Journal of Mechanical Engineering Research and Developments
ISSN: 1024-1752
Website: http://www.jmerd.org
Vol. 41, No. 1, 2018, pp. 86-96

An Experimental Investigation of Process Parameters of Tungsten Inert Gas Welding for improvement of Mechanical Properties on Duplex Stainless Steel (2205) weldments Using Design of Experiments

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ABSTRACT: The present work deals with optimization of tungsten inert gas welding process on Duplex Stainless Steel (2205). The present investigation is to find out the best influence of welding current, welding speed, welding position and filler material on mechanical properties. Taguchi L9 orthogonal array method was employed to optimize the welding process parameters for improvement of mechanical properties of weld bead such as tensile strength, hardness and toughness. Four variable welding parameters and their three levels were selected and design of experiments was implemented as per Taguchi L9 array approach.

KEYWORDS: Tungsten inert gas welding; Mechanical; Properties; Taguchi technique; Duplex stainless steel.

INTRODUCTION

Duplex Stainless steel DSS typically comprises of microstructure consisting approximately equal proportion of ferrite (δ) and austenite (γ). DSS is a commonly used for structural material in the oil, gas, manufacturing industries and has special application in chemical, wastewater, marine engineering field. The influences of welding parameters on the mechanical properties of the weld bead is analyzed by using MINITAB18 software after conducting Tungsten Inert gas welding experiments and there influences are stated. The plots of means and S/N ratio (larger the better) are considered for optimization. Many researchers studied on parametric optimization of TIG process parameters using Taguchi and Grey Taguchi analysis. They used the stainless steel 304 grade plate which dimensions are 1.2 mm thickness ,250 mm length, 30 mm wide specimens are welded by changing the process parameters which are current (40-85A), gas flow rate (5-20 lit./ min), welding speed (8-14m/min) and gun angle (500 -800). The taguchi method L16 orthogonal array technique was used for optimization and found experimentally that the optimal setting for steel with a current 40 A, gas flow rate 5 ltr/min, welding speed 12 m/min and gun angle 800, for stainless steel, the final work piece give the tensile load (294.1Mpa), area of penetration (13.05 mm2), penetration (2.215 mm) maximum Bead width (5.22 mm) and bead height (0.055 mm) are minimum [1].

The experimental investigations of weld characteristics for a single pass TIG welding were conducted with SS304 using the specimen of 100 mm length ,25 mm wide , (1or 2 or 3mm) thickness of welding plate. The input parameters of welding current (15-180 Amp), shielding gas flow (1-18 lpm), and work piece thickness (1-3mm) and apply the regression analysis technique. It is observed that as thickness of the work piece increases the front width and back width value across the weld also increases [2].The effect of pulsed current on the characteristics of weldments were investigated by GTAWon 3 mm thick of 304 stainless steel. The welding current 80-83 Amp and arc travel speed 700-1230 mm/min was selected.The more hardness value was found on the heat affected zone of all the weldments, may be due to grain refinement. Higher tensile strength found in the non-pulsed current welded area and it was observed that UTS and YS value of non-pulsed current were more than the parent metal and pulsed current weldments [3].The pulsed Tungsten Inert Gas welding of 2.14 mm thickness of AA5456 Al alloy were welded with welding current (40-90) amps, welding speed (210-230) mm/min. The taguchi method was employed to optimize the pulsed TIG welding process parameters for increasing the mechanical properties and a regression models were developed. Microstructures of all the welds were studied and correlated with the mechanical properties. Almost 10-15% improvement in mechanical properties was observed after planishing due to redistribution of internal stresses in the weld [4].

The effect of welding speed is more on tensile strength of the welded joint by TIG welding process of AA6351 Aluminium alloy of 4 mm thickness. The welding was conducted on specimens of single ‘V’ butt joint with welding speed

DOI: 10.7508/jmerd.2018.01.011

of 1800 -7200 mm/min and investigated the strength. The welded joint was tested by a universal tensile testing machine and it was revealed that strength of the weld zone is less than base metal and tensile strength increases with reduction of welding speed [5]. The high strength aluminium alloy joints produced by gas metal arc welding and gas tungsten arc welding under the effect of continuous current and pulsed current technique were studied and found that the pulsed current gas metal arc weld joints produced high strength values and high joint efficiency than other welded joints. Pure argon used as a shielding gas. Due to that of fine grains the base metal and heat affected zone regions produced high hardness values than weld metal. The pulsed current gas tungsten arc weld joints produced high hardness values and continuous current gas metal arc weld joints produced low hardness values. A very fine grain in the welded region was produced by the pulsated current gas metal arc welding [6]. The AA6061 material joints were welded by Metal Inert Gas (MIG) and Friction Stir Welding (FSW). The FSW was carried out by 3 axis computer numerical controlled milling machine CIMTRIX. With semiautomatic welding machine (MIG 350), the welding were carried out with the welding speed of 110 mm per minute. The FSW showed 10-100 times smaller grains than the MIG welding in the microstructure of the weld joints. The MIG welding specimens produced the less tensile strength than FSW. The amount of heat input affected the weld material hardness and the width of hardness was determined by shoulder diameter and heat input. The FSW reduced production cost, pre operations and increased the weld quality [7].

The Mechanical Properties of MIG welded dissimilar joints under the effect of heat input was inestigated. The welding current, speed of wire and voltage determines the heat input. The IS 2062, IS 45 C8, IS 103Cr1 were used as a base material. 1.2 mm diameter copper coated mild steel was used as a filler wire. The both joints (IS 2062 & IS 45 C8) and (IS2062 & IS 103 Cr1) increased the tensile strength when increased with the heat input and also increased the hardness value when decreased with the heat input [8]. The effect of welding process parameters on the mechanical properties of stainless steel -316 (18Cr-8N) welded by TIG welding. The specimen size is 40x15x5mm for experimentation observed that the welding current has a significant effect though filler rod do have some effect similar to current but compared to current it is less significant. MINITAB software is used for the prediction of the hardness, depth of penetrations and impact strength [9]. The influence of welding parameters like welding speed, current on strength of low carbon steel on AA1050 materials during welding. A Taguchi method has been used to obtain the data and experimentally work carried with 1mm thick low carbon steel & 2mm AA1050 aluminium alloy were used, size is (150 mm width & 300mm length). In this study L9 orthogonal array is used. An analysis of variance (ANOVA), orthogonal array and S/N ratio are used to investigate the welding characteristics of dissimilar welding joint and to optimize the process parameters. The experiment value that is observed from optimal welding parameters are strength is 61.37 MPa & S/N ratio is 16.45[10].The present work deal with TIG welding on duplex stainless 2205 and experimentally investigated the tensile strength, hardness and impact strength of welded specimens by appying taguchi approch.

MATERIAL AND METHODOLOGY

The tungsten inert gas welding (TIGW) was used for welding of 2205 duplex stainless steel (DSS) plates of 200 mm x 75 mm x 6 mm plate dimensions. The welding process parameters, which could influence the mechanical properties, were selected are weld current (A), weld time (T), electrode material (F) and position of welding (Z). The materials for filler rods were 316 L, 308L and 310 L. The chemical composition of the base metal and filler rods are given in Table 1.The weld joint design is shown in figure 1. The experiments were conducted using arc gap 2 mm, V-groove angle of 60º, root gap of 3 mm. The direct current electrode negative DCEN (Straight polarity) was employed during TIGweldingprocess.

Table 1. Base material and filler material chemical composition (Wt%).

composition	Base material composition 2205 DSS (base material)	Filler material ER 316L	Filler material ER 308L	Filler material ER 310L
C	0.024	0.03	0.03	0.08
Cr	22.821	18.5	21.5	25.5
Si	0.457	0.45	0.47	0.49
Mn	1.72	1.75	1.75	1.75
P	0.019	0.03	0.03	0.03
S	0.017	0.03	0.03	0.03
Mo	3.22	2.8	0.75	0.75
Ni	5.75	11.5	9.5	20.5
Fe	Rem	Rem	Rem	Rem
Cu	0.73	0.75	0.75	0.75

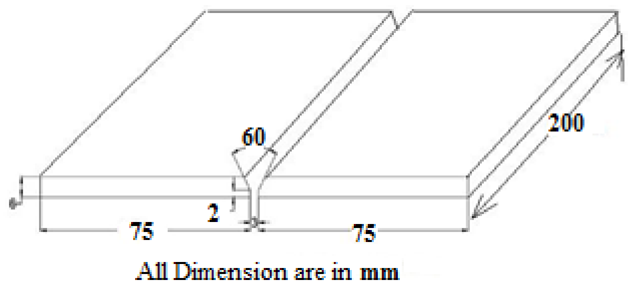

Figure 1. Weld joint Design (Edge Preparation).

The Taguchi optimization method was selected to maximize the mechanical properties of welded metal.The four variable parameter welding current (A), welding time (T), welding position (Z), filler Material (F) and their three levels were selected, the TIGW process parameter are given in the Table 2. The two plates were held as per the design using fixtures for the flat, horizontal and vertical position of welding with 3 mm root gap between the welding plates as shown in figure 2. A grooved copper back up plate having dimensions 2mm x 5mm was fixed below the welding plates to avoid the flow-off and root reinforcement of the weld metal between two edge prepartion of plate. The electrode diameter used was 3 mm for all experiments. Two and half electrode was consumed for each 200 mm weld length. The L9 orthogonal array matrix is tabulated in Table 3.

Table 2. TIG Welding process parameter and three levels.

	Parameter	**Level-1**	**Level-2**	**Level-3**
A	Welding current	120amp	140amp	160amp
B	Welding speed(Duration)	7min	9min	11min
C	Welding position	1G	2G	3G
D	Electrode wire	316L	308L	310L

Table 3. Design of Experiments as per Taguchi L9 orthogonal array.

Exp no	**(A)weld current (amp)**	**(B) weld duration (min)**	**(C) weld position**	**(D) electrode wire**
1	120	7	1G	316L
2	120	9	2G	308L
3	120	11	3G	310L
4	140	7	2G	310L
5	140	9	3G	316L
6	140	11	1G	308L
7	160	7	3G	308L
8	160	9	1G	310L
9	160	11	2G	316L

Flat position horizontal position vertical position

Figure 2.

After conducting nine welding processes as per design of experiment (DOE), the experiments were carried out to measure the tensile strength, hardness, toughness of weld metal by using universal testing machine (UTM), vickers hardness test and universal pendulum impact testing machine respectively in a bead on welded plates

Tensile Strength Test

This test is used to measure the tensile strength of a welded joint. The tensile strength, which is defined as stress in kgf per square meter. It is calculated by dividing the breaking load of the test piece by the original cross section area of the specimen. This test is used to measure the strength of a welded joint. A portion of the welded plate is locating the weld midway between the jaws of the testing machine, and then the load is applied gradually on the specimen until the specimen breaks. Then the breaking load is recorded. The width, thickness of the test specimen are measured before testing, and the area in square inches is calculated by multiplying width and thickness before testing , the area in square inches is calculated. The tensile test is conducted for two trails and average of the two test results are considered for taguchi analysis in Minitab. The ASTM standard tensile specimens after performing ultimate tensile test are shown in Figure 3. The width, thickness, initial cross sectional area, initial gauge length and final gauge length are measured and stated in Table 4 and Table 5 of trail 1 and trail 2 respectively.

Table 4. Tensile test experiment value Trail1.

Tensile test table, DSS (2205) Trail 1												
	Input data							**Results**				
Experiment No:	**Specimen position**	**Specimen width (mm)**	**Specimen thickness (mm)**	**C/S area (mm^2)**	**Original gauge length (mm)**	**Final gauge length (mm)**	**Extenso meter gauge length (mm)**	**Ultimate load (kN)**	**Ultimate tensile strength (MPa)**	**Elongation (%)**	**0.2% Proof stress (Mpa)**	**0.2% Proof load (KN)**
1	Flat	12.5	5.99	74.875	50	54.72	50	47.22	630.609	9.44	452.21	33.859
2	Horizontal	12.53	6	75.18	50	54.66	50	52.98	704.709	9.32	512.514	38.513
3	Vertical	12.55	5.98	75.049	50	55.23	50	53.58	713.924	10.46	544.341	40.852
4	Horizontal	12.54	6.01	75.365	50	52.57	50	33.84	448.985	5.14	402.518	30.336
5	Vertical	12.52	5.96	74.619	50	58.96	50	55.44	742.964	17.92	522.37	38.979
6	Flat	12.51	5.99	74.935	50	54.21	50	44.76	597.358	8.42	453.568	33.988
7	Vertical	12.5	5.99	74.875	50	55.75	50	54.54	728.365	11.5	517.417	38.742
8	Flat	12.5	6.02	75.25	50	53.15	50	46.08	612.359	6.3	510.16	38.39
9	Horizontal	12.54	5.98	74.989	50	58.14	50	53.82	717.696	16.28	494.395	37.074

Figure 3. Tensile test specimens.

Table 5. Tensile test experiment values trail 2.

Tensile test table, DSS (2205) T01 B trail 2												
	Input data							**Results**				
Experiment no:	**Specimen position**	**Specimen width (mm)**	**Specimen thickness (mm)**	**C/S area (mm^2)**	**Original gauge length (mm)**	**Final gauge length (mm)**	**Extenso meter gauge length (mm)**	**Ultimate load (kN)**	**Ultimate tensile strength (MPa)**	**Elongati on (%)**	**0.2% Proof stress (Mpa)**	**0.2% Proof load (KN)**
1	Flat	12.56	5.93	74.481	50	57.59	50	53.46	717.777	15.18	473.364	35.257
2	Horizontal	12.55	5.92	74.296	50	57.08	50	53.04	713.863	14.16	470.564	34.961
3	Vertical	12.53	5.92	74.178	50	55.8	50	52.38	706.12	11.6	495.715	36.771
4	Horizontal	12.52	5.93	74.244	50	54.13	50	33.78	455.011	8.26	361.918	26.87
5	Vertical	12.5	5.92	74	50	58.25	50	55.26	746.757	16.5	548.096	40.559
6	Flat	12.54	5.93	74.362	50	56.15	50	54	726.197	12.3	529.12	39.347
7	Vertical	12.51	5.92	74.059	50	56.84	50	54.3	733.189	13.68	502.549	37.218
8	Flat	12.53	5.92	74.178	50	53.73	50	41.46	558.911	7.46	469.046	34.793
9	Horizontal	12.54	5.93	74.362	50	59.83	50	55.38	744.755	19.66	520.124	38.678

Vickers Hardness Test

The Vickers hardness test is conducted by indenting the test material with a diamond indenter which is in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 50 kgf. The full load is applied perpendicularly to the surface for 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average is calculated. The area of the sloping surface of the indentation is calculated as shown in Figure 4. The Vickers hardness is obtained by dividing the kgf load by the area of indentation**.** The specimens are shown in figure 5. The hardness is calculated at the weld zone, transition zone, heat effected zone and base zone and stated in table 6. The average of the three welds zone hardness values are considered for analysis in Minitab.

d = Arithmetic mean of the two diagonals, d_1 and d_2 in mm
HV = Vickers hardness F= load in kgf

$$HV = \frac{2F\sin\frac{136^o}{2}}{d^2} \qquad HV = 1.854\frac{F}{d^2} \text{ approximately}$$

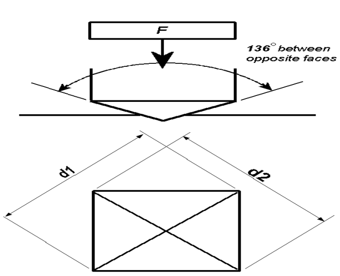

Figure 4. Area measurement diagram.

Figure 5. Hardness specimens.

Impact Test

The two kinds of specimens used for impact testing are known as Charpy and Izod. Both test pieces are broken in an impact testing machine. The only difference is in the manner that they are anchored. The charpy piece is supported horizontally between two anvils and the pendulum strikes opposite the notch. The Izod piece is supported as a vertical cantilever beam and is struck on the free end projecting over the holding vise

A Charpy test was conducted and measures the welds ability to withstand an impact force. The low charpy test readings indicate brittle weld metal higher charpy readings indicate the samples toughness. The toughness values of the weld-pieces are tabulated in table 7. Weld-pieces are placed at the impact testing machine as simply supported. The hammer of the heavy weight is then released and corresponding values of weight provides the toughness values for weld-piece

RESULTS AND DISCUSSION

Tensile Test Results

After preparing tensile test specimens (150 mm x 20 mm x 6 mm) as per ASTM standards as shown in figure 3.The total 18 welded specimen were tested on universal testing machine and experimentally investigated ultimate tensile strength, elongation, proof stress and proof load of weld metal which are detail tabulated in Table 4 for trail 1 and Table 5 for trail 2.

Vickers Hardness Test Results

The total ten vicker hardness value (base metal trail 1 (left), base metal trail 2(right), heat affected zone trail 1(left), heat affected zone trail 2(middle), heat affected zone trail 3 (right), thermal affected zone (left), thermal affected zone (right), weld zone trail 1, weld zone trail 2, weld zone trail 3 of nine welded specimens are detailed in Table 6.

Table 6. Vicker Hardness values at ten location of welded specimen.

S.NO	**Base Metal trail 1 (left)**	**Base Metal trail 2(Right)**	**Heat affected zone trail 1(left)**	**Heat affected zone trail 2(middle)**	**Heat affected zone trail 3 (right)**	**Thermal affected zone (left)**	**Thermal affected zone (right)**	**Weld zone trail 1**	**Weld zone trail 2**	**Weld zone trail 3**
1	344.15	337.93	320.22	320.22	314.63	314.63	298.7	249.56	249.56	245.71
2	274.72	283.95	303.87	303.87	270.27	261.69	261.69	253.51	253.51	253.51
3	303.87	303.87	320.22	320.22	320.22	283.95	293.66	245.71	245.71	245.71
4	293.66	298.7	320.22	320.22	309.18	253.51	279.28	214.71	241.71	217.85
5	298.7	283.95	365.93	279.28	288.74	270.27	265.93	224.35	221.07	221.07
6	293.66	283.95	320.22	320.22	320.22	298.66	293.65	265.93	265.93	279.28
7	309.18	309.11	314.63	309.18	337.93	303.87	303.87	265.93	265.93	265.93
8	298.7	298.7	314.63	309.18	309.18	261.69	261.69	241.94	257.55	238.27
9	279.28	283.95	303.87	309.18	320.22	221.07	227.72	191.82	191.82	191.82

Impact Test Results

The nine charpy impact test specimen is rectangular 45^0 V-notch bar with dimension (55mm x 10 mm x10 mm) were preparation on wire cut EDM machine from each of nine welded DSS plates such that welded portion comes at center. Each specimen is simply supported horizontally between two anvils and the pendulum type hammer strikes opposite the V-notch and determines the amount of energy absorbed by a material during fracture that is Impact energy (Joules) of weld metal were investigated and it's tabulated in Table 7. This test result gives the indication of the characteristics of weld metal during fracture.

Table 7. Charpy Impact test.

S.No	Impact energy (joules)
Exp.No:T01	52
Exp.No:T02	34
Exp.No:T03	62
Exp.No:T04	35
Exp.No:T05	70
Exp.No:T06	69
Exp.No:T07	65
Exp.No:T08	34
Exp.No:T08	76

TAGUCHI ANALYSIS

Design summary: The four factors are welding current, welding time, welding position and welding material with three levels each are shown in the following table 8.

Table 8. Design summary.

Taguchi Array	L9(3^4)
Factors:	4
Runs:	9

Taguchi Analysis: Ultimate tensile strength versus welding current, welding time, welding position and filler wire material Response

Table 9. Signal to Noise Ratios of ultimate tensile stress.

Level	Welding current	Welding time	Welding position	Welding material wire
1	57.09	55.86	56.69	57.34
2	55.95	56.76	55.89	57.20
3	56.83	57.24	57.28	55.32
Delta	1.14	1.38	1.39	2.02
Rank	4	3	2	1

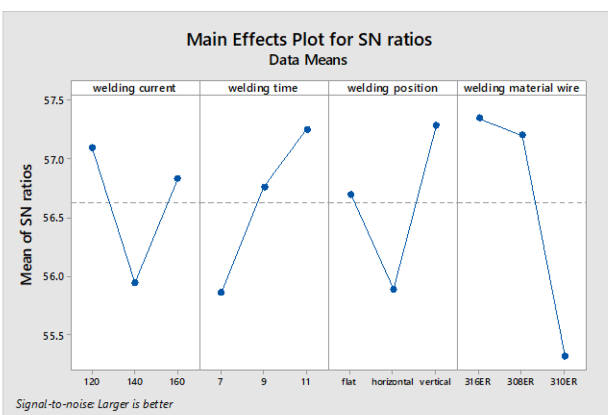

Figure 6. Ultimate tensile stresses.

Table 10. Means Ratios of ultimate tensile stress.

Level	Welding current	Welding time	Welding position	Welding material wire
1	715.2	635.3	685.4	736.4
2	642.7	691.0	637.9	724.4
3	696.8	728.3	731.3	593.8
Delta	72.5	93.0	93.4	142.7
Rank	4	3	2	1

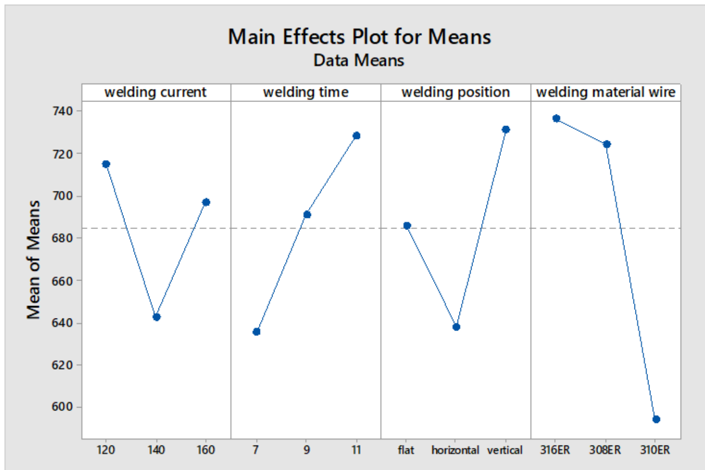

Figure 7. Ultimate tensile stresses.

It is observed that from table 9 and 10 the order of effect of input process parameters are welding current, welding time, and welding position and filler material. From Figures 6 and 7 the ultimate tensile stress is maximum when input parameters are welding current 120 Amps, welding time 11 minutes, vertical position and filler material is 316ER.

Taguchi Analysis: Vickers hardness versus welding current, welding time, welding position and filler wire material

It is observed that from Table 11 and 12 the order of effect of input process parameters are welding time, welding current, welding position and filler material. From Figurs 8 and 9 the Vickers hardness is maximum when input parameters are welding current 120amps, welding time 7 minutes, flat position and filler material is 308ER.

Table 11. Signal to Noise Ratios of Vickers hardness.

Level	Welding current	Welding time	Welding position	Welding material wire
1	47.93	47.81	48.12	46.83
2	47.54	47.61	46.92	48.40
3	47.32	47.37	47.75	47.55
Delta	0.61	0.44	1.19	1.57
Rank	3	4	2	1

Table 12. Means of Vickers hardness.

Level	Welding current	Welding time	Welding position	Welding material wire
1	249.2	246.3	254.9	220.8
2	239.1	240.5	223.4	263.3
3	234.6	236.0	244.6	238.8
Delta	14.6	10.4	31.5	42.5
Rank	3	4	2	1

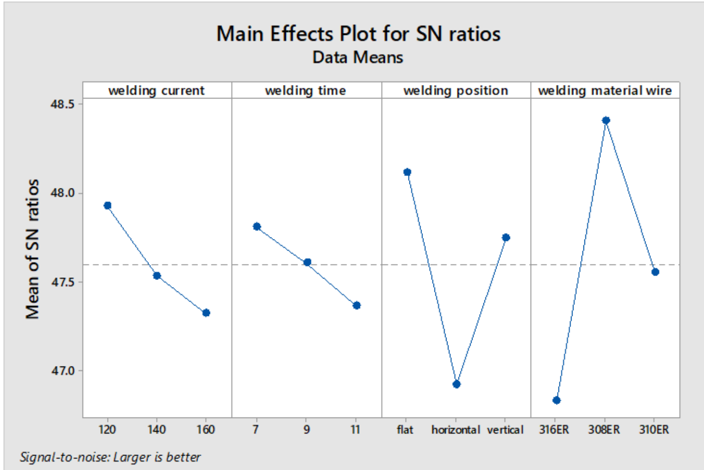

Figure 8. Vickers hardness.

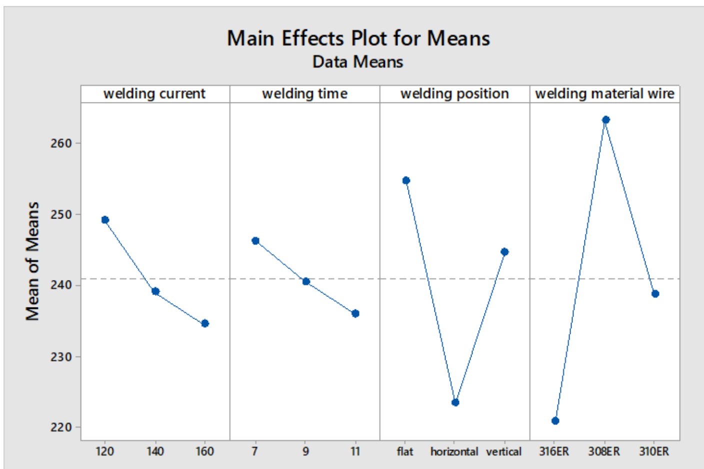

Figure 9. Main Effect plot for Vickers hardness.

Taguchi Analysis: impact energy versus welding current, welding time, welding position and filler wire material

Table 13. Signal to Noise Ratios of impact energy.

Level	Welding current	Welding time	Welding position	Welding material wire
1	33.60	33.82	33.91	36.28
2	34.85	32.72	33.04	34.55
3	34.83	36.75	36.34	32.45
Delta	1.25	4.03	3.29	3.83
Rank	4	1	3	2

Table 14. Means of impact energy.

Level	Welding current	Welding time	Welding position	Welding material wire
1	49.33	50.67	51.67	66.00
2	58.00	46.00	48.33	56.00
3	58.33	69.00	65.67	43.67
Delta	9.00	23.00	17.33	22.33
Rank	4	1	3	2

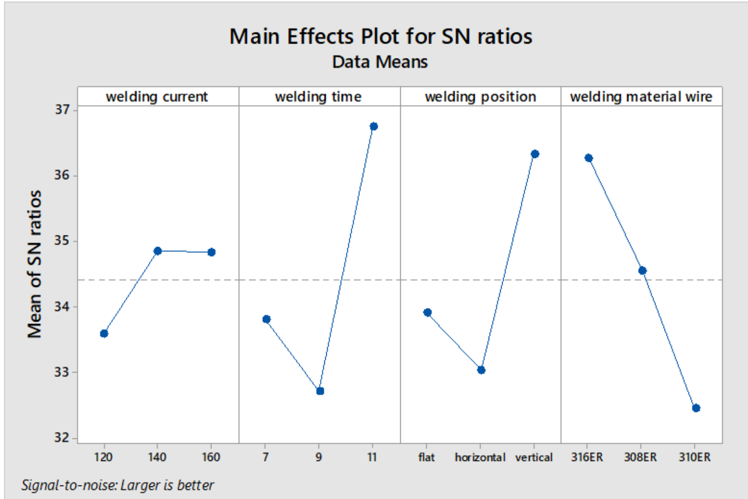

Figure 10. Main Effect Plot for S/N ratios of Impact energy.

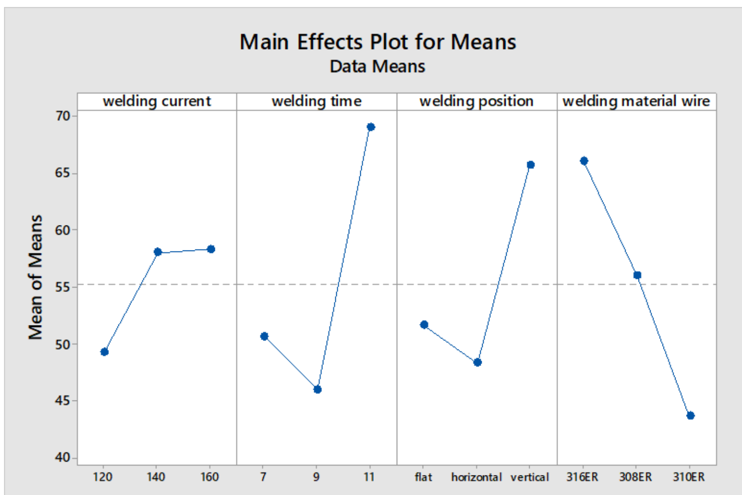

Figure 11. Impact energy.

It is observed that from Table 13 and 14 the order of effect of input process parameters are welding current, welding position, filler material, and welding time. From fig 10 and 11 the impact energy is maximum when input parameters are welding current 140amps, welding time 11 minutes, vertical position and filler material is 316ER

CONCLUSIONS

In this investigation, it was found that the influence of welding wire material on the ultimate tensile stress is minimum and welding current is maximum. From the result it was also observed that the maximum ultimate tensile stress is occurring for, when input parameters are welding current 120amps, welding time 11 minutes, vertical position and filler material is 316ER

In this investigation, it was found that the influence of welding wire material on the hardness is minimum and weld time is maximum. From the result it was also observed that the maximum hardness is occurring when input parameters are welding current 120 Amps, welding time 7 minutes, flat position and filler material is 308ER

In this investigation, it was found that the influence of welding time on the impact energy is minimum and welding current is maximum. From the result it was also observed that the maximum impact energy is occurring when input parameters are welding current 140 Amps, welding time 11 minutes, vertical position and filler material is 316ER

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