OPTIMIZATION OF SUBMERGED ARC WELDING PARAMETERS FOR JOINING SS304 AND MS1018 DISSIMILAR METAL WELDING

DISSERTATION-II

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CERTIFICATE

This is certify that the thesis report entitled **"OPTIMIZATION OF SUBMERGED ARC WELDING PARAMETERS FOR JOINING SS304 AND MS1018 DISSIMILAR METAL WELDING."** being submitted by Sukhbaj singh to Lovely Professional university, Phagwara, Punjab, in partial fulfillment of the requirement for the award of the Degree of Master of Technology (Spl. in Manufacturing Technology) is a record of student's own work carried my supervision and guidance.
The matter presented in this dissertation has not been submitted by me anywhere for the award of any other degree or to any other institute.

(Sukhbaj singh)

This is to certify that the above statement made by the candidate is correct to best of my knowledge.

(Mr. Jasvinder singh)
(Supervisor)

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(External)

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ABSTRACT

SAW process has successfully used for joining a dissimilar metal AISI 304L stainless steel and mild steel. In this study, a statistical design of experiment (DOE) was used to optimize selected parameters (welding Current (I), Voltage (V), Welding Speed (S), Nozzle to plate distance (D)). Half frictional factorial approach was used to design the experimental layout, each factors having 2 levels. Tensile strength, micro Hardness, Impact load was determined using the universal testing machine (UTM), micro vicker Hardness machine and Impact load by charpy method. The main objective of this dissertation is optimizing various Submerged arc welding parameters including welding Voltage (V), welding Current (I), Nozzle to plate distance (D) (NPD) and Welding Speed (S) by developing a mathematical model for weld Tensile strength, Hardness, Impact load of a mild steel and stainless steel(309)specimen. This mathematical model is developed with the help of the design of Matrix. This experimental study aims at half Factorial design approach has been applied for finding the relationship between the various process parameters. And after that we can easily find out that which parameter will be more affect or which parameter will be more influence variable to mechanical properties of the material.

Key Words: SAW, HAZ, Impact load, flux, residual stresses, Mechanical Properties, Micro Hardness, mild steel, SS 304, Tensile Strength.

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Nomenclature and Abbreviations

SS	Stainless steels
MS	Mild steel
SAW	Submerged arc welding
HAZ	Heat affected zone
U.T.S	Ultimate Tensile strength
Y.S	Yield strength
MPa	Mega Pascal
DCEN	Direct Current (I) electrode negative
DCEP	Direct Current (I) electrode positive
AC	Alternating Current (I)
Q	Heat input
I	Welding Current (I)
V	Welding Voltage (V)
S	Welding Speed (S)
N	Nozzle to plate distance (D)
K	Thermal efficiency factor
Kj	kilo joules
Kj/mm	Heat input per unit length per pass
DOE	Design of experiment
DF	Degree of freedom

CHAPTER 1

INTRODUCTION

1.1 Welding:-

Welding is the process of joining two same or different metals with the application of heat with pressure or without pressure with or without filler rod. Welding is used in every branch of science and technology. Such as electronic industries, mechanical industries, computer industries.

1.2 Classification of welding:-

There are many ways in which welding can be classified:-

I.Arc welding process

a. Shield metal welding
b. Submerged Arc Welding
c. Gas metal arc welding
d. Plasma arc welding

II.Resistance welding process

a. Spot welding
b. Seam welding
c. Projection welding

III.Solid state welding

a. Friction welding
b. Explosive welding
c. Ultrasonic welding

IV.Oxy-fuelgas welding

a. Gas welding

V.Thermit welding process

VI.Radiant energy welding process

a. Electron beam welding
b. Laser beam welding

1.3 Advantages of welding:-

a. Welding joints are stronger as stronger as the base metal.
b. Welding joints has efficiency upto 100%.
c. Appearance of the welding joints is very good.
d. Welding joints are light in weight.
e. Welding is a permanent joint.

1.4 **<u>Limitation of welding</u>**:-

a. Distortion due to high temperature possible in workpiece.
b. Skill persons are required for the welding.
c. Ultra-violet rays and infrared rays generate during the welding which very harmful for operator's skin as well as eyes.
d. Weld heat produces metallurgical change in workpiece.
e. Special jigs and fixture are required.

1.5 **<u>Application of weldings</u>:-**

a. Automobiles industries
b. Railroad industries
c. Storage tanks
d. Pipeline
e. Shipbuilding industries
f. Pressure vessels and tanks
g. Building industries

1.6 **<u>Submerged arc welding</u>:-**

It is the arc welding process which is produced by heating with an arc setup between electrode and workpiece under a blanket of flux. Metal electrode continuously feed and acts as a filler material. No any pressure is applied during this process. This process is completed without usual spark, smoke and spatter.

1.7 **Working principle**:-

As the trigger is pulled the flux starts deposing from the hopper on the joint to be welded, arc may be generate either by touching the electrode with the job or by placing the steel wool in between the electrode and workpiece before switching on the Current (I). the arc length can keep constant by using the principle of self adjustment of the arc.

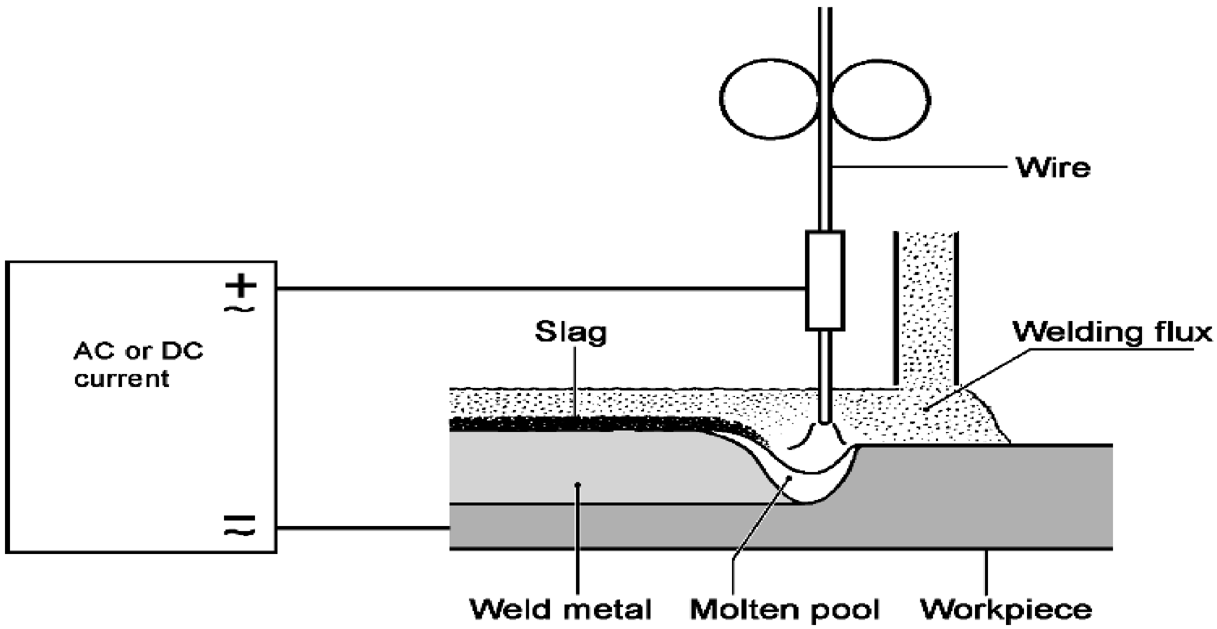


Figure 1.1 principle of submerged arc welding.

1.8 **Welding equipments**:-

a. Flux hopper
b. Welding head
c. Welding power source
d. Flux
e. Electrode

1.9 Welding parameters:-

a. Arc Voltage (V)
b. Arc Current (I)
c. Welding Speed (S)
d. Nozzle to plate distance (D)

1.9.1 Arc Voltage (V):-

Arc Voltage (V) is also known as welding Voltage (V). It means the potential difference between the electrode and the molten weld. As the arc Voltage (V) increases, the bead will be wider and also decrease in penetration. As the arc Voltage (V) decrease, the bead width will be shorter and alternately increase in penetration of the weld.

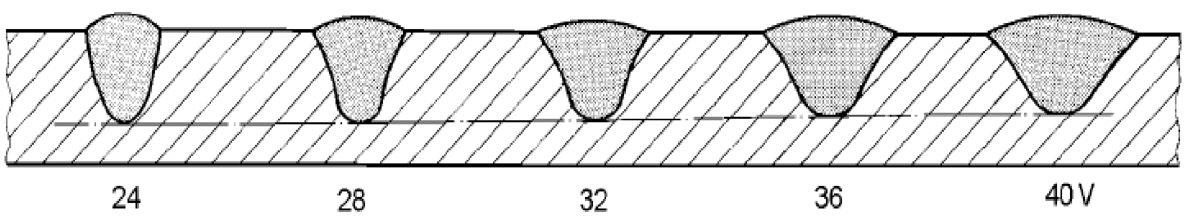


Figure 1.2 Effect on the weld due to Arc Voltage (V).

1.9.2 Welding Current (I) :-

Welding Current (I) is a parameter that has greatest factor on the penetration of the weld. The Current (I) setting depends upon the thickness of the metal and also depends upon the type of joint. The Current (I) has no special effect on the width of the bead, but very high Current (I) can make hole in the base metal, so as increasing the welding Current (I) there is increase in the penetration or as we decrease the welding Current (I) there is decrease in the penetration of the weld.

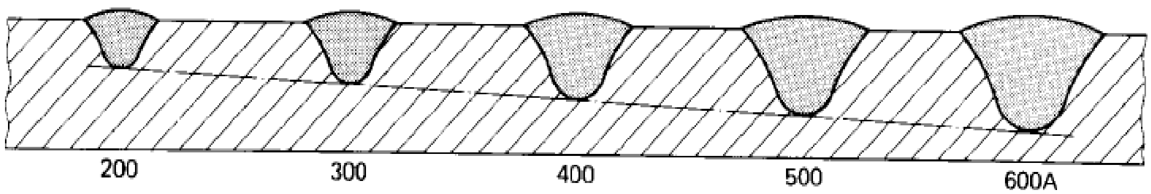


Figure 1.3 Effect on the weld due to welding Current (I).

1.9.3 Welding Speed (S):-

By Increasing in the Welding Speed (S) there is lesser penetration, lower the heat input per unit length of the weld. Very high Speed of the arc travel decrease in the fusion between the weld deposit and the parent metal, and increase in arc blow, porosity and irregular bead shape. As the travel Speed of the arc decreased there is increment in the penetration. If the Welding Speed (S) has to changed while keeping constant penetration, it is compulsory to do adjustment in the welding Current (I).

1.9.4 Nozzle to plate distance (D):-

Nozzle to plate distance (D) is an important parameter that affects on the heating of the tip of the wire. If the stick-out is less, a little heat will be generate in the wire and penetration become increase. And as the stick-out length becomes increased, the temperature of the wire increases and penetration become reduced, so the rate of deposition will increased.

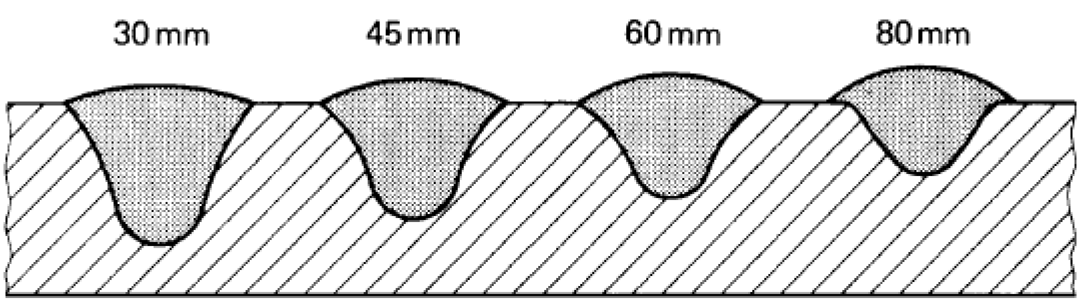


Figure 1.4 Effect on the weld due to Nozzle to plate distance (D).

1.10 Advantage of submerged arc welding:-

a. High weld metal quality.
b. High electrode deposition efficiency.
c. No smoke generated, hence minimum need for protecting clothing.
d. Smooth and uniform weld finish with no spatters.
e. Very high deposition rate and Welding Speed (S).
f. Welder's manipulative skill not required; minimum operator fatigue.

1.11 Applications:-

a. Pressure vessels
b. Pipelines
c. Storage tanks
d. Ships
e. Railways wagons and coaches

1.12 Types of flux used in submerged arc welding:

1. Fused flux
2. Agglomerated flux

1.12.1 Fused flux:-

A **fused flux** is a homogeneous substance that melted together to form a glass-like substance, which will then crushed and ground before finally classified to suitable grain size. The constituents such as manganese dioxide(MnO_2) and limestone with small quantities of fluorspar and aluminum oxide(Al_2O_3) are melted in an electric arc furnace where MnO_2 is reduced to MnO. The grain size varies from 0.2 to 1.6 mm dia. this is one the oldest flux used.

1.12.2 Agglomerated flux:-

In an **agglomerated flux**, this flux can be formed by 'rolling' the various constituents on rotating drum, cone or dish, with water glass as additive. The final product will be then dried at a temperature of 800 -900 °C. After drying the flux, it gives an approximately the same grain size as the size of fused flux.

Element to Add in flux to produce extra properties:-

1. Easy slag removal and good weld appearance.
2. High resistance to porosity.
3. Low specific flux consumption.

Type of the flux	**Benefits of the flux**	**Drawbacks of the flux**
Fused flux	Fused flux is Non-hygroscopic It has High grain strength.	Alloying elements cannot be incorporated in the flux High specific density (approx. 1.6 kg/l)
Agglomerated	Alloying elements can be included in the flux. It has Low specific density (approx. 0.8 kg/l)	Hygroscopic Relatively low grain strength

Table 1.1 Different type of flux and there benefits and drawbacks.

1.13 **Residual stress**:-

Residual stress may be defined as the stress inside the component of structure after removing all the external applied force.

Compressive residual stress acts while we compress the material together. These forces are generally negative (-) in nature.

Tensile residual stress acts while we pull the material apart from each other. These forces are generally positive in nature.

Unites of stress:-

The SI units for the residual stress are in MPa

6.895 MPa=1 ksi*

*ksi stands for kilo pound force per square inch.

1.13.1 **Types of residual stress**:-

1. Macro-stress
2. Micro-stress

1.13.2 **Causes and factor of residual stress**:-

1. **Causes**:-
   a. By different melting temperature.
   b. By different thermal expansion coefficient.
   c. By different thermal conductivity.
2. **Factors** :-
   a. Quality of the parent metal, filler rod, quality electrode of electrode.
   b. Joint nature and method of welding.
   c. Value of Current (I).

d. Speed of the welding arc.

e. Cooling rate.

Chapter 2

Literature review

2.1 Introduction :-

Literature survey is the important part of any project work. A large volume of literature is available in journals and books on this particular grade i.e. AISI 304 and mild steel explaining various mechanical effects. Following are some of the literature worth mentioning to get the direction of work and relevance to a large extent.

2.2 Literature Surveyed :-

Ramazan et. al. [2002] studied the mechanical properties of austenitic stainless steels welded by GMAW and GTAW. In this study, AISI 304L and 316L types of austenitic stainless steels were welded by GMAW using only ER 316LSi filler metal and GTAW using ER 308L and ER 316L filler metals, respectively. Mechanical properties of 304L and 316L austenitic stainless steel weldments, such as Tensile properties, Hardness and Impact properties were determined. The results show that the yield and Tensile strength, Hardness and Impact energy values of 304L and 316L stainless steels welded by GTAW are higher than that of welded by GMAW.[1]

Behcet gulence et. at. [2003] discovered that the submerged arc welding process is mostly used due to the high Current (I) and ability to deposit a large amount of weld metal using more than one wire at the same time and especially in the restoration of the worn parts. The results shows that the hardest weld metal has higher wear resistance, and the low hard weld metal showed low wear resisctance.[2]

A. joseph et. at. [2005] discovered that the maximum Tensile residual stress in the dissimilar welded joints with or without the buttering layer are almost the same. however the residual stress present in the HAZ of the ferrite steel of the dissimilar joints with a buttering layer are less significantly than those of a dissimilar welded joints without buttering layer.[3]

Ana. Ma. Paniagua Mercado et. al.[2005] discovered that the effect of flux composition for Tensile properties and microstructure of a submerged-arc weld AISI 1025 steel. There were three flux composition used with a low-carbon electrodes. The welding condition was allmost same as before. Tension tests did at the room temperature. Macrostructure and microstructure of welds were observed with the light and scanning electron microscopes (SEM). The presence of ferrite was detected for welds of fluxes with the highest value of titanium oxide. The ultimate and yield Tensile strengths were affected by the presence of ferrite. The elongation and area reduction percentages were influanced by the volume percentage. Microstructure and Tensile properties were compared with the values predicted by the computer programs.[4]

D. Gery et. at. [2005] discovered that heat source model is based on Goldak's double-ellipsoid heat flux distribution. C++ programme was developed to investigate heat inputs into finite element thermal simulation of the plate butt joint welding. The temperature variations and transient temperature distributions of welded plates during welding were predicted and the heat affected zone and fusion zone were obtained. Effects of energy input, Welding Speed (S) and heat source distribution on temperature changes for the further calculations.[5]

Keshav Prasad et. at. [2006] discovered that the affect of the submerged arc welding on the Hardness, microstructure and the microstructure of the plain carbon steel weld joint. He analyze the result on the basis of heat input. SAW process was used for welding a 16 mm thickness plates of plain carbon steel. Results shows that Hardness changes from weld center line to the base metal and the peak Hardness was found at the heat affected zone .the increase in the heat input coarsen of the grain structure both in the weld metal and Hardness. The increase in the welding Current (I) at given Speed increased toughness and increase in the welding Current (I) lower the toughness.[6]

Kannan et. al. [2006] concluded that Dilution increases with the rise in welding Current (I) and Welding Speed (S) and decreases with the rise in Nozzle-to-plate distance and welding torch angle. Weld bead width increases with the rise in welding Current (I). Penetration increases with the rise in welding Current (I) and Welding Speed (S) and decreases with the rise in Nozzle-to-plate distance and welding torch angle. Bead width increases with the increase in welding Current (I) at all levels of Welding Speed (S).[7]

P.kanjilal et. al. [2006] discovered that Among all the welding parameters, polarity has a highest influence on weld metal's chemical composition. The influence of Welding Speed (S) on the weld metal carbon content through oxidation reaction; whereas weld metal sulphur and phosphorous contents are affected by the dilution of weld deposit.[8]

Karzov and Timofeev et. al. [2006] had analyzed the events of failure of pipelines made of austenitic stainless steel because from the experience of operation of power generating equipments at nuclear power plant in Russia and the other countries shows that some elements of this equipment (for most part, welded joints made of austenitic stainless steels) fails during designed service life. On the basis of the analysis it was concluded that the condition required for the initiation of inter crystalline corrosion cracking (ICCC) in austenitic stainless steels can be formulated as combined action of following three factors: the structural state of steel, chemical composition of the aqueous media and high level of stress. By changing even one of these factors, the process can be decelerated or even completely eliminated.[9]

S kumanana et. al. [2007] discovered that detremination of the submerged arc welding process parameter. In this signal-to-noise ratios are computed to determine the optimum parameters. The percentage contribution of each factor is validated by analysis of variance techniques. the result from the ANOVA indicate that the welding Current (I) and arc Voltage (V) are the significant welding process parameters that affect the bead witdh,depth of penetration and bead Hardness.[10]

E.m. anawa et. at. [2008] found that the Welding Speed (S) has the strongest effect on the residual stress among the studied parameter. So increasing in the Welding Speed (S) decreasing in the residual stress and lesser in the Welding Speed (S) can be applied successfully for the joining dissimilar metals.[11]

Serdar Karaog lu et. al. [2008] discovered that the process parameter that have high influence on the quality of the welded connection. Mathematically modeling can be used in the optimization of the process parameters. The study mainly focus on the sensitivity analysis of the parameters and very less adjustment requirement such as welding Voltage (V), welding Current (I) and Welding Speed (S) are used as design variables. Effect of all three variables play an important role in the good quality of welding process. The result also showed that the penetration is almost non-sensitive to the variation in the Welding Speed (S) and welding Voltage (V).[12]

Saurav Datta et. al. [2008] have used application of taguchi philosophy for parametric optimization of bead geometry and HAZ width in submerged arc welding using mixture of fresh flux and fused flux. The experiment was performed on mild steel plate of 100x40x12mm using L9 orthogonal array. From this they concluded that 10% slag mix can be used to obtain optimum bead width and depth of HAZ. 15 to 20% slag mix for reinforcement and depth of penetration.[13]

Paul Colegrove et. al. [2009] discovered that how the diferent welding process influences on the distortion and residual stresses. In this study he compare the welds made by SAW the gas metal arc welding(DC), gas metal arc welding (pulsed), autogenous laser and laser hybrid welding on butt welds havind thickness of 4mm . laser hybrid and Laser welding were studied to produce the lesser distortion. He studied that the higher the heat input and distortion of the SAW is abundantly clear: both are nearly twice as the other arc welding processes. Therefore there is an advantage in using an alternate welding processfor the lesser distortion. Overall, a distortion reduction of 20-70% is realizable with the GMAW processes over the submerged arc welding(SAW) process and 80-95% reduction is possible by using the laser processes.[14]

Ahmed Khalid Hussain et. al. [2010] discovered the Influence of Welding Speed (S) on Tensile Strength of Welded Joint in TIG Welding Process. This paper deals with the investigation of effect of Welding Speed (S) on the Tensile strength of the welded joint. Experiments are conducted on specimens of single v butt joint having different bevel angle and bevel heights. The material selected for preparing the test specimen is Aluminium AA6351 Alloy. The strength of the welded joint is tested by a universal Tensile testing machine and the results are evaluated. Tensile strength is higher with lower weld Speed. This indicates that lower range of weld Speed is suitable for achieving maximum Tensile strength. The heat affected zone, strength increased with decreasing heat input rate.[15]

James amanie et. at. [2011] discovered that the effects of submerged arc welding (SAW) and Speed Current (I) on the microstructures of SA516 grade 70 and A709 grade 50 steel welds were studied in this study. Steel plates 17 mm-thick were submerged arc welded using different welding Current (I)s (from 700 to 850 A) and Welding Speed (S)s (from 5.3 to 15.3 mm/s). The results showed that it is difficult to discribe changes in microstructure that generate in the heat affected zone (HAZ) and the weld metal regions to single welding process parameter. Inclusion analysis shows that two types of inclusions formed in the weld metals for both steels. They are faceted and spherical inclusions. It was also observed that ferrite nucleated only on the spherical inclusions. energy dispersive X-ray spectroscopy (EDS) analysis showed that these two inclusions both have different chemical composition.[16]

D.kathersan et. al. [2012] discovered that the optimization of flux cored arc welding by solving the gray relationals and desirable analysis and using the desire design for determining welding parameters was successfully done. In this experiment torch angle has the most effective parameter followed by the wire feed rate, travel Speed and Voltage (V). It was confirmed that higher the depth of penetration lesser wil be the bead width.[17]

Shen et. al. [2012] discovered a series of measurements was carried out on specimens of submerged arc welded plates of ASTM A709 Grade 50 steel. The bead reinforcement, bead width, penetration depth, HAZ size, deposition area and penetration area increased with increasing heat input but the bead contact angle decreased with it. The electrode melting efficiency increased initially and then decreased with increasing heat input but the plate melting efficiency and percentage dilution changed only slightly with it. Cooling time exhibited a very good linear relationship with the total nugget area, heat transfer boundary length, and nugget parameter.[18]

Bhaskar Vishwakarma et. al. [2013] discovered the Investigation of Welding Parameters On Mechanical Properties of Different Welding Joints of Mild Steel. The effect of welding Current (I), electrode diameter, Voltage (V) and welding techniques on mechanical properties of mild steel weldments have been studied in this paper. It was observed from these tests that with increase in Current (I), Tensile strength and Hardness decreased significantly while absorbed energy increased .Increasing electrode diameter improves Tensile strength and Hardness while absorbed energy has been decreased. With increase in Voltage (V), Tensile strength and Hardness decreased while absorbed energy increased. As Voltage (V) increases Impact strength while Hardness decreased. With increase in welding Current (I) ultimate Tensile strength decreased.[19]

Pranesh B. Bamankar et. al. [2013] Study of the effect of process parameters on depth of penetration and bead width in saw (submerged arc welding) process. Experiments are conducted using submerged arc process parameters viz. welding Current (I), arc Voltage (V) and Welding Speed (S) (Trolley Speed) on mild steel of 12 mm thickness, to study the effect of these parameters on penetration depth.he discovered that Current (I) is main factor influence the bead width. Bead width almost linearly increases with arc Voltage (V) and Current (I) and decreases, with Welding Speed (S).[20]

Radha Raman Mishra et. al. [2014] discovered the Tensile strength of mig and tig welded dissimilar joints of mild steel and stainless steel. In his study, stainless steel of grades 202, 304, 310 and 316 were welded with mild steel by Tungsten Inert Gas (TIG) and Metal Inert Gas (MIG) welding processes. The percentage dilutions of joints were calculated and Tensile strength of dissimilar metal joints was investigated. The results were compared for different joints made by TIG and MIG welding processes and it was observed that TIG welded dissimilar metal joints have better physical properties than MIG welded joints. The dissimilar metal joint of SS 316 and mild steel has the best ductility for both TIG and MIG welding processes.The yield strength of dissimilar joint of SS 202 and mild steel is best for both TIG and MIG welding process.The dissimilar metal joint of SS 304 and mild steel has poor ultimate Tensile stress for both TIG and MIG welding processes.[21]

Saha et. al. [2014] discovered that the Optimization of process parameters in submerged arc welding experiments have been conducted using welding Current (I), arc Voltage (V), Welding Speed (S) and electrode stick out as input process parameters for evaluating multiple responses namely weld bead width and bead Hardness. The optimum values were analyzed by means of multi objective Taguchi's method for the determination of total normalized quality loss (TNQL) and multi response signal to noise ratio (MRSN). The optimum parameters for smaller bead width and higher bead Hardness are weld Current (I) at low level (12.186 A), arc Voltage (V) at low level (12.51 V), Welding Speed (S) at low level (12.25 mm/min) and electrode stick out at low level (12.29 mm).[22]

2.3 Research gap:-

From the available literature it was found that although attempts have been made by researchers to weld dissimilar materials by different welding processes. However most of the researchers are interested to weld similar materials by using welding processes like ARC, TIG, MIG. There is very less work has been done to optimize on the SAW arc welding parameters for different material to produce the good joint as it has been mostly used to weld pressure vessels, aircraft parts and in ship welding.

However this study aims to analyzing the characteristic of Tensile strength, Hardness toughness, microstructure and residual stresses. The dissimilar material welding is complicated because of the difference in the melting points of the two materials. The thermal conductivity and the coefficient of the thermal expansion of different materials are also different. Therefore, the residual stresses are the most critical problem associated with the joining of dissimilar materials because of uneven heating and cooling of the welded components. The residual stresses affect the mechanical properties of the welded joint. The distortion of the welded joints occurs because of residual stresses. The mechanical properties such as Tensile strength and Impact toughness reduced because of residual stresses present during the welding. The residual stresses can be reduced by using the correct welding parameters during the process.

2.4 SCOPE OF THE WORK:-

Based upon the literature survey, the following aspects of submerged arc welding have been taken up:-

1. To study the weld's Tensile strength, Hardness, Impact load and to find the best welding parameters.
2. To suggest some parameters required for optimal Strength and minimize failure in the weld.
3. To study the distortion and residual for the different welding parameters.

Chapter 3
Experimentation

3.1 Selection of Material:-

In my present thesis work I select two material that are **mild steel (1018)** and **stainless steel (304)**. The main reason for selecting these material is only the wide use of these two material in the industry, especially in boilers and pipelines and they are also easy available in nearest market.

	C	Si	Mn	P	S	Cr	Ni	Fe
AISI 304	0.08*	0.75*	2*	0.04	0.014*	20*	12*	Balance
MS 1018	0.18	0.6	0.6-0.9	0.04	0.05	-	-	Balance

Table no. 3.1 chemical composition of material AISI304 and MS1018

*Shows the maximum % of the total wt.

3.2 Selection of welding data:-

By conducting no. of trial runs I come to decide the following variables:-

S. No.	Parameters	Range	
		Maximum	Minimum
1	Current (I)	290	270
2	Voltage (V)	31	33
3	Nozzle to plate distance (D)	22	24
4	Welding Speed (S)	18	20

Table 3.2 Selection of welding data

3.3 **Welding procedure** :-

Test sample were prepared by butt welding 304 austenitic stainless steel specimens to mild steel by using a welding electrode made from the same material. SAW (manual/automatic) welding process was used. First of all, trial runs were conducted to find out the Current (I) range to be used and three set of SAW parametric combinations were decided, because of well-established fact that among all the welding variables in SAW welding processes welding Current (I) is the most influential variable since it affects the Current (I) density and thus the melting rate of the filler as well as the base material. The heat input from the welding process plays a major role in the heating and cooling cycles experienced by the weld and parent plate during welding. For a given plate thickness, a high heat input is likely to result in a slower cooling rate than a low heat input, and will therefore produce a softer microstructure in the HAZ. However, that does not mean that welding should always be carried out with a high heat input, because this brings with it other problems, such as loss of mechanical properties and an increased risk of solidification cracking. So it is necessary to select a heat input to give a good weld with the desired mechanical properties.

Welding heat input 'Q' was calculated as:

$Q = (K \text{ x } V \text{ x } I \text{ x } 60)/ (\text{Sx}1000)$ KJ/mm

Where V is arc Voltage (V), I is welding Current (I), and S is Welding Speed (S) in mm/min. Thermal efficiency factors k was considered 0.7. The value derived from this formula may be multiplied by a factor k, the thermal efficiency factor for the welding process.

3.4 **Half friction factorial design method**:-

To find out the best parameter out of all parameter i.e Welding Speed (S), welding Current (I), welding Voltage (V) and Nozzle to plate distance (D). I am using "half factorial design" method.

No. of experiments required=no. of level^No. of parameters - 1

So in my thesis I am using four parameters and 2 levels, so the required experiments are:-

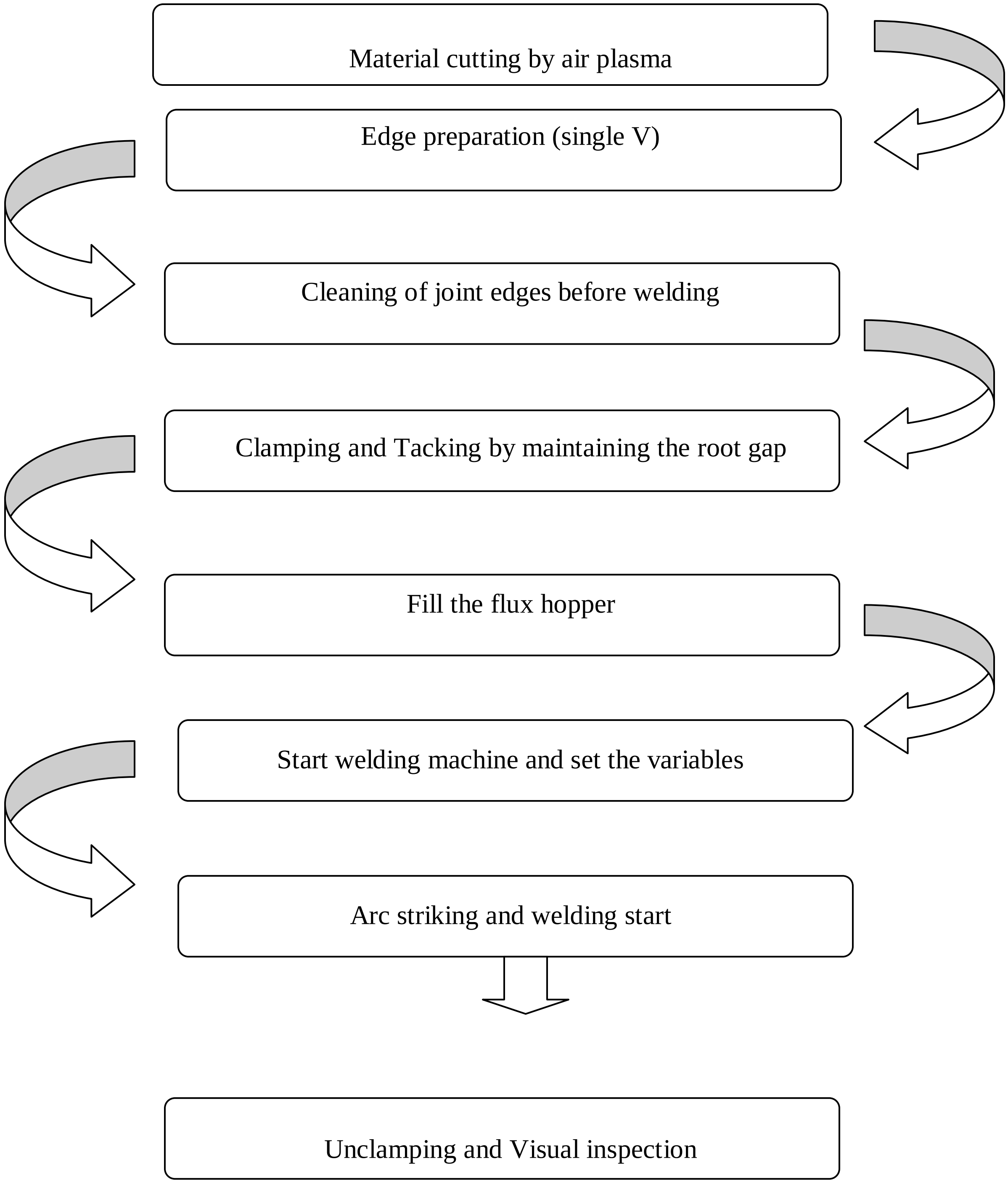
N=k^p-1

Here, N is no. of experiments, k is no. of levels, p is no. of parameters. So the required no. of experiments are 8.

Required matrix for experiments:-

S. no.	Current (I)	Voltage (V)	Speed (m/h)	Nozzle to plate distance (mm)
1	290	33	24	20
2	290	33	22	18
3	290	31	24	18
4	290	31	22	20
5	270	33	24	18
6	270	33	22	20
7	270	31	24	20
8	270	31	22	18

Table 3.3 Half factorial design matrix



Flow chart:- Procedural steps for experimentation.

3.5 Testing :-

Tensile strength, micro Hardness and Impact strength tests were performed on as welded specimen. Firstly, testing was done on as welded samples to find out the welding parameters for further work on optimization studies and further testing was carried out on welded specimens to decide best parameters after testing.

3.5.1 Specimen Sampling :-

In order to evaluate the mechanical and micro structural properties of the SS 304 and MS weldments, the specimens for transverse Tensile testing, Impact strength and micro Hardness testing studies were machined out from welded pads.

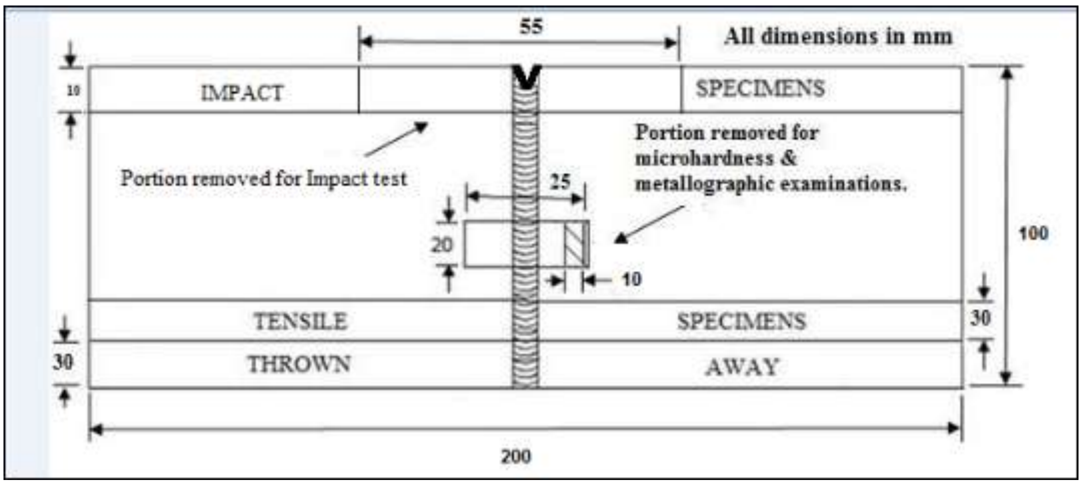


Figure 3.1 Illustration of weld samples for the tests.

3.5.2 Tensile Test :-

It is also called tension test and is used to determine Tensile strength of the material when subjected under uniaxial loading. By pulling something, it will be very quickly determined how the material will react of forces being applied in tension. Tensile test helps in determining.

- Tensile properties such as Tensile strength, yield strength.

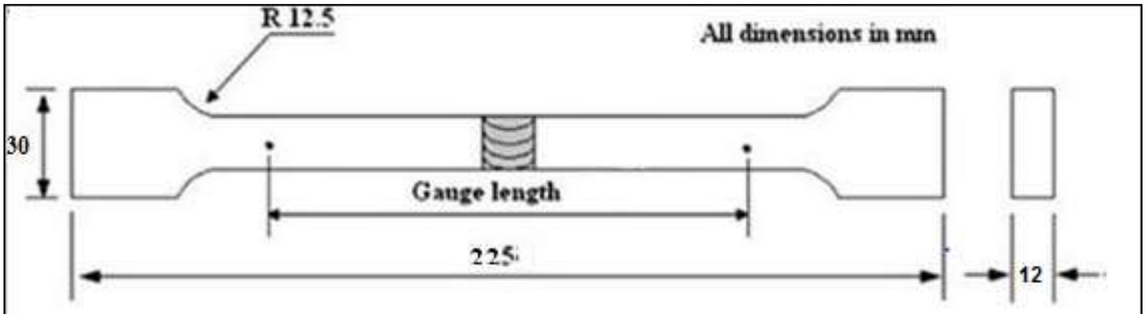


Figure 3.2 Dimensions of the Tensile specimen.

Specimens for Tensile were taken as perpendicular to weld direction. Tensile tests were conducted at Indian pvt. Ltd. at mohali. Speed of Tensile testing was 8 mm/min. The specimens were tested on FIE make Universal Testing Machine, UTE-60, it is an electronic type, hydraulically controlled digital Tensile testing machine of 600 /KN capacity. Fig. shows the location of fracture of the as welded samples.

Figure 3.3 Universal testing machine (UTM)

Figure 3.4 The location of fracture of the samples.

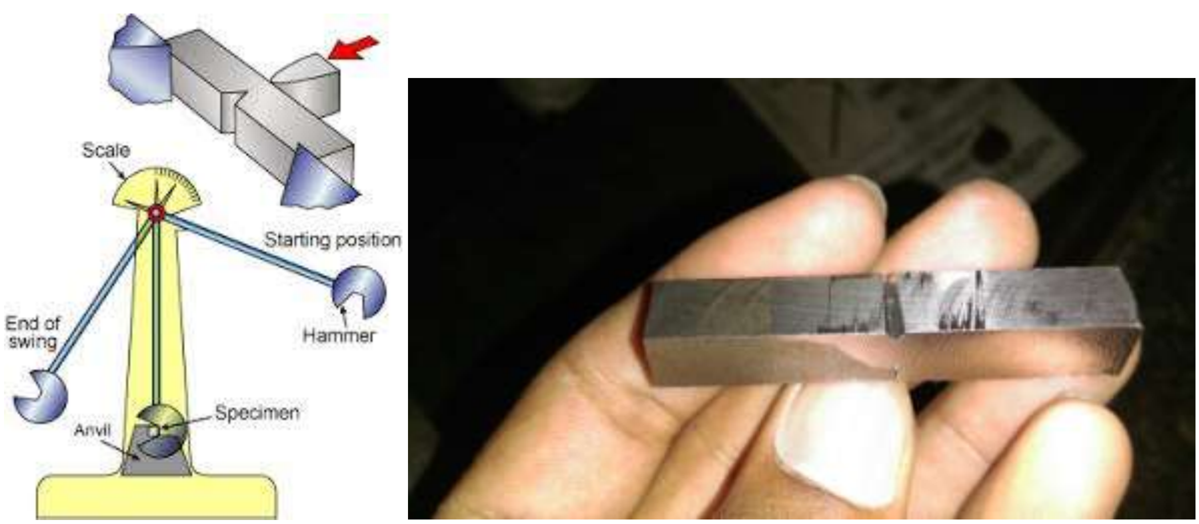
3.5.3 <u>Micro vicker Hardness Measurements</u> :-

The term micro Hardness tests usually refer to static indentation made with loads not exceeding 1 kgf. The surface being tested generally requires a metallographic finish; the smaller the load, the higher the surface finish is required. The procedure for micro Hardness testing is very similar to that of the standard Vickers Hardness, except that it is done on a microscopic scale with higher precision instruments. Micro Hardness measurements were carried out across the HAZ using Vickers Hardness testing machine shown in figure 3.5 in accordance with IS 1501:2002 (Method for Vickers Hardness test for metallic materials) at CTR, Ludhiana.

Figure 3.5 Vickers Hardness testing machine.

3.5.5 <u>Impact strength Examination</u> :-

Impact strength, is the material capability to withstand a suddenly load and is expressed in terms of energy. Often measured with the charpy Impact and Izod Impact tester, both of which measure the Impact energy required to fracture. Impact strength examinations were performed at LPU SOM lab.



(A) **(B)**

Figure 3.6 Charpy Impact test machine (A) and sample for Impact load (B).

Chapter 4

Results and Discussion

After the experimentation according to the half frictional factorial design matrix the following result are taken:-

A. Level 1

S. No.	Current	Voltage	Welding Speed	Nozzle to plate distance	Tensile strength (MPa)	Hardness(HV)	Impact load(N/mm^2)
1	290	33	24	20	380.694	306.33	0.98
2	290	33	22	18	328.212	305.00	0.76
3	290	31	24	18	386.065	250.33	1.32
4	290	31	22	20	360.13	284.67	1.15
5	270	33	24	18	383.776	297.33	1.79
6	270	33	22	20	387.954	264.33	1.01
7	270	31	24	20	322.462	314.33	1.20
8	270	31	22	18	271.967	286.33	1.12

Table 4.1 Results of Tensile strength, Hardness, Impact load of level 1.

B. Level 2

S. No.	Current	Voltage	Speed	Nozzle to plate distance	Tensile Strength (MPa)	Hardness (HV)	Impact load(N/mm^2)
1	290	33	24	20	271.967	339.33	0.73
2	290	33	22	18	375.386	349.33	0.74
3	290	31	24	18	339.396	262.67	1.77
4	290	31	22	20	384.912	297.33	0.9
5	270	33	24	18	390.064	294.67	1.47
6	270	33	22	20	370.399	271.33	1.31
7	270	31	24	20	344.462	308.67	1.38
8	270	31	22	18	362.219	291.33	1.4

Table 4.2 Results of Tensile strength, Hardness, Impact load of level 2.

4.1 <u>ANOVA matrix for Tensile strength</u>:-

Source	Sum of Squares	D.O.F	Mean Square	F value	P-value Prob >F	
Model	15287.31	6	2547.89	5.31	0.0133	Significant
A-Current (I)	1292.73	1	1292.73	2.69	0.1353	
B-Voltage (V)	4509.86	1	4509.86	9.39	0.0135	
C-Speed	1047.85	1	1047.85	2.18	0.1737	
D-Nozzle distance	1160.199	1	1160.199	2.42	0.1545	
AB	7173.5	1	7173.5	14.94	0.0039	
AD	103.2	1	103.2	0.21	0.65399	
Residual	4321.42	9	480.16			
Lack of fit	786.72	1	86.2	1.78	0.2188	Not significant

Table 4.3 ANOVA matrix of Tensile strength

4.2 <u>Effect of Current (I) on Tensile strength</u> :-

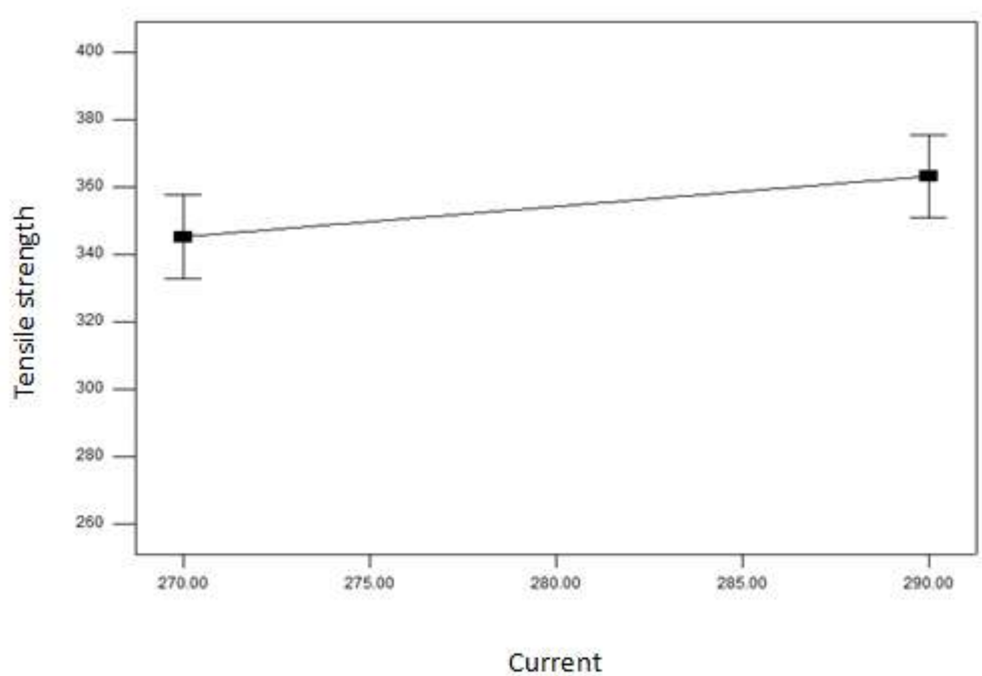


Figure 4.1 Change in Tensile due to Current (I).

On having a glance on the above graph it is ostensible that the Tensile strength increase with increase in Current (I). Initially when the Current (I) is 270A the value of Tensile is 344 and at the end the Tensile value become 360 when Current (I) is 290A. As increase in the welding Current (I) the penetration become high so to increase in Current (I) lead to high Tensile strength.

4.3 <u>Effect of Voltage (V) on Tensile strength</u> :-

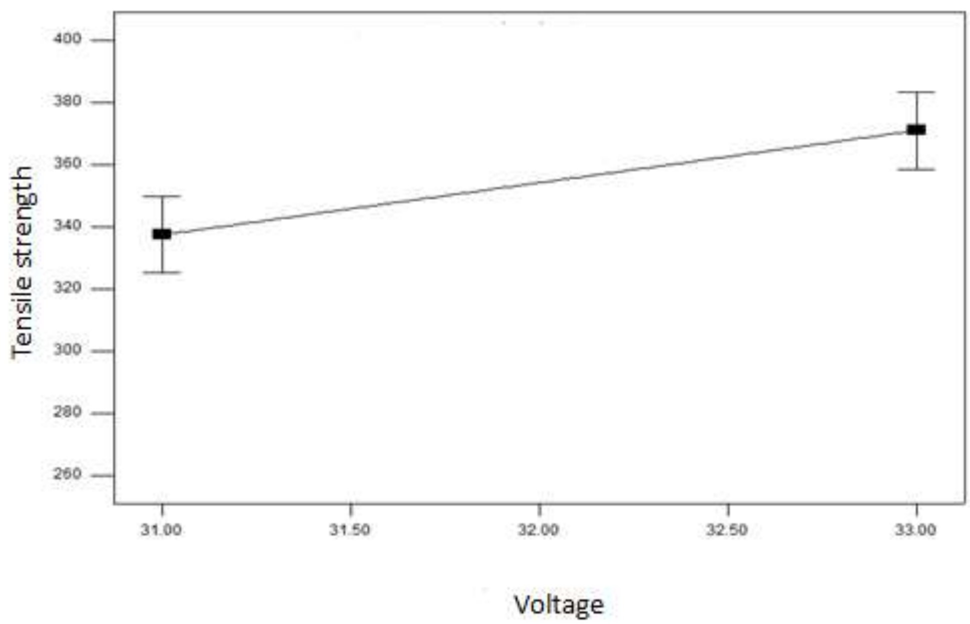


Figure 4.2 Change in Tensile strength due to Voltage (V).

On having a glance on the above graph it is ostensible that the Tensile strength increase with increase in Voltage (V). Initially when the Voltage (V) is 31V the value of Tensile is 339 and at the end the Tensile value become 365 when the Voltage (V) is 33V. As we increase the arc Voltage (V) more will be the heat input because Voltage (V) is directly proportional to heat input so as we increase in welding Voltage (V) results more the Tensile strength.

4.4 Effect of Speed on Tensile strength :-

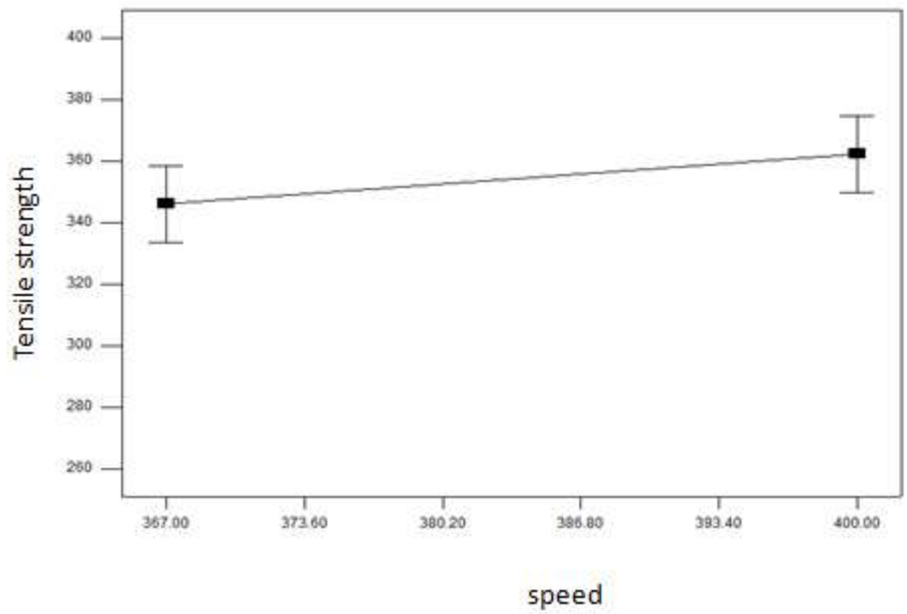


Figure 4.3 Effect on Tensile strength due to Speed.

In the graph it shows that with Increase in the Welding Speed (S) there is slightly increase in the Tensile strength. Initially when the Speed is 367* the value of Tensile strength is 347 after that the value reaches on 360 when the Welding Speed (S) is 400*. As the Welding Speed (S) high lesser the heat affected zone became increase in Tensile strength.

*All values in mm/min

4.5 Effect of Nozzle to plate distance (D) on Tensile strength:-

In the graph it shows that with Increase in the Nozzle to plate distance (D) there is slightly increase in the Tensile strength. Initially when the Nozzle to plate distance (D) is 18* the value of Tensile strength is 347 after that the value reaches on 360 when the Nozzle to plate distance (D) is 20*.

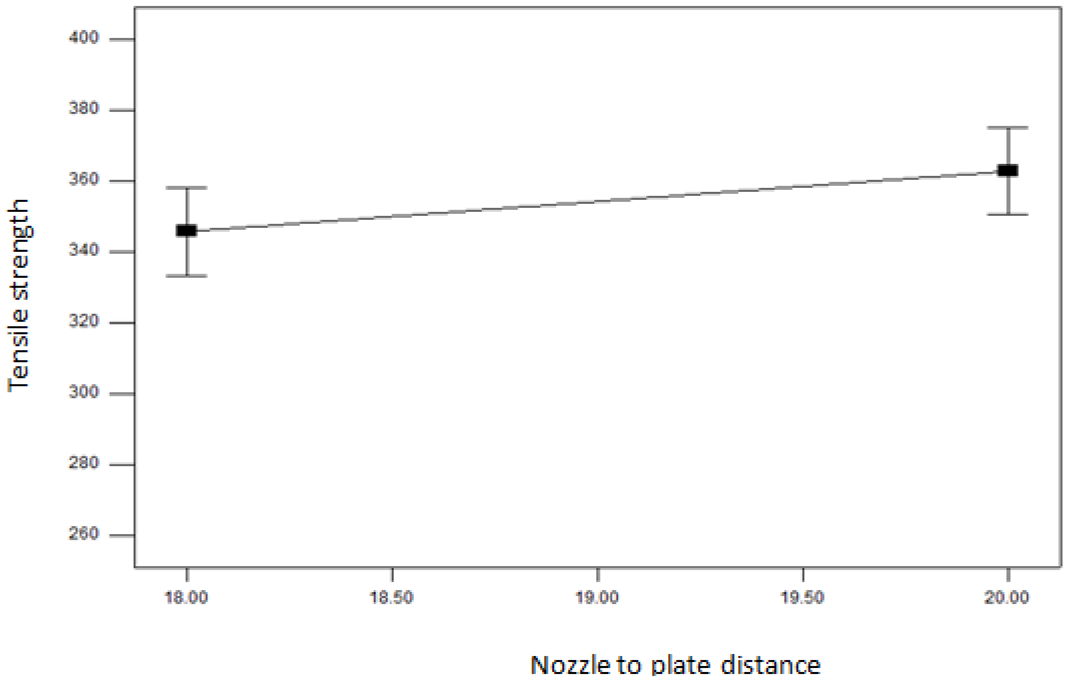


Figure 4.4 Change in Tensile strength due to Nozzle to plate distance (D).

4.6 <u>Combined effect of Current (I) and Voltage (V) on Tensile strength</u> :-

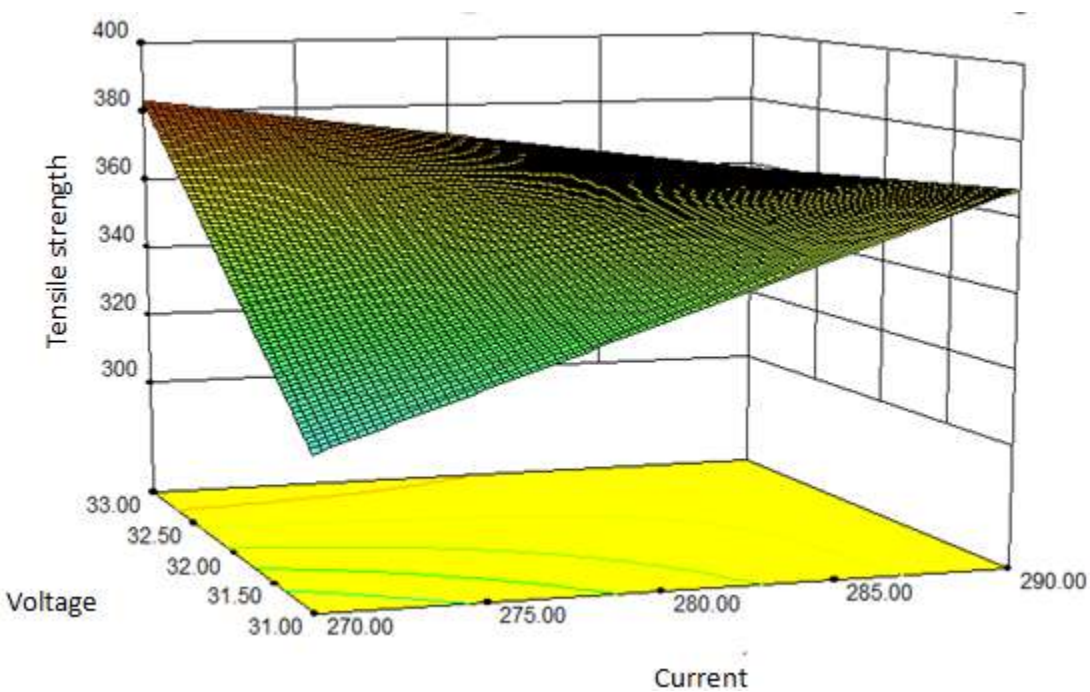


Figure 4.5 3D combined effect of Current (I) and Voltage (V) on Tensile strength.

4.7 ANOVA matrix for Hardness :-

Source	Sum of Squares	D.O.F	Mean Square	F value	p-value prob>f	
Model	8939.5	6	1489.92	5.82	0.0099	Significant
A-Current (I)	462.25	1	462.25	1.81	0.2118	
B-Voltage (V)	529	1	529	2.07	0.1843	
C-Speed	0	1	0	0	1	
D-Nozzle dis	420.25	1	420.25	1.64	0.232	
AB	6.08E+03	1	6.08E+03	23.78	9.00E-04	
AC	1444	1	1444	5.64	0.0415	
Residual	2302.25	9	255.81			
Lack of fit	90.25	1	90.24	0.33	0.5835	Not significant

Table 4.4 ANOVA matrix for Hardness.

4.8 Effects on Hardness due to change in parameter:-

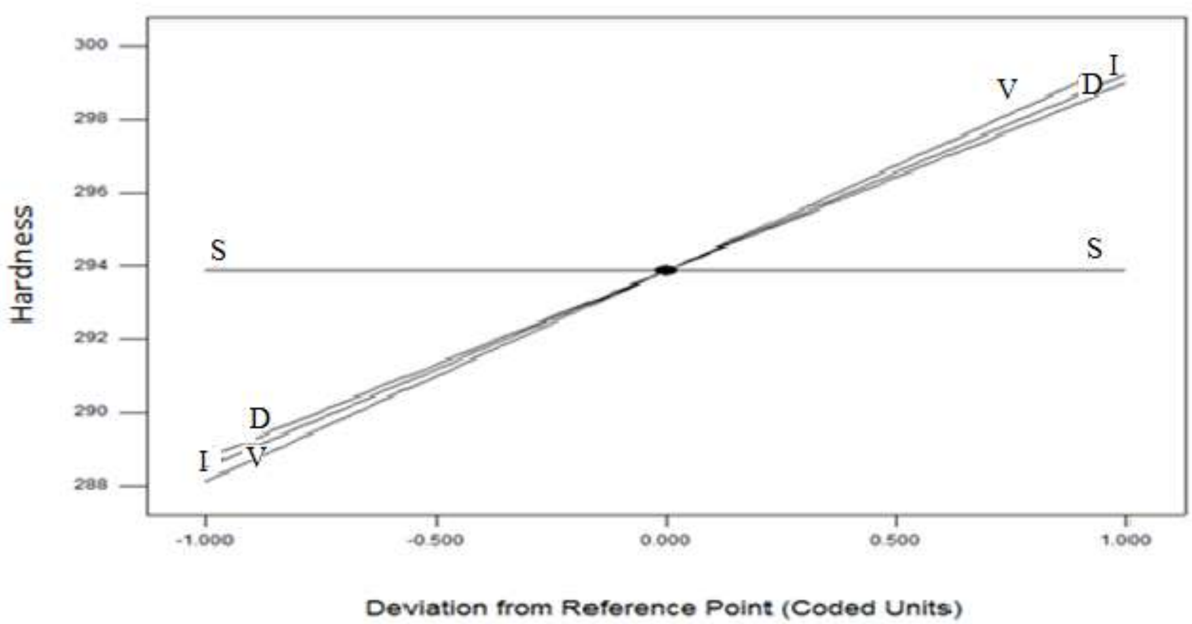


Figure 4.6 Effects on Hardness due to change in Current (I), Voltage (V), Speed and Nozzle to plate distance (D).

It is evident from the above figure that the Hardness increase due to increase in Current (I), Voltage (V) and Nozzle to plate distance (D) but there is no any change in Hardness due to change in Speed.

1. Increase in the welding Current (I) leads to high heat input so it takes more time to cool down. Due to normalization the Hardness of the welding bead became high.
2. Increase in welding Voltage (V) again leads to high heat input so it takes more time to cool down. Due to normalization the Hardness of the welding bead became high.
3. There is no any change observed due to change in Welding Speed (S).

4.9 Combined effect of Current (I) and Voltage (V) on Hardness:-

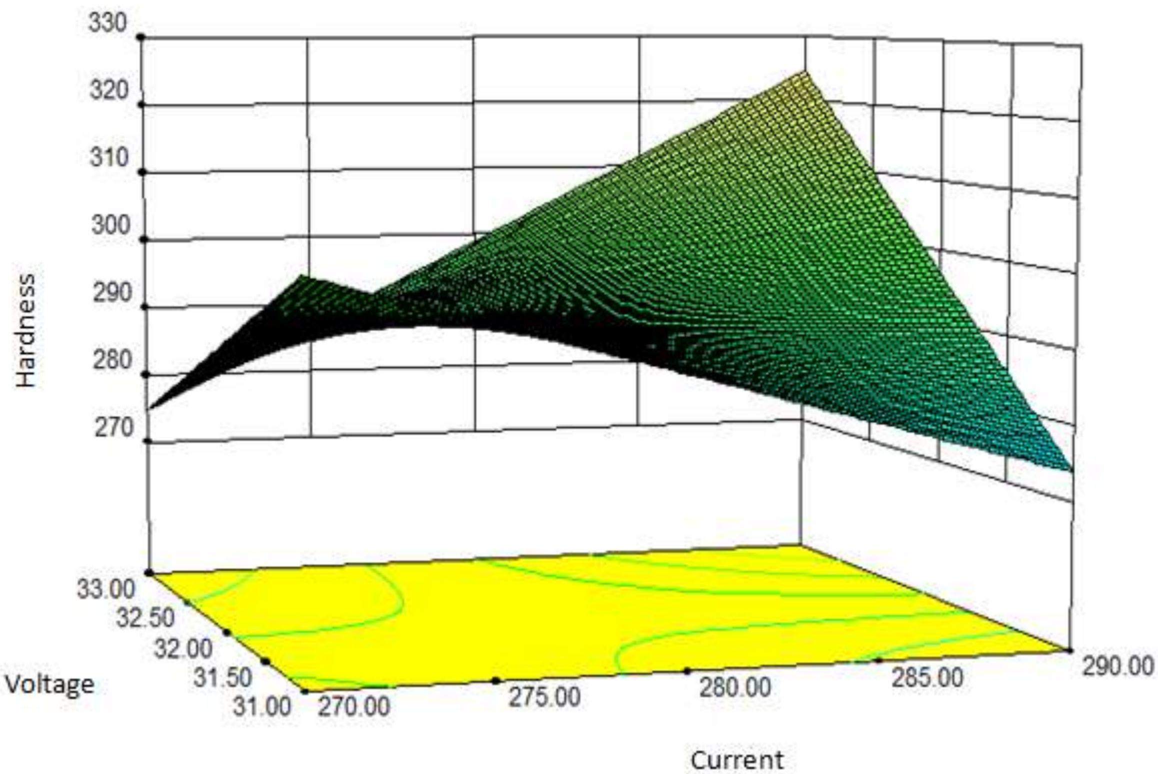


Figure 4.7 3D combined effect of Current (I) and Voltage (V) on Hardness.

4.10 ANOVA matrix for Impact load:-

Source	Sum of Squares	D.O.F	Mean Square	F value	p-value prob>f	
Model	1.52	6	0.25	6.65	0.0064	Significant
A-Current (I)	0.93	1	0.93	24.38	0.0008	
B-Voltage (V)	0.081	1	0.081	2.13	0.1787	
C-Speed	0.099	1	0.099	2.6	0.1414	
D-Nozzle dis	0.37	1	0.37	9.58	0.0128	
AB	1.00E-02	1	1.00E-02	0.26	6.21E-01	
AC	0.036	1	0.036	0.95	0.3563	
Residual	0.034	9	0.038			
Lack of fit	0.12	1	0.12	4.05	0.0788	not significant

Table 4.5 ANOVA matrix for Impact load.

4.11 Effect on Impact load due to change in different variables :-

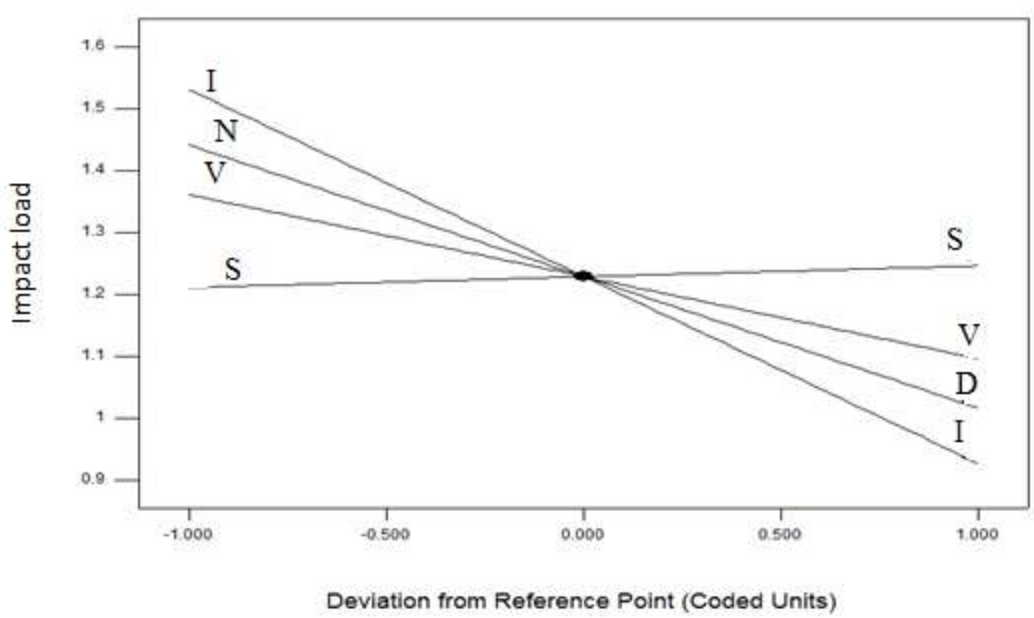


Figure 4.8 Effects on Impact load due to change in Current (I), Voltage (V), Speed and Nozzle to plate distance (D).

On having a glance on the above figure it can be ostensible that initially Impact load decrease with increase in the Current (I), Voltage (V) and Nozzle distance but Impact load start increasing with increase in the Welding Speed (S).

1. In order to increase in heat input by increase in Current (I), Voltage (V) the heat effected zone became more or due to high heat input the material became more brittle so it is observed that due to increase in heat input the Impact strength is decreasing continuously.
2. When we increase the Welding Speed (S) it leads to low heat input because heat input is inversely propositional to the Welding Speed (S). Due to lesser heat input lesser the heat affected the Impact load of the material increase with increase in Welding Speed (S).

4.12 <u>Combined effect of Current (I) and Voltage (V) on Impact load</u> :-

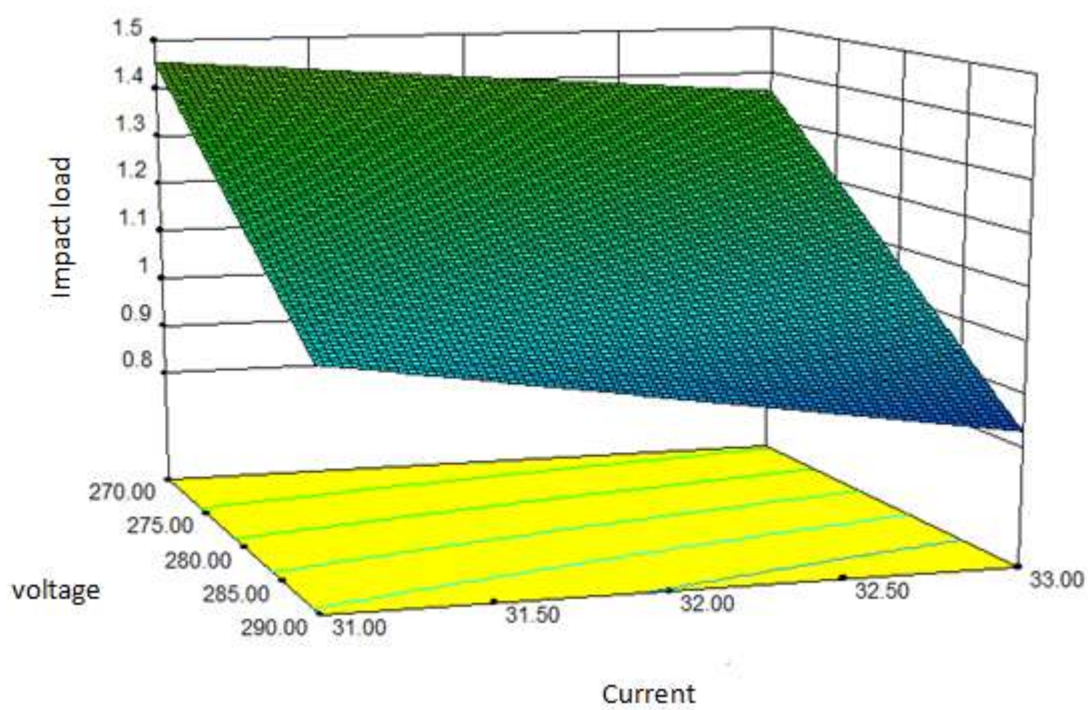


Figure 4.9 3D combined effect of Current (I) and Voltage (V) on Impact load.

Chapter 5

Conclusions and future scope

5.1 Conclusion:-

In this work, an attempt was made to determine important welding process parameters for multiple performance characteristics Tensile strength, micro Hardness, Impact load in the SAW process using half factorial method. Careful attention is necessary to select the welding parameters to obtain a desirable weld quality, the major key process parameters affecting the bead geometry are arc Voltage (V), welding Current (I), Welding Speed (S) and Nozzle to plate distance (D). Based on the results of the present study, the following conclusions are drawn:

1. The dissimilar metal joint of SS 304 and mild steel has poor ultimate Tensile stress for SAW welding processes.
2. Tensile strength was found to be increase with increasing in heat input.
3. Hardness was found to be increase with increase in Current (I), Voltage (V), Nozzle to plate distance (D) but decrease with increase in Welding Speed (S).
4. Impact load was found to be decrease with increase in Current (I), Voltage (V), Nozzle to plate distance (D) but decrease with increase in Welding Speed (S).
5. The optimum parameters for smaller bead width and higher bead Hardness are: welding Current (I) 270 I, Voltage (V) 32.80 V, Welding Speed (S) 400, Nozzle to plate distance (D) 19.65 mm.

5.2 Future scope:-

In future this study can be extended by developing and analyzing Response Surface Methodology and also various techniques like ANN, Genetic Algorithm and Influence of flux density on weld bead geometry, residual stresses and HAZ. Study of HAZ, microstructure can be applied for optimization of process parameter.

Chapter 5

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