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Weldability and Process Parameter Optimization of Dissimilar Pipe Joints Using GTAW

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Abstract
The aim of the work is welding of dissimilar metals, carbon steel and stainless steel pipes which find wide application in the field of chemical, oil and petroleum industries. GTAW (Gas Tungsten Arc Welding) process is commonly applied to a wide range of metals which uses a non-consumable tungsten electrode. Carbon steel pipe specimen (A106 Grade B) and stainless steel pipe specimen (A312 TP 316L) of Ø6" ID, thickness 7.11mm and length 150 mm each were selected. Taguchi method is used to formulate the experimental layout to rank the welding input parameters which affects the quality of the weld and is influenced by the parameters like gas flow rate followed by current and bevel angle. The weldments are subjected to tensile testing to find qualitative properties. Heat Inputs for the welded specimens were calculated which influences the mechanical and metallurgical properties of the weld. Non-destructive test of the welded specimens was carried out using Radiography test method. Also susceptibility to inter granular corrosion of the welded specimens is studied for varying heat inputs and its microstructure is studied. The percentage contribution of each parameter and prediction of tensile strength is found by analysis of variance (ANOVA) technique. The experimental tests show that high tensile strength is obtained for intermediate values.

Keywords: GTAW, Heat Input, Intergranular Corrosion, Tensile Strength

1. Introduction

Welding is a process of permanent joining two materials (usually metals) through localized coalescence resulting from a suitable combination of temperature, pressure and metallurgical conditions. Depending upon the combination of temperature and pressure from a high temperature with no pressure to a high pressure with low temperature, a wide range of welding processes has been developed.

1.1 Principles of GTAW

Gas Tungsten Arc Welding (GTAW), also known as tungsten inert gas (TIG) welding is a process that produces an electric arc 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 atmospheric contamination by a blanket of inert gas fed through the GTAW torch. Inert gas (usually Argon) is inactive or deficient in active chemical properties. The shielding gas serves to blanket the weld and exclude the active properties in the surrounding air.

2. Literature Review

S.P.Gadewar et al. [1] investigated the effect of process parameters of TIG welding like weld current, gas flow rate, work piece thickness on the bead geometry of SS304. It was found that the process parameters considered affected the mechanical properties with great extent.

N.Lenin et al. [2] optimized the welding input process parameters for obtaining greater welding strength in manual metal arc welding of dissimilar metals. The higher-the-better quality characteristic was considered in the weld strength prediction. Taguchi method was used to analyze the effect of each welding process parameters and optimal process parameters were obtained.

K.Kishore et al. [3] analyzed the effect of process parameters for welding of AA 6351 using TIG welding. Several control factors were found to predominantly influence weld quality. The % contributions from each parameter were computed through which optimal parameters were identified. ANOVA method was used to checking the adequacy of data obtained. The experiment revealed that low current values have created lack of penetration and high travel speed has caused lack of fusion in welding AA6351.

Ugur Esme et al. [4] investigated the multi response optimization of TIG welding process to yield favorable bead geometry using Taguchi method and Grey relation analysis. The significance of the factors on overall quality characteristics of the weldment has been evaluated quantitatively by ANOVA. The experimental results show that the tensile load, HAZ, area of penetration, bead width, and bead height are greatly improved by using grey relation analysis in combination with Taguchi method.

Bandhita Plubin et al. [5] determined the optimal factors of FCAW for steel ST37 using response surface methodology and central composite design for optimizing the tensile strength of weldments.

T.Senthil Kumar et al. [6] studied the effect of pulsed TIG welding parameters and pitting corrosion potential of aluminium alloys. ANOVA method was used to find significant parameters and regression analysis has been used to develop the mathematical model to determine the pitting corrosion potential. It was found that peak current and pulse frequency have direct proportional relationship, while base current and pulse-on-time have inverse proportional relationship with the pitting corrosion resistance.

Ahmed Khalid Hussain et al. [7] studied the influence of welding speed on tensile strength on welded joints in GTAW process of aluminium alloys. Experiments were conducted on specimens of single V butt joint having different bevel angles and bevel heights. The experimental results show that depth of penetration of weld bead decreases with increase in bevel height. The tensile strength increased with lower weld speed and decreasing heat input rate. It was also found that bevel angle of the weld joint has profound effect on the tensile strength.

L.Suresh Kumar et al. [8] discussed the mechanical properties of austenitic stainless steel AISI 304 and 316 and found out the characteristics of welded metals using TIG & MIG welding process. Voltage was taken constant and various characteristics such as strength, hardness, ductility, grain structure, HAZ were observed in two processes, analyzed and finally concluded.

Farhad Kolahan et al. [9] established input-output relationships for metal active gas welding for gas pipelines. Regression analysis was performed on data collected as per Taguchi design of experiments. Data adequacy was verified using ANOVA method.

S.Kumanan et al. [10] determined submerged arc welding process parameters using Taguchi method and regression analysis. The % contribution of each factor is validated by analysis of variance method. The planned experiments were conducted in the semi-automatic submerged arc welding machine and SN ratios are computed to determine the optimum parameters.

P.Atanda et al. [11] conducted sensitization study of normalized 316L stainless steel. The work was concerned with the study of the sensitization and desensitization of 316L steel at the normalizing temperatures of 750-950°C and soaking times of 05, 1, 2 and 8 hours.

Sunniva R. Collins et al. [12] conducted weldability and corrosion studies of AISI 316L electro polished tubing and were orbitally and autogenously welded with welding parameters varied to achieve an acceptable weld.

A.K.Lakshminarayanan et al. [13] used two different methods, response surface methodology and artificial neural network to predict the tensile strength of friction stir welded AA7039 aluminium alloy. Sensitivity analysis was carried out to identify critical parameters. The results obtained through response surface methodology were compared with those through artificial neural networks.

3. Materials Used

3.1 Carbon Steel Chemical Composition

The chemical composition of carbon steel pipe specimen A106 Grade B is given in the table

Elements	C	Si	Mn	P	S
Wt %	0.19	0.23	0.87	0.017	0.013
Elements	Cr	Mo	Ni	Cu	V
Wt %	0.03	<0.01	0.01	<0.01	<0.01

Table 1: Chemical composition of carbon steel A106 GradeB

3.1.1 Tensile Testing Observation for Carbon Steel Specimen

Test Parameters	Values
Ultimate Tensile Strength	485.80 Mpa
Yield Strength	328.00 Mpa
% Elongation in 50 mm GL	32.50 %

Table 2: Tensile test observation of CS specimen

3.1.2 Carbon Steel Microstructure

The microstructure of carbon steel pipe specimen A106 Grade B is shown below.

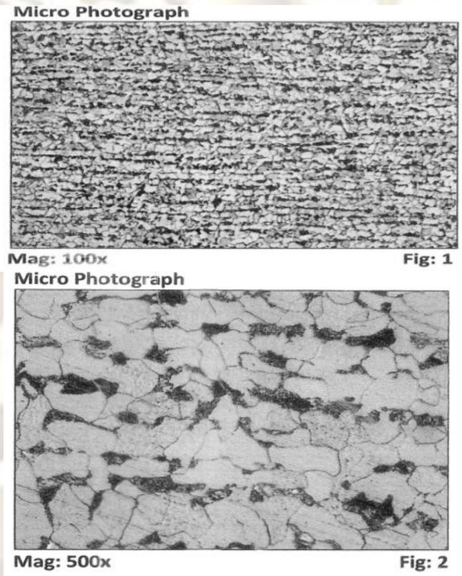

Figure 1: Microstructure of carbon steel A106 Grade B

The microstructure of carbon steel reveals the specimen in normalized condition. Fine grains of ferrite with pearlite are observed in the specimen. Black flakes indicate pearlite banding in the structure.

3.2 Stainless Steel Chemical Composition

The chemical composition of stainless steel pipe specimen A312 TP 316L is given in the Table3.

Elements	C	Si	Mn	P
Wt %	0.02	0.29	1.58	0.027
Elements	S	Cr	Mo	Ni
Wt %	0.003	16.25	2.27	11.90

Table 3: Chemical composition of stainless steel A312 TP 316L

3.2.1 Tensile Testing Observation for Stainless Steel Specimen

Test Parameters	**Values**
Ultimate Tensile Strength	513.18 Mpa
Yield Strength	255.90 Mpa
% Elongation in 50 mm GL	55.50 %

Table 4: Tensile test observation of SS specimen

3.2.2 Stainless Steel Microstructure

The microstructure of stainless steel pipe specimen is shown below.

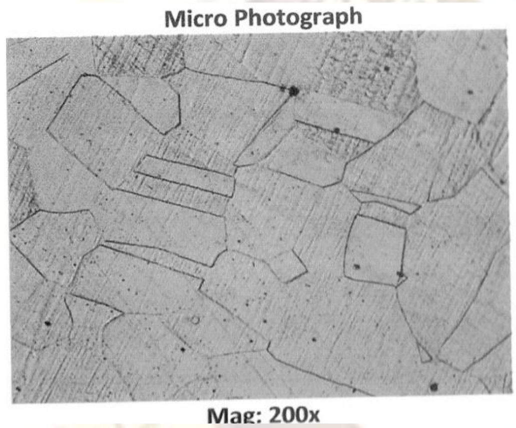

Figure 2 : Microstructure of stainless steel A312 TP 316L

The microstructure of stainless steel reveals the specimen in solution annealed condition. It is observed that particles of carbides (indicated by small black dots) are present and step between the grains with annealed twin boundaries are present in the matrix.

3.3 Filler Metal

The filler metal used in this project is a stainless steel 309L grade filler rod of Ø2.5mm x 1000mm.

The chemical composition of filler rod is given below

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Element	C	Mn	Si	S	P	Cr	Ni
Wt %	0.028	1.97	0.39	0.012	0.017	23.15	13.95

Table 5: Chemical Composition of Filler Rod

3.4 Edge Preparation

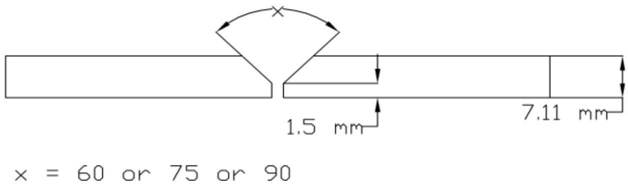

Figure 3: Joint Preparation

The edges of the specimen are prepared using a portable grinding machine. The edge preparations are arranged to make the weld joint. A gap (1 mm to 2 mm) is maintained between the pieces to ensure proper penetration of the weld.

4. Formation of Orthogonal Array by Taguchi Method

In this study three level process parameters i.e. welding current, bevel angle, and shielding gas flow rate are considered.

Parameters	**Level 1**	**Level 2**	**Level 3**
Current (Amps)	100	110	120
Bevel Angle (degrees)	30	37.5	45
Gas flow rate (LPM)	10	12.5	15

Table 6: Process parameters and their levels

S.NO	Current (Amps.)	Bevel Angle (degrees)	Gas Flow Rate (LPM)
T1	100	30	10
T2	100	37.5	12.5
T3	100	45	15
T4	110	30	12.5
T5	110	37.5	15
T6	110	45	10
T7	120	30	15
T8	120	37.5	10
T9	120	45	12.5

Table 7: L9 Orthogonal array after assignment of parameters

5. Heat Input

Heat input is a relative measure of the energy transferred per unit length of weld. It is an important characteristic because it influences the cooling rate, which may affect the mechanical properties and metallurgical structure of the weld and the HAZ. Heat input is typically calculated as the ratio of the power (i.e., voltage x current) to the speed of the heat source (i.e., the arc) as follows:

$$H = (60 \times E \times I) / S$$

Where,

H = heat input (J/mm)

E = arc voltage (volts)

I = current (amps)

S = travel speed (mm/min)

Arc voltage in this process remains constant as 12V. Travel speed is calculated based on the time taken for each pass and the length of the weld. The time is observed using a stop watch for each weld pass. For a thickness of 7.11mm four passes have been welded: root pass, hot pass, filler 1 and filler 2 respectively and the average heat input is calculated.

S.NO	Current (Amps.)	Bevel Angle (degrees)	Gas Flow Rate (LPM)	Avg. Heat input (J/mm)
T1	100	30	10	1523
T2	100	37.5	12.5	1619
T3	100	45	15	1303
T4	110	30	12.5	1539
T5	110	37.5	15	2141
T6	110	45	10	2019
T7	120	30	15	1749
T8	120	37.5	10	2053
T9	120	45	12.5	1605

Table 8: Heat input values

6. Experimental Observations

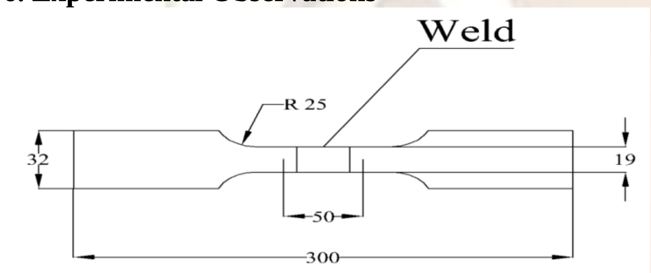

Figure 4: Tensile test specimen

The tensile strength of the dissimilar welded pipe joints are measured in Universal Testing Machine (UTM) and the results are found. The specimens are machined according to ASTM standards as shown in Figure 4 to hold it in the UTM.

S.NO	Current (Amps.)	Bevel Angle (degrees)	Gas Flow Rate (LPM)	Avg. Heat input (J/mm)	Ultimate Tensile Strength (Mpa)
1	100	30	10	1523	503.8
2	100	37.5	12.5	1619	505.79
3	100	45	15	1303	489.77
4	110	30	12.5	1539	520.26
5	110	37.5	15	2141	498.77
6	110	45	10	2019	516.26
7	120	30	15	1749	460.91
8	120	37.5	10	2053	487.71
9	120	45	12.5	1605	508.76

Table 9: Experimental observations

7. Radiography Results

Radiography is based on the differential absorption of short wavelength radiations such as X-rays and gamma rays on their passage through matter because of differences in density and variations in thickness. The gamma ray source used in this project is Iridium-192. The radiography test procedure specification follows ASME Section V.

DESCRIPTION	
Source to Film distance	16 inches
Source	Ir 192
Strength	18 Ci
Technique	Single wall single image
Penetrameter	ASTM 15
Lead screens	0.1mm (inside cover) 0.15mm (outside cover)
Film	Kodak AA 400
Specimen thickness	7.11mm
Film Density	2 to 2.5
Sensitivity	2T-2

Table 10: Radiography test description

Figure 5: Radiography images

The radiographic examination revealed that no significant defects were found in the weld and are acceptable as per ASME Section IX.

8. Analysis of Variance (ANOVA)

The purpose of ANOVA is to investigate which welding process parameters significantly affect the quality characteristics. The percentage contribution by each of the welding process parameters can be used to evaluate the importance of the process parameter change on the quality characteristic.

Term	Coef	SECoef	T	P
Constant	1.76792	0.03541	49.921	0.000
Current 100	-0.44448	0.05008	-8.875	0.012
Current 110 A	-0.02408	0.05008	-0.481	0.678
Bevel 30^0	-0.28601	0.05008	-5.711	0.029
Bevel 37.5	0.38275	0.05008	7.642	0.017
Gas flow 10Lpm	-0.42018	0.05008	-8.390	0.014
Gas flow 12.5 Lpm	0.34433	0.05008	6.875	0.021

Table 11: Estimated model coefficients

S = 0.1062 R – Sq = 99.2% R – Sq = 96.9%

Source	DF	Seq.SS	Adj.SS	Adj.MS	F	P
Current	2	1064.5	1064.5	532.24	7.62	0.116
Bevel angle	2	161.8	161.8	80.90	1.16	0.463
Gas flow rate	2	1269.8	1269.8	634.91	9.09	0.099
Residual Error	2	139.6	139.6	69.82		
Total	8	2635.7				

Table 12: ANOVA for Means

9. Contribution of Parameters

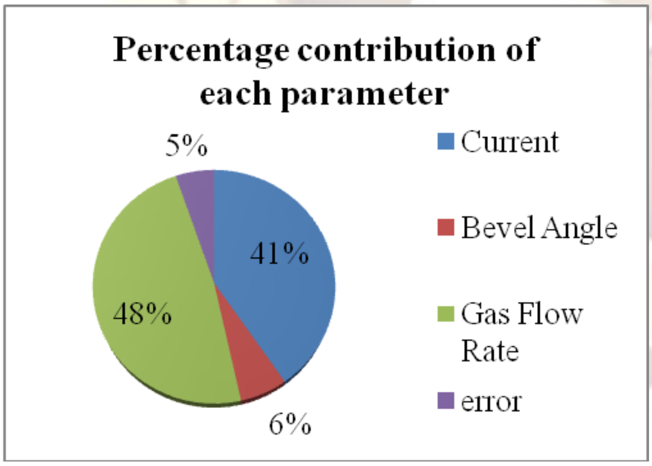

Figure 6 : % contribution of each parameter

From the result, the percentage contribution of shielding gas flow rate is more, compared with welding current and bevel angle.

10. Sensitization and Intergranular Corrosion

During welding of carbon steel and austenitic stainless steel, the material is subjected to elevated temperature (due to higher heat input). Due to this carbide precipitation can cause the occurrence of chromium-depleted zones at the boundaries, leading to a phenomenon known as sensitization, in which the depleted zones become the focus of intense corrosion. Higher heat input means slower cooling rate which can again lead to chromium carbide precipitation and become sensitized when subjected to sensitizing temperature for a longer time. At these elevated temperature the carbon diffuses to the grain boundaries, and then precipitates in the form of very small and thin chromium carbides which grow at grains and into the adjacent grain boundaries. In these areas the chromium level is substantially lower than required to form a protective film. The chromium depleted layer is actively corroded while the major portion of the grain remains un-attacked. This gives higher rate of corrosion even before being put into service and eventual failure. This is known as intergranular corrosion.

Three specimens (3, 5, 4) having the lowest, highest and intermediate values of heat input are selected for studying the specimens' susceptibility to intergranular corrosion.

Microstructure of specimen with lowest heat input

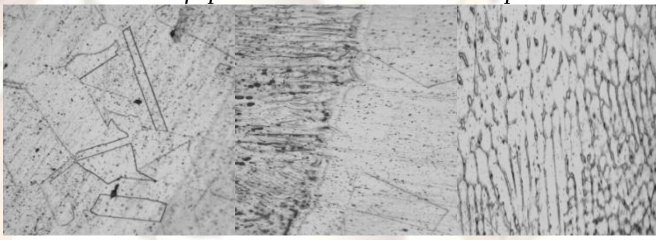

Figure 7: Microstructure of Base Metal, HAZ & Weld Zone

Microstructure of specimen with highest heat input

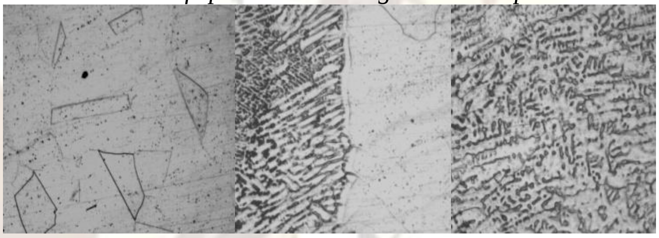

Figure 8: Microstructure of Base Metal, HAZ & Weld Zone

Microstructure of specimen with intermediate heat input

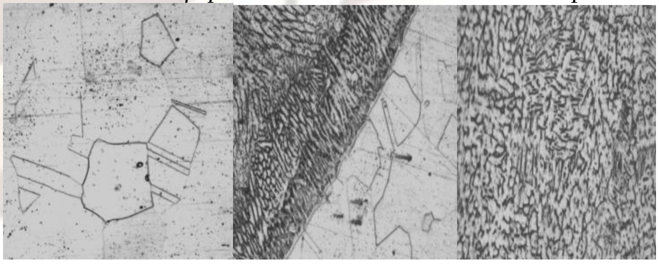

Figure 9: Microstructure of Base Metal, HAZ & Weld Zone

The test specimens are tested according to ASTM A262 Practice-A to determine the susceptibility to IGC. The specimens were initially sensitized at 675ºC for 1 hour. Then the specimens were electrolytically etched using oxalic acid. The specimens' microstructure after sensitizing and etching were studied under a metallurgical microscope. Microstructures of the all 3 specimens revealed "step structure" as in parent metal and interdendritic delta ferrite which reduces hot cracking and micro fissures are found in weld metal. The structures are found to be acceptable as per ASTM A262.

11. Statistical Plot

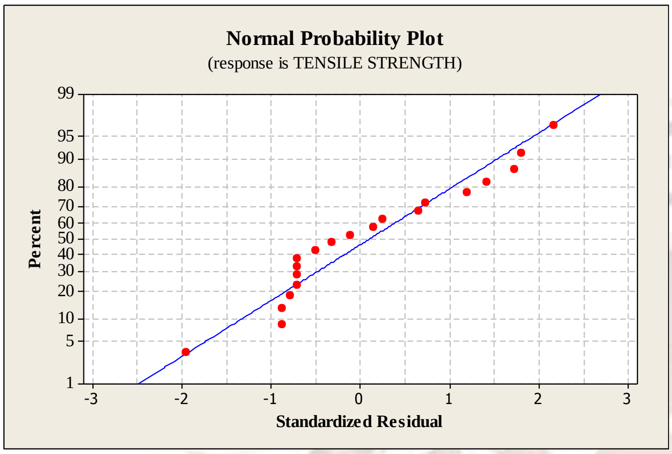

Figure 10 (Normal Probability plot)

The (distribution line) at the centre of the graph shows the desired tensile strength value in the normal probability plot. The dots which lie close to the distribution line in the graph show the degree of closeness of the values.

CONCLUSION

The following conclusions are derived from this project:

- Variation in heat input resulted in significant changes in the mechanical properties of the weld.
- Results show that lower heat input resulted in lower tensile strength and too high heat input also resulted in reduced tensile strength. An intermediate value of average heat input in the range of 1500 to 1600 J/mm gave the highest tensile strength.
- Gas flow rate is the factor that significantly contributed to a higher percentage and has greater influence on the tensile strength followed by contributions from current and bevel angle.
- The optimum range includes current of 110 to 115 amperes, shielding gas flow rate of 12.5 LPM, and bevel angle of 45 degrees.
- It was also found that the weld and the SS base metal was free from susceptibility to IGC and also gave higher tensile strength for the heat input range mentioned above.

REFERENCES

[1] S.P.Gadewar, Peravli Swaminadhan, M.G.Harkare, S.H.Gawande, "Experimental investigation of weld characteristics for a single pass TIG welding with SS304", International Journal of Engineering Science and Technology, Vol. 2(8), 2010, 3676-3686.

[2] Lenin N., Sivakumar M., Vigneshkumar.D, "Process parameter optimization in ARC welding of dissimilar metals", Thammasat Int.J.Sc. Tech, Vol.15, No.3, 2010.

[3] K.Kishore, P.V.Gopal Krishna, K.Veladri, G.Kiran Kumar, "Analysis of defects in Gas Shielded Arc welding of AA 6351 using Taguchi methods", International Journal of Applied Engineering Research, Vol.5, pp.393-399, 2010.

[4] Ugur Esme, Melih Bayramoglu, Yugut Kazancoglu, Sueda Ozgun, "Optimization of weld bead geometry in TIG welding process using grey relation analysis and Taguchi method", Materials and technology 43 (2009) 3, 143-149.

[5] Bandhita Plubin, Narongchai Sathavornvichit, Putipong Bookkamana, "Central composite design in optimization of the factors of automatic flux cored arc welding", Proceedings of the 2nd IMT-GT Regional Conference on Mathematics, Statistics and Applications, June 13-15, 2006.

[6]. T.Senthil Kumar, V.Balasubramanian, M.Y.Sanavullah, S.Babu, "Effect of pulsed current TIG welding parameters on pitting corrosion behavior of AA6061 aluminium alloy", Journal of Material Science Technology, Vol.23 No.2, 2007.

[7]. Ahmed Khalid Hussain, Abdul Lateef, Mohd Javed, Pramesh.T, "Influence of welding speed on tensile strength of welded joint in TIG welding process", International Journal of Applied Engg Research, Vol.1 No.3, 2010.

[8] L.Sureshkumar, S.M.Verma, P.Radhakrishna Prasad, P.Kiran Kumar, T.Siva Shanker, "Experimental investigation for welding aspects of AISI 304 & 316 by Taguchi technique for the process of TIG & MIG welding", International Journal of Engineering Trends and Technology, Vol.2 issue 2, 2011.

[9] Farhad Kolahan, Mehdi Heidari, "Modeling and optimization of MAG welding for gas pipelines using regression analysis and simulated annealing algorithm", Journal of Scientific & Industrial Research, Vol.69, April 2010, pp.259-265.

[10] S.Kumanan, J.Edwin Raja Dhas & K.Gowthaman, "Determination of submerged arc welding process parameters using Taguchi method and regression analysis", Indian Journal of Engineering & Material Sciences Vol.14, June 2007, pp.177-183.

[11] P.Atanda, A.Fatudimu, O.Oluwole, "Sensitization study of normalized 316L stainless steel", Journal of Minerals & Materials Characterization & Engineering, Vol.9, no.1, pp.13-23, 2010.

[12] Sunniva.R.Collins, Peter.C.Williams, "Weldability and corrosion studies of AISI 316L electropolished tubing", Swagelok Research

[13] A.K.Lakshminarayanan, V.Balasubramanian, "Comparison of RSM with ANN in predicting tensile strength of FSW of AA7039", Transactions of Nonferrous metals Society of China, vol.19, 9-18, 2009.

[14] R.Scott Funderburk, "A look at Heat Input: Key Concepts in Welding Engineering, Welding Innovation Vol.XVI, No.1, 1999.