chemical composition. These steels usually come from the steel manufacturer in the annealed, normalized and tempered, or quenched and tempered condition. These steels are also used in pressure vessels and pipe lines operating at elevated temperature. [1]

LOW ALLOY STEEL ELECTRODES AND FLUXES

LOW ALLOY STEELS usually have less than 10 percent of any one alloying element. Low alloy steel weld metal may be deposited by solid alloy steel electrodes, fluxes containing the alloying elements, and composite electrodes where the core contains the alloying elements. Alloy steel electrodes and composite electrodes are normally welded under a neutral flux. AlIoy-bearing fluxes are generally used with carbon steel electrodes to deposit alloyed weld metal. Many electrode-flux combinations are available.

STAINLESS STEELS

STAINLESS STEELS ARE capable of meeting a wide range of final needs such as corrosion resistance, strength at elevated temperatures, and toughness at cryogenic temperatures,
and are selected for a broad range of applications. The stainless steels most widely used for welded industrial applications are classified as follows:
(1) Martensitic
(2) Ferritic
(3) Austenitic
(4) Precipitation hardening
(5) Duplex or ferritic-austenitic

Chromium and Chromium-Nickel Steel Bare and Composite Metal Cored and Stranded Welding Electrodes and Welding Rods. Not all stainless steels are readily weld able by the submerged arc process, and some require that special considerations be followed. In stainless steels and nickel base alloys the main advantage of submerged arc welding, its high deposition rates, sometimes becomes a disadvantage. As deposition rates increase, so docs heat input and in stainless alloys high heat inputs may cause deleterious microstructural changes.

Nickel Alloy Steels

NICKEL ALLOY STEELS contain between 1 and 3.5 percent nickel. These steels are used in low temperature applications [below -50°F (-46”C)I because they have good notch toughness properties at low temperatures. When electrode/flux consumables are selected, the important factors to match are both the minimum tensile strength and the minimum notch toughness of the base metal. [1]

Nickel and Nickel Alloy Electrodes and Fluxes

NICKEL AND NICKEL alloy electrodes in wire form are available for submerged arc welding. ANSI/AWS A5.14, Specification for Nickel and Nickel Alloy Bare Welding Electrodes and Rods, covers nickel and nickel alloy filler metals. The electrodes are classified according to their chemical compositions, as manufactured. [1]

GENERAL PROCESS APPLICATIONS

SAW IS USED in a wide range of industrial applications. High weld quality, high deposition rates, deep penetration, and adaptability to automatic operation make the process suitable for fabrication of large weldments. It is used extensively in pressure vessel fabrication, ship and barge building, railroad car fabrication, pipe manufacturing, and the fabrication of structural members where long welds are required. Automatic SAW installations manufacture mass produced assemblies joined with repetitive short welds. The process is used to weld materials ranging from 0.06 in. (1.5 mm) sheet to thick, heavy weldments. Submerged arc welding is not suitable for all metals and alloys. It is widely used on carbon steels, low alloy structural steels, and stainless steels. It joins some high-strength structural steels, high-carbon steels, and nickel alloys. However, better joint properties are obtained with these metals by using a process with lower heat input to the base metal, such as gas metal arc welding.

Submerged arc welding is used to weld butt joints in the flat position, fillet welds in the flat and horizontal positions, and for surfacing in the flat position. With special tooling and fixturing, lap and butt joints can be welded in the horizontal position.

OPERATING VARIABLES

CONTROL OF THE operating variables in submerged arc welding is essential if high production rates and welds of good quality are to be obtained. These variables, in their approximate order of importance, are the following:

(1) Welding amperage
(2) Type of flux and particle distribution
(3) Welding voltage
(4) Welding speed
(5) Electrode size
(6) Electrode extension
(7) Type of electrode
(8) Width and depth of the layer of flux

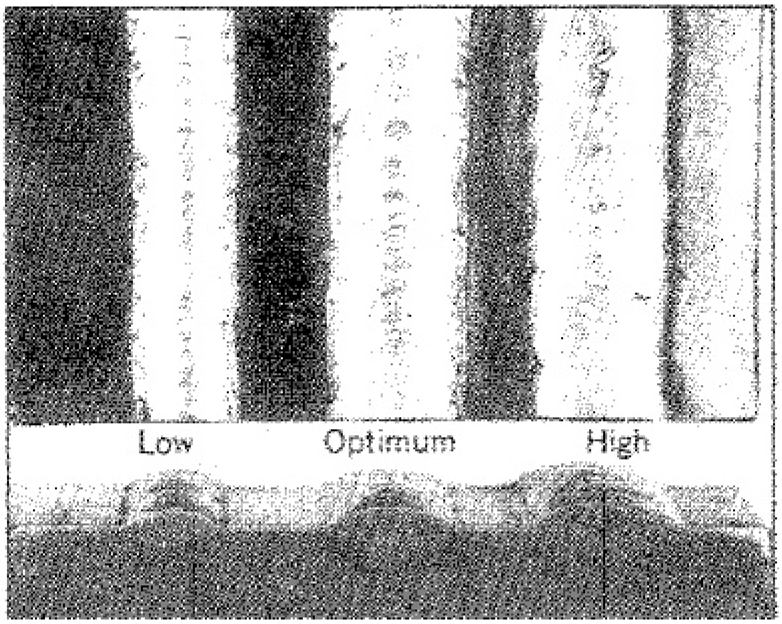
WELDING AMPERAGE

WELDING CURRENT IS the most influential variable because it controls the rate at which the electrode is melted and therefore the deposition rate, the depth of penetration, and the amount of base metal melted. If the current is too high at a given travel speed, the depth of fusion or penetration will be too great. The resulting weld may tend to melt through the metal being joined. High current also leads to waste of electrodes in the form of excessive reinforcement. This oven welding increases weld shrinkage and causes greater distortion.

If the current is too low, inadequate penetration or incomplete fusion may result.

Following are three rules concerning welding current:

(1) Increasing current increases penetration and melting rate
(2) Excessively high current produces a digging arc and undercut, or a high, narrow bead.
(3) Too low welding current produces an unstable arc.



Amperage Varied Welds

Fig. 11: Amperage varied welds

WELDING VOLTAGE

WELDING VOLTAGE ADJUSTMENT varies the length of the arc between the electrode and the molten weld metal. If the overall voltage is increased, the arc length increases; if
the voltage decreased, the arc length decreases. Voltage has little effect on the electrode deposition rate, which is determined by welding current. The voltage principally determines the shape of the weld bead cross section and its external appearance
Increasing the welding voltage with constant current and travel speed will:

(1) Produce a flatter and wider bead.
(2) Increase flux consumption.
(3) Tend to reduce porosity caused by rust or scale on
(4) Help bridge an excessive root opening when fit-up is poor.
(5) Increase pickup of alloying elements from an alloy flux.

Excessively high-arc voltage will:

(1) Produce a wide bead shape that is subject to
(2) Make slag removal difficult in groove welds.
(3) Produce a concave shaped weld that may be subject
(4) Increase undercut along the edge(s) of fillet welds,

Lowering the voltage produces a “stiffer” arc, which improves penetration in a deep weld groove and resists arc blow. An excessively low voltage produces a high, narrow bead and causes difficult slag removal along the bead edges. [9]

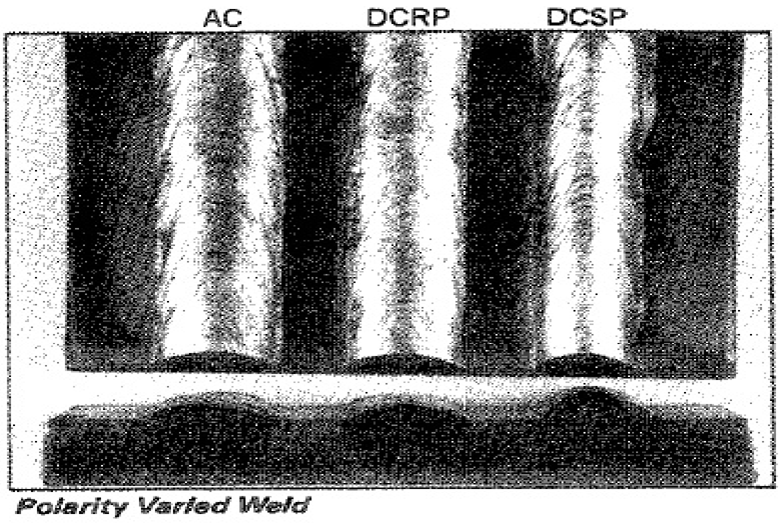


Fig. 12: Polarity varied weld

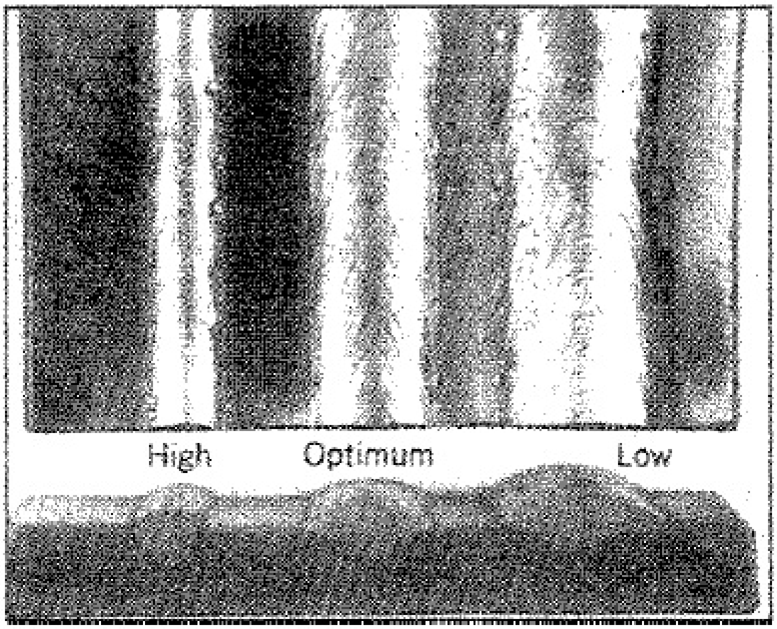
TRAVEL SPEED

WITH ANY COMBINATION of welding current and voltage, the effects of changing the travel speed conform to a general pattern. If the travel speed is increased, (1) power or heat input per unit length of weld is decreased, and (2) less filler metal is applied per unit length of weld, resulting in less weld reinforcement.

Weld penetration is affected more by travel speed than by any variable other than current. This is true except for excessively slow speeds when the molten weld pool is beneath the welding electrode. Then the penetrating force of the arc is cushioned by the molten pool. Excessive speed may cause undercutting.

Within limits, travel speed can be adjusted to control weld size and penetration. In these respects, it is related to current and the type of flux. Excessively high travel speeds promote undercut, arc blow, porosity, and uneven bead shape. Relatively slow travel speeds provide time for gases to escape from the molten metal thus reducing porosity. Excessively slow speeds produce

(1) A convex bead shape that is subject to cracking,
(2) Excessive arc exposure, which is uncomfortable for the operator,
(3) A large molten pool that flows around the arc, resulting in a rough bead and slag inclusions.



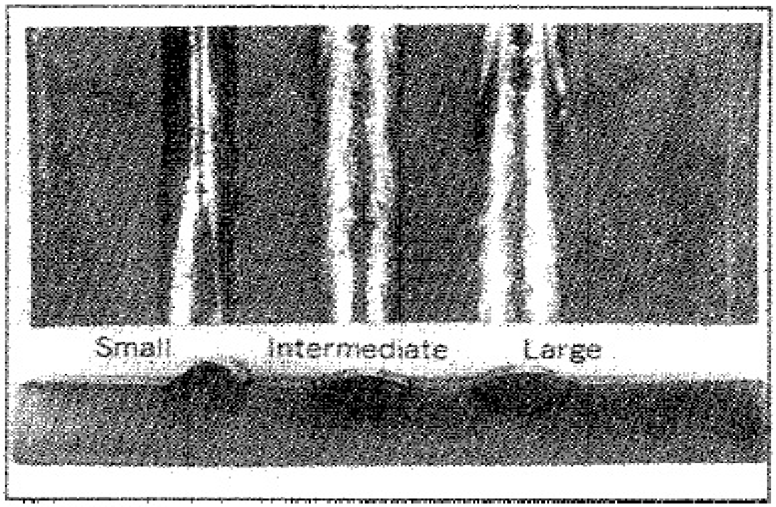
Travel Speed Varied Weld

Fig. 13: Travel speed varied weld

ELECTRODE SIZE

ELECTRODE SIZE AFFECTS the weld bead shape and the depth of penetration at a fixed current. Small diameter electrodes are used with semiautomatic equipment to provide flexibility of movement. They are also used for multiple electrodes, parallel power equipment.

Where poor fit-up is encountered, a larger diameter electrode is better than small ones for bridging large root openings. Electrode size also influences the deposition rate. At any given current, a small diameter electrode will have a higher current density and a higher deposition rate than a larger electrode. However, a larger diameter electrode can carry more current than a smaller electrode, and produce a higher deposition rate at higher amperage. If a desired electrode feed rate is higher (or lower) than the feed motor can maintain, changing to a larger (or smaller) size electrode will permit the desired deposition rate. [9]



Wire Sizes

Fig. 14: Wire sizes

ELECTRODE EXTENSION

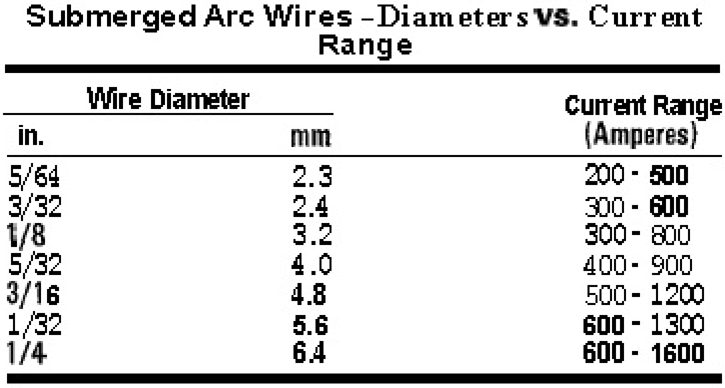
AT CURRENT DENSI'T'IES above 80 000 A/in2 (125 A/mm2), electrode extension becomes an important variable. At high-current densities, resistance heating of the electrode between the contact tube and the arc increases the electrode melting rate. The longer the extension, the greater is the amount of heating and the higher the melting rate. This resistance heating is commonly referred to as 12R heating. 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. Increased electrode extension adds a resistance element in the welding circuit and consumes some of the energy previously supplied to the arc. With lower voltage across the arc, bead width and penetration decrease because lower arc voltage increases the convexity of the bead, the bead shape will be different from one made with a normal electrode extension. Therefore, when the electrode extension is increased to take advantage of the higher melting rate, the voltage setting on the machine should be increased to maintain proper arc length. The condition of the contact tube affects the effective electrode extension. Contact tubes should be replaced at predetermined intervals to insure consistent welding conditions. Deposition rates can be increased from 25 percent to 50 percent by using long electrode extensions with no change in welding amperage. With single electrode automatic SAW, the deposition rate may approach that of the two wire method with two power sources.

An increase in deposition rate is accompanied by a decrease in penetration, therefore changing to a long electrode extension is not recommended when deep penetration is needed. When melt-through is a problem, as may be encountered when welding thin gage material, increasing the electrode extension may be beneficial. However, as the electrode extension increases, it is more difficult to maintain the electrode tip in the correct position with respect to the joint.

The following arc suggested maximum electrode extensions for solid steel electrodes for SAW

(1) For 5/64, 3/32, and 1/8 in. (2.0,2,4, and 3.2 mm)

(2) For 5/32,3/16, and 7/32 in. (4.0,4.8a,n d 5.6 mm) electrodes, 3 in. (75 mm) electrodes, 5 in. (125 mm) [9]



Submerged Arc Wires –Diameters vs. Current Range

Wire Diameter		Current Range
in.	mm	(Amperes)
5/64	2.3	200 - 500
3/32	2.4	300 - 600
1/8	3.2	300 - 800
5/32	4.0	400 - 900
3/16	4.8	500 - 1200
1/32	5.6	600 - 1300
1/4	6.4	600 - 1600

TABLE 1: Diameter vs current range

WIDTH AND DEPTH OF FLUX

THE WIDTH AND depth of the layer of granular flux influence the appearance and soundness of the finished weld as well as the welding action. If the granular layer is too deep,

the arc is too confined and a rough rope like appearing weld will result. The gases generated during welding cannot readily escape, and the surface of the molten weld metal becomes irregularly distorted. If the granular layer is too shallow, the arc will not be entirely submerged in flux. Flashing and spattering will occur. The weld will have a poor appearance, and it may be porous. The effects on weld bead surface appearance of proper and shallow depths of flux. An optimum depth of flux exists for any set of welding conditions. This depth can be established by slowly increasing the flow of flux until the welding arc is submerged and flashing no longer occurs. The gases will then puff up quietly around the electrode, sometimes igniting. During welding, the unfused granular flux can be removed a short distance behind the welding zone after the fused flux has solidified. However, it may be best not to disturb the flux until the heat from welding has been evenly distributed throughout the section thickness. Fused flux should not be forcibly loosened while the weld metal is at a high temperature [above 1100°F (6OO"C)]. Allowed to cool, the fused material will readily

detach itself. Then it can be brushed away with little effort. Sometimes a small section may be forcibly removed for quick inspection of the weld surface appearance. It is important that no foreign material be picked up when reclaiming the flux. To prevent this, a space approximately 12 in. (300 mm) wide should be cleaned on both sides of the weld joint before the flux is laid down. If the recovered flux contains fused pieces, it should be passed through a screen with openings no larger than 1/8 in, (3.2 mm) to remove the coarse particles.

The flux is thoroughly dry when packaged by the manufacturer. After exposure to high humidity, it should be dried by baking it before it is used. Moisture in the flux will cause porosity in the weld. [8]

Fig. 15: SAW flux width

TYPES OF WELDS

SUBMERGED ARC WELDING is used for making groove, fillet, plug, and surfacing welds. Groove welds are usually made in the flat position and fillet welds are usually made in the flat and horizontal positions. This is because the molten weld pool and the flux are most easily contained in these positions. However, simple techniques are available for producing groove welds in the horizontal welding position. Good submerged arc welds can be made downhill at angles up to 15 degrees from the horizontal. Surfacing and plug welding are done in the flat position. Welds made by this process may be classified with respect to the following:

(1) Type of joint
(2) Type of groove
(3) Welding method (semiautomatic or machine)
(4) Welding position (flat or horizontal)
(5) Single or multiple pass deposition
(6) Single or multiple electrode operation
(7) Single or multiple power supply (series, parallel, or separate connections).

WELDING PROCEDURES

To FULLY REALIZE the high production benefits of SAW, consideration must be given to pre weld operations. Joint design, edge preparation, fit-up, and fixturing the work piece must be considered.

JOINT DESIGN AND EDGE PREPARATION

TYPES OF JOINTS used in submerged arc welding include chiefly butt, T-, and lap joints, although edge and corner joints can also be welded. The principles of joint design and methods of edge preparation are similar to other arc welding processes. Typical welds include fillet, square groove, single and double V-groove, and single and double U-groove welds. Joint designs, especially for plate welding, often call for a root opening of 1/32 to 1/16 in. (0.8 to 1.6 mm) to prevent angular distortion or cracking due to shrinkage stresses. However, a root opening that is larger than that required for proper welding will increase welding time and costs. This is true for both groove and fillet welding. Edge preparation may be done by any of the thermal cutting methods or by machining. The accuracy of edge preparation is important, especially for machine or automatic welding. For example, if a joint designed with a 1/4 in. (6.4 mm) root face were actually produced with a root face that tapered from 5/16 to 1/8 in. (7.9 to 3.2 mm) along the length of the joint, the weld might be unacceptable because of lack of penetration at the start and excessive melt-through at the end. In such a case, the capability of the cutting equipment, as well as the skill of the operator, should be checked and corrected.

JOINT FIT-UP

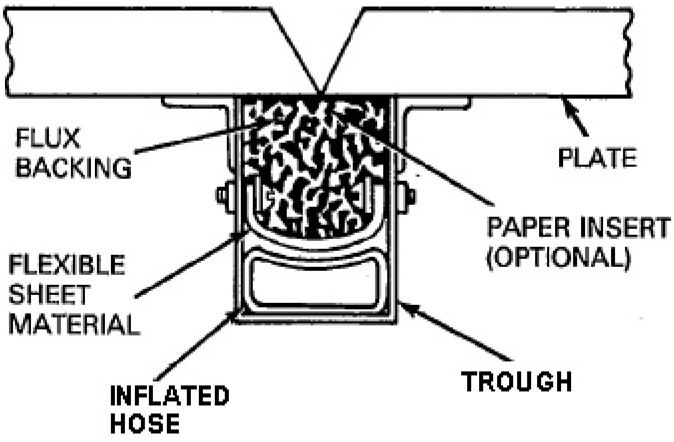
JOINT FIT-UP IS an important part of the assembly or subassembly operations, and it can materially affect the quality, strength, and appearance of the finished weld. When welding plate thicknesses, the deeply penetrating characteristics of the submerged arc process emphasize the need for close control of fit-up. Uniformity of joint alignment and of the root opening must be maintained.

WELD BACKING

SUBMERGED ARC WELDING creates a large volume of molten weld metal which remains fluid for an appreciable period of time. This molten metal must be supported and contained until it has solidified. There are several methods commonly used to support molten weld metal when complete joint penetration is required:

(1) Backing strips
(2) Backing welds
(3) Copper backing bars
(4) Flux backing
(5) Backing tapes

In the first two methods, the backing may become a part of the completed joint. The other three methods employ temporary backing which is removed after the weld is completed. Methods 1 and 2 may require removing the backing, depending on the design requirements of the joint. In many joints, the root face is designed to be thick enough to support the first pass of the weld. This method may be used for butt welds (partial joint penetration), for fillet welds, and for plug or slot welds. Supplementary backing or chilling is sometimes used. It is most important that the root faces of groove welds be tightly butted at the point of maximum penetration of the weld.



A Method of Supporting Flux Backing for Submerged Arc Welding

Fig. 16: Backing of SAW

Backing Strip

IN THIS METHOD, the weld penetrates into and fuses with a backing strip which temporarily or permanently becomes an integral part of the assembly.
Backing strips must be compatible with the metal being welded. When the design permits, the joint is located so that a part of the structure forms the backing. It is important that the contact surfaces be clean and close together; otherwise porosity and leakage of molten weld metal may occur.

Backing Weld

IN A JOINT backed by weld metal, the backing pass is usually made with some other process, such as FCAW, GMAW, or SMAW, This backing pass forms a support for subsequent SAW passes made from the opposite side. Manual or semiautomatic welds are used as backing for submerged arc welds when alternate backing methods are not convenient because of inaccessibility, poor joint penetration or fit-up, or difficulty in turning the weldment. The weld backing may remain as a part of the completed joint or may be removed by oxygen or arc gouging, by chipping, or by machining after the submerged arc weld has been made. It is then replaced by a permanent submerged arc surfacing bead.

Copper Backing

WITH SOME JOINTS, a copper backing bar is used to support the molten weld pool but does not become a part of the weld. Copper is used because of its high thermal conductivity, which prevents the weld metal from fusing to the backing bar. Where it is desirable to reinforce the underside of the weld, the backing bar may be grooved to the desired shape of the reinforcement. The backing bar must have enough mass to prevent it from melting beneath the arc, which would contaminate the weld with copper. Caution must be used to prevent copper pickup in the weld caused by harsh arc starts. Sometimes water is passed through the interior of the copper backing bar to keep it cool, particularly for high-production welding applications. Care must be taken to prevent water condensation from forming on the copper backing bar. Copper backing is sometimes designed to slide so a relatively short length can be used in the vicinity of the arc and the molten weld pool. In still other applications, the copper backing is a rotating wheel

Flux Backing

FLUX, UNDER MODERATE pressure, is used as backing material for submerged arc welds. Loose granular flux is placed in a trough on a thin piece of flexible sheet material. Beneath the flexible sheet, there is an inflatable rubberized canvas fire hose. The hose is inflated to no more than 5 to 10 psi (35 to 70 kPa) to develop moderate flux pressure on the backside of the weld. [1]

FIXTURING

THE MAIN PURPOSE of fixturing is to hold a work piece assembly in proper alignment during handling and welding. Some assemblies may require stiffening fixtures to maintain their shape. In addition, some type of clamping or fixturing may be required to hold the joint alignment for welding and to prevent warpage and buckling from the heat of welding. For assemblies that are inherently rigid, tack welding alone may suffice. Heavy section thicknesses in themselves offer considerable restraint against buckling and warpage.

In intermediate cases, a combination of tack welding, fixturing, and weld sequencing may be required. For joints of low restraint in light gage materials, clamping is needed.

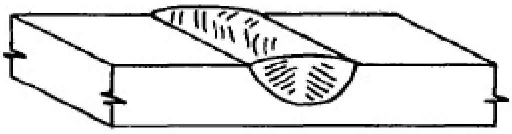
Clamping bars maintain alignment and remove heat to reduce or prevent warpage. Tack welds are usually necessary. Fixtures also include the jigs and tooling used to facilitate the welding operation. Weld seam trackers and travel carriages are used to guide machine or automatic welding heads. Turning rolls are used to rotate cylindrical work pieces during fit-up and welding. Rotating turntables with angular adjustment are used to position weld joints in the most favourable position for welding. Manipulators with movable booms are used to position the welding head and sometimes the weld operator, for hard-to-reach locations.

INCLINATION OF WORK

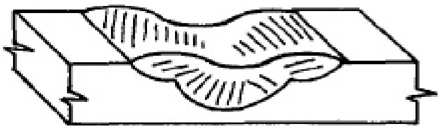
THE INCLINATION OF the work during welding can affect the weld bead shape. Most submerged arc welding is done in the flat position. However, it is sometimes necessary or desirable to weld with the work slightly inclined so that the weld progresses downhill or uphill. For example, in high-speed welding of 0.050 in. (1.3 mm) steel sheet, a better weld results when the work is inclined 15 to 18 degrees, and the welding is done downhill.

Penetration is less than when the sheet is in a horizontal plane. The angle of inclination should be decreased as plate thickness increases to increase penetration. Downhill welding affects the weld the weld pool tends to flow under the arc and preheat the base metal, particularly at the surface. This produces an irregularly shaped fusion zone. As the angle of inclination increases, the middle surface of the weld is depressed, penetration decreases, and the width of the weld increases.

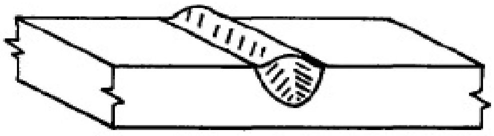
Uphill welding affects the fusion zone contour and the weld surface, the force of gravity causes the weld pool to flow back and lag behind the welding electrode. The edges of the base metal melt and flow to the middle. As the angle of inclination increases, reinforcement and penetration increase, and the width of the weld decreases. Also, the larger the weld pool, the greater the penetration and centre build up. These effects are exactly the opposite of those produced by downhill welding. The limiting angle of inclination when welding uphill with currents up to 800 amperes is about 6 degrees, or a slope of approximately one in ten. When higher welding currents are used, the maximum workable angle decreases. Greater inclination than approximately 6 degrees makes the weld uncontrollable.



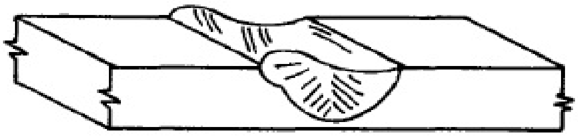
(A) FLAT POSITION WELD



(B) DOWNHILL WELD (1/8 SLOPE)



(C) UPHILL WELD (1/8 SLOPE)



(D) LATERAL WELD (1/19 SLOPE)

Fig. 17: Position of welds

ARC STARTING METHODS

THE METHOD USED to start the arc in a particular application will depend on such factors as the time required for starting relative to the total setup and welding time, the number of pieces to be welded, and the importance of starting the weld at a particular place on the joint. There are six methods of starting:

Steel Wool Ball Start

A TIGHTLY ROLLED ball of steel wool about 3/8 in. (10 mm) in diameter is positioned in the joint directly beneath the welding electrode. The welding electrode is lowered onto the steel wool until the ball is compressed to approximately one-half its original height. The flux is then applied and welding is started. The steel wool ball creates a current path to the work, but it melts rapidly while creating an arc.

Sharp Wire Start

THE WELDING ELECTRODE, protruding from the contact tube, is snipped with wire cutters. This forms a sharp, chisel-like configuration at the end of the wire. The electrode is then lowered until the end just contacts the work piece. The flux is applied and welding is commenced. The chisel point melts away rapidly to start the arc.

Scratch Start

THE WELDING ELECTRODE is lowered until it is in light contact with the work, and the flux is applied. Next, the carriage is started and the welding current is immediately applied. The motion of the carriage prevents the welding wire from fusing to the work piece.

Molten Flux Start

WHENEVER there is a molten puddle of flux, an arc may be started by simply inserting the electrode into the puddle and applying the welding current. This method is regularly used in multiple-electrode welding. When two or more welding electrodes are separately fed into one weld pool, it is only necessary to start one electrode to establish the weld pool. Then the other electrodes will arc when they are fed into the molten pool.

Wire Retract Start

RETRACT ARC STARTING is one of the most positive methods, but the welding equipment must be designed for it. It is cost effective when frequent starts have to be made and when starting location is important. Normal practice is to move the electrode down until it just contacts the work piece. Then the end of the electrode is covered with flux, and the welding current is turned on. The low voltage between the electrode and the work signals the wire feeder to withdraw the tip of the electrode from the surface of the work piece. An arc is initiated as this action takes place. As the arc voltage builds up, the wire feed motor quickly reverses direction to feed the welding electrode toward the surface of the work piece.

Electrode feed speeds up until the electrode melting rate and arc voltage stabilize at the preset value. If the work piece is light gage metal, the electrode should make only light contact, consistent with good electrical contact. The welding head should be rigidly mounted. The end of the electrode must be clean and free of fused slag. Wire cutters are used to snip off the tip of the electrode (preferably to a point) before each weld is made. The electrode size should be chosen to permit operation with high current densities since they enable easier starting.

High-Frequency Start

THIS METHOD REQUIRES special equipment but requires no manipulation by the operator other than closing a starting switch. It is particularly useful as a starting method for intermittent welding, or for welding at high-production rates where many starts are required.

When the welding electrode approaches to within approximately 1/16 in. (1.6 mm) above the work piece, a high-frequency, high-voltage generator in the welding circuit causes a spark to jump from the electrode to the work piece. This spark produces an ionized path through which the welding current can flow, and the welding action begins. This is a commonly used arc starting technique. [1]

ELECTRODE POSITION

IN DETERMINING THE proper position of the welding electrode, three factors must be considered:
(1) The alignment of the welding electrode in relation
(2) The angle of tilt in the lateral direction
(3) The forward or backward direction in which the tilt in a plane perpendicular to the joint (work angle) welding electrode points (travel angle) Forward is the direction of travel. Hence, a forward pointing electrode is one that makes an acute angle with the finished weld. A backward pointing electrode makes an obtuse angle with the finished weld.

Most submerged arc welds are made with the electrode axis in a vertical position. Pointing the electrode forward or backward becomes important when multiple arcs are being used, when surfacing, and when the work piece cannot be inclined. Pointing the electrode forward results in a weld configuration similar to downhill welding; pointing the electrode backward results in a weld similar to uphill welding. Pointing the electrode forward or backward does not affect the weld configuration as much as uphill or downhill positioning of the work pieces. When welding horizontal fillets, the centre line of the electrode should be aligned below the root of the joint and toward the horizontal piece at a distance equal to one fourth to one-half the electrode diameter. The greater distance is used when making larger sizes of fillet welds. Careless or inaccurate alignment may cause undercut in the vertical member or produce a weld with unequal legs,

CIRCUMFERENTIAL WELDS

CIRCUMFERENTIAL WELDS DIFFER from those made in the flat position because of the tendency for the molten flux and weld metal to flow away from the arc. To prevent spillage or distortion of the bead shape, welds must solidify as they pass the 6 or 12 o’clock positions.

SLAG REMOVAL

ON MULTIPLE PASS welds, slag removal becomes important because no subsequent passes should be made where slag is present. The factors that are particularly important in dealing with slag removal are bead size and bead shape. Smaller beads tend to cool more quickly and slag adherence is reduced, Flat to slightly convex beads that blend evenly with the base metal make slag removal much easier than very concave or undercut beads. For this reason, a decrease in voltage will improve slag removal in narrow grooves. On the first pass of two-pass welds, a concave bead that blends smoothly to the top edges of the joint is much easier to clean than a convex bead that does not blend well.

PROCESS VARIATIONS

SUBMERGED ARC WELDING lends itself to a wide variety of wire and flux combinations, single and multiple electrode arrangements, and use of ac or dc welding power sources.

The process has been adapted to a wide range of materials and thicknesses. Various multiple arc configurations may be used to control the weld profile and increase the deposition rates over single arc operation. Weld deposits may range from wide beads with shallow penetration for surfacing to narrow beads with deep penetration for thick joints. Part of this versatility is derived from the use of ac arcs. The principles which favour the use of ac to minimize arc blow in single arc welding are often applied in multiple arc welding to create a favourable arc deflection. The current flowing in adjacent electrodes sets up interacting magnetic fields that can either reinforce or diminish each other. In the space between the arcs, these magnetic fields are used to produce forces that will deflect the arcs (and thus distribute the heat) in directions beneficial to the intended welding application. Various types of power sources and related equipment are designed and manufactured especially for multiple arc welding. These relatively sophisticated machines are intended for high production on long runs of repetitive-type applications. The following are typical SAW process configurations used in production welding today. They may be used for welding both carbon steel and low alloy steels within the limitations noted previously.

SINGLE ELECTRODE WELDING

SINGLE ELECTRODE WELDING is the most common of all SAW process configurations, using only one electrode and one power source. It is normally used with direct current electrode positive (DCEP) polarity, but may also be used with direct current electrode negative (DCEN) polarity when less penetration into the base metal is required. The process may be used in the semiautomatic mode where the welder manipulates the electrode, or in the machine mode. A single electrode is frequently used with special welding equipment for completing horizontal groove welds in large storage tanks and process vessels. The unit rides on the top of each ring as it is constructed and welds the circumferential joint below it. A special flux belt or other equipment is used to hold the flux in place against the shell ring. In addition, both sides of the joint (inside and outside) are usually welded simultaneously to reduce fabrication time.

NARROW GROOVE WELDING

A NARROW GROOVE configuration is often adopted for welding material 2 in. (50 mm) thick and greater, with a root opening between 1/2 and 1 in. (13 and 25 mm) wide at the bottom of the groove and a total included groove angle between 0 and 8 degrees. This process variation usually powers a single electrode with either DCEP or alternating current, depending on the type of electrode and flux being used. It is essential to use welding fluxes that have been developed for narrow groove welding because of the difficulty in removing slag. These fluxes have special characteristics for easier removal from the narrow groove.

MULTIPLE WIRE SYSTEMS

MULTIPLE WIRE SYSTEMS combine two or more welding wires feeding into the same puddle. The wires may be current- carrying electrodes or cold fillers. They may be supplied from single or multiple power sources. The power sources may be dc or ac or both. Multi wire welding systems not only increase weld metal deposition rates, but also improve operating flexibility and provide more efficient use of available weld metal. This increased control of metal deposition can also achieve higher welding speeds, up to five times those obtainable with a single wire.

Twin Electrode SAW Process

THIS WELDING CONFIGURATION uses two electrodes feeding into the same weld pool. The two electrodes are connected to a single power source and wire feeder, and are normally used with DCEP. Because two electrodes are melted, this mode offers increased deposition rates compared to single electrode submerged arc welding. The process is used in the machine or automatic welding mode and can be used for flat groove welds and horizontal fillet welding.

Tandem Arc SAW Process

THERE ARE TWO variations of two-electrode tandem arc SAW. One configuration uses a DCEP lead electrode and an alternating current trail electrode. The electrodes are separated 0.75 in. (19 mm) but are active in the same weld puddle. This process offers higher deposition rates compared to the single electrode SAW process, up to 40 lbs per hour when using larger diameter electrodes. This configuration is used in the machine or automatic modes for welding thicker materials, 1 in. (25.4 mm) and greater, in the flat welding position. It should be noted that additional ac trailing electrodes may be added to the configuration to increase deposition rates even more. The second configuration uses two ac power sources electrically connected. This configuration is called a Scott connection and the interaction of the magnetic fields of the two arcs result in a forward deflection of the trail arc. The forward deflection allows for greater welding speeds without undercutting the base metal.

WELD QUALITY

POROSITY PROBLEMS

SUBMERGED ARC DEPOSITED weld metal is usually clean and free of injurious porosity because of the excellent protection afforded by the blanket of molten slag. When porosity does occur, it may be found on the weld bead surface or beneath a sound surface. Various factors that may cause porosity are the following:

(1) Contaminants in the joint
(2) Electrode contamination
(3) Insufficient flux coverage
(4) Contaminants in the flux
(5) Entrapped flux at the bottom of the joint
(6) Segregation of constituents in the weld metal
(7) Excessive travel speed
(8) Slag residue from tack welds made with covered electrodes

As with other welding processes, the base metal and electrode must be clean and dry. High travel speeds and associated fast weld metal solidification do not provide time for gas to escape from the molten weld metal. The travel speed can be reduced, but other solutions should be investigated first to avoid higher welding costs. Porosity from covered electrode tack welds can be avoided by using electrodes that will not leave a porosity-causing residue.

CRACKING PROBLEMS

CRACKING OF WELDS in steel is usually associated with liquid metal cracking (centre bead cracking). This cause may be traced to the joint geometry, welding variables, or stresses at the point where the weld metal is solidifying. This problem can occur in both butt welds and in fillet welds, including grooves and fillet welds simultaneously welded from two sides.

One solution to this problem is to keep the depth of the weld bead less than or equal to the width of the face and etching a sample weld. To correct the problem, the welding variables or the joint geometry must be changed. To decrease the depth of penetration compared to the width of the face of the joint, the welding travel speed as well as the welding current can be reduced. Cracking in the weld metal or the heat-affected zone may be caused by diffusible hydrogen in the weld metal; the hydrogen may enter the molten weld pool from the following sources: flux, grease or dirt on the electrode or base metal, and hydrogen in the electrode or base metal. Cracking due to diffusible hydrogen in the weld metal is usually associated with low alloy steels and with increasing tensile and yield strengths. It sometimes can occur in carbon steels. There is always some hydrogen present in deposited weld metal, but it must be limited to relatively small amounts. As tensile strength increases, the amount of diffusible hydrogen that can be tolerated in the deposited weld decreases. Cracking due to excessive hydrogen in the weld is called delayed cracking, it usually occurs several hours, up to approximately 72 hours, after the weld has cooled to ambient temperature. Hydrogen will diffuse out of the base metal at elevated temperatures [above approximately 200°F (93”C) without resulting in cracking. It is at ambient temperatures that hydrogen accumulated at small defects in the weld metal or base metal results in cracking.

To keep the hydrogen content of the weld metal low:

(1) Remove moisture from the flux by baking in an oven (follow the manufacturer’s recommendations).
(2) Remove oil, grease, or dirt from the electrode and base material.
(3) Increase the work temperature to allow more hydrogen to escape during the welding operation. This may be done by continuing the “preheat” until the seam is completely welded, or by post heating the weld joint for several hours before letting it cool to ambient temperature.

CHAPTER 2
LITERATURE REVIEW

Different papers have been studied for this project. The purpose to study different papers to acquaint self with different work already done on submerged arc welding and to decide what new work can be done through this project.
Refer to paper titled **"Determination of submerged arc welding parameter using Taguchi analysis"** authored **Kumaran, Raja Dhas and K Gowthmann**. [13] The quality of weld in SAW is mainly influenced by independent variables such as welding current, arc voltage, welding speed and electrode stick out. The quality of engineering methods of Taguchi employing design of experiment provides an efficient and systematic to optimize design for performance, quality and cost. It is one of the most important statistical tools for designing high systems at reduced cost. The use of Taguchi method simplifies the optimization procedure for determining the optimal welding parameters in the SAW process. The quality engineering methods of Taguchi employing design of experiment (DOE) is one of the most important statistical tools for designing high quality systems at reduced cost. Taguchi methods provide an efficient and systematic way to optimize designs for performance, quality and cost. Optimization of process parameters is the key step in the Taguchi to achieve high quality without increasing cost. This is because optimization of process parameters can improve quality characteristics and the optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. Classical process parameter design is complex and not an easy task. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with a small number of experiments only.. Furthermore, Taguchi has created a transformation of the repetition data to another value, which is a measure of the variation present. The transformation is known as signal to noise (S/N) ratio. The S/N ratio consolidates several repetitions into one value, which reflects the amount of variation present. There are several S/N ratios available depending on the type of characteristics, lower is better, nominal is best or higher is better. The S/N ratio for each level of process parameters is compiled based on the S/N analysis. Regardless of the quality of the quality characteristics a large S/N corresponds to better quality characteristics. Therefore the optimal level of the process parameters is the level with the highest S/N ratio. A statistical analysis of variation (ANOVA) is performed to see which process parameters are statically significant. Economical layout of welding experiments is optimized by the Taguchi method on design of experiments. The results from ANOVA indicate that welding current and arc voltage are the significant welding parameters that affect the bead width. The mathematical model is built by SPSS package for bead width, bead reinforcement, depth of penetration and bead hardness. The output results from the predicted model are calculated for the corresponding input data. Measured values from the experiment and the predicted values from the multiple regression analysis. Experimentation was done according to Taguchi's design of experiment using the signal to noise ratio and the ANOVA technique the influence of each welding parameter are studied and the prediction of the bead geometry is done by building a mathematical model in SPSS. The proposed mathematical model is used to predict the SAW process parameters for any given welding conditions.

Refer to paper titled **"Multi-objective optimization of Submerged arc welding process"** authored by **Saurav Dutta Et. Al. [17].** In order to obtain an efficient joint, several process parameters of SAW need to be studied and precisely selected to improve weld quality. Many methodologies were proposed in the past research to address this issue. However, a good number of past work seeks to optimize SAW process parameters with a single response only. In practical situations, not only is the influence of process parameters and their interactive effects on output responses are to be critically examined but also an attempt is to be made to optimize more than one response, simultaneously. To this end, the present study considers four process control parameters viz. voltage (OCV), wire feed rate, and traverse speed and electrode stick-out. The selected weld quality characteristics related to features of bead geometry are depth of penetration, reinforcement and bead width. In the present reporting, an integrated approach capable of solving the simultaneous optimization of multi-quality responses in SAW was suggested. In the proposed approach, the responses were transformed into their individual desirability values by selecting appropriate desirability function. Assuming equal importance for all responses, these individual desirability values were aggregated to calculate the overall desirability values. Quadratic Response Surface Methodology (RSM) was applied to establish a mathematical model representing overall desirability as a function involving linear, quadratic and interaction effect of process control parameters. This model was optimized finally within the experimental domain using PSO (Particle Swarm Optimization) algorithm. A confirmatory test showed a satisfactory result. Submerged arc welding (SAW) is a multi-factor, multi objective metal joining technology in which several process control parameters interact in a complicated manner and influence differently on quality of the prepared weld. Weld quality depends on various features of bead geometry, mechanical-metallurgical characteristics of the weld as well as on weld chemistry. Moreover, the cumulative effect of combined aforesaid quality features determines the extent of joint strength that determines functional aspects if the weld is subjected to practical field of application. Therefore, preparation of a satisfactory good quality weld seems to be a challenging job. Complete knowledge regarding the mode of influence of the process control parameters and their interactions are to be exactly known prior to select an optimal process environment capable of producing desired quality weld. However, SAW optimization is a difficult task due to simultaneous fulfillment of multi-quality features which should be close to the desired target value at the optimal setting. In practice, it may happen that an improvement of one response may cause severe loss to another quality feature for a particular parametric combination. **Tay and Butler (1996) [20]** proposed an application of an integrated method using experimental designs and neural network technologies for modelling and optimizing a metal inert gas (MIG) welding process. **Correia et al. (2004) [21]** used Genetic Algorithm (GA) to decide near-optimal settings of a GMAW welding process. **Dongcheol et al. (2002) [22]** suggested the use of Genetic Algorithm and Response Surface Methodology (RSM) for determining optimal welding conditions. **Hsien-Yu Tseng (2006)** [23] proposed an integrated approach to address the welding economic design problem. The integrated approach applied general regression neural network (NN) to approximate the relationship between welding parameters (welding current, electrode force, welding time, and sheet thickness) and the failure load. An analytical formula was generated from the trained general regression neural network, and the mathematical model for the economic welding design was constructed. GA was then applied to resolve the mathematical model and to select the optimum welding parameters. These parameters were recommended for use to obtain the preferred welding quality at the least possible cost. **Zhao et al. (2006)** [24] focused on the performance –predicting problems in the spot welding of the body-galvanized steel sheets. Artificial Neural Networks (ANNs) were used to describe the mapping relationship between welding parameters and welding quality. After analysing the limitation that existed in standard back propagation (BP) networks, the original model was optimized based on a lots of experiments. A lot of experimental data about welding parameters and corresponding spot-weld quality were provided to the ANN for study. The results showed that the improved BP model can predict the influence of welding currents on nugget diameters, weld indentation and the shear loads ratio of spot welds. The forecasting precision was quite high satisfying the practical application value. **Pasandideh and Niaki (2006) [25]** presented a new methodology for solving multi-response statistical optimization problems. This methodology integrates desirability function and simulation approach with a genetic algorithm. The desirability function was used for modelling the multi-response statistical problem whereas the simulation approach generated required input data and finally the genetic algorithm was implemented to optimize the model. **Praga-Alejo et al. (2008) [26]** highlighted that the Neural Network (NN) with GA as a complement are good optimization tools.

The authors compared its performance with the RSM that is generally used in the optimization of the process, particularly in welding. Many designed experiments require the simultaneous optimization of multiple responses. The common trend to tackle such an optimization problem is to develop mathematical models of the responses. These indicate the entire process behaviour. The effect of process parameters on different responses can be analysed from the developed models. Multiple linear regression and Response Surface Methodology are two common tools available for developing the mathematical models of the responses as a function of process parameters. Depending on the requirement, each quality features/responses are optimized (maximized or minimized) to determine the optimal setting of the parameters. However, this method is applicable for the optimization of a single objective function. In a multi objective case, it is essential to convert these multiple objectives to an equivalent single objective function which has to be optimized finally. A common approach is to use a desirability function combined with an optimization algorithm to find the most desirable settings. In the desirability function approach, individual response desirability values are calculated depending on the target as well as prescribed tolerance limit of the response variables. Individual desirability values are then aggregated to calculate the overall desirability value. The optimal setting is one which can maximize the overall desirability. In doing so, a mathematical model is required for overall desirability. The model is then optimized finally. However, as the number of factors that affect the complexity of a multiple response problem increases, conventional optimization algorithms can fail to find the global optimum. For these situations, a common approach is to implement a heuristic search procedure like the GA and ANN or other optimization algorithms like Controlled Random Search (CRS) **Price, W. L. (1977)**. However, it has been found that GA was adapted many times by previous researchers; less effort was made on application of CRS and even PSO in optimizing features of submerged arc weld. In consideration of the above, the present study aims at evaluating a near optimal parameter setting for the optimization of bead geometry parameters of a submerged arc weld. The study proposes integrating RSM-based desirability function approach and a PSO algorithm for multi-response optimization of SAW. Bead geometry parameters of submerged arc weld on mild steel were selected as multi-objective responses and they were optimized to select the optimal process environment. Finally, the study concludes the effectiveness and application feasibility of the proposed integrated approach. Individual desirability values related to each of the quality parameters are calculated using the formula proposed by **Derringer and Suich in1980**.

There are three types of desirability function: Lower the- Better (LB), Higher-the-Better (HB) and Nominal the- Best (NB). In the present investigation, for reinforcement and bead width LB criteria; and for penetration depth HB criteria have been selected. This is because, the objective of the work was to minimize reinforcement and bead width (to reduce weld metal consumption) and to maximize penetration depth as strength of the welded joint directly depends on penetration depth. The NB criterion is generally selected in cases where responses have their fixed target value. The value of ˆy is expected to be the lower the better. When ˆy is less than a particular criteria value, a desirability value i d equal to 1; if ˆy exceeds a particular criteria value, the desirability value equals to 0. i d varies within the range 0 to 1. Here, min y denotes the lower tolerance limit of ˆy, the max y represents the upper tolerance limit of ˆy and r represents the desirability function index, which is to be assigned previously according to the consideration of the optimization solver. If the corresponding response is expected to be closer to the target; the index can be set to the larger value, otherwise a smaller value. The value of ˆy is expected to be the higher the better. When ˆy is exceeds a particular criterion value, according to the requirement, the desirability value i d is equals to 1; if ˆy is less than a particular criteria value, i.e. less than the acceptable limit, the desirability value is equals to 0. Here, min y denotes the lower tolerance limit of ˆy, the max y represents the upper tolerance limit of ˆy and r represents the desirability function index, which must have been previously according to the consideration of the optimization solver. If the corresponding response is expected to be closer to the target, the index can be set to the larger value, otherwise to a smaller value.

The Response Surface Methodology (RSM) is an efficient tool, which is widely applied for modelling the output response(s) of a process in terms of the important controllable variables and then finding the operating conditions that optimize the response. The method of least squares can be used to estimate the regression coefficients. Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by **Dr. Eberhart and Dr. Kennedy in 1995**, inspired by the social behaviour of bird-flocking or fish-schooling. PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles. Each particle keeps track of its coordinates in the problem space which is associated with the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called pbest. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the neighbours of the particle. This location is called lbest. When a particle takes all the population as its topological neighbours, the best value is a global best and is called gbest. The particle swarm optimization concept consists of, at each time step, changing the velocity of (accelerating) each particle toward its pbest and lbest locations (local version of PSO). Acceleration is weighted by a random term, with separate random numbers being generated for acceleration toward pbest and lbest locations. In the past several years, PSO has been successfully applied in many research and application areas. It has been demonstrated that PSO gets better results in a faster, cheaper way than other methods. Another reason that PSO is attractive is that there are few parameters to adjust. One version, with slight variations, works well in a wide variety of applications. Particle swarm optimization was used for approaches that can be used across a wide range of applications, as well as for specific applications focused on a specific requirement. Weld quality in SAW depends on features of bead geometry, mechanical-metallurgical characteristics of the weld as well as on weld chemistry. The weld quality improvement is treated as a multi-factor, multi-objective optimization problem. The practical application of SAW requires efficient optimization methodology because process parameters are expected to interact in a complex manner. Therefore, any optimization algorithm must seek to identify interaction effects of input factors and be incorporated in the course of an optimization procedure in a convenient way for developing an efficient methodology. The developed methodology based on RSM, desirability function and PSO algorithm can be applied in practice for continuous quality improvement and off-line quality control. The desirability Function approach converts each of the responses (objectives) into their individual desirability value. Corresponding to each objective, these individual desirability values are then accumulated to compute the overall/composite desirability function, which is to be optimized (maximized) finally. RSM has been applied to derive a mathematical model of overall desirability represented as a function of process control parameters. This mathematical model has been optimized within an experimental domain. Although the paper considers SAW, the procedure is quite generic and can be applied to any process where complex relations among input and output parameters are difficult to predict.

Prediction and optimization of weld bead value for the SAW using mathematical models was carried out by **Gunang** [27]. Prediction and control of weld bead geometry and shape relationship, in SAW of pipes was studied by **Murgan [28]**. The quality engineering methods of Taguchi employing design of experiment provide an efficient and systematic way to optimize design for performance, quality and cost. It is one of the most important statistical tools for designing high quality systems at reduced cost. The use of Taguchi method simplifies the optimization procedure for determining the optimal welding parameters in the SAW process. **Unal & Dean [29]** explain the approach of Taguchi to obtain design optimization in the manufacturing process. **Abdul Ghani Khan [15]** explores the friction welding parameters that influence the output, namely tensile strength such as friction pressure, forging pressure, friction time and forging time using Taguchi method. **Fujimati Ryoichi** proposed Taguchi method for the optimization of vibratory drill machining conditions for hard to cut material applied for aero engine engineering development. **Syrcos** used Taguchi method to optimize die casting process. **Chen** applied Taguchi method in the optimization of laser micro engraving of photo masks. **Tarng** used grey based Taguchi method to determine SAW process parameters in hardfacing. **Tang** used fuzzy logic in the Taguchi method for the optimization of SAW process. The finite element analysis of SAW process using finite element package ABACUS was done by **Wen**. **Yang** used linear regression technique to establish mathematical models for the prediction of SAW process parameters. **Luke** developed multiple regression models to predict the surface roughness in turning operation via accelerometer.

Refer to the paper titled **"A REVIEW ON EFFECT OF ARC WELDING PARAMETERS ON MECHANICAL BEHAVIOUR OF FERROUS METALS/ALLOYS"** authored by **Bipin Kumar Srivastava, S.P. Tewari and Jyoti Prakash. [19]** In any fabrication industry Submerged Arc Welding (SAW) is used as a heavy metal deposition rate welding process. The process is characterized by the use of granular flux blanket that covers the molten weld pool during operation. Protection through atmospheric contamination of the weld bead and slower cooling rate, achieved by this arrangement can enhance mechanical properties of the weldment. Selection of process parameters has great influence on the quality of a welded connection. Welding input parameters play a very significant role in determining the quality of a weld joint. The joint quality can be defined in terms of properties such as weld-bead geometry, mechanical properties, and distortion. Generally, all welding processes are used with the aim of obtaining a welded joint with the desired weld-bead parameters, excellent mechanical properties with minimum distortion. This paper presents the exhaustive research review on effect of arc welding parameter on quality of welds. The advantages of welding, as a joining process, include high joint efficiency, simple set up, flexibility and low fabrication costs. Because of its high reliability, deep penetration, smooth finish and high productivity, submerged arc welding (SAW) has become a natural choice in industries for fabrication. As it is well known, the residual stresses have a strong influence on weld deformation, fatigue strength, fracture toughness and buckling strength. Submerged arc welding (SAW) is widely recognized as a very productive welding process which over the years has developed from the single wire approach to more productive variants such as twin wire, and metal powder addition. Welding with cored wires continues the drive for increased productivity with the SAW process. Electrode stick out seems to be an important process parameter in submerged arc welding with its direct significant effects on bead quality as well as bead performance parameters like hardness and impact value, yield strength and ultimate tensile strength of the joint. Only by improving the microstructure of the HAZ can the properties of a welded joint be improved. For weld metals in submerged arc welding, it is necessary to obtain the optimal microstructure of acicular ferrite, because both the strength and toughness of weld metals strongly depend on the volume fraction of acicular ferrite. Because of its high reliability, deep penetration, smooth finish and high productivity, submerged arc welding (SAW) has become a natural choice in industries for fabrication. Mechanical properties of weld are influenced by the composition of the base metal and to a large extent by the weld bead geometry and shape relationship as well. In turn; the weld bead geometry is influenced by the direct and indirect welding parameters. In welding, not only the productivity, but also the bead geometry, is also important. Therefore, researchers have made extensive study in evaluating the effect of process control parameters on features of bead geometry, which indirectly influence mechanical strength of the weldment. The independent controllable process parameters affecting mechanical properties are voltage, current, stick out, wire feed rate, welding speed or travel, etc. Direct effect of electrode stick out on hardness, yield strength, Impact strength and UTS of the weldment. With increase in electrode stick out, hardness of the weldment increases, yield strength and impact value decreases, ultimate tensile strength of the joint initially decreases but thereafter increases provided welding current and voltage are kept at constant levels. In submerged arc welding (SAW), selecting appropriate values for process variables is essential in order to control heat-affected zone (HAZ) dimensions and get the required bead size and quality. Effects of process variables on HAZ parameters. The dimensions of the different HAZ layers increases with the increases in Voltage, wire feed rate, heat input but decreases with increases in welding speed. [19]

L.J. Yang, R.S. Chandel and M.J. Bibby [30] while investigating the effects of process variables on the bead width of submerged-arc weld deposits concluded that bead width is affected by the electrode polarity, electrode diameter, and electrode extension, welding current, welding voltage and welding speed. A positive electrode polarity, a large electrode diameter, a small electrode extension and a high welding voltage encourages a large bead width in most cases. The bead width is not affected significantly by the power source, constant voltage or constant current, when an acidic fused flux is used. However, when a basic fused flux is used, constant-current operation gives somewhat larger bead widths.

N. Murugan, R.S. Parmar and S.K. Sud, [31] while discussing the effect of submerged arc process variables on dilution and bead geometry in single wire surfacing said that the control parameters are required to be fed to the system according to some mathematical formulation to achieve the desired end results. The responses, namely, penetration, reinforcement, width and dilution as affected by open-circuit voltage, wire feed-rate, welding speed and nozzle-to-plate distance, have been investigated. The main and interaction effects of the control factors are shown in graphical form, which is more useful in selecting the process parameters to achieve the desired quality of the overlay.

B. Chan, R.S. Chandel, L.J. Yang and M.J. Bibby, while describing a software system for anticipating the size and shape of submerged arc welds told that the system consists of a specially designed interface for welding/materials/design/fabrication engineers, automated plotting for parametric studies, a simplified data base for storing/editing/retrieving frequently used welding parameters and pictorial graphics for displaying weld size and shape.

R.S. Chandel, H.P. Seow, F.L. Cheong [32] while predicting the effect of increasing deposition rate on the bead geometry of submerged arc welds concluded that for a given current (and heat input) the melting rate can be increased by using electrode negative, longer electrode extension, and smaller diameter electrodes. There are two other ways to increase the deposition rate without increasing the heat input, these being: (i) using a twin-arc mode and (ii) adding metal powders.

J.Tusek, M. Suban while dealing with, high-productivity multiple-wire submerged-arc welding and cladding with metal-powder addition, It was found that the use of metal powder will increase the deposition rate, and the welding arc efficiency and reduce the shielding-flux consumption. By using the metal-powder addition it is possible to alloy a weld or a cladding with optional chemical elements.

K. Y. Benyounis, A. G. Olabi [33] while dealing with optimization of different welding processes using statistical and numerical approaches, developed a mathematical relationship between the welding process input parameters and the output variables of the weld joint in order to determine the welding input parameters that lead to the desired weld quality.

Serdar Karaoğlu and Abdullah Seçgin [34] focus on the sensitivity analysis of parameters and fine tuning requirements of the parameters for optimum weld bead geometry. Changeable process parameters such as welding current, welding voltage and welding speed are used as design variables.

Effects of all three design parameters on the bead width and bead height show that even small changes in these parameters play an important role in the quality of welding operation. The results also reveal that the penetration is almost non-sensitive to the variations in voltage and speed.

Abhay Sharma, Navneet Arora, Bhanu K. Mishra,[19] while doing the analysis of Flux Consumption in Twin- Wire Submerged Arc Welding Process with unequal wire diameters concluded that flux accomplishes different functions including covering the arc, elimination of spatter and smoke, control of arc stability, governing the bead shape and influencing weld chemistry. Therefore, the flux consumption remains a function of process parameters and directly influences the productivity of the process. Unequal wire diameters lead to more stable magnetic file with less deflection, thus, results in lesser flux consumption.

P. Yongyutph ,K. Ghoshp, C. Guptaa, K. Patwardha and Satya Prakash [19] while studying the Influence of Macro/Microstructure on the Toughness of' all Weld multi pass Submerged Arc Welded C-Mn steel deposits concluded that Welding parameters have no effect on the chemical composition, the overall hardness and microstructure in the as-welded condition. Impact toughness decreased with the increase in welding current.

N.D. Pandey, A. Bharti and S.R. Gupta [35], while studying the effect of submerged arc welding parameters and fluxes on element transfer behaviour and weld-metal chemistry concluded that welding current and voltage have an appreciable influence on element transfer, as well as on weld composition. Weldments properties such as strength, toughness and solidification cracking behaviour are affected by chemical composition.

Juha Lukkari, OY, Helsinki, Shaun Studholme, Waltham Cross while discussing the submerged arc welding with cored wires summarized that deposition rates with cored wires at the same welding current are between 20 and 30% higher than with the equivalent diameter solid wire.

S. W. Wen, P. Hilton and D. C. J. Farrugia [36] , while doing Finite element modelling of a submerged arc welding process concluded that the geometrical distortion and residual stresses and strains caused by welding can be minimized through process optimization. It is therefore demonstrated that finite element analysis can be applied to better understand the SAW process and hence be a useful tool for future process development and control with the view of optimizing product properties.

Ana Ma. Paniagua-Mercado, Victor M. López-Hirata and Maribel L. Saucedo Muñoz while conducting study on influence of the chemical composition of flux on the microstructure and tensile properties of submerged-arc welds shows the importance of the selection for flux composition in order to improve the mechanical properties of steel welds.

P. Kanjilal, T.K. Pal and S.K. Majumdar, while studying the combined effect of flux and welding parameters on chemical composition and mechanical properties of submerged arc weld metal concluded that the results show that flux mixture related variables based on individual flux ingredients and welding parameters have individual as well as interaction effects on responses. Amongst welding parameters, polarity is found to be important for all responses under study.

Prasanta Kanjilal; Tapan Kumar Pal ;Sujit Kumar Majumdar [37] , studying the prediction of mechanical properties in submerged arc weld metal of C-Mn Steel, the prediction model has been developed for steel weld metal mechanical properties as a function of flux ingredients such as CaO, MgO, CaF2 and Al2O3 in submerged arc welding carried out at fixed welding parameters, and

concluded that Among the flux ingredients, MgO appears to be important on its own in influencing the mechanical properties.
De-liang Ren, Fu-ren Xiao, Peng Tian, Xu Wang and Bo Liao, [40] investigate the effects of welding wire composition and welding process on the weld metal toughness of submerged arc welded pipeline steel and concluded that the contents of alloying elements need to vary along with the welding heat input. The microstructures mainly consisting of acicular ferrite can be obtained in weld metals using the wires with a low carbon content and appropriate contents of Mn, Mo, Ti-B, Cu & Ni, resulting in the high low-temperature impact toughness of weld metals.

A Sharma, N Arora, B K Mishra [38] during study of statistical modelling of deposition rate in twin-wire submerged arc welding concluded that a significant amount of material loss may occur in the case of single- wire SAW. Material losses also depend on the polarity. In the case of Direct current electrode positive (DCEP), the loss is, on average, about 4 percent, whereas in the case of DCEN, the same is about 8 per cent.

Viano, D.M.; Ahmed, N.U.; Schumann, G.O.[39], while discussing the influence of heat input and travel speed on microstructure and mechanical properties of double tandem submerged arc high strength low alloy steel concluded that increase in heat input results in a decrease in cooling rate and the widths of the different zones of the HAZ increase steadily with the increase in heat input.

Ana Ma. Paniagua-Mercado; V ctor M. L pez-Hirata ; Arturo F. M ndez-S nchez ;Maribel L. Saucedo-Mu oz, while studying the effect of Active and Non active Fluxes on the Mechanical Properties and Microstructure in Submerged-Arc Welds of A-36 Steel Plates concluded that the non-active flux promoted the formation of pearlite and ferrite in the weld having the highest toughness and ductility. In contrast, the active fluxes with Cr and Mo promoted the formation of acicular ferrite and fine carbides in the welds showing the highest tensile strength and hardness.

Saurav Datta, Asish Bandyopadhyay and Pradip Kumar Pal has been applied Taguchi philosophy for obtaining optimal parametric combinations to achieve desired weld bead geometry and dimensions related to the heat-affected zone (HAZ), such as HAZ width, in submerged arc welding.

Keshav Prasad; D. K. Dwivedi, [7] describing the Microstructure and Tensile Properties of Submerged Arc Welded 1.25Cr-0.5Mo Steel Joints concluded that the increase in the heat input affects the proportions of different micro constituents both in the weld metal and heat affected zone (HAZ). It is observed that the tensile strength (UTS, YS) decreases with increase in heat input.

It is understood that several process control parameters in SAW influence bead geometry, microstructure as well as weld chemistry. Their combined effect is reflected on the mechanical properties of the weld in terms of weld quality as well as joint performance. The study of the various works, review that, the selection of the suitable process parameters are the primary means by which acceptable heat affected zone properties, optimized bead geometry and minimum residual stresses are created. Some researchers realized that the mechanical properties of weld are influenced by the composition of the base metal and to a large extent by the weld bead geometry and shape relationship as well. Some of the researchers observed that with increase in electrode stick out, hardness of the weldment increases, yield strength and impact value decreases, ultimate tensile strength of the joint initially decreases but thereafter increases provided welding current and voltage are kept at constant levels. While discussing the submerged arc welding with cored wires few researchers summarized that deposition rates with cored wires at the same welding current are between 20 and 30% higher than with the equivalent diameter solid wire. Some researchers studied the function of flux ingredients such as CaO, MgO, CaF2 and Al2O3 in submerged arc welding and concluded that among the flux ingredients, MgO appears to be important on its own in influencing the mechanical properties.

Refer to the paper titled **"Multiple objective optimization of submerged arc welding process parameter using Grey Based fuzzy logic"** authored by **Raja Dhas and Sateesh. [16]** In the present work, an attempt has been made to apply an efficient technique, Grey based fuzzy logic method to solve calculated multiple response optimization problem, in the field submerged arc welding. This approach converts the complex multiple objectives into a single grey fuzzy reasoning grade. Based on grey fuzzy reasoning grade, optimum levels of parameters (welding current, arc voltage & welding speed) are identified. Nine experiments based on an orthogonal array of Taguchi method were performed. Weld bead hardness and material deposition rate were selected as the quality targets. The optimal procedure is proposed and developed for solving the optimal multi response problem which applies the grey relational coefficient in each response and converts a grey fuzzy reasoning grade so as to evaluate multiple responses. The significant computations of parameters are estimated using Analysis of Variance (ANOVA). Confirmation test is conducted and reported. It is found that the welding current is the most significant controlled factor for the process according to the weighted sum grade of the maximum weld bead hardness and material deposition rate. This evaluation procedure can be used in intelligent decision making for a welding operation. The proposed and developed method has good accuracy and competency. The paper highlights a detailed methodology of the proposed scheme & its effectiveness. The proposed technique provides manufacturers to develop intelligent manufacturing system to achieve the highest level of automation. Welding is one of the major and principal manufacturing processes widely used because of its inherent properties of joining similar or dissimilar metals efficiently and economically. It is a multi- input multi output process since the output variables being closely coupled together, a great deal of time and cost are expender by trial and error methods to obtain optimal weld conditions through the combination of the various welding process parameters to produce consistent weld quality. SAW process is a widely used industrial arc welding process needs a better prediction & monitoring of its parameters. Process planners use different technique to estimate the influence of the welding parameters (welding current, arc voltage and welding speed) on bead hardness and deposition rate which are the most sought weld quality indicator in the SAW process. Weld is sound and economical if it achieves maximum deposition rate and hardness. Usually, the desired welding parameters are determined based on welder's experiences which are simple and inexpensive. However the obtained results may not guarantee optimal performance. It is necessary to select the most appropriate weld parameter settings to improve weld efficiency, process at low cost and produce high quality products. Weld parameters optimization through experimental methods & mathematical models has grown substantially over time to achieve a common goal of improving higher weld efficiency. The applications of Taguchi's method optimize the performance characteristics through the setting of process parameters and reduce the sensitivity of the system performance to sources of variation and have become a powerful design of experiments method. Traditional Taguchi method can solve single and simple objective problem of. But in the real world engineering application most of the problems are multi objective. It is cumbersome to optimize simultaneously objectives in complex process by single objective method and engineering judgement is primarily used to resolve such complication problems. An engineering judgement often increases the degree of uncertainty during efficient decision making process. Hence solving multiple objectives problem needs attention. Grey relational analysis theory initiated by Deng makes use of this technique to handle uncertain systematic problem with only partial known information. Grey relational analysis theory is adopted for solving the complicated interrelationships among the multiple objectives in various fields of manufacturing. The theory of fuzzy logic originated by **Zadal** has been proven to be useful for dealing with uncertain & vague information.

The definition of objectives contains certain degree of uncertainty with vagueness. Hence, the fuzzy logic is applied to establish the optimal setting of parameter for multiple objectives. This method is applied to optimize the parameters of electric discharge machining. The grey based fuzzy logic approach combines the advantage of both the methods. The objectives in grey methods such as lower the better, higher the better and nominal the better contains certain degree of uncertainty and vagueness which is overcome by fuzzy logic. This method was successfully applied to optimize multiple objectives of complicated problems in machining parameter optimization, optimize parameter in light guide plate printing process and optimize parameters in CNC turning process. Fuzzy bead desirability function approach was used to optimize of bead geometry of submerged arc weld. In this study, the effect of weld parameters on bead hardness and deposition rate are reported using grey based fuzzy logic. The significant contribution of each cutting parameters to the multiple objectives are calculated using ANOVA analysis. The proposed approach combines the grey relational analysis with fuzzy logic in order to determine the process parameter with optimal performance characteristics. Grey relational analysis is used to solve complicated interrelationship among the multiple performance characteristics problems effectively. In grey relational analysis, system has a level of information between black and white. In other words, in a grey system some information is known and some is unknown. In a white system, the relationships among factors in the system are certain; in a grey system, the relationship among factors in the system is uncertain. Data pre-processing is normally required since the range and unit in one data sequence may differ from the other. Data pre- processing is also necessary when the sequence scatter range is too large or when the directions of the target in the sequences are different. Data pre- processing is a means of transferring the original sequence to a comparable sequence. Depending on the characteristics of a data sequence, there are various methodologies of data pre- processing available for the grey relational analysis. Fuzzy logic is a way to represent information that mimics human reasoning about information. One most interesting fact about fuzzy logic is that fuzzy inferences make it possible to deducible a proposition similar to the consequence from same proposition that is similar to antecedent. It is an effective mathematical model of resolving problems in a simple way which contain the uncertain and huge information. In fuzzy logic analysis, the fuzzifier uses membership functions to fuzzify the grey relational coefficient. The fuzzy inference engine then performs a fuzzy inference on fuzzy rules in order to generate a fuzzy value. Finally, the defuzzifier converts the fuzzy value into a grey fuzzy reasoning grade. The effect of welding parameters and the optimum welding parameters for a SAW process on the multiple performance characteristics are systematically investigated by grey relational analysis and fuzzy logic with orthogonal array. The following conclusions are made:

1) Approach of grey based fuzzy logic analysis is a productive method for optimizing the multi-objective problems predicting the deposition rate and hardness in welding of mild steel.
2) From ANOVA computation, it is revealed that welding current and welding voltage are predominant factor which affect the welding of mild steel.
3) Through the optimum procedure of grey fuzzy logic with orthogonal array, the level constitution of optimal welding parameters are acquired and verified in confirmation test. Final results verify that the multiple objectives are improved simultaneously through the approach. [16]

Refer to the paper titled **“Optimization of submerged arc welding parameters in hard facing”** authored by **Tsai, Tarng and Tseng**. [14] In this paper, a feed Jbrward neural network is used to model
submerged are' welding (SAW) processes in hard facing. The relationships between process parameters (arc current, arc voltage, welding speed, electrode protrusion, and preheat temperature) and welding performance (deposition rate, hardness, and dilution) are established, based on the neural network. A simulated annealing (SA) optimisation algorithm with a performance index is then applied to the neural network for searching the optimal process parameters. Experimental results

have shown that welding performance can be enhanced by using this new approach. It has been reported that continuous casting of steel has become the most widely used manufacturing process in the steel industry for the last two decades. The dramatic manufacturing change in the steel industry is mainly due to the high productivity of continuous casting. However, it has also been found that steel mill rolls are easily damaged in the continuous casting of steel because of the harsh working conditions. Purchasing and reinstalling a new steel mill roll are very costly in terms of time and money. Therefore, a hard facing technique has been proposed to repair damaged steel mill rolls.

Basically, hard facing of steel mill rolls is the application of a hard, wear-resistant material to the surface of steel mill rolls by welding. To obtain a high-quality weld deposit at a very economical price, submerged arc welding (SAW) processes are often adopted for hard facing of steel mill rolls in the steel industry. However, in the past, a lack of knowledge for the selection of process parameters in hard facing has contributed too many failures in the repair of damaged steel mill rolls. Neural networks are a highly flexible modelling tool with an ability to learn the mapping between input variables and output feature spaces. It has been shown that neural networks are superior to traditional approaches in modelling manufacturing processes. Therefore, neural networks are considered in this paper for modelling the SAW process in hard facing. Based on the developed neural network, the effect of the process parameters (arc current, arc voltage, welding speed, electrode protrusion, and preheat temperature) on the welding performance (deposition rate, hardness, and dilution) can be obtained. Once the SAW process model is constructed, an appropriate optimisation algorithm with a performance index is then carried out for searching the optimal welding parameters. In this paper, a sound optimisation method of simulated annealing (SA) is adopted. Traditionally, the annealing process, used in metal working, involves heating the metal to a high temperature and then letting it gradually cool down to reach a minimum energy state. The SA algorithm is a simulation of the annealing process for minimising the performance index. It has been shown that SA can provide an effective way to escape from a local optimum and to approach a global optimum. As a result, the SA algorithm has emerged as a general tool for optimisation of arbitrary functions and has been successfully applied in VLSI layout generation, noise filtering in image processing, discrete tolerance design, etc. In what follows, a description of the SAW process in hard facing is given first. The experimental details of using a neural network in modelling of the SAW process are then described. The theory of SA is briefly introduced and applied to searching the optimal process parameters in SAW. The submerged arc welding process as an effective reclamation process permits repeated extension of the service life of worn rolls and reduced capital cost for stocks of spares. The use of relatively low-cost base metals for the steel mill rolls combined with martensitic stainless steel hard facing deposit may reduce capital equipment costs. Saving on both downtime and maintenance costs may be obtained, owing to the service life improvements compared with non-hard faced mill rolls. The variations in welding parameters, such as arc current, arc voltage, welding speed, electrode protrusions, and preheat temperature, may mutually influence the dilution behaviour of the weldment and subsequently affect the microstructure of the hard facing layer. The hardness of the weld deposit depends directly on the microstructure which is very important in determining the performance such as wear resistance and thermal fatigue resistance. In most circumstances, economic criteria determine the acceptance for hard facing. In practical situations the deposition rate is 'most concerned. It is an important variable in any evaluation of the economic viability of a particular process. In this study, a martensitic stainless steel hard facing layer was deposited by the SAW process on the surface of 30 mm thick mild steel plates having dimensions of 120 mm× 80 ram. The chemical compositions of the mild steel plates and the stainless steel flux cored electrode of 4 mm diameter used in this work are shown in Table I. The electrode was connected to the positive terminal of a Lincoln DC-1500 power source with a NA-3A controller. The flux was baked for 2 h at 523 K before use. The base metal preheat was carried out by an oxyacetylene gas torch with heating nozzle, and measured using a temperature indicator with 1% accuracy of rated temperature. Forty-two hard facing experiments were carded out by varying the welding current in the range of 450- 550 A, the welding voltage in the range of 28-30 V, the welding speed in the range of 3040 cm min -~, the electrode protrusion in the range of 19-25 ram, and the preheat temperature in the range of 185-215 K. In the experiments, a total of 4 layers with 4 passes on each layer were deposited on each plate. The length of deposit in each pass was about 100 mm. The hard facing performance is evaluated by the following measurements. First, the deposition rate was simply calculated by multiplying the cross-section area of weld deposit above the surface of the base metal by the welding speed and the density of steel. Secondly, 10 Rockwell C hardness measurements were taken on the surface of the weld deposit along the longitudinal direction at every 10ram for each hard facing deposit. These measurements were averaged for use in the following analysis. Thirdly, the deposition dilution was measured after a weld cross-section was polished and etched. The deposition dilution is defined by the ratio of the area of fused base metal to the total area of the weld and is usually expressed as a percentage, The welding performance with the corresponding process parameters. A feed forward neural network is adopted here to model the SAW process. The feed forward neural network is composed of many interconnected artificial neurons that are often grouped into input, hidden, and output layers. The artificial neuron evaluates the inputs and determines the strength of each through its weighting factor calculated by the back-propagation learning algorithm. The weighted inputs are summed to determine the output of the neuron using a sigmoidal transfer function. The output of the neuron is then transmitted along the weighted outgoing connections to serve as an input to subsequent neurons. In this study, the neurons of the input layer are used to receive the process parameters, that is, arc voltage, arc current, welding speed, electrode protrusion, and preheat temperature. The neurons of the output layer are used to send out the welding performance, that is, deposition rate, hardness, and dilution. As a result, there are 5 input variables and 3 output variables in the neural network. The number of neurons in the hidden layer is determined by trial-and-error experimentation. To properly establish the input and output relationships of the SAW process with the neural network, finite discrete samples of experimental data listed are used to train the neural network. During the training process, several neural network configurations are studied. The number of iterations during the training process using various neural network configurations. It is found that two hidden layers can provide better convergence in modelling the SAW process. The best neural network is the network with the fastest convergence speed. Therefore, a feed forward neural network with a 5-11-8-3 type is adopted here to associate the process parameters with the welding performance. The corresponding root mean square (r.m.s.) error between the desired and predicted outputs versus the number of iterations in the training process. In condensed matter physics, annealing is referred to as a physical process that is used to reconstruct the crystal structure of a solid with a low energy state. A solid in a heat bath is first heated up to a temperature above the melting point of the solid. At this temperature, all particles of the solid are in a violent random motion. The temperature of the heat bath is then slowly reduced. All particles of the solid rearrange themselves and tend toward a low energy state. If the cooling of the particle is carried out sufficiently slowly, lower and lower energy states are obtained until the lowest energy state is reached. In 1953, Metropolis et al. proposed a criterion used to simulate the cooling of a solid for reaching a new energy state. Based on the Metropolis criterion, an optimisation algorithm called "simulated annealing" was developed by **Kirkpatrick et al**,. It has been shown that the simulated annealing algorithm possesses several advantages in comparison with traditional optimisation algorithms. First, the simulated annealing algorithm does not need to calculate the gradient descent that is required for most traditional optimisation algorithms. This means that the simulated annealing algorithm can be applied to all kinds of objective and constraint functions. Next, the simulated annealing algorithm with probabilistic hill climbing characteristics can find the global minimum more efficiently instead of trapping in a local minimum where the objective function has surrounding barriers. Furthermore, the simulated annealing search is independent of the initial conditions. In this paper, the simulated annealing algorithm is used to search the optimal process parameters. The paper describes a neural network approach for modelling and optimisation of the SAW process. A feed forward neural network is used to construct the SAW process model. Based on this model, the complicated relationships between the process parameters and welding performance can be obtained. A global optimisation algorithm, simulated annealing (SA), is then applied to this network for solving the optimal process parameters based on an objective function. Therefore, the efficiency of determining optimal SAW process parameters in hard facing of steel mill rolls can be dramatically improved by using this approach. [14]

Refer to the paper **“Effect of welding parameters on bead geometry and flux consumption”** authored by **Bipin Kumar and S.P. Tewari**. [19] In the present study, an attempt has been made to investigate the effect of open circuit voltage, welding current, welding speed and basicity index on bead geometry and shape relationships (bead width, weld penetration and height of reinforcement, weld penetration shape factor and weld reinforcement form factor), using developed fluxes, through experiments based on design matrix. The analysis of variance (ANOVA) technique has been adopted to check the level and degree of the direct or interactive effect of welding current, voltage, welding speed and flux basicity index on features of bead geometry and shape relationship. Response surface methodology has been applied to derive mathematical models that correspond to the welding phenomena using developed fluxes. Predictive equations have been used to represent graphically the effects of process parameters on various responses. No work so far has been performed which considers the four important process parameter used in this study using fluxes developed from waste flux dust. Control of the operating variables in submerged arc welding is essential if high production rates and the welds of good quality are to be obtained. The following are the important variables:

Welding amperage

Welding current is the most influential parameter because it affects bead shape, controls the rate at which electrode is melted and therefore also controls the deposition rate, heat affected zone, the depth of penetration, and the amount of base metal melted. Penetration and reinforcement increase with the increase in welding current. If the current is too high at a given welding speed, the depth of fusion or penetration will also be too high so that the resulting weld may tend to melt through the metal being joined. High current also leads to waste of electrodes in the form of excessive reinforcement and produces digging arc and undercut. This over welding increases weld shrinkage and causes greater distortion. Bead width increases with welding current until a critical value is reached and then starts decreasing if the polarity used is DCEP. When DCEN polarity is employed bead width increases with the increase in current for entire range **(McGlone, 1982)**. For the same flux, heat affected zone also increases with the increase in welding current **(Kaushal and Gupta, 1988).** If the current is too low, inadequate penetration or incomplete fusion may result. Too low current also leads to unstable arc, inadequate penetration and overlapping.

Welding voltage

Welding voltage varies with the length of the arc between the electrode and molten weld metal. With the increase in arc length, the arc voltage increases because lengthening of the arc exposes more of the arc column to the cool boundary of the arc. Also, the arc column continuously loses the charge carriers by radial migration to the cool boundary of the arc and therefore, imposing a greater requirement of potential for maintaining appropriate charge carriers between the electrode and weld plate **(Weiman, 1981)**. The voltage principally determines the shape of the weld bead cross section and its external appearance. Increasing the welding voltage with constant current and welding speed produces flatter, wider, less penetrated weld beads and tends to reduce the porosity caused by rust or scale on steel. Higher voltage also bridges an excessive root opening when fit-up is poor. Increase in arc voltage also increases the size of droplets and hence decreases the number of droplets. The time of the movement of droplet transfer also increases. Further increase in voltage increases the possibility of breaking the arc and disrupting the normal welding process. Increase in voltage also enhances flux consumption which increases pick up or loss of the alloying elements and therefore affects the mechanical and metallurgical properties of the weld metal **(Gupta and Gupta, 1988; Pandey and Mohan, 2003)**. Excessively high voltage produces a wide bead shape that is subject to cracking, increases undercut and creates difficulty in removing slag. Lowering the voltage produces stiffer arc, which improves penetration in a deep weld groove and resists arc blow. An excessively low voltage produces a narrow bead and causes difficult slag removal along the bead edges.

Welding speed

Welding speed is the linear rate at which an arc is moved along the weld joint. With any combination of welding voltage and welding current, the effect of changing the welding speed confirms to a general pattern. If the welding speed is increased, power or heat input per unit length of weld is decreased and less filler metal is applied per unit length of the weld, resulting in less weld reinforcement. Thus, the weld bead becomes smaller. Weld penetration is affected more by welding speed than any variable other than current. This is true except for excessively slow speeds when the molten weld pool is beneath the welding electrode. Then the penetrating force of the arc is cushioned by the molten pool. Excessive speed any cause undercutting, porosity, arc blow, uneven bead shape, cracking and higher slag inclusion in the weld metal. Higher welding speed results in less heat affected zone and finer grains **(Aksoy et al.1999).** Within limits, welding speed can be adjusted to control weld size and penetration. Relatively slow welding speed provides time for gases to escape from the molten metal, thus reducing porosity. An excessive slow speed produces a convex bead shape which is subject to cracking and excessive arc exposure which is uncomfortable for the operator. Too low welding speed may also result in a large molten pool that flows around the arc, resulting in rough bead, slag inclusions and burn through of the weld plate. **Jackson and Shrubsa (1953)** reported that the welding speed did not affect the metal deposition rate significantly.

Electrode size

Electrode size affects the weld bead shape and the depth of penetration at fixed current. Electrode size also influences the deposition rate. At any given current, a small diameter electrode will have a higher current density and a higher deposition rate than a larger electrode. However, a larger diameter electrode can carry more current than a smaller electrode, and produce a higher deposition rate at higher amperage. For the same values of current, arc voltage and welding speed, an increase in electrode diameter results in a slight increase in the spread of the bead **(Cornu, 1988)**.

Electrode work angle The electrode may be held perpendicular to the workpiece or, tilted forward or backward with respect to the weld pool. As the arc stream tends to align itself along the axis of the electrode, the weld pool shape is different in each case, and so is the shape of the weld bead. It is observed that in forehand welding, molten metal flows under the arc, the depth of penetration and reinforcement are reduced while the width of the weld increases, whereas in backhand welding the pressure of the arc scoops the molten metal from beneath the arc, the depth of penetration and height of reinforcement increases while the width of the weld is reduced **(Nadkarni, 1988).** The electrode in perpendicular position results in bead geometry in between those obtained in the above two cases.

Electrode stick-out and melting rate The distance between the current pick-up tip and the arc root, called electrode stick out, has a considerable effect on the weld bead geometry. Normally the distance between the contact tip and the work is 25-40 mm. The increase in melting rate of the electrode as a result of increase in electrode stick-out is proportionate to the product of current density and stick-out. **Chandel et al. (1997)** reported that the melting rate of the electrode increased with the increase in the stick out. This effect is particularly more significant with smaller diameter electrode since electrode heating is caused by the electrode electric resistance, which increases with the decrease in the electrode diameter. The depth of penetration decreases with the increase in electrode stick-out. This factor needs to be given due consideration where deeper penetration is required. **Gunaraj and Murugan (1999)** reported that heat affected zone decreased with the increase in stick- out. **Janez (2000)** reported that a mutual influence of the arcs was quite strong and consequently melting rate was high in twin-wire welding. He further reported that arc energy melted more filler material per wire in twin-wire welding than in single-wire welding and with the same welding parameters; this required higher wire feed speed in twin-wire welding.

Depth of flux The depth of the layer of the granular flux influences the appearance and soundness of the finished weld as well as welding action. If the granular flux layer is too shallow, the arc will not be entirely submerged in flux. Flashing and spattering will occur. Apart from injurious to the eyes of the operator, this may lead to poor appearance of weld and it may also be porous. If the flux layer is too thick, the arc will be too confined and a rough ropelike appearing weld will result and the weld bead may be narrow and humped. The gases generated during welding may not be able to escape, and the surface of the molten weld metal becomes irregularly distorted. Optimum depth of flux can be established by slowly increasing the flow of flux until the welding arc is submerged and flashing no longer occurs. The gases will then puff up quietly around the electrode, sometimes igniting.

Polarity

The amount of heat generated at the electrode and work piece, deposition rate, bead geometry and mechanical properties are affected by polarity. The change in polarity from DCEP to DCEN changes the amount of heat generated at electrode and the work piece and, hence the metal depositing rate, weld bead geometry and mechanical properties of the weld metal **(Robinson, 1983)**. **Little (1976)** observed that the two third of the total heat was generated at the positive electrode and the one third of the total heat was generated at the negative electrode. It has been reported by **Renwick et al. (1976)** that DCEN polarity produced higher deposition rate and reinforcement than with DCEP polarity in submerged arc welding. **Ghosh et al. (1991)** observed high yield strength, ultimate tensile strength and hardness of the weld metal with DCEN polarity as compared to DCEP polarity.

Flux basicity index Flux basicity index also influences the penetration **(Gupta and Gupta, 1988)**. In general higher penetration 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. **Patchett and Dancy (1980)** reported that the penetration increased with the increase in slag viscosity and surface tension. They also observed that an increase in viscosity, arc stability and surface tension resulted in deeper penetration.

Weld Bead Shape The weld bead shape is an indication of bead geometry which affects the load carrying capacity of the weldments **(Baach et al., 1981., Samiti, 1986)** and number of passes needed to fill the groove of a joint. The bead geometry is specified by bead width, reinforcement, penetration, penetration shape factor and reinforcement form factor.

Weld 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. Weld bead width is directly proportional to arc current, welding voltage and electrode diameter and indirectly proportional to the welding speed. The bead width increases with an increase in electrode diameter **(McGlone, 1982)**. **Gupta and Arora (1991)** observed that bead width increased with an increase in current until it reaches a critical value and then it decreases with an increase in welding current. **Yang et al. (1992)** investigated that the bead width was not affected significantly by the types of power source (constant voltage or constant current) when an acidic fused flux was used. However, using a basic fused flux with constant current operation showed somewhat larger bead width than with welds laid using acidic fused flux.

Penetration

Weld bead penetration is the maximum distance between the base plate top surface and depth to which the fusion has taken place. The more the penetration, the less is the number of welding passes required to fill the weld joint which consequently results in higher production rate. It is observed that the penetration is influenced by welding current, polarity, arc travel speed, electrode stick-out, basicity index and physical properties of the flux. **McGlone (1982**) observed that penetration was directly proportional to welding current. He also observed that the deepest penetration was achieved when DCEP polarity was used and the least with DCEN polarity. He further investigated that the penetration was indirectly proportional to welding speed and electrode diameter. Penetration decreases with the increase in welding speed because the time during which the arc force is allowed to penetrate into the material‟s surface decreases. The penetration decreases with the increase in electrode diameter due to decrease in current density **(Cornu, 1988). Chandel et al. (1987)** reported that the penetration increased with the decrease in electrode extension and included angle of the joint. **Caddle (1967)** reported that the penetration increased with a decrease in thermal conductivity of the weld metal.

Reinforcement Reinforcement is the maximum distance between the base metal level and the top point of the deposited metal. Reinforcement is the crown height of the weld bead from the base plate. It affects the strength of the weld joint and welding wire consumption rate. It increases with the increase in welding wire feed rate irrespective of the welding current and the type of polarity employed **(Gunaraj and Murugan 1999).** It is indirectly proportional to welding voltage, welding speed and electrode diameter. The reinforcement is more with DCEN polarity and less with DCEP polarity. Increase of reinforcement with an increase of welding filler wire feed rate is mainly due to the larger amount of metal deposited per unit length. The decrease of reinforcement with the increase in voltage is due to increase in weld bead width.

Weld penetration shape factor (WPSF) and weld reinforcement form factor (WRFF)

WPSF and WRFF are also called as coefficients of internal shape and external shape respectively. The ratio of bead width to penetration and bead width to reinforcement are termed as Weld Penetration Shape Factor (WPSF) and Weld Reinforcement Form Factor (WRFF) respectively. The smoothness of the weld increases with the increase in WRFF **(Cornu, 1988). Mandotov (1969) and Srihari (1992)** reported that WPSF and WRFF increased with an increase in voltage.

Flux Consumption

Flux consumption influences the economic aspects of welding and chemical composition of the weld metal. Flux consumption depends upon the welding parameters such as welding current, arc voltage, welding speed, polarity and type of flux. Flux consumption increases with the increase in arc voltage and decrease in current. The electrode extension has no significant effect on flux consumption **(Gupta and Gupta, 1988).** Agglomerated fluxes have low flux consumption as compared to fused fluxes **(Vishvanath, 1982).**

PROBLEM STATEMENT

After studying lots of technical papers on Submerged Arc Welding, the aim of the project has been developed. It has been decided to do project on the topic “Determination of SAW process parameters using Design of Experiments and Regression Analysis”. Design of experiment is done using five levels of arc voltage, welding current, welding speed and electrode stick out and parameters like width, reinforcement and depth of penetration have been calculated. We can predict these parameters i.e. width, reinforcement and depth of penetration using regression modelling. Regression modelling gives the equation for width, reinforcement and depth of penetration and these equations are dependent on arc voltage, welding current, welding speed and electrode stick out. On putting different values of arc voltage, welding current, welding speed and electrode stick out in the equations of width, reinforcement and depth of penetration, values of parameters can be predicted. Regression modelling can be done linearly and non- linearly. Definitely for non- linear modelling, prediction would be more accurate. These predictions are very important as optimization of welding can be done efficiently and effectively through these predictions.

CHAPTER 3
EXPERIMENTAL PROCEDURE

INTRODUCTION

Here, I use application of Design of Experiment and regression analysis to determine the optimal process parameters for Submerged Arc Welding (SAW). The planned experiments are conducted in the semi-automatic submerged arc welding machine and the signals to noise ratios are computed to determine the optimum parameters. Multiple regression analysis (MRA) is conducted using statistical software and the mathematical model is built to predict the bead geometry for any given welding conditions. The quality of weld in SAW is mainly influenced by independent variable such as welding current, arc voltage, welding speed and electrode stick out.

Submerged Arc Welding

SAW involves formation of an arc between a continuously feed bare wire electrode and the work piece. The process uses a flux to generate protective gas and slag, and also helps to control the composition of the deposited metal by providing alloying elements to the weld pool. Prior to welding a thin layer of flux powder is placed on the work piece surface. The arc moves along the joint line with the arc fully submerged in flux. As the arc is completely covered by the flux layer, heat loss is minimum. This provides a thermal efficiency as high as 95%. It produces no visible arc light, welding is spatter free and there is no need for fume extraction. The flux, apart from shielding the arc and the molten pool from atmosphere contamination, plays the following role:

a) The stability of arc is dependent on the flux.
b) Chemical and thus the mechanical properties of the weld metal can be controlled by flux.
c) The quality of the weld may be affected by the quality and quantity of flux used over the arc.

DESIGN OF EXPERIMENTS

Design of experiments (DOE) or experimental design is the design of any information-gathering exercises where variation is present, whether under the full control of the experimenter or not. However, in statistics, these terms are usually used for controlled experiments. Formal planned experimentation is often used in evaluating physical objects, chemical formulations, structures, components, and materials. Other types of study, and their design, are discussed in the articles on opinion polls and statistical surveys (which are types of observational study), natural experiments and quasi-experiments (for example, quasi-experimental design). In the design of experiments, the experimenter is often interested in the effect of some process or intervention (the "treatment") on some objects (the "experimental units"), which may be people, parts of people, groups of people, plants, animals, etc. Design of experiments is thus a discipline that has very broad application across all the natural and social sciences and engineering.

In an experiment, we deliberately change one or more process variables (or factors) in order to observe the effect the changes have on one or more response variables. The (statistical) design of experiments (DOE) is an efficient procedure for planning experiments so that the data obtained can be analysed to yield valid and objective conclusions.

DOE begins with determining the objectives of an experiment and selecting the process factors for the study. An Experimental Design is the laying out of a detailed experimental plan in advance of doing the experiment. Well-chosen experimental designs maximize the amount of "information" that can be obtained for a given amount of experimental effort.

Design of experiments, or DOE, is a practical and ubiquitous approach for exploring multifactor opportunity spaces. Methodical experimentation has many applications for efficient and effective information gathering. To reveal or model relationships between an input or factor and an output or response, the best approach is to deliberately change the former and see whether the latter changes, too. Actively manipulating factors according to a pre-specified design is the best way to gain useful, new understanding.

However, whenever there is more than one factor – that is, in almost all real-world situations – a design that changes just one factor at a time is inefficient. To properly uncover how factors jointly affect the response, you need to use design of experiments (DOE).

In addition to a complete library of tried and tested classical DOE designs, DOE also offers an innovative custom design capability that tailors your design to answer specific questions without wasting precious resources. Once the data has been collected, DOE streamlines the analysis and model building so you can easily see the pattern of response, identify active factors and optimize responses.

MATERIALS AND EQUIPMENT USED IN EXPERIMENT

The experiment was conducted at welding laboratory of DTU, Delhi with the semi-automatic SAW equipment with a constant voltage, rectifier type power source with a 1200 Amp capacity was used to join the mild steel plate of size 200 m.m. (Length) X 75 m.m. (Width) X 10 m.m. (Height). Copper coated electrode, 3.15 m.m. diameter of coil from ESAB brand and basic fluoride type granular flux was used. Samples were cut from the slab and were polished, etched and the bead geometries were measured.

Fig. 18: Welding samples

SOFTWARES USED

1. DESIGN EXPERT 8.0.7.1
2. XLSTAT 2012

EXPERIMENT DESIGN

PROCESS PARAMETER LEVEL

The operating variable of SAW are welding current, arc voltage, welding speed, electrode extension, type of flux, width and depth of flux layers and polarity and current type (AC or DC) Welding current directly influence the depth of penetration and the extend of base metal fusion. The welding arc voltage has a direct influence on the shape of weld bead and external bead appearance. At a given current, the weld bead shape and the depth of penetration affected by electrode diameter. In the present study, I took five levels of the four process parameters i.e. arc voltage, welding current, welding speed and electrode stick out was considered as shown in Table 2. In this study, orthogonal array was used. The experimental layout for the welding process parameters using the orthogonal array and the experimental result for the weld bead geometry using the orthogonal array are shown in Table 3.

Table 2: Welding Parameters and their level

Symbol	Welding parameter	Level 1	Level 2	Level 3	Level 4	Level 5
A	Welding current, Amp	330	350	370	390	410
B	Arc Voltage, Volts	19	21	23	25	27
C	Welding speed, mm/min	380	400	420	440	460
D	Electrode Stick out, m.m.	18	20	22	24	26

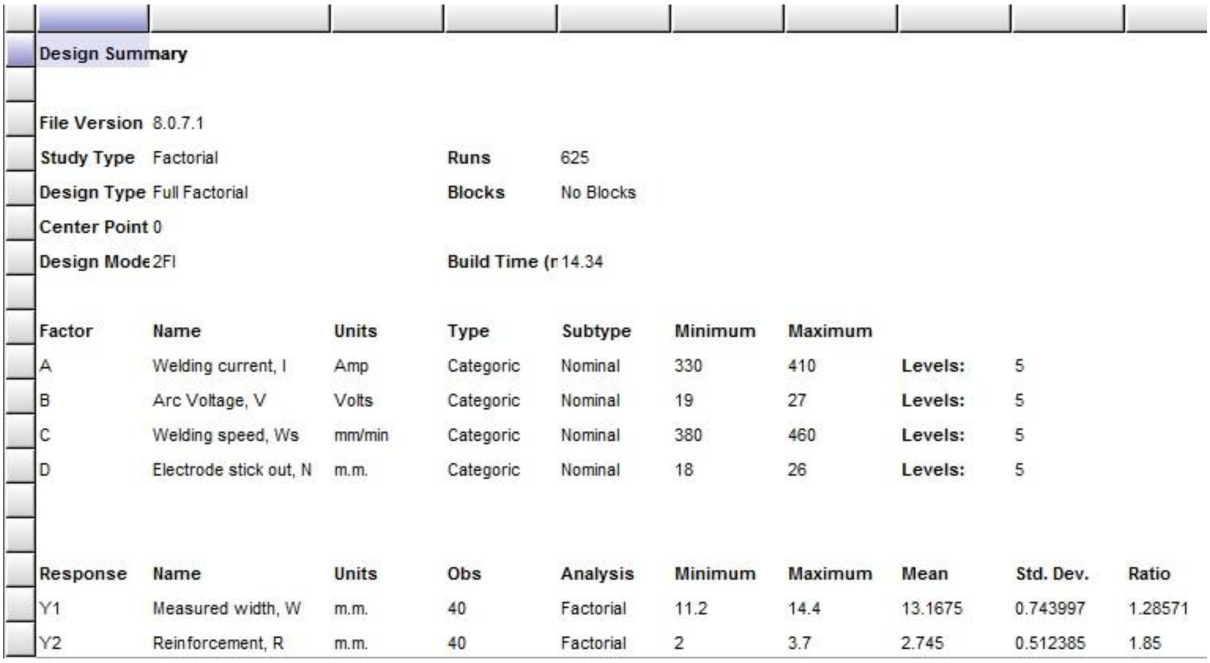
Table 3: Design of experiment & data related to bead geometry parameters

Trail No	I, Welding current	V, Arc Voltage	Ws, Welding Speed	N, Electrode stick out	W, Measured Width, m.m.	R, Reinforcement	Depth of penetration, P
1	1	1	1	1	10	2	3.2
2	1	1	1	2	10.2	2.2	3.4
3	1	2	3	1	10.5	3	3
4	1	2	2	3	10.2	2.4	3
5	2	1	3	2	10.5	2.2	3.1
6	2	1	3	3	10.5	2.5	3.5
7	2	3	1	2	11	2.4	3.5
8	2	3	2	3	11.2	3.2	3.3
9	3	1	1	1	10.1	3.3	3.4
10	3	2	1	1	10.3	2.5	3.2
11	3	2	2	3	10.5	2.7	3.4
12	3	3	2	4	10.2	2.8	3.3
13	3	4	2	4	10.5	2	3.4
14	3	5	3	4	11.1	2.2	3.2
15	3	5	2	3	11.3	2.2	3.5
16	3	5	3	4	10.5	2	3.1
17	3	5	5	3	10.5	2.6	3.2
18	4	1	2	2	10.2	2.5	3
19	4	2	2	3	10.2	3	3.1
20	4	3	1	1	10.5	3.2	3.2
21	4	3	2	2	10.1	3.5	3.3
22	4	4	3	2	10.4	3.7	3.4
23	4	4	4	1	10.2	3.6	3.2

24	4	5	4	2	10.2	3.2	3.3
25	4	5	5	2	10.5	2.4	3.3
26	4	4	5	5	10.5	2	3.2
27	4	5	5	3	10	2.2	3.5
28	5	1	1	1	10	2.3	3.1
29	5	2	1	1	10.5	2.5	3.4
30	5	2	2	1	10.7	2.7	3.4
31	5	3	1	1	10	2.5	3.2
32	5	3	1	2	10.6	3	3.4
33	5	3	2	2	10.5	3.2	3.2
34	5	3	3	2	10.2	3.5	3.2
35	5	3	4	2	10.7	3.7	3.3
36	5	3	4	3	10.5	3	3.1
37	5	3	4	4	10.5	3.3	3.2
38	5	3	4	5	10.6	2.5	3
39	5	4	1	2	10.2	3.1	3.4
40	5	5	3	2	10.3	3	3.5

DESIGN SUMMARY

Using software Design Expert 8.0.7.1, design summary of above table has been made.



Design Summary

File Version	8.0.7.1		
Study Type	Factorial	**Runs**	625
Design Type	Full Factorial	**Blocks**	No Blocks
Center Point	0		
Design Mode	2FI	**Build Time (r**	14.34

Factor	**Name**	**Units**	**Type**	**Subtype**	**Minimum**	**Maximum**		
A	Welding current, I	Amp	Categoric	Nominal	330	410	**Levels:**	5
B	Arc Voltage, V	Volts	Categoric	Nominal	19	27	**Levels:**	5
C	Welding speed, Ws	mm/min	Categoric	Nominal	380	460	**Levels:**	5
D	Electrode stick out, N	m.m.	Categoric	Nominal	18	26	**Levels:**	5

Response	**Name**	**Units**	**Obs**	**Analysis**	**Minimum**	**Maximum**	**Mean**	**Std. Dev.**	**Ratio**
Y1	Measured width, W	m.m.	40	Factorial	11.2	14.4	13.1675	0.743997	1.28571
Y2	Reinforcement, R	m.m.	40	Factorial	2	3.7	2.745	0.512385	1.85

Fig. 19: Design summary

CHAPTER 4
RESULTS AND DISCUSSIONS

Design of experiment and its analysis is done by Design expert version 8.0.7.1 The mathematical model for linear and non- linear modelling is built by XLSTAT package for bead width, bead reinforcement and depth of penetration. Predicted values from mathematical model and residuals are shown in the above tables. Comparison of bead width, weld reinforcement and depth of penetration between the experimental values and the predicted multiple regression analysis can be done.

GRAPHS

The graph has been plotted between welding current and measured width and all forty runs have been plotted. In y-axis, plot is measured width and in x-axis, plot is welding current. In the graph, scatter points have been taken. Analysing the graph, most of the values of measured width have been plotted against value 410 amp. of welding current. However other values of measured width are similar for other values of welding current. The scatter values of measured width are between11 to 14.5 m.m. Definitely the values of measured width depends upon other values also i.e. voltage, welding speed, electrode stick out etc.

If there is more current, there would be more heat and width will be more. This happens because of more energy deposition and hence there will be more melting and hence more width. Many metals change their crystallographic structure at specific temperatures. The temperature at which one phase is changed into another phase is known as the critical temperature. This type of phase change in a crystalline structure in the solid state is known as an allotropic transformation. Chemical composition, the cooling rate, and the presence of stress influence the temperature at which the transformation takes place. Metals also undergo a phase change when they melt or solidify. Pure metals melt and solidify at a single temperature.

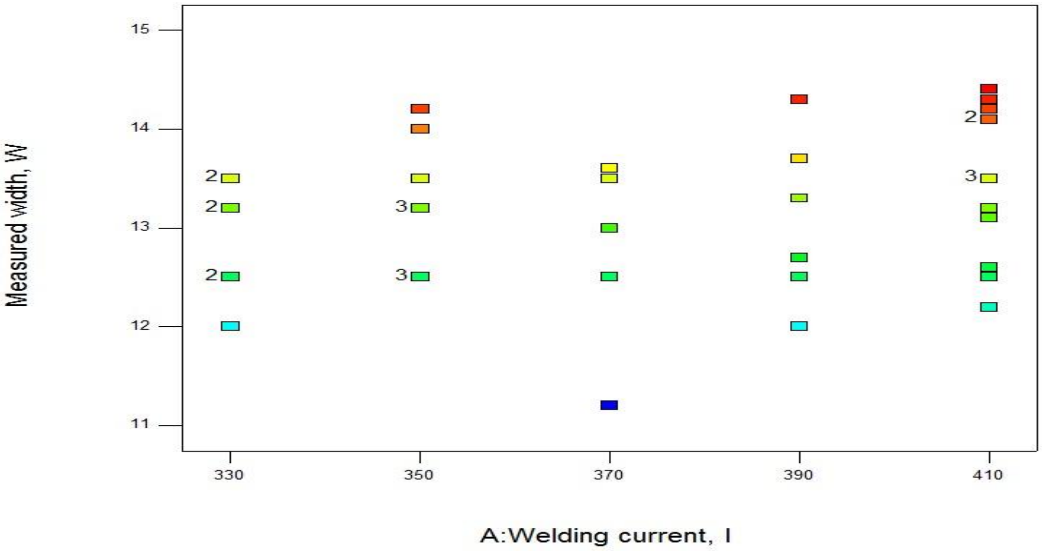


Fig 20: Graph between Welding current and Measured width

The graph has been plotted for measured width and welding speed for forty runs. The values of welding speed are between 380 and 460 m.m./ sec. Simultaneous values for measured width are marked between 11 to 15 m.m. In x- axis, plot of welding speed has been taken and in y-axis, plot of measured width has been taken. Scatter values have been taken on the graph. Most of the measured width values are plotted against 400 m.m./ min welding speed. Definitely, width also depends upon the other values i.e. welding current, voltage, electrode stick out etc.

When welding speed increases in SAW, width of welding increases. This happens due to more energy deposition and hence more melting of metal and hence more width in SAW. A welded joint consists of weld metal (which has been melted), heat-affected zones, and unaffected base metals. The metallurgy of each weld area is related to the compositions of the base and weld metals, the welding process, and the procedures used. Typical weld metals solidify rapidly and have a fine-grained dendritic microstructure. When a weld is deposited, the first grains to solidify initiate growth off the unmelted base metal, maintaining the same crystal orientation as that of the base metal grain off which they have grown. Depending upon the rates of composition and solidification, the weld solidifies in a cellular or a dendritic growth mode.

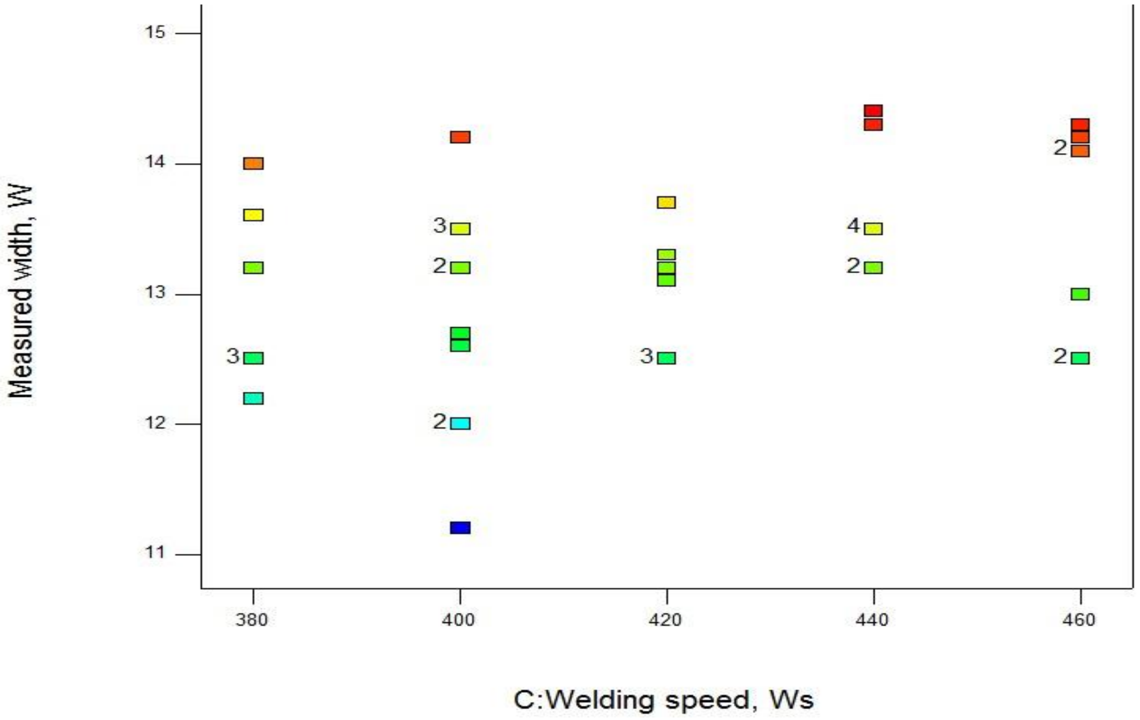


Fig. 21: Graph between Welding speed and Measured width

The graph has been plotted for reinforcement and welding current for forty runs. The values of welding speed are between 330 and 410 amp. Simultaneous values for reinforcement are marked between 2 to 4 m.m.. In y-axis, plot has been taken for reinforcement and in x-axis, plot have been taken for welding current. Most of the values of reinforcements have been taken for 410 amp. welding current. Though, reinforcement values also depend upon other factors i.e. voltage, welding speed, electrode stick out etc.

The unmelted portions of grains in the heat-affected zone at the solid-liquid interface serve as an ideal substrate for the solidification of the weld metal. Metals grow more rapidly in certain crystallographic directions. Therefore, favourably orientated grains grow for substantial distances, while the growth of grains that are less favourably oriented is blocked by the faster-growing grains. For this reason, weld metal often exhibits a columnar macrostructure in which the grains are relatively long and parallel to the direction of heat flow. This structure is a natural result of the influence of favourable crystal orientation, given the competitive nature of solidification grain growth.

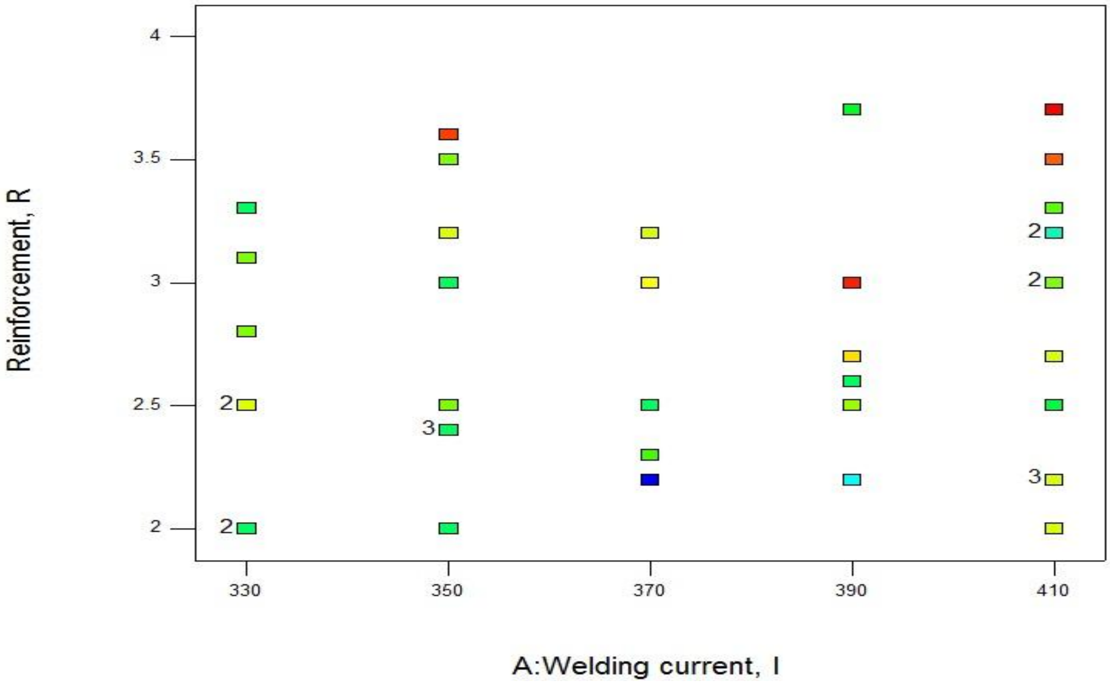


Fig. 22: Graph between Welding current and Reinforcement

The graph has been plotted for reinforcement and welding speed for forty runs. The values of welding speed are between 380 and 460 mm/sec. Simultaneous values for reinforcement are marked between 2 to 4 m.m. In y-axis, plot has been taken for reinforcement and x-axis; plot has been taken for welding speed. Scatter diagram has been plotted in the graph. Most of the reinforcement values are plotted for 400 m.m./ sec. Though, the other values of reinforcement also depend upon other factors i.e. welding current, voltage, electrode stick out etc.

When the welding speed is more in SAW, reinforcement of welding would be more. This happens because of more energy deposition and hence more melting of weld and hence more reinforcement deposition. The spacing between dendrite arms is a measure of alloy segregation. Spacing is determined by the rate of solidification. The more rapid the solidification, the more closely spaced the dendrites will be. The general tendency is for weld-metal grain size to increase with heat input, but no. fixed relationship exists. Grain size may also be influenced by nucleating agents, vibration, or other process variables, whereas the dendrite arm spacing is exclusively a function of solidification rate, which is controlled by heat input.

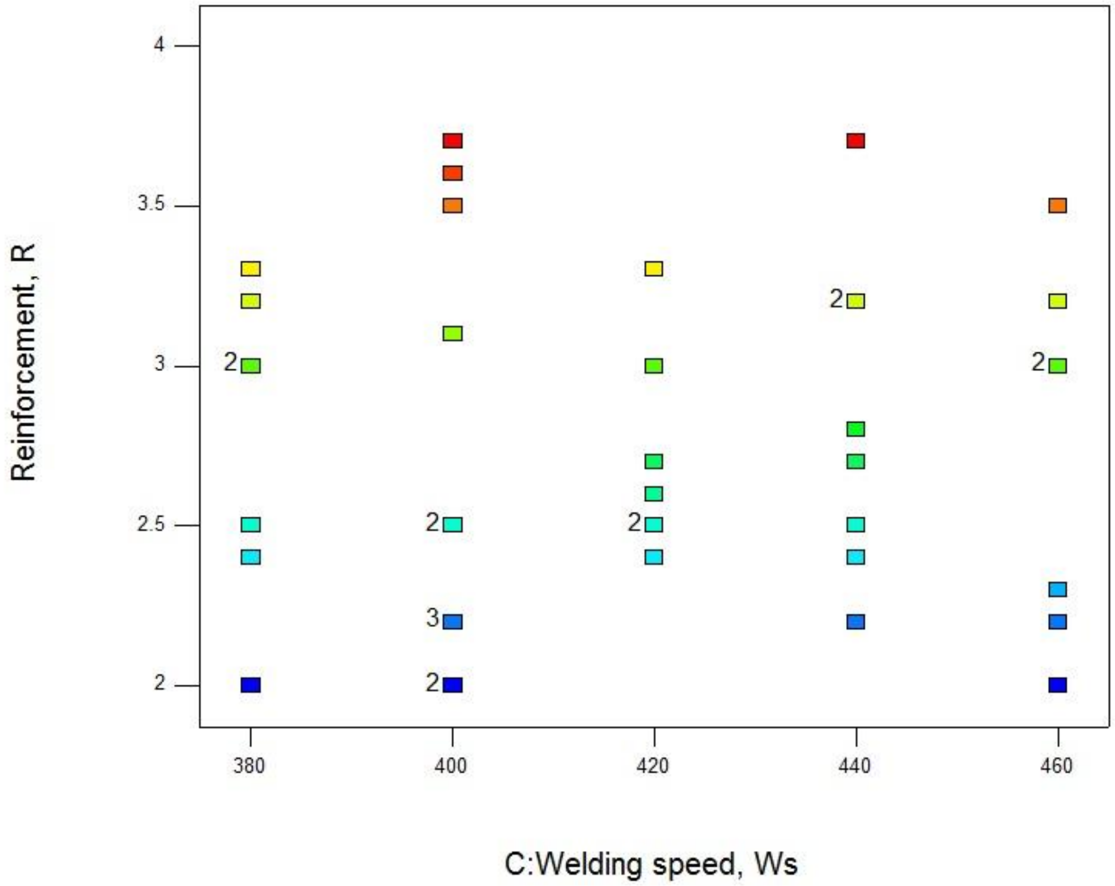


Fig. 23: Graph between Welding speed and Reinforcement

3D SURFACE MODEL

3D surface model has been made for width and reinforcement.

The graph has been plotted between measured width, welding speed and arc voltage. Values of measured width are from 10 m.m. and 13 m.m. in y-axis. The values of welding speed are from 380 to 460 m.m./ sec. in 5 levels in x-axis. Values of arc voltage are taken from 19 to 27 volts in 5 levels in z- axis. The 3D surface model has been plotted between these three coordinates. 3D surface model gives better idea of variation in measured width than 2D graph.

When welding speed and voltage are more, width would also be more. This is because of energy deposition and hence more melting would be there and hence there would be more width in the welding. Slags produced in the submerged arc welding processes are designed to absorb deoxidation products and other contaminants produced in the arc and molten weld metal. The quantity and type of nonmetallic deoxidation products generated during the arc welding of steel are directly related to the specific shielding and deoxidants used. These products- primarily silicates of aluminum, manganese, and iron-generally float to the surface of the molten weld pool and become incorporated in the slag. However, some can become trapped in the weld metal as inclusions. The cleanliness of the weld metal is influenced by the quantity of nonmetallic products produced and the extent to which they can be removed with the slag. Clearly, the more strongly oxidizing the arc environment is, the more deoxidation is required, and the greater the quantity of nonmetallic products is produced.

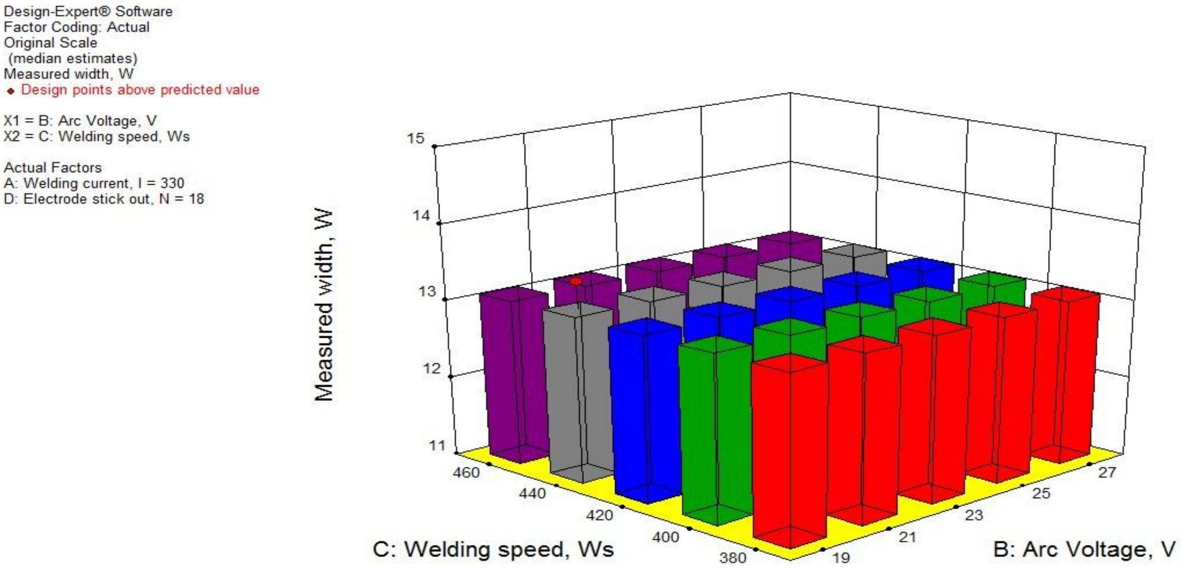


Fig. 24: 3D SURFACE MODEL FOR MEASURED WIDTH

The graph has been plotted between reinforcement, welding speed and arc voltage. Values of reinforcement are from 2 m.m. and 4 m.m. in y-axis. The values of welding speed are from 380 to 460 m.m./ sec. in 5 levels in x-axis. Values of arc voltage are taken from 19 to 27 volts in 5 levels in z-axis. The 3D surface model has been plotted between these three coordinates. 3D surface model gives better idea of variation in reinforcement than 2D graph.

The reinforcement would be more, when welding speed and arc voltage are more. The interaction of the liquid and solid state is the weld discontinuity referred to as hot cracking. This phenomenon arises during the solidification of the weld metal whenever the interdendritic liquid (i.e., the last region to freeze) has a substantially lower freezing temperature than the previously solidified metal. Under these conditions, shrinkage stresses produced during solidification become concentrated in the small liquid region, producing microcracks between the dendrites. The term “hot cracking” is used because these cracks occur at temperatures close to the solidification temperature. They are promoted by any compositional variations produced by segregation in the weld metal that produce a low-melting interdendritic liquid.

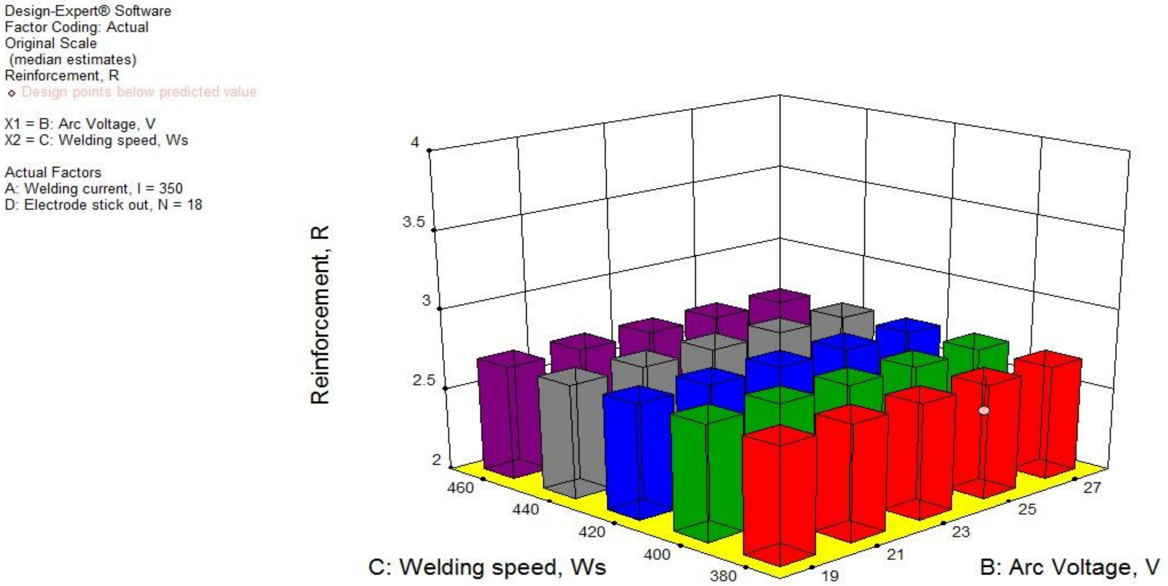


Fig. 25: 3D SURFACE MODEL FOR REINFORCEMENT

NORMAL PLOT OF RESIDUALS

The graph has been plotted between Studentized residuals and normal probability for measuring width. In y-axis, values of normal probability % have been taken and in x-axis, internally studentized residuals have been taken. The variation is between 1 to 100 % normal probability for -3 to 2 internally studentized residuals. Scatter points have been plotted in the graph.

Deposition of steel electrodes during SAW has been studied to determine the sizes and shapes of droplets leaving the electrode tip and passing through the arc to the weld pool. The time-of-fight of the droplets was also measured. Lower welding currents form larger, fluctuating-shape droplets that tend to slide down the walls of the arc cavity or crater into the weld pool. Higher welding currents tend to form much finer droplets that stream from a pointed electrode tip and transfer directly into the molten weld pool. Although the time required for a droplet to accomplish this transfer is extremely short, perhaps less than a tenth of a second, there is a time difference between large and small droplets (because of employing lower, or higher welding current, respectively).

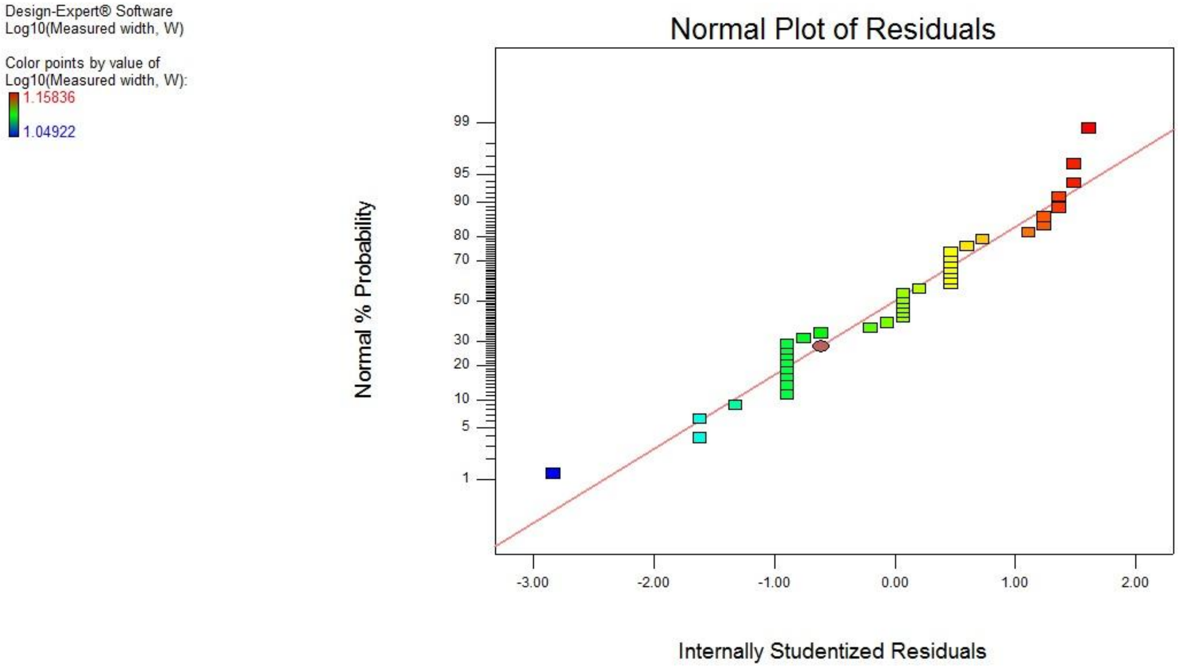


Fig. 26: NORMAL PLOT OF RESIDUALS FOR MEASURING WIDTH

The graph has been plotted between studentized residuals and normal probability for reinforcement. In y-axis, values of normal probability % have been taken and in x-axis, internally studentized residuals have been taken. The variation is between 1 to 100 % normal probability for -2 to 2 internally studentized residuals. Scatter points have been plotted in the graph.

The melting rate of the electrode increases as the current increases. Changes in anode or cathode voltages produced by changes in flux composition or changes in voltage level, travel speed, or in electrode preheat will influence the exact melting rates.

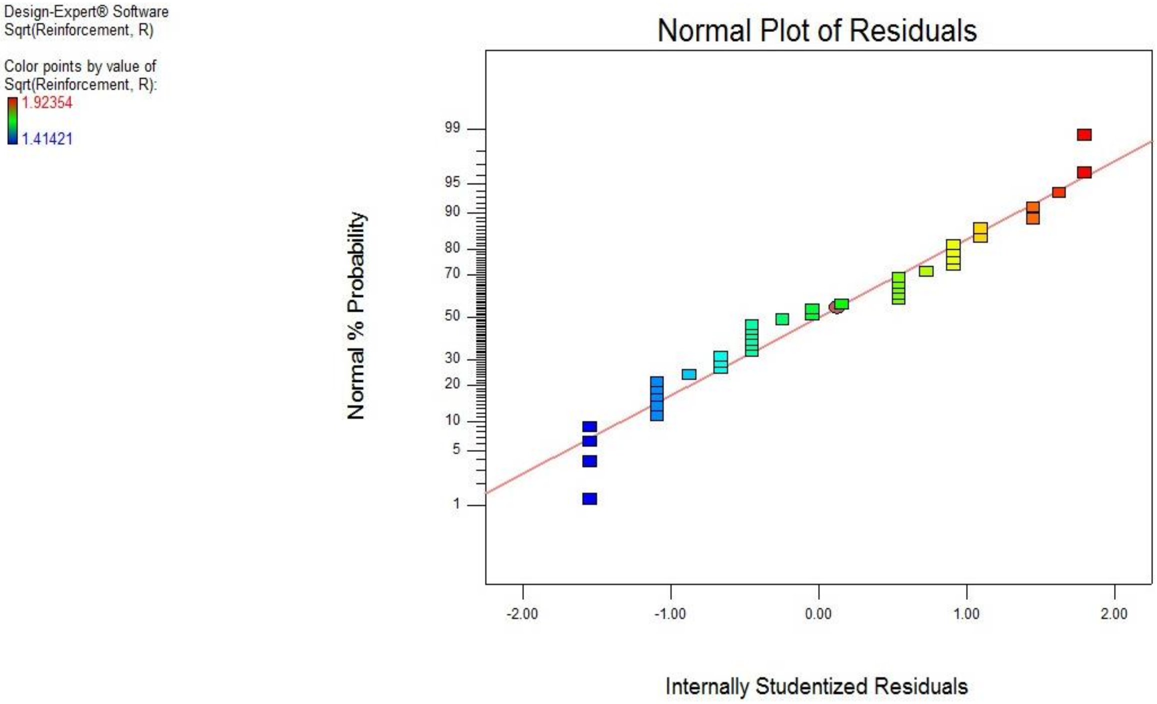


Fig. 27: NORMAL PLOT OF RESIDUALS FOR REINFORCEMENT

RESIDUALS VS. RUN

The graph has been plotted between studentized residuals and run numbers for measuring width. Each point is joined to get the final graph. In y-axis, internally studentized residuals have been taken and x- axis, 40 run numbers have been taken. Plotted graph is similar to sinusoidal graph.

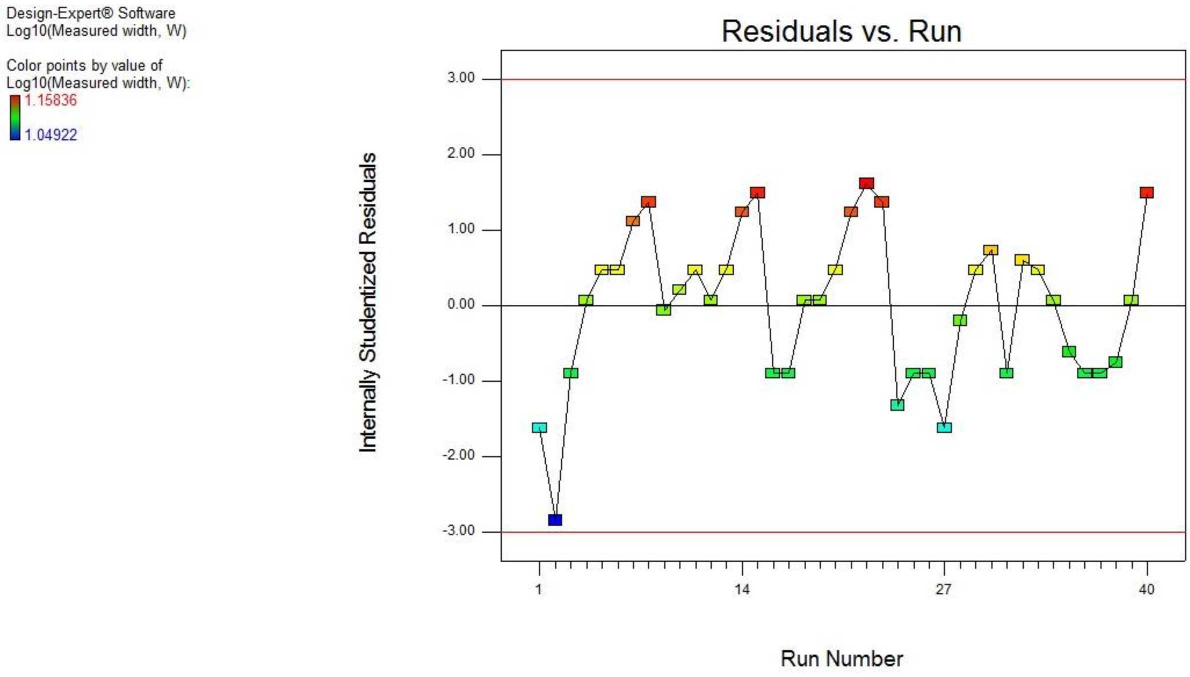


Fig. 28: RESIDUAL VS RUN FOR MEASURING WIDTH

The graph has been plotted between studentized residuals and run numbers for reinforcement. Each point is joined to get the final graph. In y-axis, internally studentized residuals have been taken and x- axis, 40 run numbers have been taken. Plotted graph is similar to sinusoidal graph.

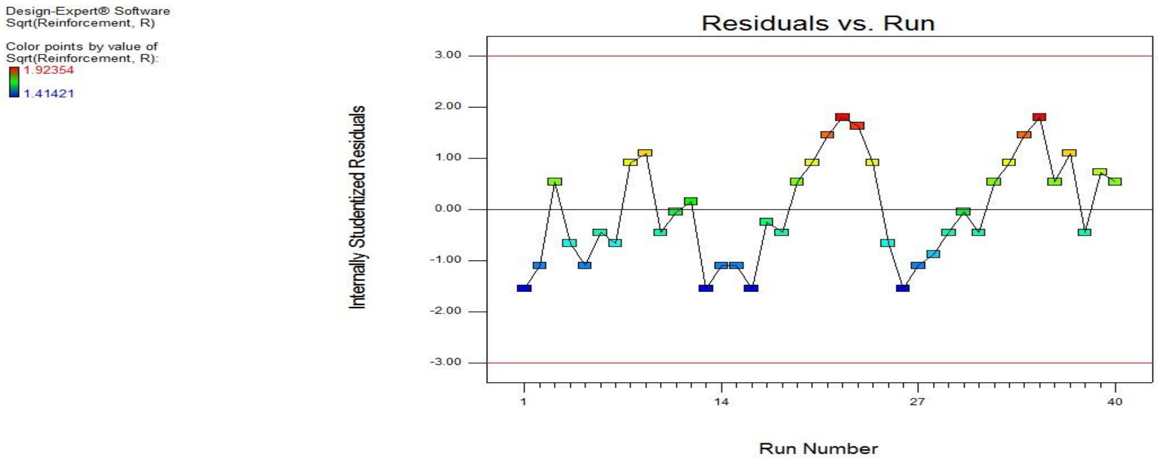


Fig. 29: RESIDUAL VS RUN FOR REINFORCEMENT

MULTIPLE REGRESSION ANALYSIS AND MATHEMATICAL MODELLING

LINEAR MODELLING

Multiple regression technique ascertains the relationship among variables. It is the most frequently used method of linear equation. The multiple linear regressions take the following form:

$$Y= a + b1X1 + b2X2 + b3X3 + \_\ \_\ \_\ \_\ \_\ \_\ \_\ \_\ \_\ \_ + bkXk$$

Where Y is the dependent variable, which is to be predicted X1, X2, X3, _ _ _ _ _ Xk are the k known variables and a, b1, b2, b3,_ _ _ _ _bk are the coefficients, the values of which are determined by the method of least square. Multiple regression analysis is used to determine the relationship between the dependent variables of bead width, weld reinforcement, and depth of penetration with welding current, arc voltage, welding speed and electrode stick out. The regression analysis was done by XLSTAT, a commercial statistical program.

In XLSTAT menu (fig. 30), first linear regression has been chosen from modelling data. Then in XLSTAT options (fig. 31), Y dependent variables have been chosen (These values are experimental values of width, reinforcement or penetration) and X explanatory variables have been chosen (These values are design experiment values). On pressing enter, it gives the equation of width, reinforcement or penetration (Fig. 32) and also gives predicted values through these equations.

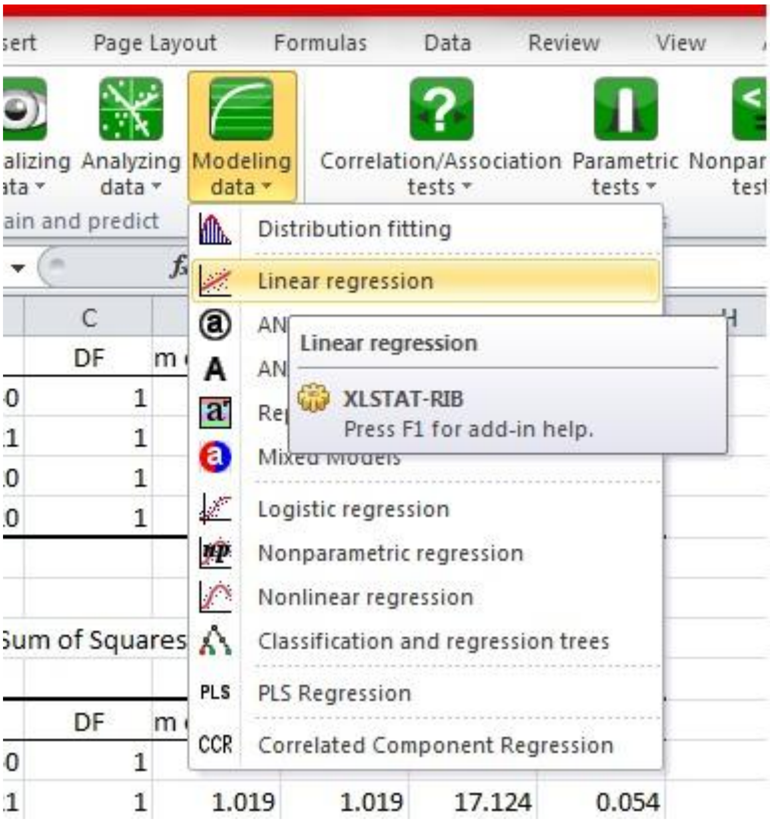
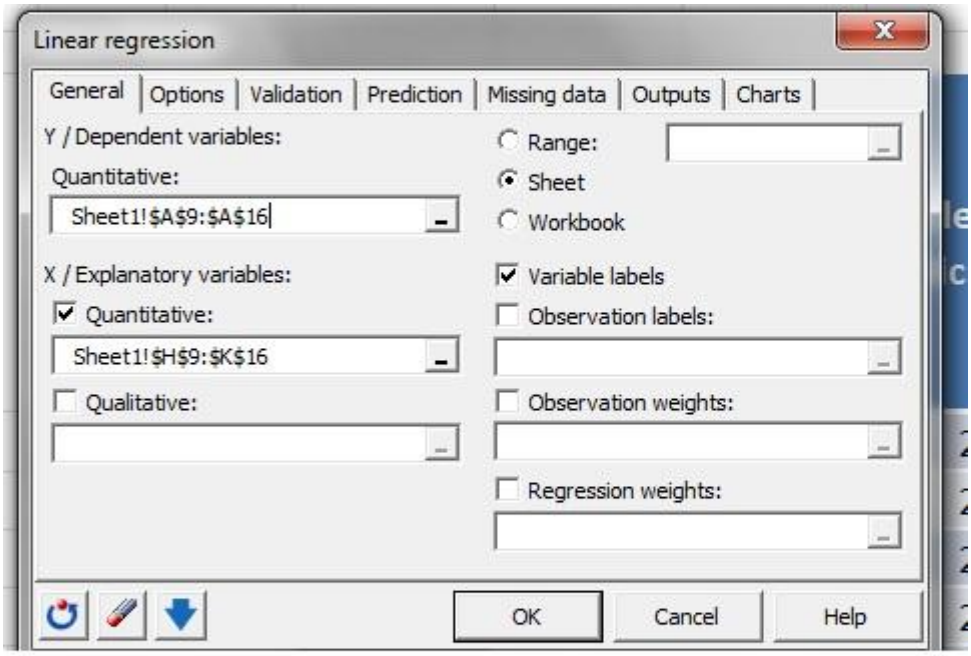


Fig. 30: XLSTAT Menu



Y / Dependent variables:

Quantitative:

Sheet1!$A$9:$A$16

○ Range:

● Sheet

○ Workbook

X / Explanatory variables:

☑ Quantitative:

Sheet1!$H$9:$K$16

☐ Qualitative:

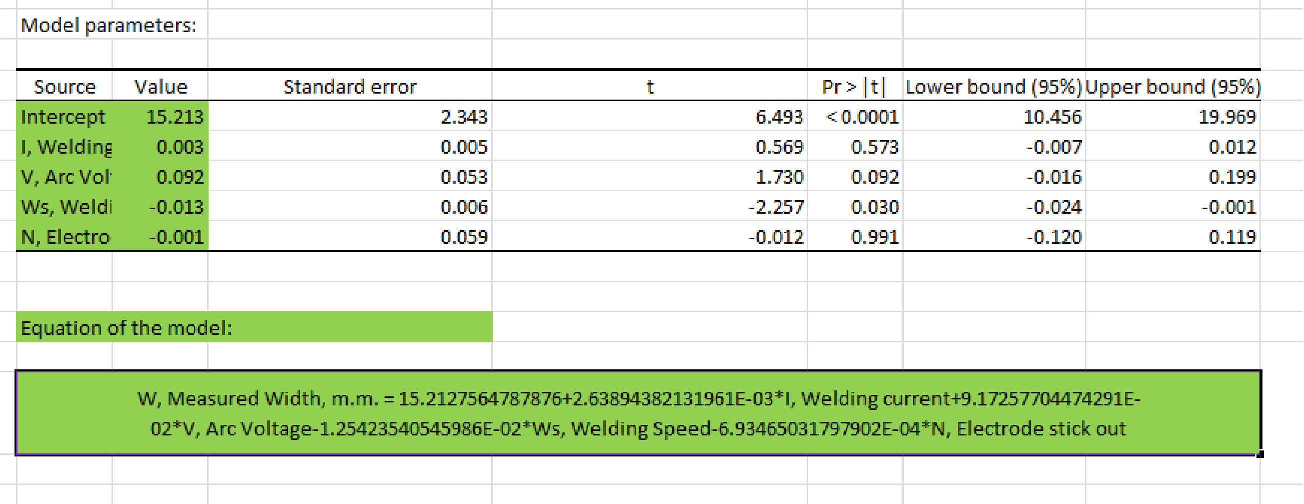
☑ Variable labels

☐ Observation labels:

☐ Observation weights:

☐ Regression weights:

Fig. 31: XLSTAT Options



Model parameters:

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	15.213	2.343	6.493	< 0.0001	10.456	19.969
I, Welding	0.003	0.005	0.569	0.573	-0.007	0.012
V, Arc Vol	0.092	0.053	1.730	0.092	-0.016	0.199
Ws, Weldi	-0.013	0.006	-2.257	0.030	-0.024	-0.001
N, Electro	-0.001	0.059	-0.012	0.991	-0.120	0.119

Equation of the model:

W, Measured Width, m.m. = 15.2127564787876+2.63894382131961E-03*I, Welding current+9.17257704474291E-02*V, Arc Voltage-1.25423540545986E-02*Ws, Welding Speed-6.93465031797902E-04*N, Electrode stick out

Fig. 32: Equation from XLSTAT

The regression analysis of the input parameters is expressed in linear equations as follows:

1) **W, Measured Width, m.m. = 15.2127564787876+ 2.63894382131961E-03* I, Welding current+9.17257704474291E-02*V,Arc Voltage-1.25423540545986E-02*Ws, Welding Speed-6.93465031797902E-04*N, Electrode stick out**
2) **R, Reinforcement = 0.349707490480944+7.04471027852236E-03*I, Welding current-4.39101576075955E-03*V, Arc Voltage+3.69105085677836E-03*Ws, Welding Speed-8.24081846306763E-02*N, Electrode stick out**
3) **Depth of penetration, P = 3.71609880347988-2.28655701436352E-04*I, Welding current+2.68547852000798E-02*V, Arc Voltage-1.99990808230079E-03*Ws, Welding Speed-7.73253577583388E-03*N, Electrode stick out**

From the above equations, values of bead width, weld reinforcement, and depth of penetration can be predicted for any given value of process parameters.

PREDICTION AND RESIDUALS

A) TABLE 4: For Measured Width

Observation	W, Measured Width, m.m.	Pred(W, Measured Width, m.m.)	Residual	Std. residual
Obs1	10	11.048	-1.048	-1.457
Obs2	10.2	11.046	-1.846	-2.567
Obs3	10.5	10.730	-0.230	-0.319
Obs4	10.2	9.978	0.222	0.309
Obs5	10.5	9.598	0.902	1.255
Obs6	10.5	9.596	0.904	1.257
Obs7	11	10.466	0.534	0.742
Obs8	11.2	10.214	0.986	1.371
Obs9	10.1	10.153	-0.053	-0.074
Obs10	10.3	10.337	-0.037	-0.051
Obs11	10.5	10.083	0.417	0.580
Obs12	10.2	10.265	-0.065	-0.091
Obs13	10.5	10.449	0.051	0.071
Obs14	11.1	10.381	0.719	0.999
Obs15	11.3	10.634	0.666	0.927
Obs16	10.5	11.381	-0.881	-1.225
Obs17	10.5	10.881	-0.381	-0.530
Obs18	10.2	9.954	0.246	0.342
Obs19	10.2	10.136	0.064	0.089
Obs20	10.5	10.573	-0.073	-0.102
Obs21	10.1	9.321	0.779	1.083
Obs22	10.4	9.253	1.147	1.594
Obs23	10.2	9.004	1.196	1.663
Obs24	10.2	11.186	-0.986	-1.371
Obs25	10.5	10.935	-0.435	-0.605
Obs26	10.5	10.748	-0.248	-0.344
Obs27	10	10.934	-0.934	-1.298
Obs28	10	10.259	-0.259	-0.360
Obs29	10.5	10.442	0.058	0.080
Obs30	10.7	10.192	0.508	0.707
Obs31	10	11.126	-1.126	-1.565
Obs32	10.6	10.624	-0.024	-0.034

Obs33	10.5	10.374	0.126	0.176
Obs34	10.2	10.123	0.077	0.107
Obs35	10.7	10.872	-0.172	-0.239
Obs36	10.5	10.871	-0.371	-0.515
Obs37	10.5	10.869	-0.369	-0.513
Obs38	10.6	10.868	-0.268	-0.372
Obs39	10.2	10.808	-0.608	-0.845
Obs40	10.3	9.490	0.810	1.127

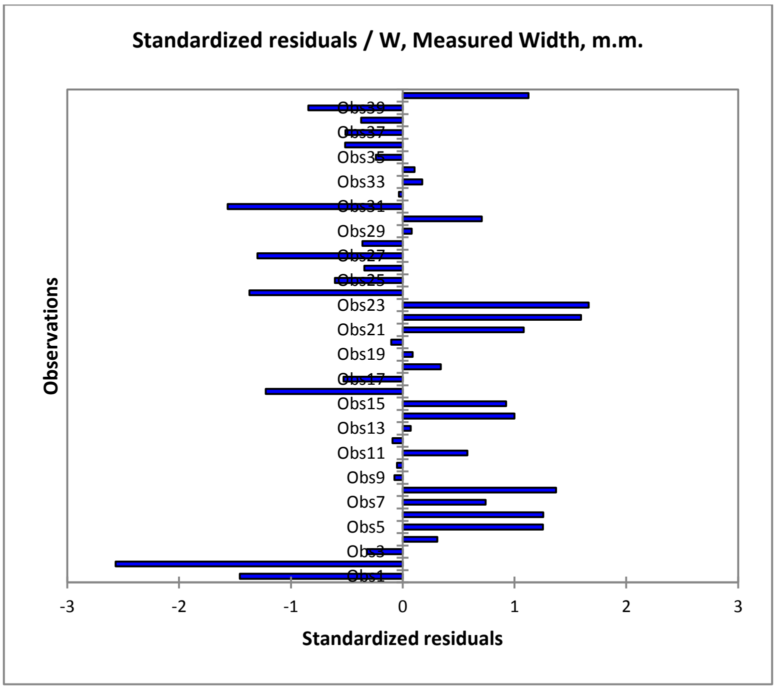


Fig. 33: Residuals for width

B) TABLE 5: For Reinforcement

Observation	R, Reinforcement	Pred(R, Reinforcement)	Residual	Std. residual
Obs1	2.000	2.510	-0.510	-1.101
Obs2	2.200	2.345	-0.145	-0.314
Obs3	3.000	2.649	0.351	0.757
Obs4	2.400	2.246	0.154	0.333
Obs5	2.200	2.634	-0.434	-0.937
Obs6	2.500	2.469	0.031	0.067
Obs7	2.400	2.469	-0.069	-0.149
Obs8	3.200	2.378	0.822	1.775
Obs9	3.300	2.792	0.508	1.096
Obs10	2.500	2.783	-0.283	-0.611
Obs11	2.700	2.527	0.173	0.372

Obs12	2.800	2.354	0.446	0.963
Obs13	2.000	2.345	-0.345	-0.745
Obs14	2.200	2.410	-0.210	-0.454
Obs15	2.200	2.501	-0.301	-0.650
Obs16	2.000	2.410	-0.410	-0.885
Obs17	2.600	2.723	-0.123	-0.265
Obs18	2.500	2.842	-0.342	-0.738
Obs19	3.000	2.668	0.332	0.716
Obs20	3.200	2.915	0.285	0.614
Obs21	3.500	2.824	0.676	1.458
Obs22	3.700	2.889	0.811	1.750
Obs23	3.600	3.128	0.472	1.019
Obs24	3.200	2.954	0.246	0.530
Obs25	2.400	3.028	-0.628	-1.356
Obs26	2.000	2.543	-0.543	-1.171
Obs27	2.200	2.863	-0.663	-1.432
Obs28	2.300	3.074	-0.774	-1.670
Obs29	2.500	3.065	-0.565	-1.220
Obs30	2.700	3.139	-0.439	-0.947
Obs31	2.500	3.056	-0.556	-1.201
Obs32	3.000	2.891	0.109	0.234
Obs33	3.200	2.965	0.235	0.507
Obs34	3.500	3.039	0.461	0.995
Obs35	3.700	3.113	0.587	1.267
Obs36	3.000	2.948	0.052	0.112
Obs37	3.300	2.783	0.517	1.115
Obs38	2.500	2.618	-0.118	-0.256
Obs39	3.100	2.883	0.217	0.469
Obs40	3.000	3.022	-0.022	-0.047

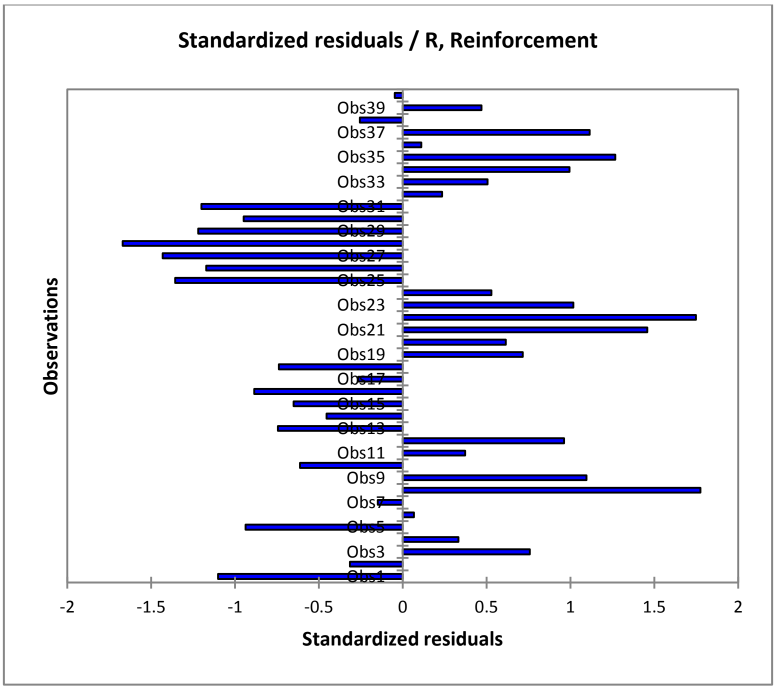


Fig. 34: Residuals for reinforcement

C) TABLE 6: For Depth of Penetration

Observation	Depth of penetration, P	Pred(Depth of penetration, P)	Residual	Std. residual
Obs1	3.200	3.252	-0.052	-0.353
Obs2	3.400	3.236	0.164	1.116
Obs3	3.000	3.225	-0.225	-1.537
Obs4	3.000	3.235	-0.235	-1.598
Obs5	3.100	3.152	-0.052	-0.352
Obs6	3.500	3.136	0.364	2.479
Obs7	3.500	3.339	0.161	1.097
Obs8	3.300	3.284	0.016	0.111
Obs9	3.400	3.243	0.157	1.073
Obs10	3.200	3.296	-0.096	-0.656
Obs11	3.400	3.225	0.175	1.190
Obs12	3.300	3.264	0.036	0.248
Obs13	3.400	3.317	0.083	0.563
Obs14	3.200	3.331	-0.131	-0.893
Obs15	3.500	3.386	0.114	0.774
Obs16	3.100	3.331	-0.231	-1.575
Obs17	3.200	3.267	-0.067	-0.453
Obs18	3.000	3.183	-0.183	-1.244

Obs19	3.100	3.221	-0.121	-0.823
Obs20	3.200	3.345	-0.145	-0.991
Obs21	3.300	3.290	0.010	0.068
Obs22	3.400	3.304	0.096	0.656
Obs23	3.200	3.279	-0.079	-0.539
Obs24	3.300	3.317	-0.017	-0.119
Obs25	3.300	3.277	0.023	0.154
Obs26	3.200	3.177	0.023	0.155
Obs27	3.500	3.262	0.238	1.623
Obs28	3.100	3.233	-0.133	-0.909
Obs29	3.400	3.287	0.113	0.769
Obs30	3.400	3.247	0.153	1.042
Obs31	3.200	3.341	-0.141	-0.960
Obs32	3.400	3.325	0.075	0.508
Obs33	3.200	3.285	-0.085	-0.582
Obs34	3.200	3.245	-0.045	-0.309
Obs35	3.300	3.205	0.095	0.645
Obs36	3.100	3.190	-0.090	-0.613
Obs37	3.200	3.174	0.026	0.174
Obs38	3.000	3.159	-0.159	-1.084
Obs39	3.400	3.379	0.021	0.142
Obs40	3.500	3.353	0.147	1.003

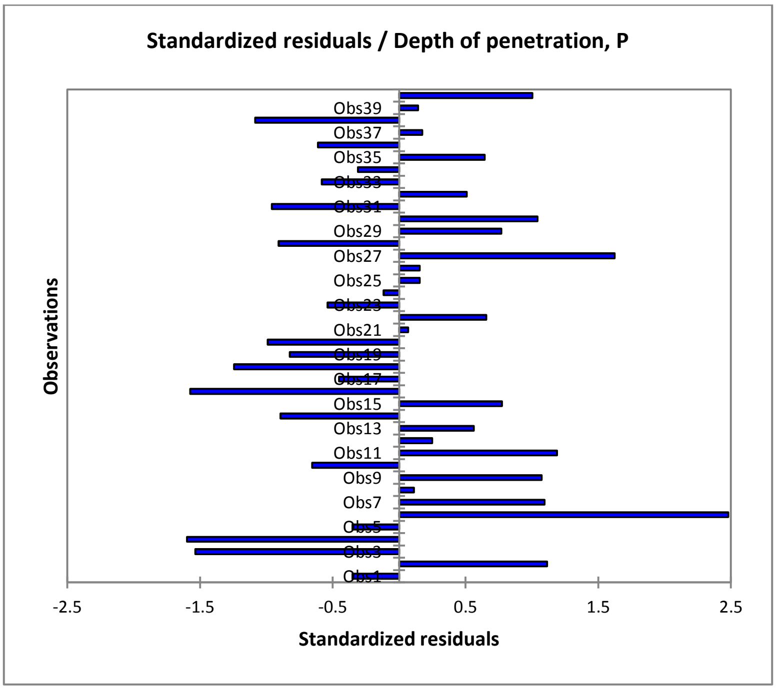


Fig. 35: Residual for depth of penetration

NON LINEAR MODELLING

Using XLSTAT software we can also do non-linear mathematical modelling and can prepare **second order quadratic equation** of the following form:

Y = pr1+pr2*X1+pr3*X2+pr4*X3+pr5*X4+pr6*X1^2+pr7*X2^2+pr8*X3^2+pr9*X4^2

In XLSTAT menu (fig. 36), first non- linear regression has been chosen from modelling data. Then in XLSTAT options (fig. 37), Y dependent variables have been chosen (These values are experimental values of width, reinforcement or penetration) and X explanatory variables have been chosen (These values are design experiment values). On pressing enter, it gives the equation of width, reinforcement or penetration and also gives predicted values through these equations.

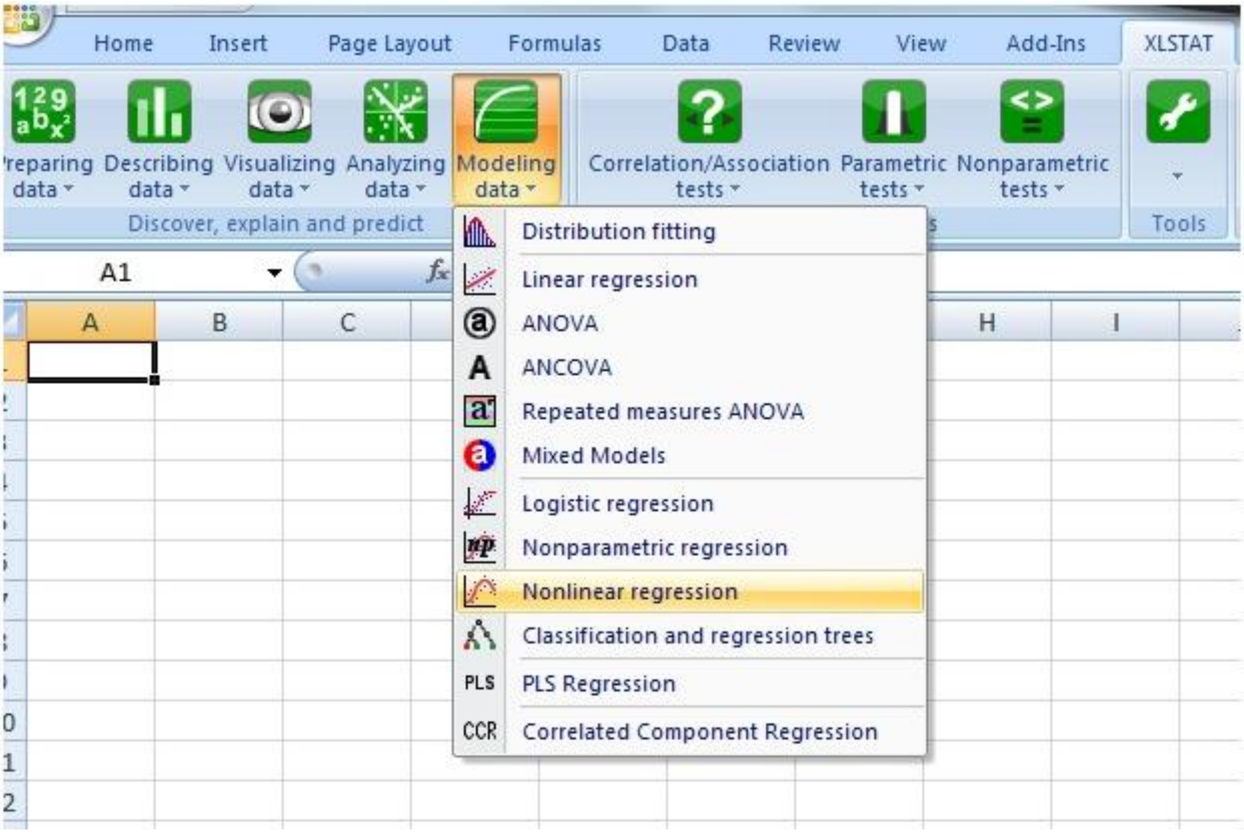
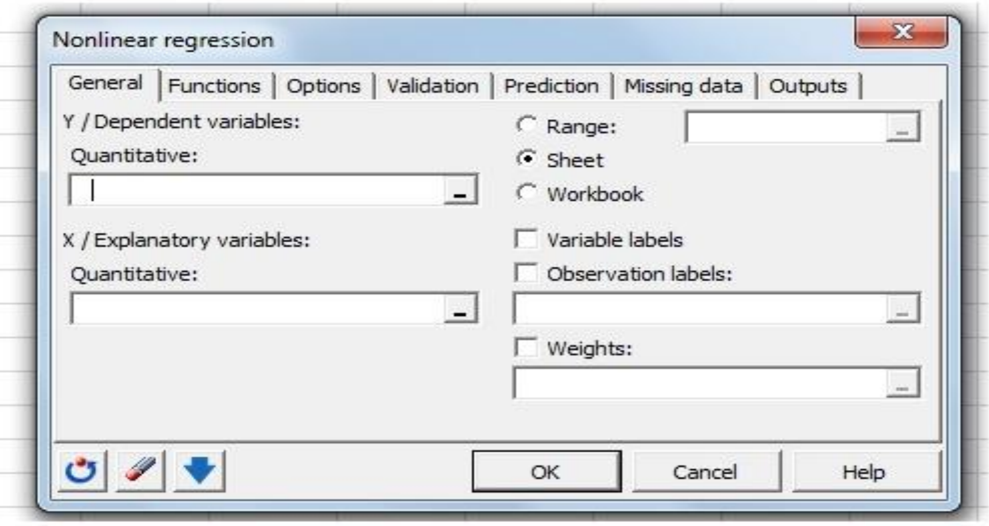


Fig. 36: XLSTAT Menu



Y / Dependent variables:

Quantitative:

X / Explanatory variables:

Quantitative:

○ Range:

● Sheet

○ Workbook

☐ Variable labels

☐ Observation labels:

☐ Weights:

Fig. 37: XLSTAT options

Following second order quadratic equations are formed using XLSTAT software:

1) Measured width, W = -162.325770520998+0.350684618047611*Welding current, I+1.09816015699273*ArcVoltage,V+0.477017382026582*Weldingspeed,Ws+ 3.59646377476071E-02*Electrode stick out, N-4.65787997155144E-04*Welding current, I^2-2.23478287842034E-02*Arc Voltage, V^2-5.84144636389704E-04*Welding Speed, Ws^2-2.72889954415582E-03*Electrode Stick out, N^2

2) Reinforcement, R = -80.7557363313801+8.38113976695177E-02*Welding current, I+1.77196093884126*Arc voltage, V+0.189722379261197*Welding Speed, Ws+0.718917409441184*Electrode Stick out, N-1.06452323777691E-04*Welding Current, I^2-3.86450252178637E-02*Arc Voltage, V^2-2.19417864462041E-04*Welding Speed, Ws^2-1.97801478732838E-02*Electrode Stick out, N^2

3) Depth of penetration, P = 5.26357005711494+2.11090398477917E-02*Welding Current, I-4.97737337654248E-02*Arc Voltage, V-4.36222078136426E-02*Welding speed, Ws+0.365241180722529*Electrode Stick out, N-2.77636530771691E-05*Welding curent, I^2+1.46781956229098E-03*Arc Voltage, V^2+4.98612671159333E-05*Welding speed, Ws^2-8.58890678538215E-03*Electrode Stick out^2

PREDICTIONS AND RESIDUALS:

A) TABLE 7: For Measured Width

Observations	Measured Width	Pred(Measured Width)	Residuals
Obs1	10	10.153	-0.153
Obs2	10.2	11.017	-0.817
Obs3	10.5	10.949	-0.449
Obs4	10.2	9.696	0.504
Obs5	10.5	10.084	0.416
Obs6	10.5	9.927	0.573
Obs7	11	10.334	0.666
Obs8	11.2	10.605	0.595
Obs9	10.1	10.138	-0.038
Obs10	10.3	10.546	-0.246
Obs11	10.5	10.681	-0.181
Obs12	10.2	10.732	-0.532
Obs13	10.5	10.783	-0.283
Obs14	11.1	10.615	0.485
Obs15	11.3	10.834	0.466
Obs16	10.5	11.615	-1.115
Obs17	10.5	10.313	0.187
Obs18	10.2	10.364	-0.164
Obs19	10.2	10.615	-0.415
Obs20	10.5	10.710	-0.210
Obs21	10.1	10.002	0.098
Obs22	10.4	10.013	0.387
Obs23	10.2	9.642	0.558
Obs24	10.2	11.379	-1.179
Obs25	10.5	10.404	0.096
Obs26	10.5	9.995	0.505
Obs27	10	10.247	-0.247
Obs28	10	9.633	0.367
Obs29	10.5	10.041	0.459
Obs30	10.7	10.469	0.231
Obs31	10	10.771	-0.771
Obs32	10.6	10.135	0.465
Obs33	10.5	10.563	-0.063
Obs34	10.2	10.524	-0.324
Obs35	10.7	10.017	-0.317
Obs36	10.5	10.859	-0.359
Obs37	10.5	10.680	-0.180
Obs38	10.6	10.479	0.121
Obs39	10.2	10.186	0.014
Obs40	10.3	9.447	0.853

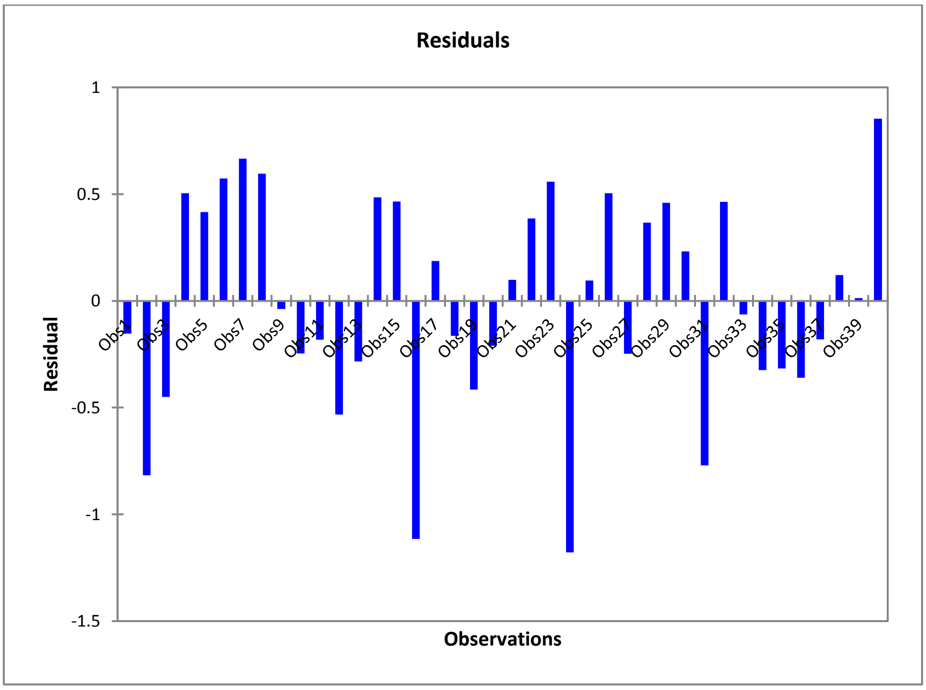


Fig. 38: Residuals for width

B) TABLE 8: For Reinforcement

Observations	Reinforcement	Pred(Reinforcement)	Residuals
Obs1	2.000	1.968	0.032
Obs2	2.200	1.903	0.297
Obs3	3.000	2.988	0.012
Obs4	2.400	2.503	-0.103
Obs5	2.200	2.699	-0.499
Obs6	2.500	2.475	0.025
Obs7	2.400	2.727	-0.327
Obs8	3.200	2.874	0.326
Obs9	3.300	2.340	0.960
Obs10	2.500	2.792	-0.292
Obs11	2.700	2.875	-0.175
Obs12	2.800	2.636	0.164
Obs13	2.000	2.470	-0.470
Obs14	2.200	2.191	0.009
Obs15	2.200	2.377	-0.177
Obs16	2.000	2.191	-0.191
Obs17	2.600	2.438	0.162
Obs18	2.500	2.704	-0.204
Obs19	3.000	2.933	0.067
Obs20	3.200	2.994	0.206
Obs21	3.500	3.300	0.200
Obs22	3.700	3.330	0.370

Obs23	3.600	3.415	0.185
Obs24	3.200	2.875	0.325
Obs25	2.400	2.720	-0.320
Obs26	2.000	2.049	-0.049
Obs27	2.200	2.496	-0.296
Obs28	2.300	2.371	-0.071
Obs29	2.500	2.823	-0.323
Obs30	2.700	3.195	-0.495
Obs31	2.500	2.966	-0.466
Obs32	3.000	2.901	0.099
Obs33	3.200	3.273	-0.073
Obs34	3.500	3.469	0.031
Obs35	3.700	3.489	0.211
Obs36	3.000	3.265	-0.265
Obs37	3.300	2.883	0.417
Obs38	2.500	2.343	0.157
Obs39	3.100	2.735	0.365
Obs40	3.000	2.827	0.173

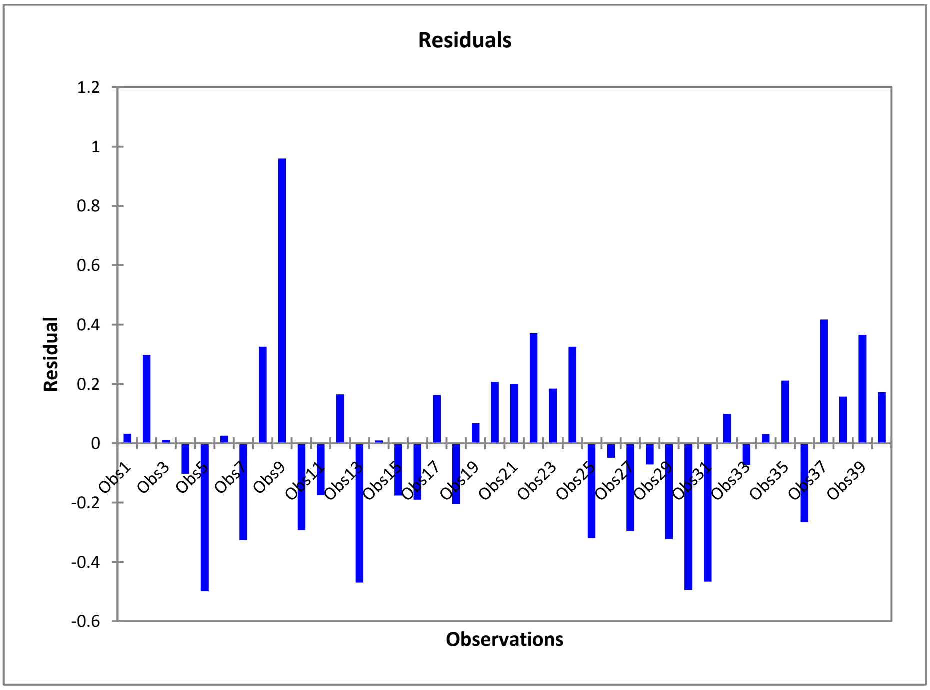


Fig. 39: Residuals for reinforcement

C) TABLE 9: For Depth of Penetration

Observations	Depth of Penetration	Pred(Depth of penetration)	Residuals
Obs1	3.200	3.205	-0.005
Obs2	3.400	3.283	0.117
Obs3	3.000	3.074	-0.074
Obs4	3.000	3.215	-0.215
Obs5	3.100	3.178	-0.078
Obs6	3.500	3.187	0.313
Obs7	3.500	3.375	0.125
Obs8	3.300	3.290	0.010
Obs9	3.400	3.272	0.128
Obs10	3.200	3.290	-0.090
Obs11	3.400	3.282	0.118
Obs12	3.300	3.252	0.048
Obs13	3.400	3.294	0.106
Obs14	3.200	3.292	-0.092
Obs15	3.500	3.406	0.094
Obs16	3.100	3.292	-0.192
Obs17	3.200	3.362	-0.162
Obs18	3.000	3.256	-0.256
Obs19	3.100	3.282	-0.182
Obs20	3.200	3.320	-0.120
Obs21	3.300	3.303	-0.003
Obs22	3.400	3.290	0.110
Obs23	3.200	3.197	0.003
Obs24	3.300	3.328	-0.028
Obs25	3.300	3.353	-0.053
Obs26	3.200	3.121	0.079
Obs27	3.500	3.362	0.138
Obs28	3.100	3.250	-0.150
Obs29	3.400	3.268	0.132
Obs30	3.400	3.174	0.226
Obs31	3.200	3.298	-0.098
Obs32	3.400	3.376	0.024
Obs33	3.200	3.281	-0.081
Obs34	3.200	3.226	-0.026
Obs35	3.300	3.212	0.088
Obs36	3.100	3.221	-0.121
Obs37	3.200	3.161	0.039
Obs38	3.000	3.032	-0.032
Obs39	3.400	3.417	-0.017
Obs40	3.500	3.321	0.179

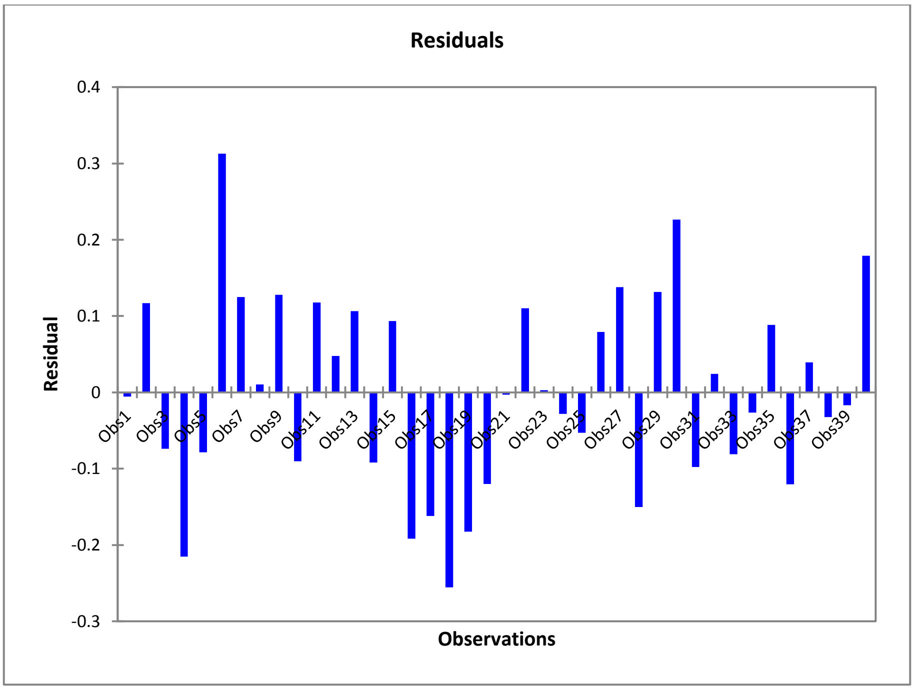


Fig. 40: Residuals for depth of penetration

We can further do the **mathematical modelling using third order equation** to get more accurate predicted value. The general equation of third order equation is given below:

Y= pr1+pr2*X1+pr3*X2+pr4*X3+pr5*X4+pr6*X1^2+pr7*X2^2+pr8*X3^2+pr9*X4^2+pr10*X1^3+pr11*X2^3+pr12*X3^3+pr13*X4^3

Following **third order quadratic equations** are formed using XLSTAT software:

1) Measuring width, W = -2077.65618096662+7.84926747620218*Welding current,I-9.58131968471277*ArcVoltage,V+7.70611255341*WeldingSpeed,Ws+10.3466700780934*Electrodestickout,N-2.07635323447165E02*I^2+0.446144005625769*V^2-1.78734136255057E-02*Ws^2-0.500488305376608*N^2+1.82493048643253E-05*I^3-6.77660998310262E-03*V^3+1.37536409327361E-05*Ws^3+7.89325151448788E-03*N^3

2) Reinforcement, R = 1002.97135822042-2.76614786754684*I-5.7645650502509*V-4.79966835483631*Ws+2.41730186245408*N+7.63738549825267E-03*I^2+0.292974229873401*V^2+1.17404250670642E-02*Ws^2-8.90551219417637E-02*N^2-6.99069053929241E-06*I^3-4.82336959089397E-03*V^3-9.53547940359182E-06*Ws^3+9.29801013218911E-04*N^3

3) DepthofPenetration,P=-236.976818960062+1.51463290967821*I-2.65377282438448*V+0.469938239734395*Ws+1.37355667970936*N-4.0630392268202E-03*I^2+0.115907391481284*V^2-1.17945238996864E-03*Ws^2-5.75635079077229E-02*N^2+3.62131355313157E-06*I^3-1.65936539779588E-03*V^3+9.7939362127702E-07*Ws^3+7.78745960896252E-04*N^3

PREDICTIONS AND RESIDUALS

A) TABLE 10: For Measured width

Observations	Measured width	Pred(Measured Width)	Residuals
Obs1	10	10.018	-0.018
Obs2	10.2	10.787	-0.587
Obs3	10.5	10.854	-0.354
Obs4	10.2	9.432	0.768
Obs5	10.5	10.587	-0.087
Obs6	10.5	10.140	0.360
Obs7	11	10.658	0.342
Obs8	11.2	11.052	0.148
Obs9	10.1	10.166	-0.066
Obs10	10.3	10.418	-0.118
Obs11	10.5	10.580	-0.080
Obs12	10.2	10.703	-0.503
Obs13	10.5	10.937	-0.437
Obs14	11.1	10.419	0.681
Obs15	11.3	10.956	0.344
Obs16	10.5	11.419	-0.919
Obs17	10.5	10.546	-0.046
Obs18	10.2	10.303	-0.103
Obs19	10.2	10.109	0.091
Obs20	10.5	10.351	0.149
Obs21	10.1	9.960	0.140
Obs22	10.4	9.939	0.461
Obs23	10.2	9.480	0.720
Obs24	10.2	10.986	-0.786
Obs25	10.5	10.521	-0.021
Obs26	10.5	10.315	0.185
Obs27	10	10.074	-0.074
Obs28	10	9.693	0.307
Obs29	10.5	10.945	0.555
Obs30	10.7	10.785	-0.085
Obs31	10	10.850	-0.850
Obs32	10.6	10.119	0.481
Obs33	10.5	10.959	-0.459
Obs34	10.2	10.704	-0.504
Obs35	10.7	11.014	-0.314
Obs36	10.5	10.567	-0.067
Obs37	10.5	10.285	0.215

Obs38	10.6	10.545	0.055
Obs39	10.2	10.352	-0.152
Obs40	10.3	9.674	0.626

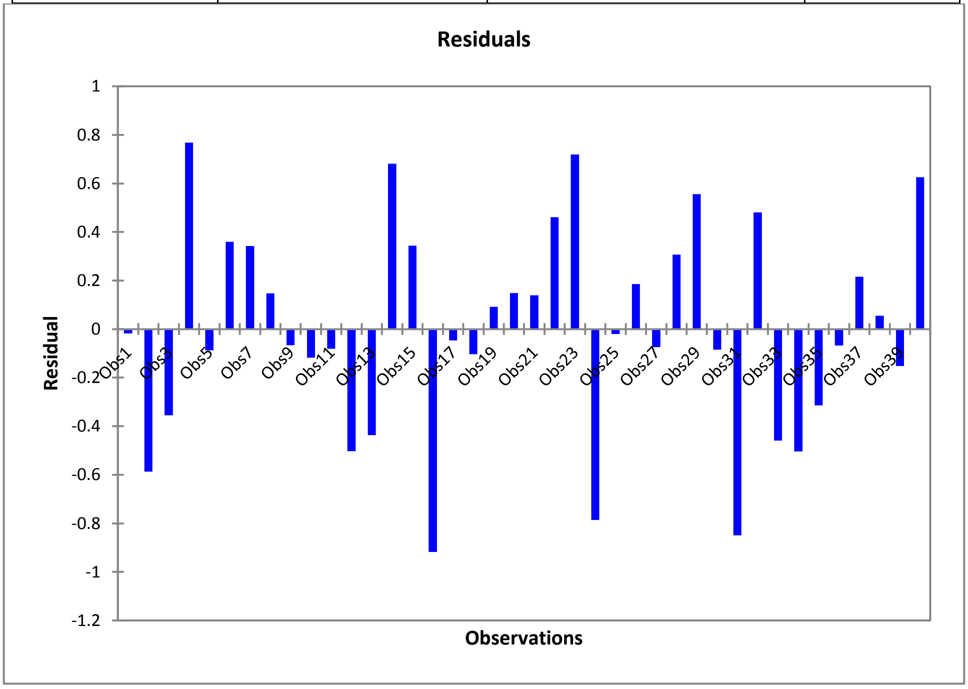


Fig. 41: Residuals for width

B) TABLE 11: For Reinforcement

Observations	Reinforcement	Pred(Reinforcement)	Residuals
Obs1	2.000	2.076	-0.076
Obs2	2.200	2.158	0.042
Obs3	3.000	2.872	0.128
Obs4	2.400	2.414	-0.014
Obs5	2.200	2.675	-0.475
Obs6	2.500	2.491	0.009
Obs7	2.400	2.761	-0.361
Obs8	3.200	2.694	0.506
Obs9	3.300	2.401	0.899
Obs10	2.500	2.725	-0.225
Obs11	2.700	2.740	-0.040
Obs12	2.800	2.571	0.229
Obs13	2.000	2.488	-0.488
Obs14	2.200	2.211	-0.011
Obs15	2.200	2.260	-0.060
Obs16	2.000	2.211	-0.211
Obs17	2.600	2.211	0.389
Obs18	2.500	2.785	-0.285
Obs19	3.000	2.924	0.076
Obs20	3.200	3.144	0.056

Obs21	3.500	3.344	0.156
Obs22	3.700	3.617	0.083
Obs23	3.600	3.671	-0.071
Obs24	3.200	3.120	0.080
Obs25	2.400	2.579	-0.179
Obs26	2.000	2.041	-0.041
Obs27	2.200	2.395	-0.195
Obs28	2.300	2.336	-0.036
Obs29	2.500	2.659	-0.159
Obs30	2.700	2.777	-0.077
Obs31	2.500	2.895	-0.395
Obs32	3.000	2.977	0.023
Obs33	3.200	3.095	0.105
Obs34	3.500	3.450	0.050
Obs35	3.700	3.587	0.113
Obs36	3.000	3.403	-0.403
Obs37	3.300	2.997	0.303
Obs38	2.500	2.415	0.085
Obs39	3.100	2.894	0.206
Obs40	3.000	2.734	0.266

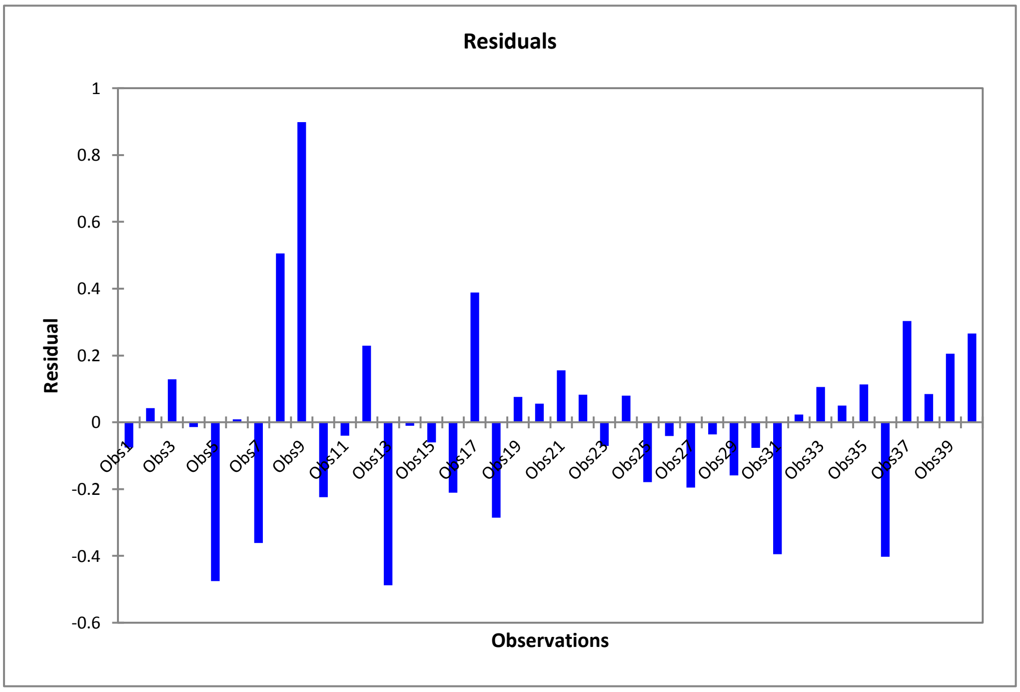


Fig. 42: Residuals for reinforcement

C) TABLE 12: For Depth of Penetration

Observations	Depth of Penetration	Pred(Depth of Penetration)	Residuals
Obs1	3.200	3.185	0.015
Obs2	3.400	3.246	0.154
Obs3	3.000	3.040	-0.040
Obs4	3.000	3.138	-0.138
Obs5	3.100	3.281	-0.181
Obs6	3.500	3.255	0.245
Obs7	3.500	3.456	0.044
Obs8	3.300	3.369	-0.069
Obs9	3.400	3.297	0.103
Obs10	3.200	3.276	-0.076
Obs11	3.400	3.250	0.150
Obs12	3.300	3.245	0.055
Obs13	3.400	3.326	0.074
Obs14	3.200	3.275	-0.075
Obs15	3.500	3.415	0.085
Obs16	3.100	3.275	-0.175
Obs17	3.200	3.400	-0.200
Obs18	3.000	3.214	-0.214
Obs19	3.100	3.167	-0.067
Obs20	3.200	3.263	-0.063
Obs21	3.300	3.263	0.037
Obs22	3.400	3.280	0.120
Obs23	3.200	3.199	0.001
Obs24	3.300	3.273	0.027
Obs25	3.300	3.343	-0.043
Obs26	3.200	3.141	0.059
Obs27	3.500	3.317	0.183
Obs28	3.100	3.270	-0.170
Obs29	3.400	3.249	0.151
Obs30	3.400	3.188	0.212
Obs31	3.200	3.319	-0.119
Obs32	3.400	3.380	0.020
Obs33	3.200	3.319	-0.119
Obs34	3.200	3.255	-0.055
Obs35	3.300	3.234	0.066
Obs36	3.100	3.208	-0.108
Obs37	3.200	3.133	0.067

Obs38	3.000	3.045	-0.045
Obs39	3.400	3.461	-0.061
Obs40	3.500	3.349	0.151

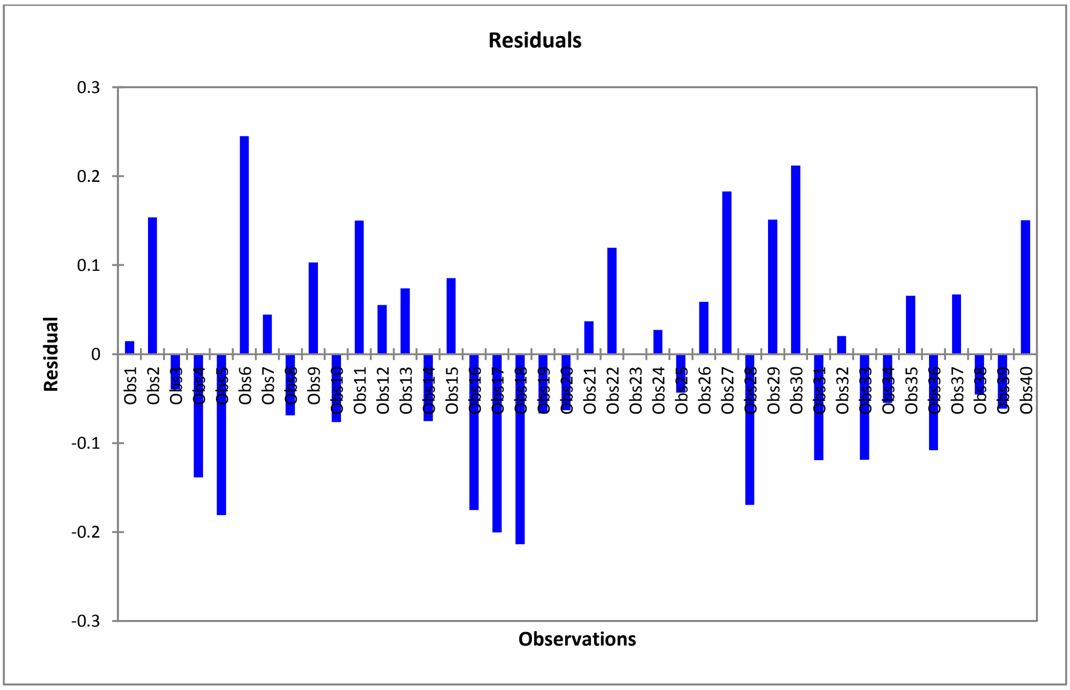


Fig. 43: Residuals for depth of penetration

MICROSTRUCTURE

Microstructure is defined as the structure of a prepared surface or thin foil of material as revealed by a microscope above 25× magnification. The microstructure of a material (which can be broadly classified into metallic, polymeric, ceramic and composite) can strongly influence physical properties such as strength, toughness, ductility, hardness, corrosion resistance, high/low temperature behaviour, wear resistance, and so on, which in turn govern the application of these materials in industrial practice.

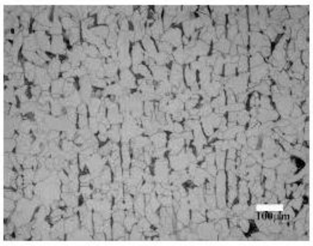
SAMPLE 1	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	410	21	380	18
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.5	2.5	3.4	

Fig. 44: Microstructure of sample 1

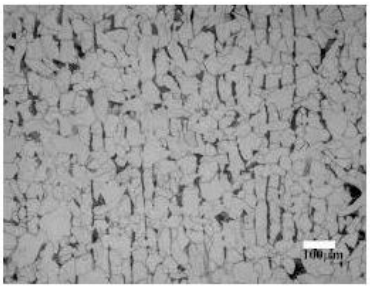
SAMPLE 2	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	410	23	380	18
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.2	2.5	3.2	

Fig. 45: Microstructure of sample 2

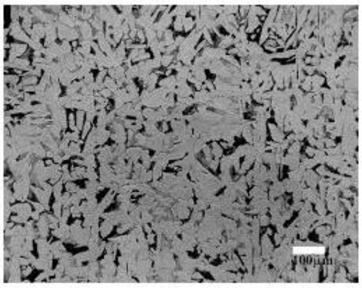
SAMPLE 3	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	410	25	380	20
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.7	3.1	3.4	

Fig. 46: Microstructure of sample 3

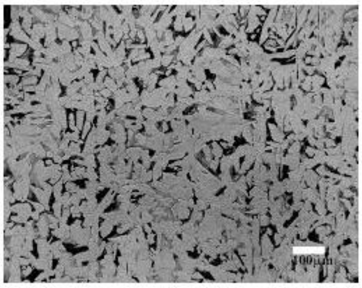
SAMPLE 4	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	410	27	420	20
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	11.3	3	3.5	

Fig. 47: Microstructure of sample 4

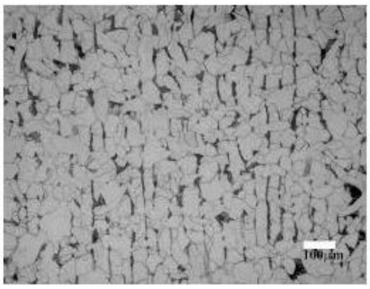
SAMPLE 5	Current (Amp)	Voltage (Volts)	Welding speed (mm/ min)	Electrode stick out (mm)
	410	21	400	18
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	13.7	2.7	3.4	

Fig. 48: Microstructure of sample 5

CONCLUSIONS

1) In this project, study on Submerged Arc Welding has been done.
2) Also, report has presented the application of Design of Experiment & regression analysis to determine the optimal process parameter for SAW process. Experimentation was done according to Design of experiments.
3) Graphs have been plotted using design expert software.
4) The proposed mathematical model is used to form the equations for linear regression analysis.
5) The proposed mathematical model is used to form the equations for non- linear (second order equations) analysis.
6) The proposed mathematical model is used to form the equations for non- linear (third order equations) analysis.
7) Predictions of welding parameters have been done using linear equations and residuals have been calculated by comparing experimental values and predicted values.
8) Predictions of welding parameters have been done using non-linear equations (second order) and residuals have been calculated by comparing experimental values and predicted values.
9) Predictions of welding parameters have been done using non-linear equations (third order) and residuals have been calculated by comparing experimental values and predicted values.
10) Residual graph has been plotted for different welding parameter.
11) Microstructures of different samples of submerged arc welds have been measured.

APPENDIX A

OBSERVATIONS OF SAMPLES

SAMPLE 1	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	330	19	380	18
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10	2	3.2	

SAMPLE 2	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	330	19	380	20
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.2	2.2	3.4	

SAMPLE 3	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	330	21	420	18
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.5	3	3	

SAMPLE 4	Current (Amp)	Voltage (Volts)	Welding speed (mm/ min)	Electrode stick out (mm)
	330	21	400	22
	Width (mm)	Reinforcement (mm)	Penetration (mm)	
	10.2	2.4	3	

SAMPLE 5	Current (Amp)	Voltage (Volts)	Welding speed (mm/ min)	Electrode stick out (mm)
	350	19	420	20
	Width (mm)	Reinforcement (mm)	Penetration (mm)	
	10.5	2.2	3.1	

SAMPLE 6	Current (Amp)	Voltage (Volts)	Welding speed (mm/ min)	Electrode stick out (mm)
	350	19	420	22
	Width (mm)	Reinforcement (mm)	Penetration (mm)	
	10.5	2.5	3.5	

SAMPLE 7	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	350	23	380	20
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	11	2.4	3.5	

SAMPLE 8	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	350	23	400	22
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	11.2	3.2	3.3	

SAMPLE 9	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	370	19	380	18
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.1	3.3	3.4	

SAMPLE 10	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	370	21	380	18
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.3	2.5	3.2	

SAMPLE 11	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	370	21	400	22
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.5	2.7	3.4	

SAMPLE 12	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	370	23	400	24
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.2	2.8	3.3	

SAMPLE 13	Current (Amp)	Voltage (Volts)	Welding speed (mm/ min)	Electrode stick out (mm)
	370	25	400	24
	Width (mm)	Reinforcement (mm)	Penetration (mm)	
	10.5	2	3.4	

SAMPLE 14	Current (Amp)	Voltage (Volts)	Welding speed (mm/ min)	Electrode stick out (mm)
	370	27	420	24
	Width (mm)	Reinforcement (mm)	Penetration (mm)	
	11.1	2.2	3.2	

SAMPLE 15	Current (Amp)	Voltage (Volts)	Welding speed (mm/ min)	Electrode stick out (mm)
	370	27	400	22
	Width (mm)	Reinforcement (mm)	Penetration (mm)	
	11.3	2.2	3.5	

SAMPLE 16	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	370	27	420	24
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.5	2	3.1	

SAMPLE 17	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	370	27	460	22
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.5	2.6	3.2	

SAMPLE 18	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	390	19	400	20
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.2	2.5	3	

SAMPLE 19	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	390	21	400	22
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.2	3	3.1	

SAMPLE 20	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	390	23	380	18
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.5	3.2	3.2	

SAMPLE 21	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	390	23	400	20
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.1	3.5	3.3	

SAMPLE 22	Current (Amp)	Voltage (Volts)	Welding speed (mm/ min)	Electrode stick out (mm)
	390	25	420	20
	Width (mm)	Reinforcement (mm)	Penetration (mm)	
	11.4	3.7	3.4	

SAMPLE 23	Current (Amp)	Voltage (Volts)	Welding speed (mm/ min)	Electrode stick out (mm)
	390	25	440	18
	Width (mm)	Reinforcement (mm)	Penetration (mm)	
	11.2	3.6	3.2	

SAMPLE 24	Current (Amp)	Voltage (Volts)	Welding speed (mm/ min)	Electrode stick out (mm)
	390	27	440	20
	Width (mm)	Reinforcement (mm)	Penetration (mm)	
	10.2	3.2	3.3	

SAMPLE 25	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	390	27	460	20
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.5	2.4	3.3	

SAMPLE 26	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	390	25	460	26
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.5	2	3.2	

SAMPLE 27	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	390	27	460	22
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10	2.2	3.5	

SAMPLE 28	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	410	19	380	18
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10	2.3	3.1	

SAMPLE 29	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	410	21	380	18
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.5	2.5	3.4	

SAMPLE 30	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	410	21	400	18
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.7	2.7	3.4	

SAMPLE 31	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/min)**	**Electrode stick out (mm)**
	410	23	380	18
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.5	2.5	3.2	

SAMPLE 32	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/min)**	**Electrode stick out (mm)**
	410	21	400	20
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.6	3	3.4	

SAMPLE 33	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/min)**	**Electrode stick out (mm)**
	410	23	400	20
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.5	3.2	3.2	

SAMPLE 34	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	410	23	420	20
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.2	3.5	3.2	

SAMPLE 35	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	410	23	440	20
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.7	3.7	3.3	

SAMPLE 36	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	410	23	440	22
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.5	3	3.1	

SAMPLE 37	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	410	23	440	24
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.5	3.3	3.2	

SAMPLE 38	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	410	23	440	26
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.6	2.5	3	

SAMPLE 39	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	410	25	380	20
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	10.2	3.1	3.4	

SAMPLE 40	**Current (Amp)**	**Voltage (Volts)**	**Welding speed (mm/ min)**	**Electrode stick out (mm)**
	410	27	420	20
	Width (mm)	**Reinforcement (mm)**	**Penetration (mm)**	
	11.3	3	3.5	

CHAPTER 5
References

1. American Society for Metals. *Metals handbook,* Vol. 6,9th Ed, *114-152.* Metals Park, Ohio: American Society for Metals, *1983,*
2. Bailey, N. and Jones, S. B. "The solidification mechanics of ferritic steel during submerged arc welding." *Welding Journal 57(8): 217s-231s;* August *1978.*
3. Butler, C. **A,,** and Jackson, C. E. "Submerged arc welding characteristics of the CaO-Ti02-Si02 system." *Welding Journal 46(10):4 48~456s*O*;* ctober *1967.*
4. Chandel, R. *S.* "Mathematical modeling of melting rates for submerged arc welding." *Welding Iournal 66(5): 135s-139s;* May *1987.*
5. Dallam, C.B., Liu, ***S.,*** and Olson, D.L. "Flux composition dependence of microstructure and toughness of submerged arc HSLA weldments." *Welding Journal 64(5): 1405-1515;* May *1985.*
6. Eager, T. W. "Sources of weld metal oxygen contamination during submerged arc welding." *WeldingJournal57 (3): 76s-80s;* March *1978.*
7. Ebert, H. W. and Winsor, F. J. ''Carbon steel submerged arc welds **-** Tensile strength vs. corrosion resistance." *Welding Journal 59(7): 193s-19 8s;* July *1980.*
8. Fled, N. **A.** et al. "The role of filler metal wire and flux composition in submerged arc weld metal transformation kinetics." *Welding Journal65(5): 113s;* May *1986.*
9. Gowrisankar, I. et al. "Effect of the number of passes on the structure and properties of submerged arc welds of AIS1 typc *316L* stainless steel." *Welding Journal 66(5): 147s-151s;* May *1987.*
10. Hantsch, H. et al. "Submerged arc narrow-gap welding of thick walled components." *Welding Journal 61(7): 27- 34;* July *1982.*
11. Hinkel, J. E., and Forsthoefel, F. W. "High current density submerged arc welding with twin electrodes." *Welding Journal* **55(3):** *175-180;* March *1976.*
12. Philips Ross J, Taguchi Technique for quality engineering (Mc Graw Hill Company), 1989
13. Peace G S, Taguchi Methods, A hand on approach, (Addison Wesley, USA), 1993
14. H.L. Tsai, Y.S. Tarng and C.M. Tseng, "Optimization of SAW process parameters in Hardfacing", 1996
15. Abdul Ghani Khan M, Prasanth, S Jebraj, A Lakshmi Narayan PR & KrishnaMohan "Optimization of friction welding parameters using Taguchi Technique", Anna University India, 2003
16. Edwin Raja Dhas, J. & Satheesh M., "Multiple objective optimization of SAW using grey based Fuzzy logic", 2007
17. Saurav Datta and Siba Sankar Mahapatra, "Multi objective optimization of SAW process", 2009.
18. Dhas J.E., R and Kumanan S., "Weld quality prediction of SAW process using a function replacing hybrid system, 2010.
19. Bipin Kumar, S.P. Tewari, Jyoti Prakash, " A review on Arc Welding parameters on Mechanical behaviours of Ferrous metals alloys", 2010.
20. Tay and Butler "An application of an integrated method using experimental designs and neural network technologies for modeling and optimizing a metal inert gas (MIG) welding process.", 1996
21. Correia et al. "Genetic Algorithm (GA) to decide near-optimal settings of a GMAW welding process.", 2004
22. Dongcheol et al. " the use of Genetic Algorithm and Response Surface Methodology (RSM) for determining optimal welding conditions.", 2002

23. Hsien-Yu Tseng " an integrated approach to address the welding economic design problem", 2006.
24. Zhao et al. " the performance –predicting problems in the spot welding of the body-galvanized steel sheets", 2006.
25. Pasandideh and Niaki " a new methodology for solving multi-response statistical optimization problems", 2006.
26. Praga-Alejo et al. " the Neural Network (NN) with GA as a complement are good optimization tools"., 2008.
27. Gunang ,"Prediction and optimization of weld bead value for the SAW using mathematical models", 2007.
28. Murgan, "Prediction and control of weld bead geometry and shape relationship, in SAW of pipes", 2002.
29. Unal & Dean "the approach of Taguchi to obtain design optimization in the manufacturing process", 2003.
30. L.J. Yang, R.S. Chandel and M.J. Bibby "investigating the effects of process variables on the bead width of submerged-arc weld deposits", 2001.
31. N. Murugan, R.S. Parmar and S.K. Sud, "discussing the effect of submerged arc process variables on dilution and bead geometry in single wire surfacing", 2007
32. R.S. Chandel, H.P. Seow, F.L. Cheong " predicting the effect of increasing deposition rate on the bead geometry of submerged arc welds", 1998
33. K. Y. Benyounis, A. G. Olabi " optimization of different welding processes using statistical and numerical approaches, developed a mathematical relationship between the welding process input parameters", 2000.
34. Serdar Karaoğlu and Abdullah Seçgin "sensitivity analysis of parameters and fine tuning requirements of the parameters for optimum weld bead geometry", 2001
35. N.D. Pandey, A. Bharti and S.R. Gupta ," studying the effect of submerged arc welding parameters and fluxes on element transfer behavior and weld-metal chemistry", 2002.
36. S. W. Wen, P. Hilton and D. C. J. Farrugia , " Finite element modeling of a submerged arc welding process", 2004
37. Prasanta Kanjilal; Tapan Kumar Pal ;Sujit Kumar Majumdar, "studying the prediction of mechanical properties in submerged arc weld metal", 2003
38. A Sharma, N Arora, B K Mishra " study of statistical modeling of deposition rate in twin-wire submerged arc welding", 2006
39. Viano, D.M.; Ahmed, N.U.; Schumann, G.O., " the influence of heat input and travel speed on microstructure and mechanical properties of double tandem submerged arc high strength low alloy steel", 2002.
40. De-liang Ren, Fu-ren Xiao, Peng Tian, Xu Wang and Bo Liao, " the effects of welding wire composition and welding process on the weld metal toughness of submerged arc welded pipeline steel", 2005.