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Process Parameter Selection for Optimizing the Mechanical Properties of Stainless Steel (SS 202 & SS 316) in the Gas Tungsten Arc Welding

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Abstract: Tungsten Inert Gas (TIG) welding is one of the widely used techniques for joining ferrous and non-ferrous metals. The TIG welding parameters are the most significant factors affecting the quality, productivity and cost of welding. In this study, SS 202 and SS 316 types of austenitic stainless steels were welded by GTAW (Gas Tungsten Arc Welding) using SS 202 and SS 316 (ER 316L) filler metals, respectively. The present study aims to search out the optimization of process parameters for Gas Tungsten Arc Welding (GTAW). The process parameters like welding current, wire diameter, shielding gas, and groove angle were varied at different levels to find out the influence of parameters on Hardness and Toughness. After performing Charpy Impact Test on SS 202 steel at room temperature, the results show that toughness mainly depends on the shielding gas chosen whereas for SS 316 steel the toughness increases as well as decreases as per the changes in the process parameters. Up to the magnitude of 150 A, the Microhardness value increases and then decreases with further rise in its magnitude.
Keywords: GTAW, SS 202, SS 316, Microhardness, Toughness

I. INTRODUCTION

Tungsten Inert Gas (TIG) welding which uses a non-consumable tungsten electrode and an inert gas for arc shielding, is a highly relevant arc welding process. It is frequently used for welding hard-to-weld metals such as aluminium, stainless steel, magnesium, and titanium. TIG welding is a multi-objective and multi-factor metal fabrication technique, where Argon or Helium is used for shielding purpose. TIG weld quality is strongly characterized by the weld pool geometry because it plays a major role in determining the mechanical properties of the weld. Therefore, it becomes necessary to select the welding process parameters for obtaining an optimal weld pool geometry.

Optimization of weld pool geometry has been attained by using TIG welding on a stainless-steel plate by varying welding parameters, and results showed that 'higher the better' quality characteristics are better used in the analysis of Signal-to-Noise ratio (S/N) and analysis of variance (ANOVA). A mathematical model has been developed to study the effects of process parameters on weld pool geometry in GTAW using ANOVA and found that wire feed rate, travel speed, and wire diameter are the major parameters that influence bead geometry in GTAW. Investigation of Weldments obtained in stainless steel (304L and 316L) by GTAW yields better mechanical properties than by GMAW, i.e., yield strength, tensile strength, hardness and impact energy values of 304L and 316L stainless steels welded by GTAW are higher than that welded by GMAW. It optimized SS 316L stainless steel and observed that Gas flow has a major impact and Bevel angle has the slightest impact in affecting the tensile strength. Use of active flux, TiO_2 in GTAW increases the depth of penetration. Peak current has the highest contribution in affecting the micro weld hardness; grain size and HAZ width in the GTA Welded Aluminium Alloy 7039. Non-pulsed current weldments yield higher tensile strength values than pulsed current during GTAW for SS 304 metal. The microstructure of weld metal structure shows the delta ferrite in a matrix of austenite steel 202 grade during GTAW.

II. EXPERIMENTAL DESIGN

Since the last four decades, there have been limitations in applying conventional experimental design techniques for technical experimentation. Dr. Genichi Taguchi, a Japanese Engineer, established a new method known as orthogonal array design, which adds a new dimension to the conventional experimental design. Taguchi's DOEs are denoted by 'Labc' where 'La' refers to the orthogonal arrays of variables or design matrix, 'b' refers to the levels of variables and 'c' to the number of variables. Taguchi's method is a broadly accepted method of DOE which has proven in producing high-quality products at subsequently low cost.

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An advantage of the Taguchi's method is that it emphasizes on mean performance characteristic value close to the target value rather than a value within certain specific limits, thus improving the product quality. Results obtained from Taguchi's method are only relative, and it does not exactly indicate which parameter has the highest effect on the characteristic performance value. Also, Taguchi's method is an off-line quality control method, where off-line refers to the fact that it is practiced away from or parallel to the production process. It is not intended to be applied while actual production is in progress. The statistical tool Minitab 17 is used for the construction of the array. With such an arrangement, completely randomized experiments can be performed. Orthogonal Arrays provide a set of well-balanced minimum experiments, and Dr. Taguchi's S/N ratios help in data analysis and prediction of optimum results.

III. EXPERIMENTAL SETUP

Experiments were conducted on TIG welding Lincoln electric Invertec 350V pro machine as shown in figure 1. The machine setup consists of the power source, machining base, welding torch, shielding gas cylinder, and filler rod. Direct Current Straight Polarity, i.e., the tungsten electrode and the workpiece are taken as cathode and anode respectively. Argon, Helium and their mixture are used to protect the weld pool from contaminants. A constant gas flow rate of 10 lt/min is maintained throughout the experimental runs.

Figure 1: GTAW Setup (Courtesy: Paanchal Weld Workshop, Faridabad)

A. *Impact Test*

Impact Strength is the ability of a material to absorb mechanical energy in the process of deformation and fracture under impact loading. The impact strength and impact energy are also described as the amount of energy absorbed before fracture.

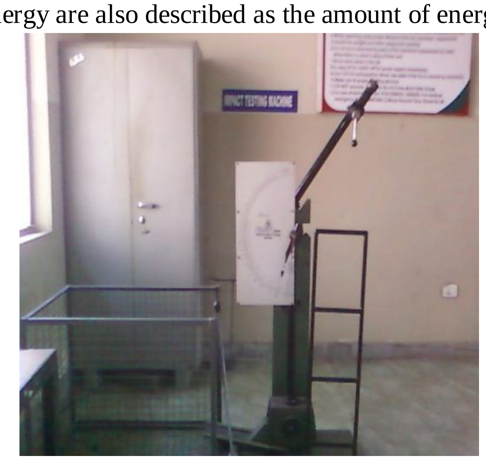

Figure 2: Impact testing machine (Courtesy: Solid Mechanics Lab, MED, MRCE, Faridabad)

Specimens were prepared according to ASTM standards A-370 (2010) and having size as cross – section of 10 mm X 6 mm (for SS 202 & SS 316) and length 55 mm.

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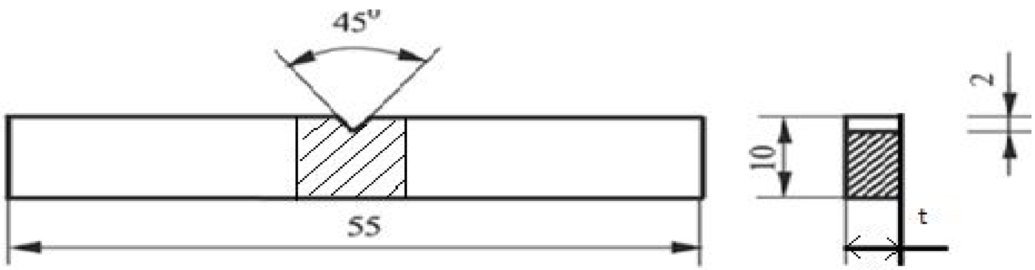

Figure 3: Standard size of impact test specimen according to ASTM standard A-370 [28]

B. Toughness test values of base metal

The Toughness Test Values of base metal have been shown in Table 1.

Table 1: Toughness test values for base metal

Base metal	Charpy Test results at room temperature (18^0 C) (Joule)
SS 202	75
SS 316	82

C. Microhardness (HV) Test

Microhardness is a term referring to the testing of hardness involving materials by using small applied loads. Also known as micro-indentation hardness testing.

The samples for microhardness test were prepared as shown below in the figure. Microhardness of the weld region was measured by using UHL VMHT microhardness tester as shown in Figure. The measurement was dependent on the size of indentation in the samples. The diagonals of the indents formed by a pyramid-shaped diamond indenter were directly measured on the touch screen at 50 X magnification, which gave a direct microhardness value (HV). The hardness values obtained were useful indicators of material properties. The load applied on the indenter was 300 gms and the dwell time was 15 sec. Figure 3.39 shows the specimen which was used for microhardness test.

Figure 4: Microhardness test machine (Courtesy: Central Workshop, MNIT, Jaipur)

D. *Process parameters*

In this study, the experimental plan has four variables namely current, groove angle, filler diameter and shielding gas and they vary in range as Current (100A-200A), Groove angle (60°-90°), Filler diameter (1.6mm-2.4mm) with Shielding gas. Selected parameters in levels are shown in Table 2.

Table 2: Process Parameters and three levels for the TIG Welding

S.No.	Parameter	Units	Symbol	Levels		
				1	2	3
1.	Welding current	Ampere	I	100	150	200
2.	Grove Angle	Degree	ϴ	60^0	75^0	90^0
3.	Electrode diameter	mm	E	1.6	2	2.4
4.	Shielding Gas	--------	G	Pure Argon	Pure Helium	50% Ar + 50%He

IV. EXPERIMENTAL PROCEDURE

In the present work, toughness, and microhardness of the specimen, SS 202 and SS 316 grade steel welded by TIG welding method is evaluated. The number of factors chosen for study is 4, each at three levels. An L9 orthogonal Array TIG welding has been performed on SS 202 and SS 316 grade steel to complete the experiment. In welding process, the cut and v-grooved samples were welded at different values of current, gas flow rate and welding speed as per array to finish the nine experiments. The matrix of L9 with the actual value of parameters is shown in Table 3.

Table 3: Orthogonal array for experimentation on both SS 202 and SS 316 grade stainless steel

S. No.	Welding Current	Groove Angle	Electrode Diameter	Shielding Gas
1	100	60	1.6	1
2	100	75	2	2
3	100	90	2.4	3
4	150	60	2	3
5	150	75	2.4	1
6	150	90	1.6	2
7	200	60	2.4	2
8	200	75	1.6	3
9	200	90	2	1

After welding, the values of toughness and microhardness are processed in ANOVA using Minitab software to optimize the results.

V. RESULTS AND DISCUSSION

In the present study toughness and microhardness of the weld specimens were identified as the responses, therefore, 'Higher the Better' (HB) characteristic is chosen for analysis purpose.

A. *For SS 202*

1) *Analysis for Toughness:* The experimental results for toughness are analyzed using ANOVA and are given in table no. 4 to 7.

Table 4: Analysis of variance for SN ratio of toughness at room temperature for SS202 material

Source	Units	DOF	SS	Variance	F	F(critical)	PC
Current	Ampere	2	5.8087	2.9044	3.4717	19.0	15.532
Groove Angle	Degrees	2	1.6997	0.8498	1.0	19.0	4.545
Wire Diameter	mm	2	7.8722	3.9361	4.6317	19.0	21.050
Shielding Gas	………	2	22.0170	11.0085	12.9542	19.0	58.873
Total		8	37.3975				100
Pooled Error		2	1.6997	0.8498			4.545

(SS= Sum of Square, F= F factor, PC = percent contribution, factor with least variance value is considered for error pooling)

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Table 5: Response table for SN ratio of toughness at room temperature for SS202 material

Level	Welding Current	Groove Angle	Wire Diameter	Shielding Gas
1	37.59	36.18	36.77	35.65
2	37.06	36.96	37.93	35.70
3	35.68	37.20	35.64	38.99
Delta	1.91	1.02	2.29	3.35
Rank	3	4	2	1

Table 6: Analysis of variance for means toughness at room temperature for SS202 material

Source	Units	DOF	SS	Variance	F	F (critical)	PC
Current	Ampere	2	320.89	160.444	7.36725	19.0	13.778
Groove Angle	Degrees -	2	43.56	21.778	1.0	19.0	1.870
Wire Diameter	mm	2	427.56	213.778	9.8162	19.0	18.359
Shielding Gas	-------	2	1536.89	768.444	35.28	19.0	65.993
Total		8	2328.89				100
Pooled Error		2	43.56	21.778			1.870

(SS= Sum of Square, F= F factor, PC = percent contribution, factor with least variance value is considered for error pooling)

Table 7: Response table for means toughness at room temperature for SS 202 material

Level	Welding Current	Groove Angle	Wire Diameter	Shielding Gas
1	76.67	68.00	69.33	60.67
2	73.33	71.33	80.00	62.67
3	62.67	73.33	63.33	89.33
Delta	14.00	5.33	16.67	28.67
Rank	3	4	2	1

2) *Analysis of Variance:* The results from ANOVA shows that nature of shielding gas is the most significant factor as its F value is greater than F critical value. It is evident from the figure that mix. of argon – helium gas gives the most efficient value of toughness. Main effects are plotted in the figure and show the variation in toughness with all the four parameters. It is evident from the figure that shielding gas has the major effect on toughness value and groove angle has an almost negligible effect on toughness value.

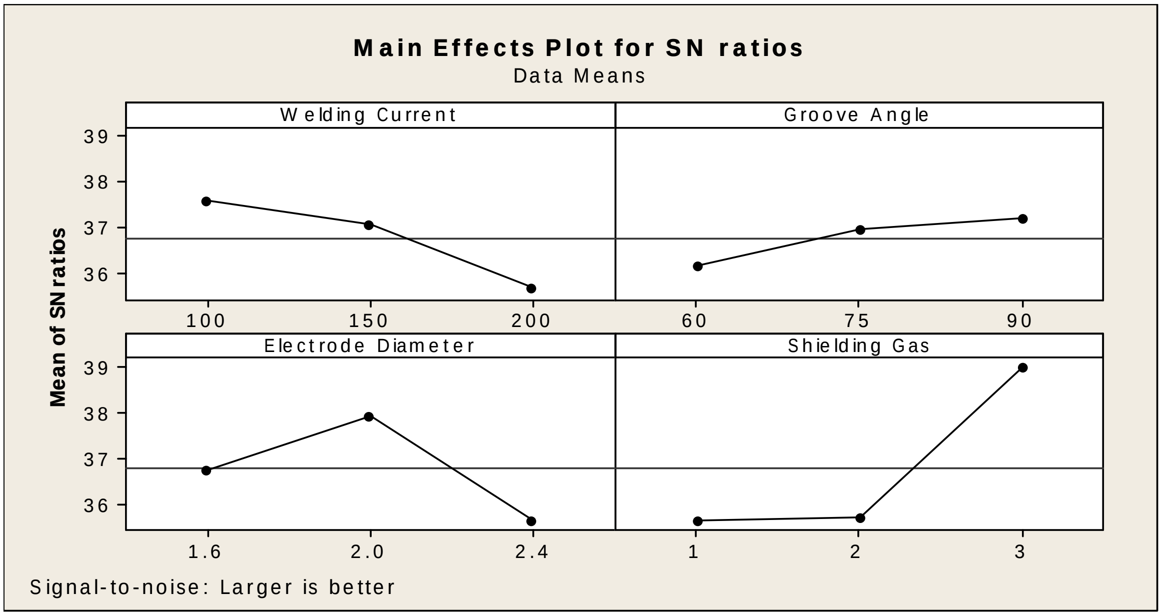

Figure 5: Main effects plots of SN ratios for the toughness of SS 202 at room temp.

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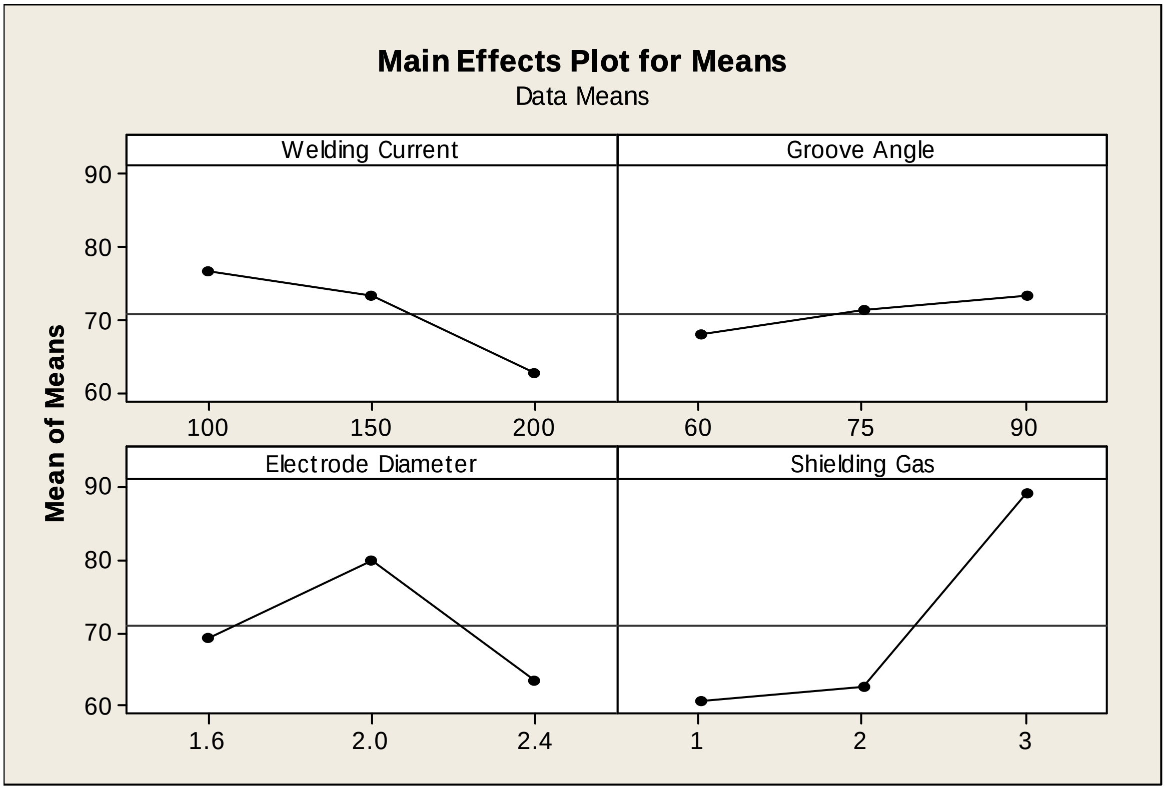

Figure 6: Main effects plots of means for the toughness of SS 202 at room temp.

3) *Analysis for Microhardness:* The experimental results are analyzed using ANOVA, and the results are shown from table 8 to 11.

Table 8: Analysis of variance for SN ratio of Microhardness (HV) for SS202 material

Source	Units	DOF	SS	Variance	F	F(critical)	PC
Current	Ampere	2	0.138412	0.069206	24.805	19.0	80.441
Groove Angle	Degrees	2	0.015358	0.007679	2.752	19.0	8.925
Wire Diameter	mm	2	0.012715	0.006358	2.279	19.0	7.390
Shielding Gas	………	2	0.005581	0.002790	1.0	19.0	3.244
Total		8	0.172067				100
Pooled Error		2	0.005581	0.002790			3.244

(SS= Sum of Square, F= F factor, PC = percent contribution, factor with least variance value is considered for error pooling)

Table 9: Response table for SN ratio of Microhardness (HV) of SS202 material

Level	Welding Current	Groove Angle	Wire Diameter	Shielding Gas
1	51.33	51.44	51.46	51.50
2	51.63	51.54	51.46	51.45
3	51.49	51.47	51.54	51.50
Delta	0.30	0.10	0.08	0.05
Rank	1	2	3	4

Table 10: Analysis of variance for means Microhardness (HV) for SS202 material

Source	Units	DOF	SS	Variance	F	F (critical)	PC
Current	Ampere	2	258.340	129.170	24.1033	19.0	80.081
Groove Angle	Degrees -	2	29.352	14.676	2.7386	19.0	9.099
Wire Diameter	mm	2	24.189	12.094	2.2567	19.0	7.498
Shielding Gas	-------	2	10.718	5.359	1.0	19.0	3.322
Total		8	322.600				100
Pooled Error		2	10.718	5.359			1.609

(SS= Sum of Square, F= F factor, PC = percent contribution, factor with least variance value is considered for error pooling)

Table 11: Response table for means of Microhardness (HV) for SS202 material

Level	Welding Current	Groove Angle	Wire Diameter	Shielding Gas
1	368.4	373.2	374.0	376.0
2	381.5	377.6	374.0	373.6
3	375.5	374.7	377.5	375.9
Delta	13.1	4.3	3.5	2.4
Rank	1	2	3	4

4) *Analysis of Variance:* It can be concluded from the ANOVA tables that Current is the most significant factor, as its F value is greater than F (critical). The maximum value of microhardness is 387.105 HV for experiment no. 5 (150A, Ar , 75^0 & 2.4 mm.). Main effects plot are shown in figure 6.2- 6.3 and it can be concluded from said figure that the value of microhardness first increases with the current up to 150A and then decreases. Shielding gas has a negligible effect on microhardness value.

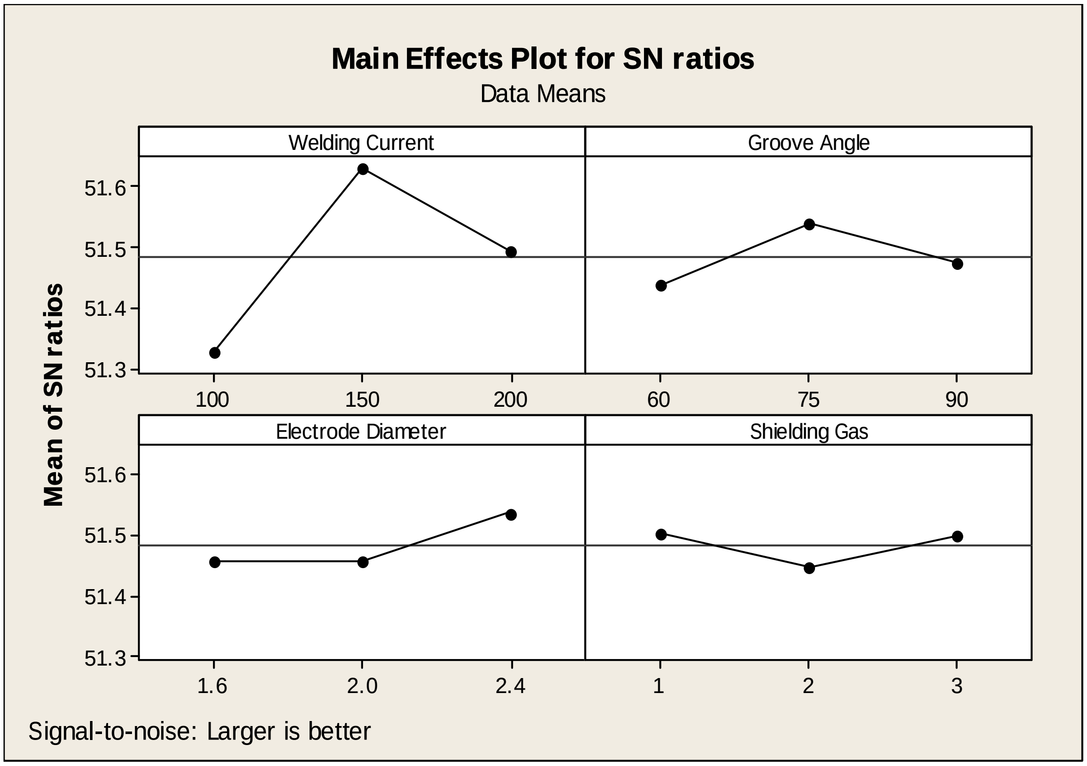

Figure 7 : Main effects plots of SN ratios for Microhardness of SS 202.

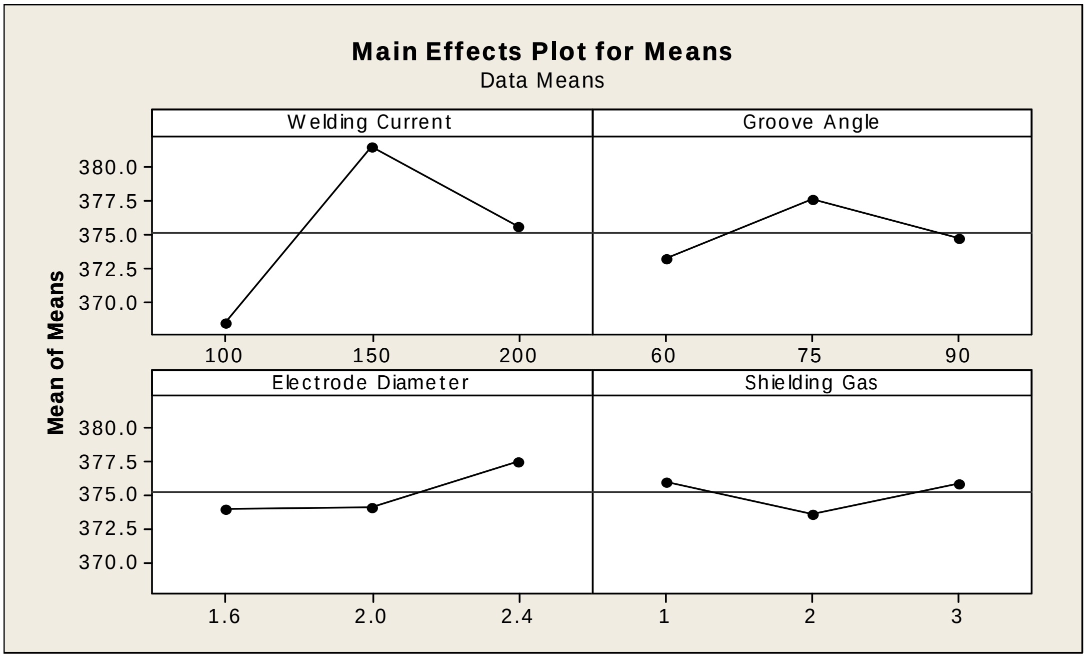

Figure 8: Main effects plots of means for Microhardness of SS 202.

B. For SS 316

1) *Analysis for Toughness:* The experimental results are analyzed using ANOVA, and the results are shown in the form of Tables 12 to 15. It is evident from the tables that current and shielding gas are the most significant factors as their F value is greater than F(critical) value, effecting toughness. Best value of toughness is obtained as 102 J for experiment no. 6 (150A, He, 90^0 & 1.6 mm).

Table 12: Analysis of variance for SN ratio of toughness at room temp. For SS 316 material

Source	Units	DOF	SS	Variance	F	F(critical)	PC
Current	Ampere	2	3.5404	1.77020	13.630	19.0	34.611
Groove Angle	Degrees	2	1.2640	0.63198	4.866	19.0	12.356
Wire Diameter	mm	2	0.2597	0.12987	1.0	19.0	2.538
Shielding Gas	………	2	5.1651	2.58254	19.885	19.0	50.495
Total		8	10.2292				100
Pooled Error		2	0.2597	0.12987			2.538

(SS= Sum of Square, F= F factor, PC = percent contribution, factor with least variance value is considered for error pooling)

Table 13: Response table for SN ratio of toughness at room temp. For SS 316 material

Level	Welding Current	Groove Angle	Wire Diameter	Shielding Gas
1	37.79	38.36	38.42	37.77
2	38.90	38.41	38.82	39.62
3	39.26	39.18	38.71	38.55
Delta	1.47	0.82	0.40	1.85
Rank	2	3	4	1

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Table 14: Analysis of variance for means of toughness at room temp. For SS 316 material

Source	Units	DOF	SS	Variance	F	F (critical)	PC
Current	Ampere	2	320.889	160.444	27.768	19.0	33.865
Groove Angle	Degrees -	2	118.222	59.111	10.230	19.0	12.476
Wire Diameter	mm	2	11.556	5.778	1.0	19.0	1.219
Shielding Gas	-------	2	496.889	248.444	42.998	19.0	52.440
Total		8	947.556				100
Pooled Error		2	11.556	5.778			1.219

(SS= Sum of Square, F= F factor, PC = percent contribution, factor with least variance value is considered for error pooling)

Table 15: Response table for means toughness at room temperature for SS 316 material

Level	Welding Current	Groove Angle	Wire Diameter	Shielding Gas
1	78.00	84.00	84.67	78.00
2	88.67	83.33	87.33	96.00
3	92.00	91.33	86.67	84.67
Delta	14.00	8.00	2.67	18.00
Rank	2	3	4	1

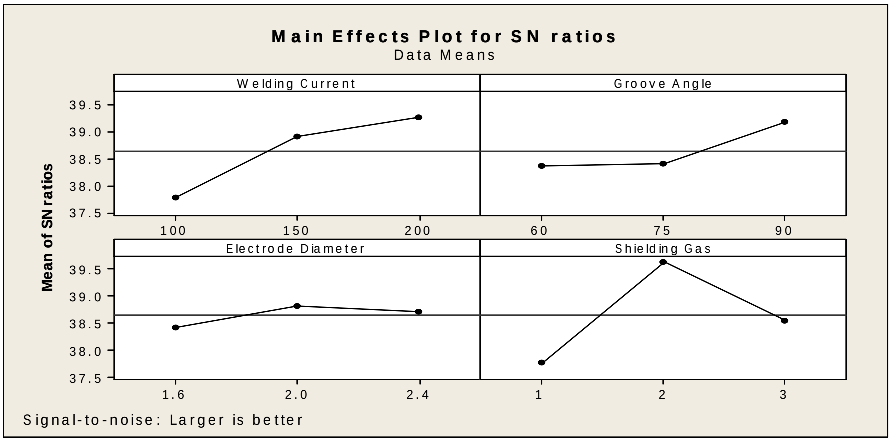

Figure 9: Main effects plots of SN ratios for the toughness of SS 316 at room temp.

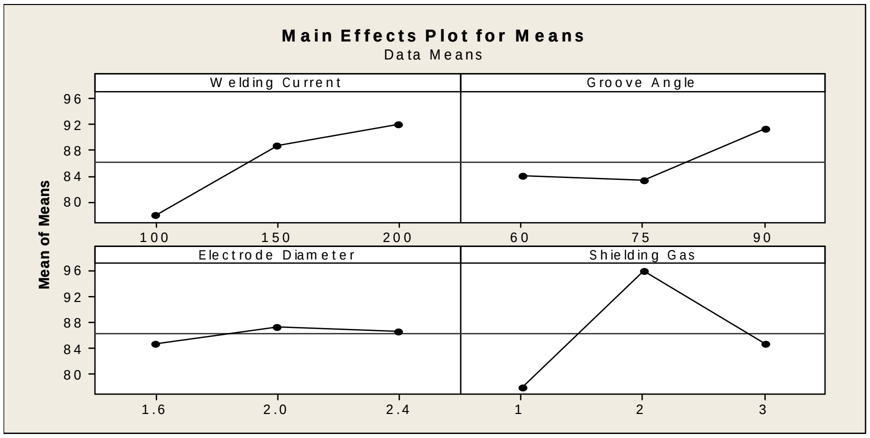

Figure 10: Main effects plots of means for the toughness of SS 316 at room temp.

Main effects plot shown in figure 10 is self-explanatory and indicates that value of toughness increases with increase in current. Helium gas results in maximum toughness followed by a mixture of argon with helium and pure Argon shows the minimum toughness. Larger groove angle results in highest toughness whereas Electrode diameter has a negligible effect on the toughness value.

2) *Analysis for Microhardness:* The results of measurement are analyzed using ANOVA are shown in the form of tables 16 to 19. It can be concluded from the tables that current and groove angle is the most significant factor for microhardness measurement whereas wire diameter is having a negligible effect on microhardness. Main effects plot are shown in figure 11 and 12.

Table 16: Analysis of variance for SN ratio of Microhardness (HV) for SS 316 material

Source	Units	DOF	SS	Variance	F	F(critical)	PC
Current	Ampere	2	0.019241	0.009261	34.0477	19.0	55.213
Groove Angle	Degrees	2	0.011770	0.005885	21.636	19.0	33.774
Wire Diameter	mm	2	0.000543	0.000272	1.0	19.0	1.558
Shielding Gas	………	2	0.003295	0.001647	6.0551	19.0	9.455
Total		8	0.034849				100
Pooled Error		2	0.000543	0.000272			1.558

(SS= Sum of Square, F= F factor, PC = percent contribution, factor with least variance value is considered for error pooling)

Table 17: Response table for SN ratio of Microhardness (HV) for SS 316 material

Level	Welding Current	Groove Angle	Wire Diameter	Shielding Gas
1	51.17	51.20	51.23	51.23
2	51.22	51.28	51.22	51.20
3	51.29	51.21	51.23	51.25
Delta	0.11	0.08	0.02	0.05
Rank	1	2	4	3

Table 18: Analysis of variance for means of Microhardness (HV) for SS 316 material

Source	Units	DOF	SS	Variance	F	F (critical)	PC
Current	Ampere	2	33.9618	16.9809	34.2012	19.0	55.036
Groove Angle	Degrees -	2	20.8774	10.4387	21.0245	19.0	33.832
Wire Diameter	mm	2	0.9931	0.4965	1.0	19.0	1.609
Shielding Gas	-------	2	5.8757	2.9378	5.9170	19.0	9.523
Total		8	61.7079				100
Pooled Error		2	0.9931	0.4965			1.609

(SS= Sum of Square, F= F factor, PC = percent contribution, factor with least variance value is considered for error pooling)

Table 19: Response table for means toughness at room temperature for SS 316material

Level	Welding Current	Groove Angle	Wire Diameter	Shielding Gas
1	361.9	362.9	364.5	364.4
2	364.0	366.3	363.7	363.1
3	366.7	363.3	364.3	365.1
Delta	4.7	3.4	0.8	1.9
Rank	1	2	4	3

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It is evident from main effects plot that the value of microhardness increases with increase in the value of current and is maximum for 200 A. Maximum value of HV is 370.012 for experiment no. 8 (200 A, 75^0, 1.6 mm. & He-Ar mix).

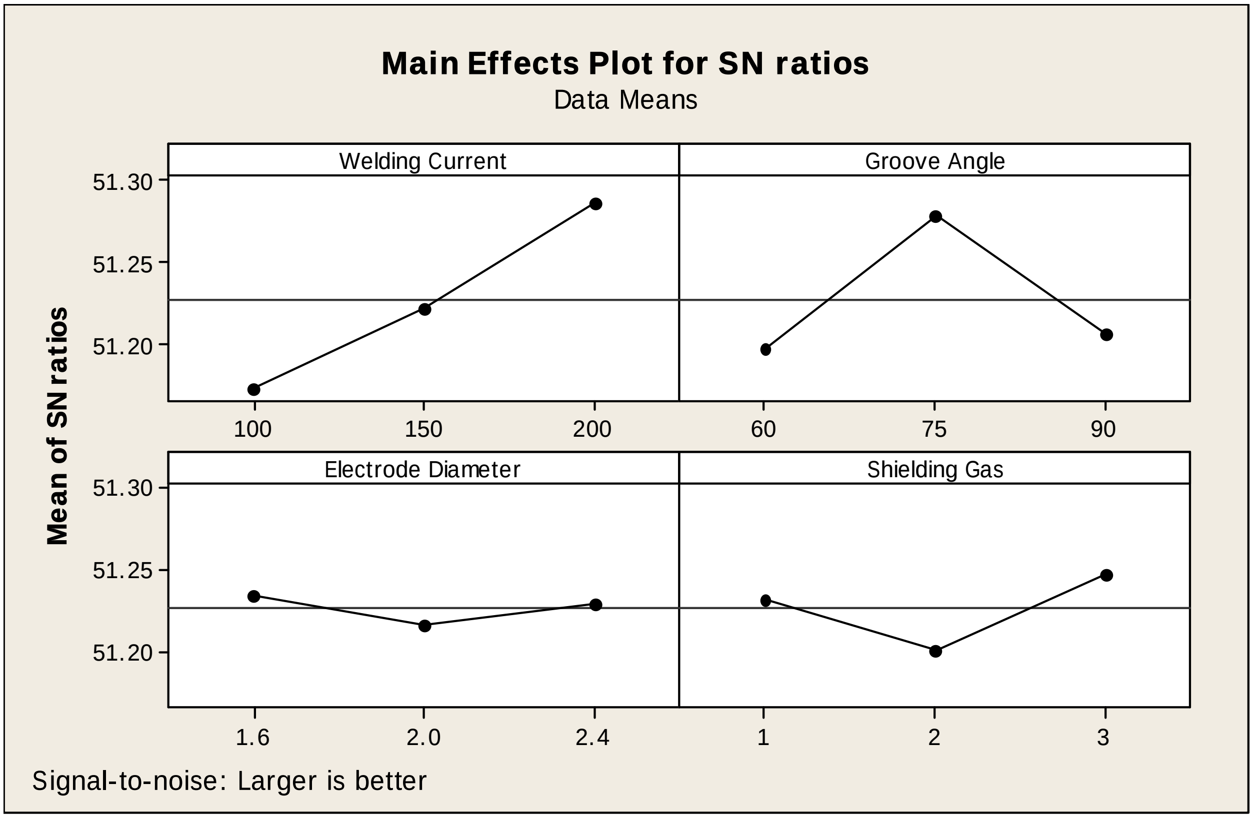

Figure 11: Main effects plots of SN ratios for Microhardness of SS 316.

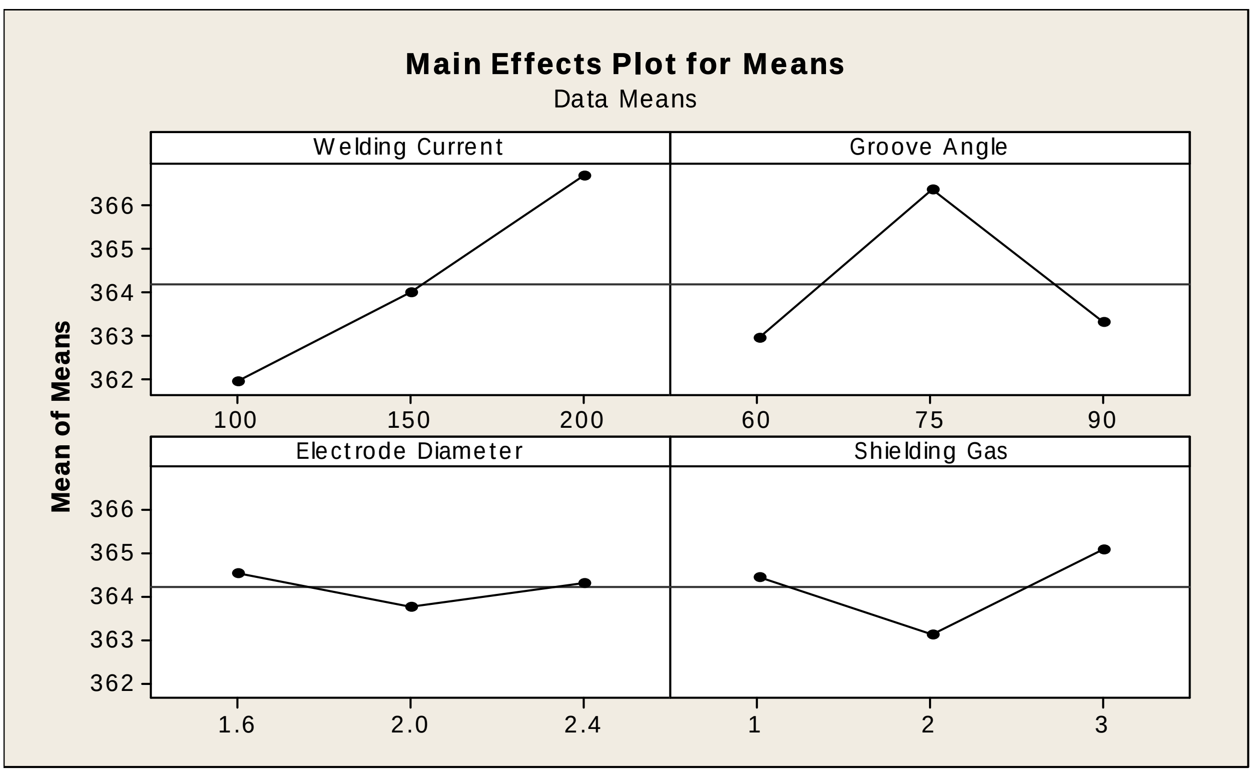

Figure 12: Main effects plots of means for Microhardness of SS 316.

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VI. CONCLUSIONS

From the analysis of the results using the Signal-to-Noise ratio (S/N) approach and analysis of variance for means, the following can be concluded:

A. Charpy Impact Test results for SS 202 steel at room temperature shows that toughness mainly depends on the shielding gas chosen. Toughness value is maximum when Argon-Helium mix. Is used as shielding gas. The highest value of toughness (98 Joules) in the welded joint of experiment no. 4 (150 A, 60^0, 2 & Ar-He mix.).

B. Charpy Test results for SS 316 at room temperature shows that toughness increases as well as decreases in welded specimens. The maximum value of toughness is 102 Joule for specimen no. 6 (150 A, 90^0, 1.6 mm. & He). Toughness is higher for 150 A and for shielding gas He and also at 90^0.

C. Microhardness Test results for SS 202 steel shows that maximum value of microhardness is 387.105 HV for experiment no. 5 (150 A, 75^0, 2.4 mm & Ar). Microhardness value mainly depends on current, and it first increases with increase in the value of current up to 150 A and then decreases.

D. Microhardness Test results for SS 316 material show that maximum value of 370.012 HV is obtained for experiment no. 8 (200 A, 75^0, 1.6 mm & Ar- He mix.). Welding current and groove angle are the relevant parameters in effecting the value of said response, and the maximum value of HV is obtained for 200 A current

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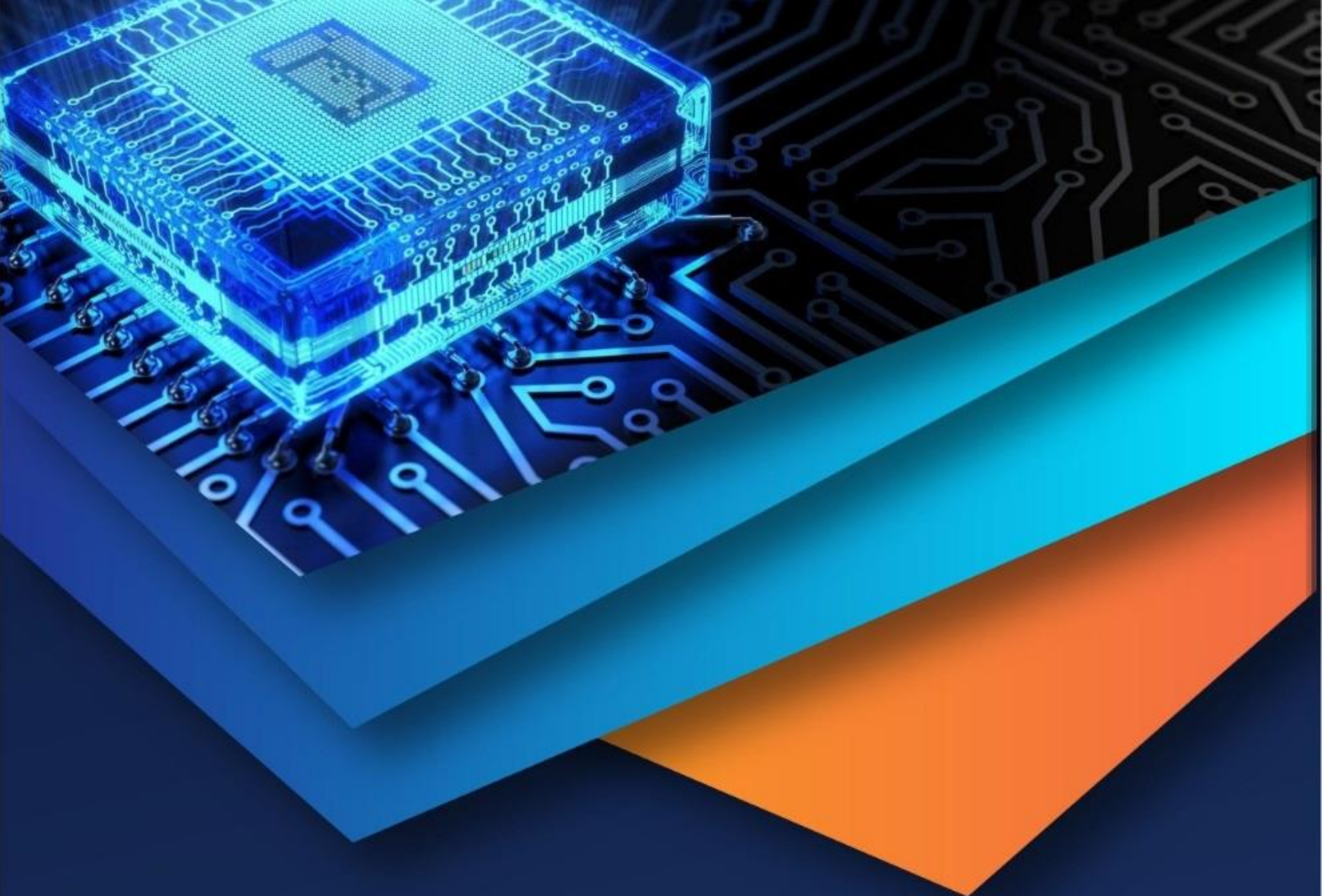

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