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Research Paper

EXPERIMENTAL INVESTIGATION OF MULTIPASS TIG WELDING USING RESPONSE SURFACE METHODOLOGY

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Stainless steel as a weld bead joint has very important applications in industry. TIG welding is an important joining process used in manufacturing industries. The major needs in the welding are high tensile strength, good surface finish and hardness. In order to produce any product with desired quality by welding, proper selection of process parameters is essential. The review of literature reveals that only few works have been reported on optimizing the welding of stainless steel. Therefore, this project is aimed at evaluating the optimal process environment which could simultaneously satisfy the requirements of both quality and strength. In this work Central composite Design Methodology of Response surface methodology is used to conduct the experiments. Analysis of variance is used to analyze the influence of parameters during machining. The results of the present work indicate that welding parameters have significant influence on tensile strength, hardness and penetration. The optimal process parameters so obtained have been verified by confirmatory experiments. In this project TIG welding of stainless steel was studied at different values of current, and electrode diameter but keeping electrode material, voltage and welding speed as constant. ATIG welding machine was used to weld 6mm thick stainless steel plates. The photographs of the welded seams were observed and tensile testing of specimens was done to evaluate the mechanical properties of the welded joint.

Keywords: TIG welding, Response surface methodology, Central composite design, Hardness, Weld penetration, Tensile strength

INTRODUCTION

Gas Tungsten Arc Welding (GTAW) is a widely used process for metal joining. Its arc is established between the tip of a no consumable tungsten electrode and the work piece with a shielding gas applied to protect the arc and the weld pool area. The GTAW process can be used in welding a wide variety

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of metals. It is typically used for root passes on pipes and thin-gauge materials. Its arc is very stable and can produce high-quality and spatter-free welds without requiring much post weld cleaning. A typical GTAW system consists of a power supply, a water cooler, a welding torch, cables, etc. For most of its applications, Direct Current Electrode Negative (DCEN) polarity is used and approximately 70% of the arc heat is applied into the work piece. Opposite to the Direct Current Electrode Positive (DCEP) polarity, the DCEN polarity produces a relatively narrow and deep weld. In order to achieve desirable welds, filler metals are typically required during GTAW. Currently, there are two commonly used approaches for filling the joint: cold-wire GTAW process and hotwire GTAW process. In the cold-wire GTAW process, the filler metal is directly added as is. To melt the wire faster, in the hot-wire GTAW, the filler metal is preheated by a resistive heat while it is being fed into the weld pool. This resistive heat is generated by a separate current (typically an alternating current, AC) supplied to the filler metal that flows from the wire directly into the weld pool.

The current is properly adjusted so that ideally the temperature of the filler metal can reach its melting point as soon as it enters the weld pool. In comparison with the cold-wire GTAW, the hot-wire GTAW process is more complicated and has a higher cost with the additional power supply, but it can provide a higher deposition rate. Unfortunately, despite the increased temperature of the filler metal when it enters into the weld pool, the wire melting is still finished by the heat generated from the weld pool during the hot-wire GTAW process. That is, part of the heat used to melt the filler metal is essentially absorbed from the weld pool. To melt the wire faster, the arc would have to establish a larger weld pool. Increasing the melting or deposition rate is at the expense of an increased weld pool. The arc energy and deposition rate are thus coupled. This coupling reduces the process controllability to provide desirable arc energy and deposition rate freely to meet the requirements from different applications. For overhead welding where the maximal mass of the weld pool is restricted, this coupling also directly reduces the amount of the filler metal that can be added in each pass. The productivity is directly reduced because of this coupling or undesirable process controllability.

TIG Welding Process

The necessary heat for Gas Tungsten Arc Welding (TIG) is produced by an electric arc is maintained between a non-consumable tungsten electrode and the part to be welded. The heat affected zone, the molten metal, and the tungsten electrode are all shielded from the atmosphere by a blanket of insert gas few through the GTAW torch. Insert gas is that which is inactive, or deficient in active chemical properties, the shielding gas serves to blanket the weld and exclude the active properties.

The shielding gas serves to blanket the weld and excluded the active properties in the surrounding air. It does not burn, and adds nothing to or takes anything from the mental. Inert gases such as argon and helium do not chemically react or combine with other gases. They possess no order and are transparent, permitting the welder maximum visibility of the arc.

In some instances a small amount of reactive gas such as hydrogen can be added to enhance travel speeds.

The GTAW process can produce temperatures of up to 35,000 °F/19,426 °C. The torch contributes only heat to the work piece.

If filler metal is required to make the weld, it may add in the oxyacetylene welding process. There are also a number of filler metal feeding systems available to accomplish the task automatically.

MATERIALS AND METHODS

In this analysis tungsten inert gas welding is used. It is a process which yields coalescence of metals by heating with a welding arc between a continuous filler metal electrode and the work piece. Firstly, specimens of dimensions 60 mm × 50 mm× 6 mm are prepared, then closed butt joint are made by these specimens. Before welding, edges of the work pieces are suitably prepared. The edges and the area adjoining them is cleared of dust using wire brush. Afterwards, the work pieces to be welded were positioned with respect to each other and welding process was performed under constant voltage and current in flat (down hand) position. But the welding speed varies for each test.

During the welding process, following data are chosen in Table 1.

Table 1: Welding Parameters and Levels

Factors	Units	Levels		
		–1	0	+1
Filler Rod Dia	(mm)	1.6	2.3	3
Welding Current (A)	Ampere	140	160	180

Material Used – Stainless Steel

In metallurgy, stainless steel, also known as inox steel or inox from French "in oxydable", is defined as a steel alloy with a minimum of 10.5% to 11% chromium content by mass.

Stainless steel does not readily corrode, rust or stain with water as ordinary steel does, but despite the name it is not fully stain-proof, most notably under low oxygen, high salinity, or poor circulation environments. It is also called corrosion-resistant steel or CRES when the alloy type and grade are not detailed, particularly in the aviation industry. There are different grades and surface finishes of stainless steel to suit the environment the alloy must endure. Stainless steel is used where both the properties of steel and resistance to corrosion are required.

Work Piece Details

The work piece used for this test is SS 304.

Dimension of the specimen: 60 mm x 50 mm x 6 mm

Specimen showed in Figure 1.

Figure 1: Specimens Prepared for Welding

Response Surface Methodology

Response surface methodology uses statistical models, and therefore practitioners need to be aware that even the best statistical model is an approximation to reality. In practice, both the models and the parameter values are unknown, and subject to uncertainty on top of ignorance. Of course, an estimated optimum point need not be optimum in reality, because of the errors of the estimates and of the inadequacies of the model.

The application of RSM to design optimization is aimed at reducing the cost of expensive analysis methods (e.g., finite element method or CFD analysis) and their associated numerical noise. The problem can be approximated as described with smooth functions that improve the convergence of the optimization process because they reduce the effects of noise and they allow for the use of derivative-based algorithms.

ANOVA

The ANOVA procedure performs analysis of variance (ANOVA) for balanced data from a wide variety of experimental designs. In analysis of variance, a continuous response variable, known as a dependent variable, is measured under experimental conditions identified by classification variables, known as independent variables. The variation in the response is assumed to be due to effects in the classification, with random error accounting for the remaining variation.

Analysis of variance is most important tool for calculating responsible factors, which significantly affects mechanical properties. For determining these affect on process parameters, F-test was performed. Results of ANOVA and percentage contributions by each process parameters are tabulated in Tables 2, 3 and 4.

Confirmation Test

Optimal level of process parameters was predicted using response graph and ANOVA. Process parameters and their levels which

Table 2: Analysis of Variance for Hardness

Source	Df	Sum of Squares	Mean of Squares	F	P	% of Contribution
Filler Wire Diameter	2	0.5788	0.1166	0.18	0.839	1.67
Current	2	28.9951	14.49	22.32	0.001	83.41
Error	8	5.1954	0.64			
Total	**12**	**34.76**				

Note: R-Sq = 85.06%.

Table 3: Analysis of Variance for Penetration

Source	Df	Sum of Squares	Mean of Squares	F	P	% of Contribution
Filler Wire Diameter	2	0.5788	0.1166	0.18	0.839	1.67
Filler wire diameter	2	0.457	0.222	108.94	0.00	94.8
Welding Current	2	0.00814	0.00407	2	0.198	1.68
Error	8	0.01632	0.002			
Total	**12**	**0.48197**				

Note: R-Sq = 96.61%.

Table 4: Analysis of Variance for Tensile Strength

Source	Df	Sum of Squares	Mean of Squares	F	P	% of Contribution
Filler wire diameter	2	7510.6	3626.2	11.35	0.005	69.6
Current	2	721.2	360.6	1.13	0.370	6.68
Error	8	2555.0	319.4			
Total	**12**	**10786.7**				

Note: R-Sq = 76.31%.

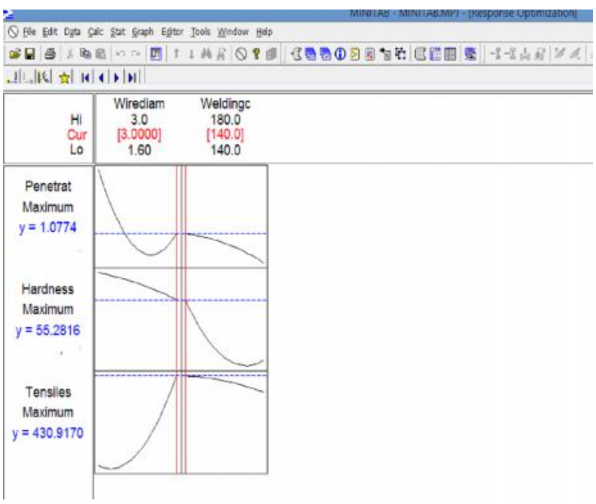
affect mechanical properties are pulse current at level 2, background current at level 5, pulse frequency at level 4, pulse duty cycle at level 2 and percentage of Helium in Argon at level 3. The obtained results were verified for the improvement in multiple quality characteristics by conducting a confirmation test based on results obtained in Table 5. The optimization plot developed using MINITAB Software is shown in the Figure 2.

% of Experimental Error = ((Actual Value – Predicted Value)/Predicted Value)

Table 5: Confirmation Test

Filler Wire Diameter	Welding Current	Penetration (mm)	Hardness (HRA)	Tensile Strength N/mm²
3	140	1.09	56	434.9
3	140	1.1	55	433.3
3	140	1.08	57	435
Mean		1.09	56	434.4

Figure 2: Optimization Plot



Model Calculation

% of Experimental Error (Penetration) = ((1.09 – 1.077)/1.077) × 100 = 1.2

% of Experimental Error (Hardness) = ((56 – 55.28)/55.28) × 100 = 1.3

% of Experimental Error (Tensile strength) = ((434.4 – 430.9)/430.9) × 100 = 0.81

Welding Parameters

Welding Speed

Speed of welding is defined as the rate of travel of the electrode along the seam or the rate of the travel of the work under the electrode along the seam. Some general statements can be made regarding speed of travel. Increasing the speed of travel and maintaining constant arc voltage and current will reduce the width of bead and also increase penetration until an optimum speed is reached at which penetration will be maximum. Increasing the speed beyond this optimum will result in decreasing penetration.

In the arc welding process increase in welding speed causes:

- Decrease in the heat input per unit length of the weld.
- Decrease in the electrode burn off rate.
- Decrease in the weld reinforcement.

If the welding speed decreases beyond a certain point, the penetration also will decrease due to the pressure of the large amount of weld pool beneath the electrode, which will cushion the arc penetrating force.

Calculations: Speed of welding is defined as the rate of travel of the electrode along the seam or the rate of travel of the work under the electrode along the seam.

Speed of welding = Travel of electrode/Arc time mm/min.

Heat input rate or arc energy = $V \times I \times 60/v$ joules per mm

where, V is arc voltage in volts, I is welding current in ampere and v is speed of welding in mm/min.

Welding Current

Welding current is the most influential variable in arc welding process which controls the electrode burn off rate, the depth of fusion and geometry of the weld elements.

Welding Voltage

This is the electrical potential difference between the tip of the welding wire and the surface of the molten weld pool. It determines the shape of the fusion zone and weld reinforcement. High welding voltage produces wider, flatter and less deeply penetrating welds than low welding voltages. Depth of penetration is maximum at optimum arc voltage.

TIG Welding Machine Set-Up

When setting up a TIG welder there are two main settings. They are amperage and gas flow. Amperage settings vary depending on the type and thickness of the metal to be welded. Gas flow rates also vary depending on draft conditions, cup size, and sometimes the

Figure 3: TIG Welding Set-Up

Figure 4: TIG Welding Machine

position of the weld. The gas flow rate could range from 5 CFH to 60 CFH for a large cup and drafty conditions. When choosing the gas to weld it is almost always assumed that you will be using pure Argon. The TIG welding set up is shown Figure 3. The photograph of TIG welding machine is shown in Figure 4.

Hardness Test

Hardness is defined as the resistance of a material to plastic deformation usually by indentation. It also refers to stiffness or resistance to scratching. Indentation hardness refers to number related to the area or depth of the impression made by an indenter of fixed geometry under a known static load.

There are many methods to determine the hardness, among those Brinell and Rockwell hardness tests are frequently used.

In our testing procedure, first test was Hardness test. For hardness test, we made different test specimen. We cut a piece of 60 mm from the length of the welded pieces. Like that we made pieces of weldment for hardness test.

Before hardness test, we need to make smooth the surface of piece which we got after cutting.

We used 220, 320 400 and 600 graded emery papers for getting the smoothness required, after getting appropriate smoothness, we have done hardness test for parent material by using which are showed in Figure 5 tested at welded zone.

Weld Penetration

It is the depth to which the base metal and filler material have melted and mixed during welding

Figure 5: Rockwell Hardness Machine

process. It depends on the weld process parameters used and can vary for different plate conditions.

To measure the depth of penetration the following processes were carried out on the specimens: (1) sectioning, (2) grinding, (3) polishing, (4) etching, and (5) profile tracing.

Sectioning: The transverse sections of each weld were cut using a bans saw. Care was taken to avoid deformation of the sensitive austenitic grade material.

Grinding: Grinding was performed in order to remove the cold work from cutting and was done at speeds of approximately 300 RPM.

Polishing: After grinding the specimens were rough polished by hand. In order to obtain better edge flatness, the specimens were polished using silicon carbide abrasive papers of grades 100, 220, 400, 600 and 800, respectively. The specimens were then polished using an abrasive-slurry of alumina (Al_2O_3) and water (H_2O) on a polishing machine.

Etching: After polishing, the specimens underwent etching. Etching was necessary for examining the microstructure of the weld bead. The etchant used was Marble's reagent which is a mixture of HCL (50 ml), $CuSO_4$ and H_2O (50 ml). The polished faces of each specimen were swabbed for about 50-60 seconds with the etchant in order to reveal the weld bead.

Profile Tracing: The bead profiles of the specimens were traced using a reflective type optical profile projector. The profile projector used is shown in Figure 6. The traced bead profiles were scanned in order to determine the depth of penetration. The depth was measured with the help of SOLID WORKS software. The photograph of welded specimen is shown in the Figure 7.

Figure 6: Profile Projector

Figure 7: Welded Jointed

Tension Test

Mechanical testing plays an important role in evaluating fundamental properties of engineering materials as well as in developing new materials and in controlling the quality of materials for use in design and construction. If a material is to be used as part of an engineering structure that will be subjected to a load, it is important to know that the material is strong enough and rigid enough to withstand the loads that it will experience in service. As a result engineers have developed a number of experimental techniques for mechanical testing of engineering materials subjected to tension, compression, bending or torsion loading.

The most common type of test used to measure the mechanical properties of a material is the Tension Test. Tension test is widely used to provide basic design information on the strength of materials and is an acceptance test for the specification of materials. The tension test machine used in this project is shown in Figure 8.

RESULTS AND DISCUSSION

This chapter deals with the results and discussions of the experimental findings of welded joints prepared at constant current,

Figure 8: Tension Test Machine

voltage, electrode size and welding technique (Down hand welding). The welded specimens prepared under varying current, filler wire diameter, and constant welding speed is having different effects. The experimental results were displayed below in the Table 6.

The Effect of Filler Diameter on Penetration

Readings of penetration is obtained from the mathematical relation and variations in the penetration are analysed with the help of graph which is plotted between filler wire diameter and penetration. Voltage (24 v) and speed (95 mm/min) are taken constant and filler diameter is varied during the welding of specimens. Increasing the filler rod diameter and maintaining constant arc voltage and penetration. High penetration will improve the mechanical properties of the welded joint. Low heat input will decrease the defects of the welded joints. So it can be concluded from experimental analysis that for the SS304 specimen having dimension 60 mm × 50 mm × 6 mm, the weld penetration is decreasing to some extent then later it is increasing when the filler wire diameter is chosen as 2.3 mm.

Table 6: Experimental Results

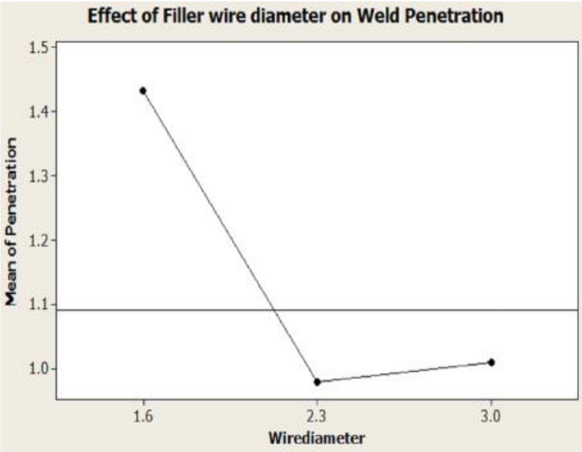
S. No.	Filler Rod Dia (mm)	Welding Current (A)	Penetration (mm)	Hardness (HRA)	Tensile Strength N/mm²
1.	1.6	140	1.40	57	326.3
2.	3.0	140	1.10	55	421.5
3.	1.6	180	1.40	52	401.2
4.	3.0	180	0.92	52	420.7
5.	1.6	160	1.50	52	384.4
6.	3.0	160	1.01	53	429.2
7.	2.3	140	0.98	56	375.4
8.	2.3	180	0.97	52	365.8
9.	2.3	160	0.99	52	363.3

The influence on filler wire diameter on penetration is shown as graph in Figure 9.

The Effect of Filler Diameter on Hardness

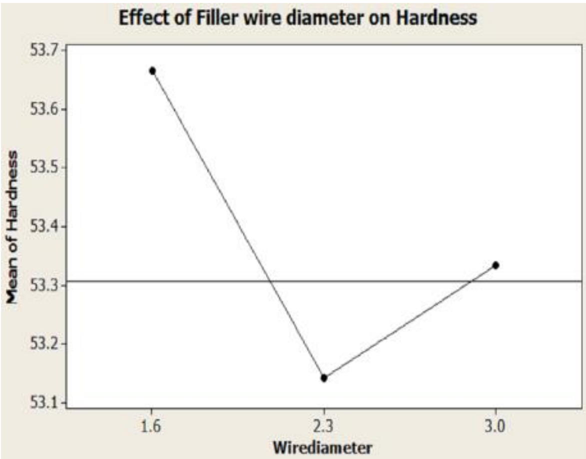
Readings of hardness is obtained from the Brinell hardness testing machine and variations in the hardness are analysed with the help of graph which is plotted between welding speed and hardness of the welded joint. Voltage (24 v) and different current are taken and welding speed is constant during the welding of specimens. The hardness decreases with increase filler diameter upto 2.3 mm which was optimum value to obtain

Figure 9: Effect of Filler Wire Diameter on Weld Penetration



maximum hardness. So it can be concluded from experimental analysis that for the SS304 specimen having dimension 60 mm × 50 mm × 6 mm, optimum weld ability can be achieved by considering the welding parameters as with different current, filler wire diameter and voltage 24 V. It is shown as graph in Figure 10.

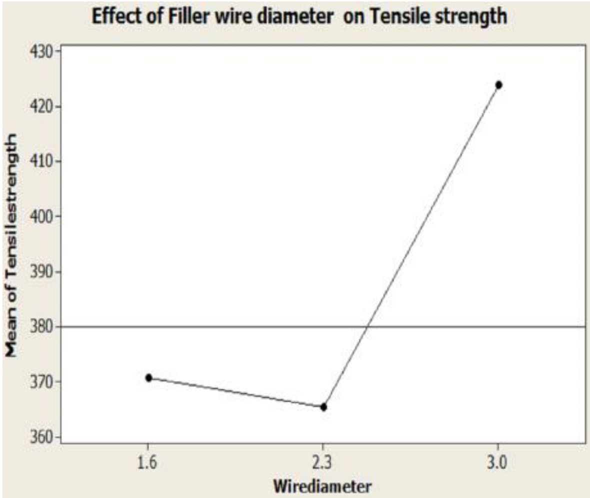
Figure 10: Effect of Filler Wire Diameter on Hardness



Effects of Filler Diameter on Tensile Strength

Readings of tensile strength is obtained from the universal testing machine and variations in the tensile are analysed with the help of graph which is plotted between filler rod diameter and tensile strength of the welded joint. It is shown in Figure 11. Voltage (24 v) and different current are taken and welding speed is constant during the welding of specimens. The tensile strength slowly decreases with increases filler wire diameter which was optimum value to obtain maximum tensile strength at filler wire diameter as 3 mm.

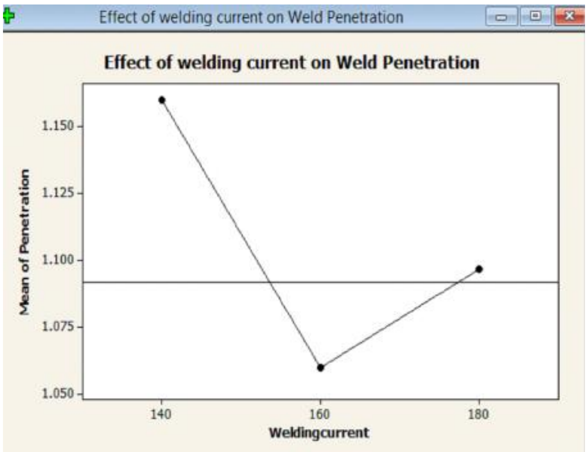
Figure 11: Effect of Filler Wire Diameter on Tensile Strength



The Effects of Welding Current on Penetration

Increasing the welding current and maintaining constant arc voltage and so that arc energy will increased. High arc energy will reduce the mechanical properties of the welded joint. Low heat input will decrease the defects of the welded joints. So it can be concluded from experimental analysis that for the SS304 specimen having dimension 60 mm × 50 mm × 6 mm, optimum weld ability can be achieved by considering the welding parameters as with different current, filler wire diameter and voltage 24 V. It is denoted in Figure 12.

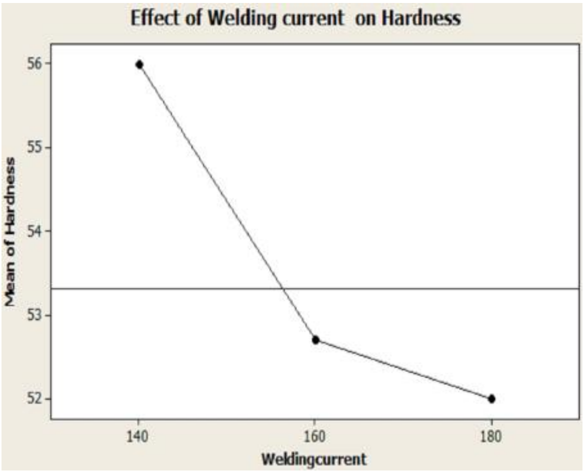
Figure 12: Effect of Welding Current on Weld Penetration



The Effect of Welding Current on Hardness

Readings of hardness is obtained from the Brinell hardness testing machine. Voltage (24 v) and different current are taken and welding speed is constant during the welding of specimens. The hardness decreases with increase in welding current up 160 Amperes current and suddenly increases. The influence of welding current on hardness is shown in Figure 13.

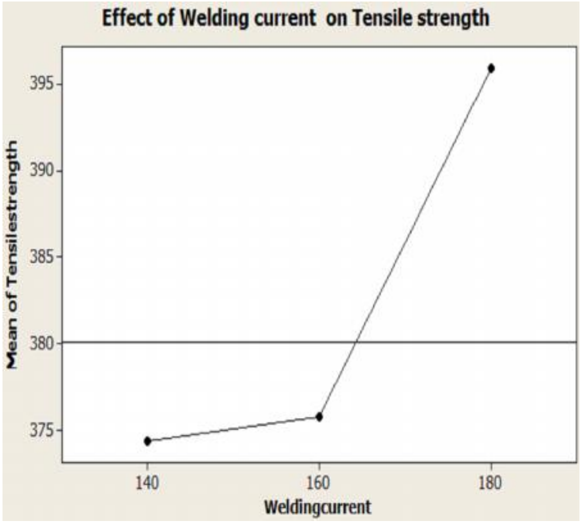
Figure 13: Effect of Welding Current on Hardness



Effects of Welding Current on Tensile Strength

Readings of tensile strength is obtained from the universal testing machine and variations in the tensile are analysed with the help of graph which is plotted between welding current and tensile strength of the welded joint. The tensile strength increases with increases welding current which was optimum value to obtain maximum tensile strength. The graph showing the effect of welding current on tensile strength is shown as graph in Figure 14.

Figure 14: Effect of Welding Current on Tensile Strength



CONCLUSION

The effects of welding parameters like current and filler diameter on tensile strength , hardness and penetration of SS 304 steel has been studied. The optimum condition in welding operation and effect of welding parameters using Response surface methodology has been found out.

As per our experimental work the most important factor affecting the tensile strength and penetration is found to be filler wire diameter whereas for hardness the major factor is welding current.

According to the order of importance, the parameters affecting the penetration, tensile strength and hardness are: Welding current and filler wire diameter.

The optimum process parameters for TIG welding of SS 304 steels are found to be:

Wire Diameter = 3 mm

Welding Current = 140 Ampere

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