Effect of MIG Welding Parameters on Mechanical Properties of Dissimilar Weld Joints of AISI 202 and AISI 316 Steels

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Abstract: In the present work dissimilar joints of AISI 202 and AISI 316 steels are produced using Metal Inert Gas (MIG) welding. Welding current, wire feed rate, flow rate of gas and edge included angle are considered as input parameters and tensile strength, Impact strength and Maximum bending load are considered as output responses. Response Surface Method (RSM) is adopted using Central Composite Design (CCD) and 31 experiments were performed for 4 factors and 5 levels. Analysis of Variance (ANOVA) is carried out at 95% confidence level and coefficient of determination (R^2) of 0.94 is obtained for all the output responses. Effect of welding parameters on output responses are studied by drawing main effect plots. Dominating parameters are identified using contour plots and surface plots are drawn to find the optimal solution. Optimal weld parameters are identified using Response optimizer.

Keywords: AISI 202, AISI 316, Dissimilar Welds, MIG Welding, Response Surface Method**,** Steels

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1 INTRODUCTION

Metal inert gas arc welding (MIG) or more appropriately called as gas metal arc welding (GMAW) utilizes a consumable electrode and hence, the term metal appears in the title. There is other gas shielded arc welding processes utilizing the consumable electrodes, such as flux cored arc welding (FCAW) all of which can be termed under MIG. Though gas tungsten arc welding (GTAW) can be used to weld all types of metals, it is more suitable for thin sheets. When thicker sheets are to be welded, the filler metal requirement makes GTAW difficult to use. In this situation, the GMAW comes handy.

Joining of dissimilar metals has found its use extensively in power generation, electronic, nuclear reactors, petrochemical and chemical industries mainly to get tailor made properties in a component and reduction in weight. However efficient welding of dissimilar metals has posed a major challenge due to difference in thermo-mechanical and chemical properties of the materials to be joined under a common welding condition. This causes a steep gradient of the thermo-mechanical properties along the weld. A variety of problems come up in dissimilar welding like cracking, large weld residual stresses, migration of atoms during welding causing stress concentration on one side of the weld, compressive and tensile thermal stresses, stress corrosion cracking, etc.

In dissimilar welds, weldability is determined by crystal structure, atomic diameter and compositional solubility of the parent metals in the solid and liquid states. Diffusion in the weld pool often results in the formation of intermetallic phases, the majority of which are hard and brittle and are thus detrimental to the mechanical strength and ductility of the joint. The thermal expansion coefficient and thermal conductivity of the materials being joined are different, which causes large misfit strains and consequently the residual stresses results in cracking during solidification.

Nabendu Ghosh et al. [1] analyzed the effects of welding parameters: welding current, gas flow rate and nozzle to plate distance, on ultimate tensile strength (UTS) and Yield Strength (YS) in MIG welding of AISI 409 ferritic stainless steel to AISI 316L Austenitic Stainless Steel materials. A. Suresh Kumar [2] investigated the process parameters of welding current, welding voltage, gas flow rate in MIG welding of SS316L and Mild steel (IS2062) plate of thickness 6mm through the optimization based on Grey Relational Analysis (GRA) method to obtain the maximum weld bead penetration (MACRO) and weld area hardness. A. Narayana and T. Srihari [3] optimized the weld bead geometry in MIG welding process using response surface methodology and itdeals the development of statistical and mathematical model response surface methodology (RSM) capable of accurate optimization of weld bead geometry, i.e., depth of penetration, weld width and height of reinforcement for input process parameters viz., arc voltage, wire feed rate, welding speed and nozzle to plate distance (Arc length).

Bahar et al. [4] investigated the process parameters of Metal inert gas (MIG) welding to optimize the hardness and ultimate tensile strength (UTS) of a weld bead formed between dissimilar materials: mild steel (MS 1020) and stainless steel (SS 316) using Taguchi technique and Grey relational analysis. K. Sivasakthivel et al. [5] studied the optimization of welding parameter in MIG Welding by Taguchi Method and welding variables like welding current, welding voltage, travel speed, wire electrode size, type of shielding gas, Electrode angle, weld joint position etc., are determined. N. Ghosh et al. [6] studied parametric optimization of dissimilar welding of AISI 409 Ferritic Stainless Steel to AISI 316L Austenitic Stainless Steel by using PCA Method.

From the worked reported by earlier researchers, it is understood that in most of the works researchers considered welding current, welding voltage, welding speed and gas flow rate. However, limited works are reported on variation of wire feed rate and edge included angle.

The objective of the paper is to study the effect of MIG welding parameters on tensile strength, impact strength and maximum bending load of dissimilar joints of AISI 202 and AISI 316 steels.

2 EXPERIMENTATION

AISI 202 and AISI 316 plates of 5 mm thickness were chosen for welding. First the plates were cut into 100mm x 200mm size using shearing machine and cleaned by using Ultrasonic cleaning and further cleaned with PCL 21 cleaner before welding. Copper sinks are fixed to the fixture to minimize weld distortion and extreme care has been taken for proper cutting of plates. Details about weld joint dimensions are shown in “Fig. 1”.

The chemical composition and tensile properties of AISI 202 and AISI 316 steel plates are given in “Table 1 to 4”. The welding has been carried out under the welding conditions presented in “Table 5”. From the earlier works carried out on MIG welding, it was understood that the Welding Current, filler wire feed rate, flow rate of gas and edge included angle are the dominating parameters which effect the weld quality characteristics. The range of the welding parameters are chosen based on trial experiments and from earlier works reported [7-10] are presented in “Table 6”. Tensile specimens are prepared as per ASTM E8M-04 guidelines using wire cut Electro Discharge Machining in the transverse direction of the weld from each welded sample.

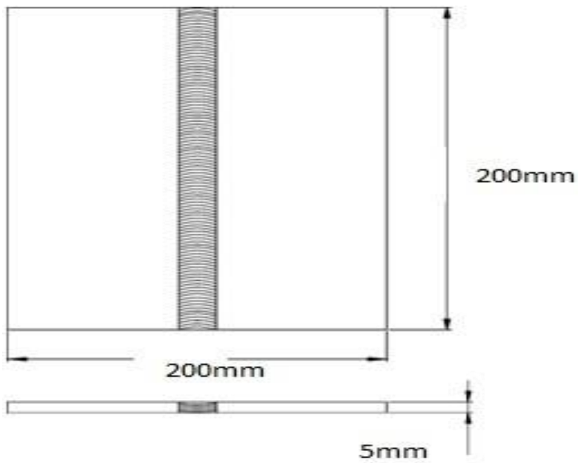


Fig. 1 Dimensions of welded joint.

Tensile tests are carried out on 100 KN computer controlled Universal Testing Machine (Model No: 8801, INSTRON). The specimen is loaded at a rate of 1.5 KN/min as per ASTM specifications, so that the tensile specimens undergo deformation. From the stress strain curve, the ultimate tensile strength of the weld joints is evaluated and the average of the results of each sample is presented in "Table 7". Charpy Impact testing was performed on the weld specimens as per ASTM E23-18. Impact strength per unit volume is measured.
Tests were carried out on Three readings are taken for each sample and the average values are reported in "Table 7". Bending test is performed as per ASTM E855-08 on the weld samples. Tests were carried out on 1000 Ton capacity TUE-C-1000, FSA (Fine Spavy Associate Pvt Ltd) machine. The maximum bending load is recorded for each weld sample and presented in "Table 7".

Table 1 Chemical composition of AISI 316 (weight %)

Eleme nt	Cr	Mn	Fe	Co	Ni	Cu	Mo
Weight %	16.8 4	1.2 4	68.0 4	0.8 1	10.5 0	0.3 8	2.1 3

Table 2 Mechanical properties of AISI 316

Prope rty	Ultimate Tensile Strength(MPa)	Yield Tensile Strength(MPa)	Vickers Hardness(BHN)	Charpy Strengt h(J)
Value	520	205	220	105

Table 3 Chemical composition of AISI 202 (weight %)

Element	Cr	Mn	Fe	Ni	Cu
Weight %	13.56	10.38	75.07	0.54	0.44

Table 4 Mechanical properties of AISI 202

Prope rty	Ultimate Tensile Strength(MPa)	Yield Tensile Strength(MPa)	Vickers Hardness(BHN)	Charpy Strengt h(J)
Value	515	275	240	100

Table 5 Welding conditions

Power source	ESAB (Auto K400))
Polarity	DCEN
Mode of operation	Continuous mode
Filler wire material	AISI 309
Filler wire diameter	1.2mm
Welding Gas	Argon + CO_2 (98%+2%)
Nozzle to plate distance	3 mm
Welding speed	240 mm/min
Torch Position	Vertical
Operation type	Semi-Automatic

Table .6 Input parameters

PARAMETER	Level				
	-2	-1	0	+1	+2
Welding Current(Amperes)	140	150	160	170	180
Gas Flow rate (Litres/minute) LPM	8	10	12	14	16
Wire Feed Rate (m/min)	2	2.5	3	3.5	4
Edge Included Angle (Degrees)	30	40	50	60	70

3 STATISTICAL ANALYSIS

Using MINTAB statistical software design matrix is generated for 4 factors, 5 levels and welding is carried out for all the 31 combination of welding parameters and the values recorded for various tests performed are presented in "Table 7".

3.1. Empirical Mathematical Modelling

A second order polynomial is some region of the independent variables is employed to develop a relation between the response and the independent variables. If the response is well modeled by a nonlinear function of the independent variables, then the approximating function in the second order model is

$$Y = b_o + \sum b_i x_i + \sum b_{ii} x_i^2 + \sum\sum b_{ij} x_i x_j + \in$$

Where, b_o, b_i are the coefficients of the polynomial and $\in$ represents noise.

Table 7 Experimental values

Input Parameters					Output Responses					
					Experimental			Predicted		
Exp.No.	Welding Current (Amps)	Flow rate of gas (LPM)	Wire Feed rate (m/min)	Edge Included Angle (Deg)	Tensile Strength (MPa)	Impact Strength (Joules)	Max. Bending Force (KN)	Tensile Strength (MPa)	Impact Strength (Joules)	Max. Bending Force (KN)
1	150	10	2.5	40	568.33	62	5.3	568.01	64	5.3
2	150	14	3.5	60	570.05	56	5.2	570.46	55	5.1
3	160	12	3	50	569.95	76	5.1	570.58	75	5.2
4	150	10	3.5	60	569.92	76	4.8	569.23	77	4.9
5	160	12	3	30	570.92	78	4.8	570.74	79	4.9
6	170	14	2.5	40	571.33	82	5.2	571.3	81	5.2
7	170	10	3.5	60	568.83	88	5.2	568.84	88	5.2
8	160	16	3	50	568.95	72	5.1	569.05	73	5.2
9	160	12	3	50	571.33	74	5.2	570.58	75	5.2
10	170	14	3.5	40	570.05	76	5.2	570.26	77	5.1
11	160	12	3	50	569.95	72	5.3	570.58	75	5.2
12	170	10	2.5	60	571.92	76	5.2	571.79	76	5.2
13	170	14	3.5	60	570.92	72	5.4	570.52	69	5.4
14	160	12	2	50	569.33	64	5.6	569.28	63	5.6
15	170	14	2.5	60	571.83	70	5.4	572.11	70	5.4
16	150	10	2.5	60	567.95	68	4.9	568.25	66	5
17	140	12	3	50	568.33	64	5.4	568.71	63	5.4
18	160	12	3	50	570.05	76	5.2	570.58	75	5.2
19	160	12	3	50	570.95	72	5.2	570.58	75	5.2
20	160	12	3	50	570.92	78	5.2	570.58	75	5.2
21	160	12	3	50	570.92	76	5.3	570.58	75	5.2
22	180	12	3	50	572.33	72	5.6	572.17	74	5.6
23	160	12	3	70	570.83	74	4.8	571.23	74	4.7
24	160	12	4	50	568.95	66	5.4	569.22	69	5.5
25	150	14	2.5	40	566.95	82	5.4	567.44	81	5.4
26	150	14	2.5	60	568.92	54	5.3	568.12	57	5.3
27	150	14	3.5	40	570.92	76	5.2	570.33	75	5.2
28	150	10	3.5	40	569.33	72	5.3	569.55	71	5.3
29	160	8	3	50	567.83	74	5.1	567.94	75	5
30	170	10	3.5	40	568.95	72	5.4	569.03	69	5.4
31	170	10	2.5	40	571.33	62	5.2	571.42	62	5.3

Using MINTAB software by considering the nonlinear model empirical models are developed by considering only the significant coefficients.

Tensile strength $=570.581+0.8667X_1+0.277X_2-0.015X_3+0.124X_4-0.521X_2^2-0.333X_3^2-0.983X1X3+0.338X_2X_3$

Impact Strength $=74.857+2.833X_1-0.500X_2+1.500X_3-1.333X_4-1.547X_1^2-2.297X_3^2+3.250X_1X_4-3.000X_2X_3-6.500X_2X_4$.

Max. Bending Load $= 5.214+0.050X_1+0.041X_2-0.025X_3-0.033X_4+0.071X_1^2-0.028X_2^2+0.071X_3^2-0.103X_4^2$.

$-0.037X_1X_2+0.037X_1X_3+0.075X_1X_4+0.087X_2X_4$.

Welding current, gas flow rate, wire feed rate and edge included angle.

3.2. Analysis of Variance (ANOVA)

The adequacy of the developed models is tested using the ANOVA. As per this technique, if the calculated value of the F_{ratio} of the developed model is less than the standard F_{ratio} (F-table value 2.56) value at a desired level of confidence of 95%, then the model is said to be adequate within the confidence limit.

ANOVA test results are presented in “Table 8” for tensile strength, impact strength and maximum bending load. From “Table 8” it is understood that the developed mathematical models are found to be adequate at 95% confidence level. Coefficient of determination ‘R^2’ for the above developed models is found to be above 0.90. The variation of Experimental and predicted values are presented in Scatter plots as shown in “Figs. 2 to 4”.

Table 8 ANOVA Table

Tensile strength						
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	14	49.234	49.234	3.516	11.52	0.000
Linear	4	20.225	20.225	5.0561	16.57	0.000
Square	4	10.993	10.933	2.7481	9.00	0.001
Interaction	6	18.017	18.017	3.0029	9.84	0.000
Residual Error	16	4.883	4.883	0.3052		
Lack-of-Fit	10	2.878	2.878	0.2878	0.86	0.603
Pure Error	6	2.005	2.005	0.3342		
Total	30	54.118				
Impact Strength						
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	14	1530.14	1530.14	109.296	20.37	0.000
Linear	4	295.33	295.33	73.833	13.76	0.000
Square	4	219.81	219.81	54.952	10.24	0.000
Interaction	6	1015.00	1015.00	169.167	31.53	0.000
Residual Error	16	85.86	85.86	5.366		
Lack-of-Fit	10	55.00	55.00	5.500	1.07	0.489
Pure Error	6	30.86	30.86	5.143		
Total	30					
Max. Bending Load						
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	14	1.10896	1.10896	0.079211	14.87	0.000
Linear	4	0.14333	0.14333	0.035833	6.73	0.002
Square	4	0.69562	0.69562	0.173906	32.64	0.000
Interaction	6	0.27000	0.27000	0.045000	8.45	0.000
Residual Error	16	0.08524	0.08524	0.005327		
Lack-of-Fit	10	0.05667	0.05667	0.005667	1.19	0.434
Pure Error	6	0.02857	0.02857	0.004762		
Total	30	1.19419				

Where SS= Sum of Squares, MS= Mean Squares, F=Fishers value.

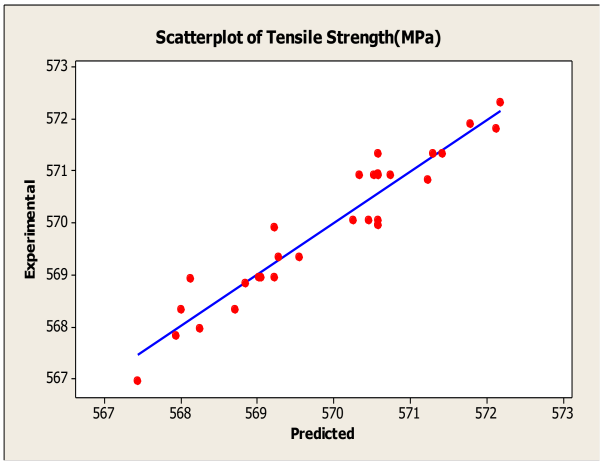


Fig. 2 Scatter plot for tensile strength.

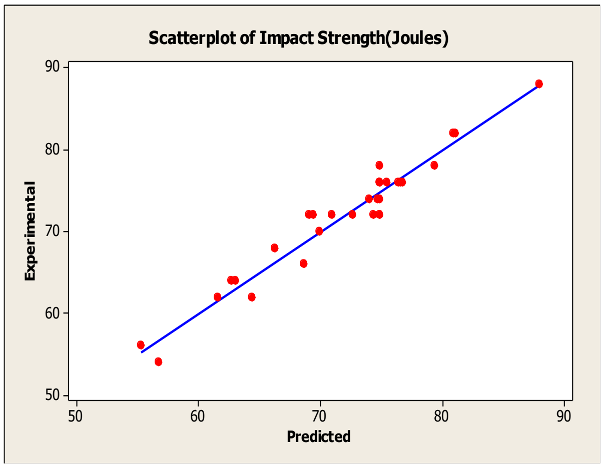


Fig. 3 Scatter plot for impact strength.

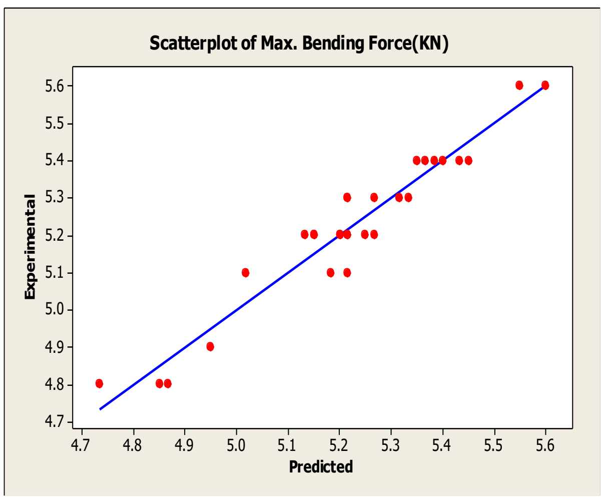


Fig. 4 scatter plot for Max. Bending Load.

3.3. Main effect plots

Main effects of tensile strength, impact strength and maximum bending load are presented in "Figs. 5, 6 and 7".

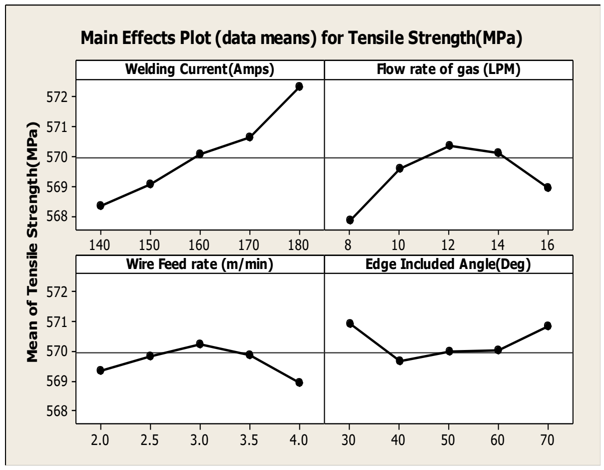


Fig. 5 Main Effects of tensile strength.

As welding current increases, heat input increases and the filler metal melts faster leading to faster deposition of filler metal in the weld group leading to higher tensile strength of the welded joint. As flow rate of the welding gas increases the burning capacity increases because of higher amount of gas available, however when the gas flow rate of gas reaches 12 LPM the filler wire will melt fast and the same time it spills on the outer side of the weld grove leading to poor weld joint and lower tensile strength. Wire feed rate of filler material used in MIG welding plays an important role. The wire feed to be proportionate to welding speed and melting rate of the filler metal. Higher feed rate with higher melting is good to some extent, but when it reaches the optimal value of molten3 m/min the molten metal tries to spill on the outer side and also there are chances for improper weld penetration. While joining thick plate, edge include angle is critical as it decides how much filler material it can accommodate. Higher angle leads to more penetration, whereas lower angle leads to less penetration. Hence optimal edge included angle is important which decides the strength. Tensile strength decreases upto 40 Deg angle and there after it increased.

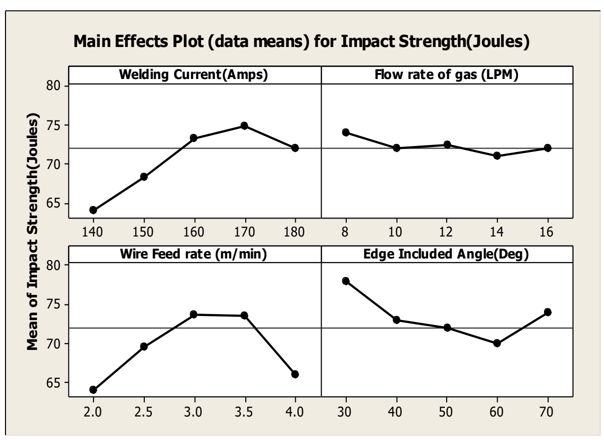


Fig. 6 Main effects of impact strength.

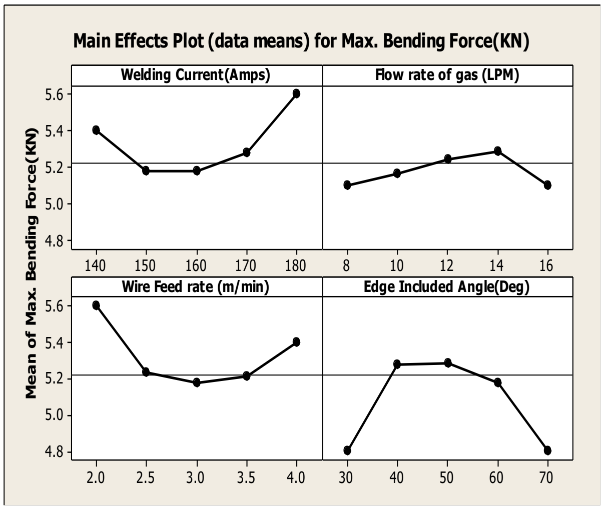


Fig. 7 Main effects of Max. Bending Load.

Impact strength of the welded joint improves with welding current because at higher current more heat, which helps in faster melting of filler wire and high deposition rate. Flow rate of welding gas has negative impact on impact strength. Higher flow rates may create blow holes and other defects, which decreases the impact strength. Impact strength improved with wire feed rate up to 3 m/min and there after it decreased, this may be due to spilling of molten metal outside the weld grove and due to joining thick plate, edge include angle is critical as it decides how much filler material it can accommodate.

Higher angle leads to more penetration, whereas lower angle leads to less penetration. Hence optimal edge included angle is important which decides the strength. At 30 Deg angle maximum impact strength is noticed, there after the strength decreased. At 60 Deg low impact strength is recorded, this may be due to incomplete penetration of filler metal.

Bending load is minimum at welding current of 150 Amps, there after it increased, this may be due to proper fusion of filler metal at higher heat input because of high current.

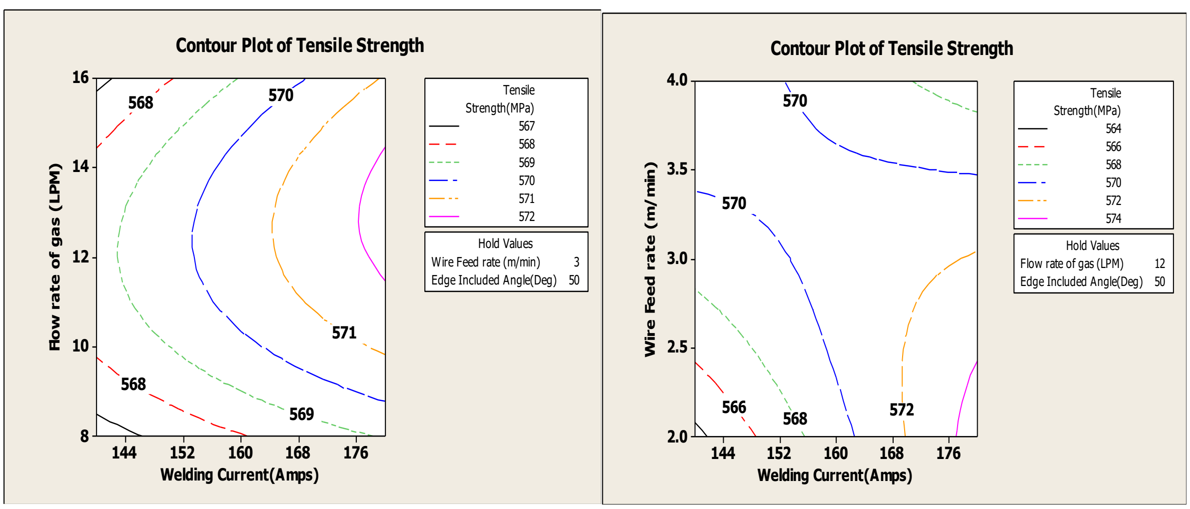
Gas flow rate along with high welding current improves the deposition rate of the filler metal, hence higher bending load. Bending load decreased with wire feed rate upto 3 m/min and there after it increased. The increase in bending load is due to higher penetration of filler metal. Higher Bending load was observed at edge include angle of 40 Deg and there after it decreased, this may be due to incomplete penetration of filler metal because of wider angle.

3.4. Contour plots

The simultaneous effect of two parameters at a time on the output response is generally studied using contour plots.

Contour plots play a very important role in the study of the response surface. By generating contour plots using statistical software (MINITAB 14) for response surface analysis, the most influencing parameter can be identified based on the orientation of contour lines. If the contour patterning of circular shaped occurs, it suggests the equal influence of both the factors; while elliptical contours indicate the interaction of the factors.

“Figs. 8 to 10” represents the contour plots for tensile strength, impact strength and maximum bending load. From the contour plots, it is understood that the most dominating parameter is welding current, followed by flow rate of gas, fire feed rate and edge included angle.



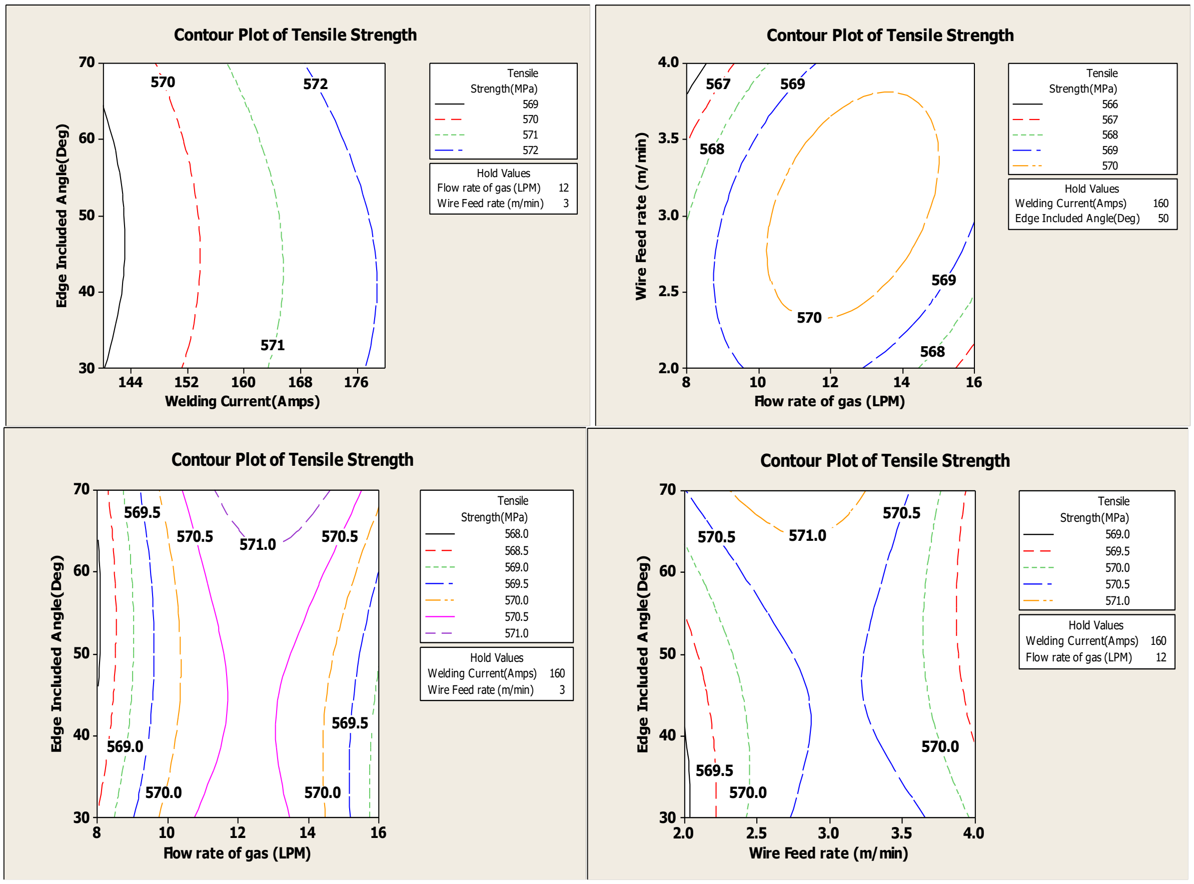
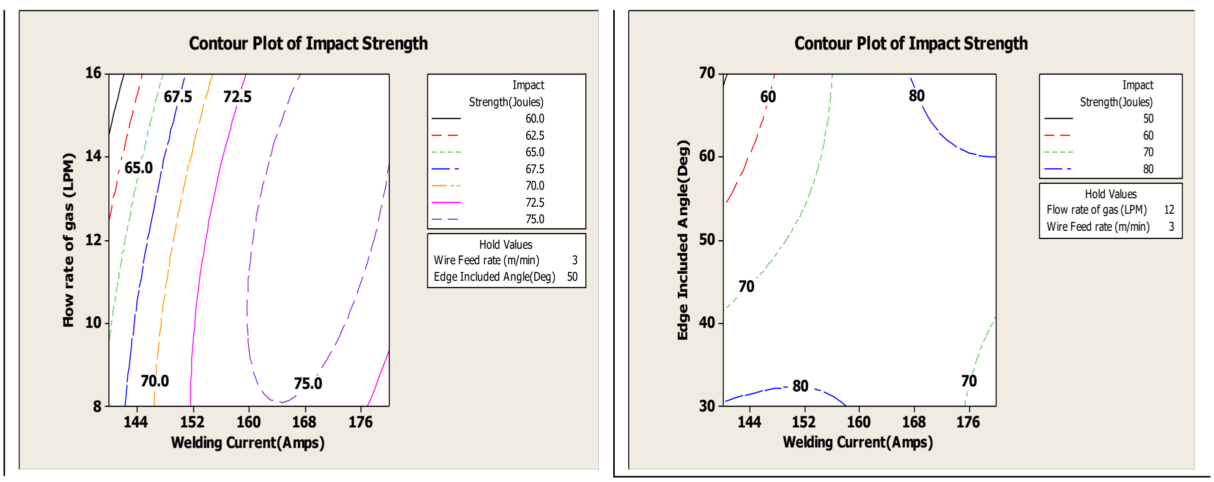


Fig. 8 Contour plots for tensile strength.



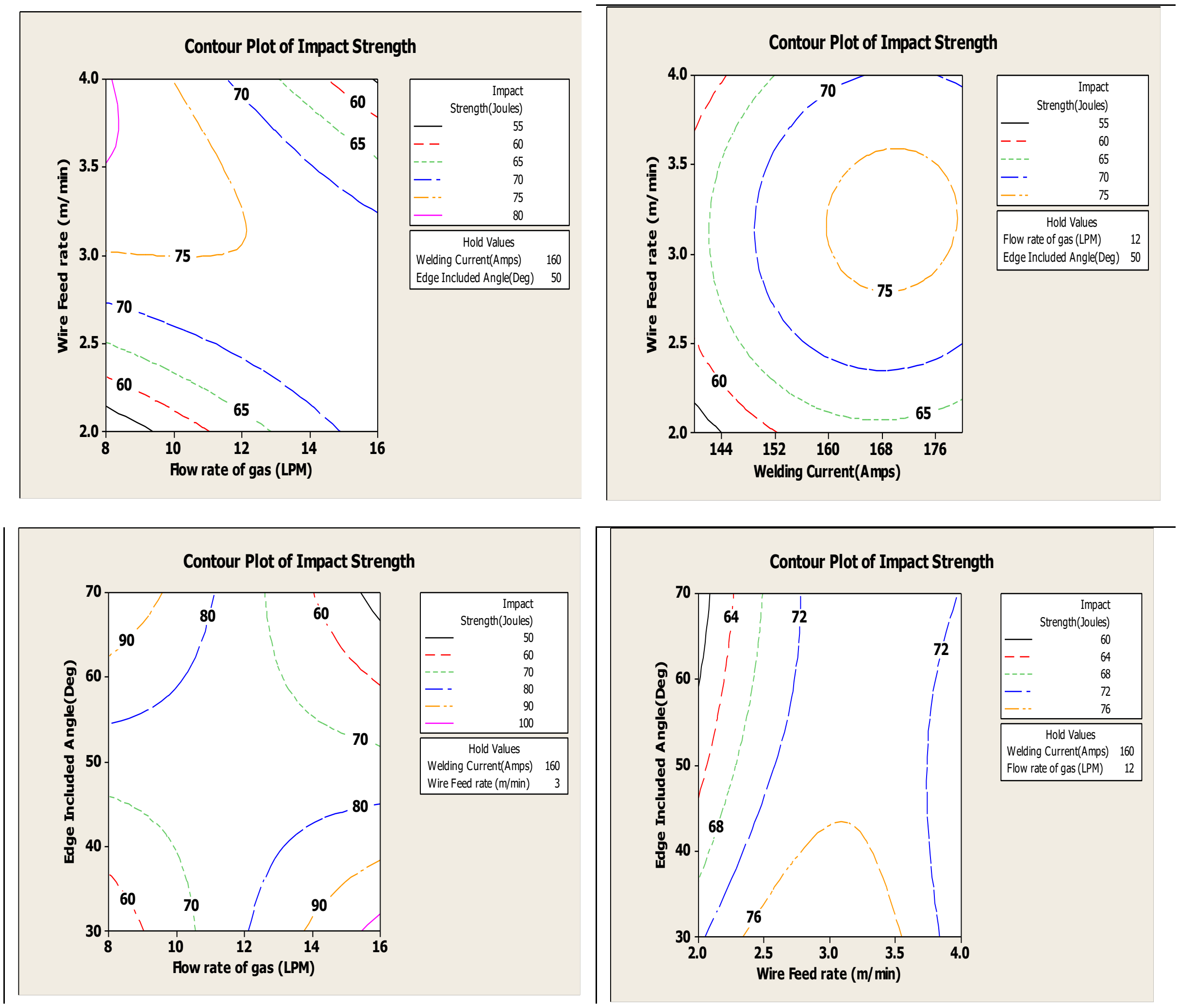
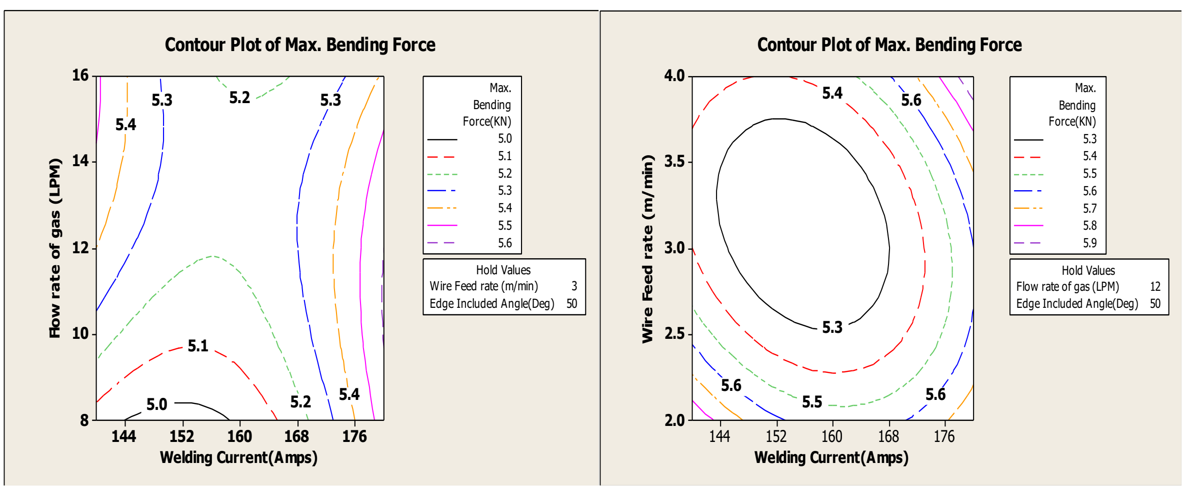


Fig. 9 Contour plots for impact strength.



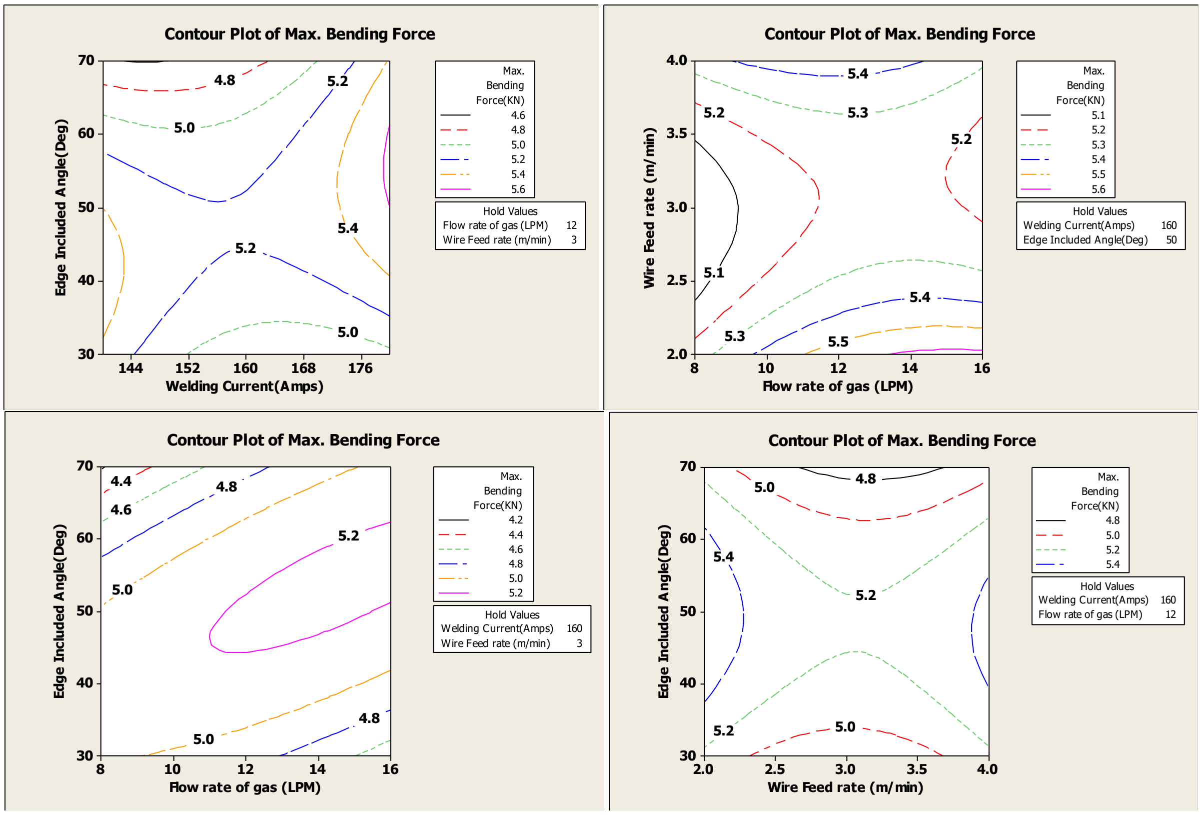


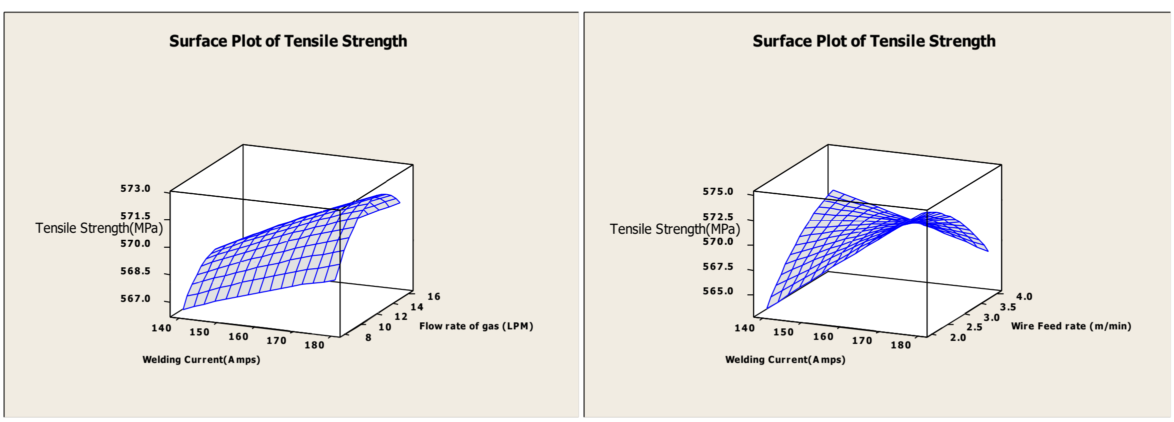
Fig. 10 Contour plots for maximum bending load.

3.5. Surface Plots

Surface plots are drawn to identify the optimal values of welding parameters. The apex and nadir of the surface plot represent maximum and minimum values of the output response. Figures 11 to 13 indicates the surface plots for tensile strength, impact strength and maximum bending load. The objective is to maximize tensile strength, impact strength and maximum bending load. From the surface plots one can find the optimum value by considering two parameters at a time. From surface plots of tensile strength ("Fig. 11"), it is understood that maximum tensile strength is obtained at welding current of 180 Amps, Gas flow rate of 14 LPM, wire feed rate of 3 m/min and edge included angle of 60 Deg.

From surface plots of impact strength ("Fig. 12"), it is understood that maximum impact strength is obtained at welding current of 170 Amps, Gas flow rate of 14 LPM, wire feed rate of 3 m/min and edge included angle of 60 Deg.

From surface plots of Max. Bending load ("Fig. 13"), it is understood that maximum Max. Bending load is obtained at welding current of 180 Amps, Gas flow rate of 14 LPM, wire feed rate of 2 m/min and edge included angle of 60 Deg.



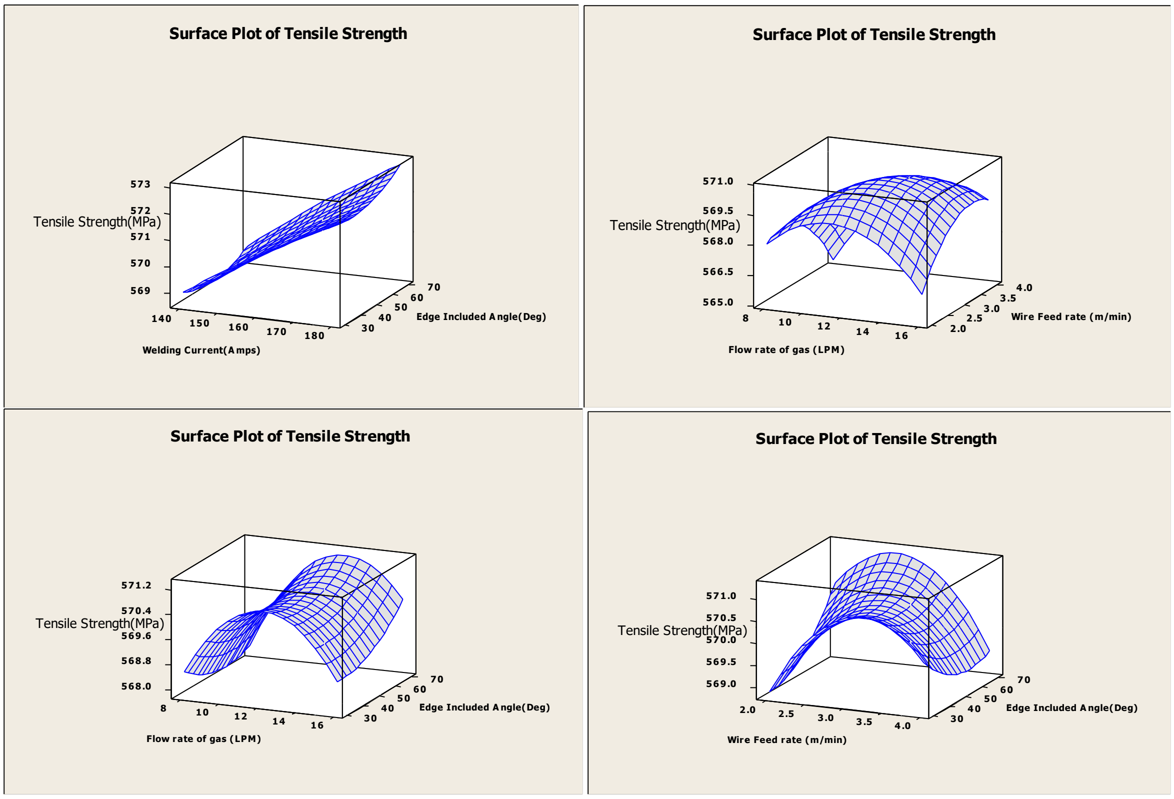
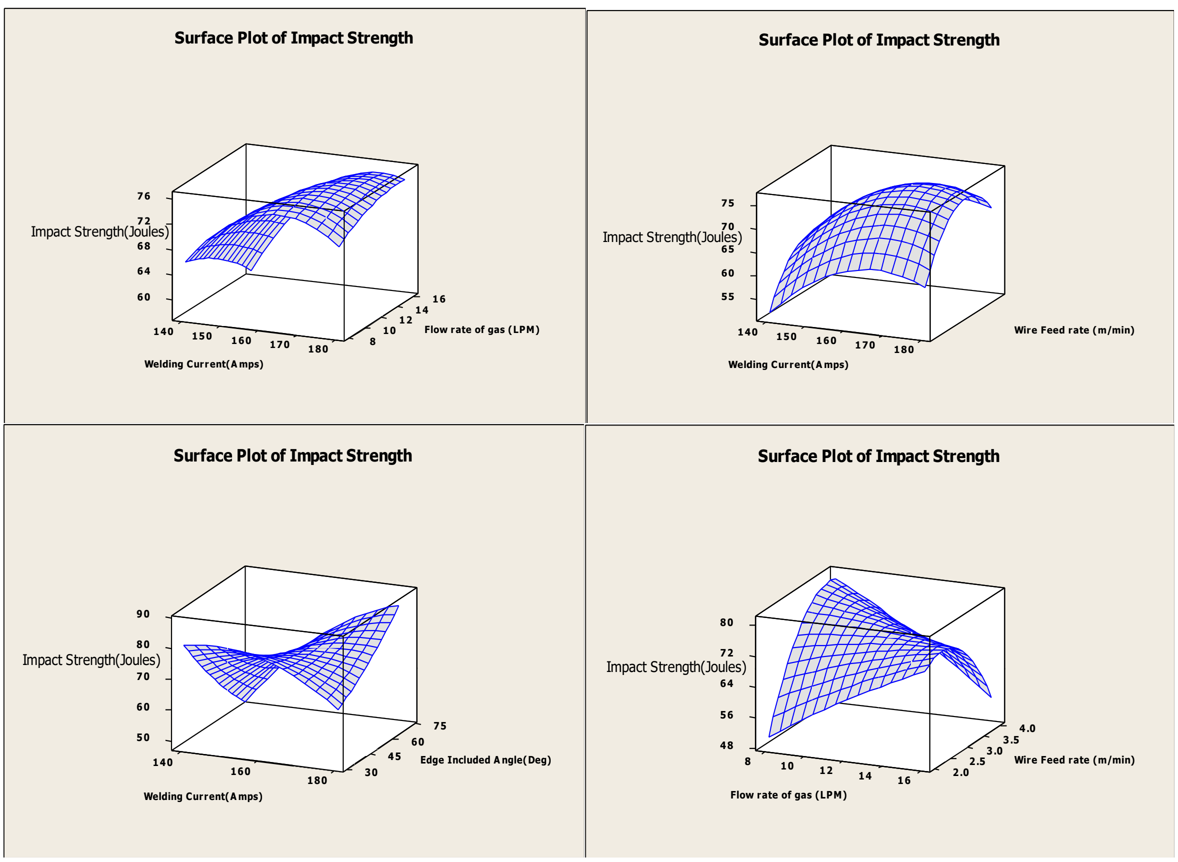


Fig. 11 surface plots for tensile strength.



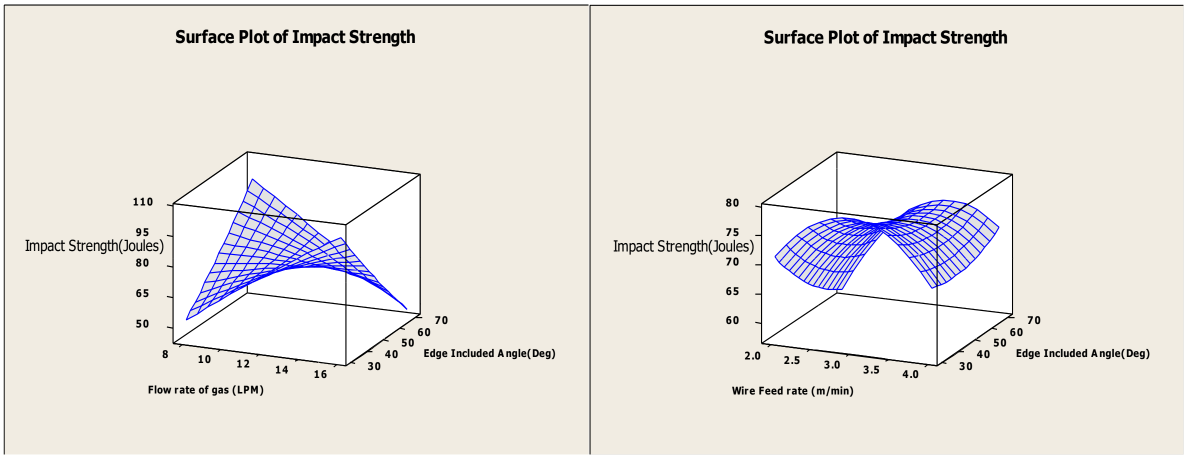
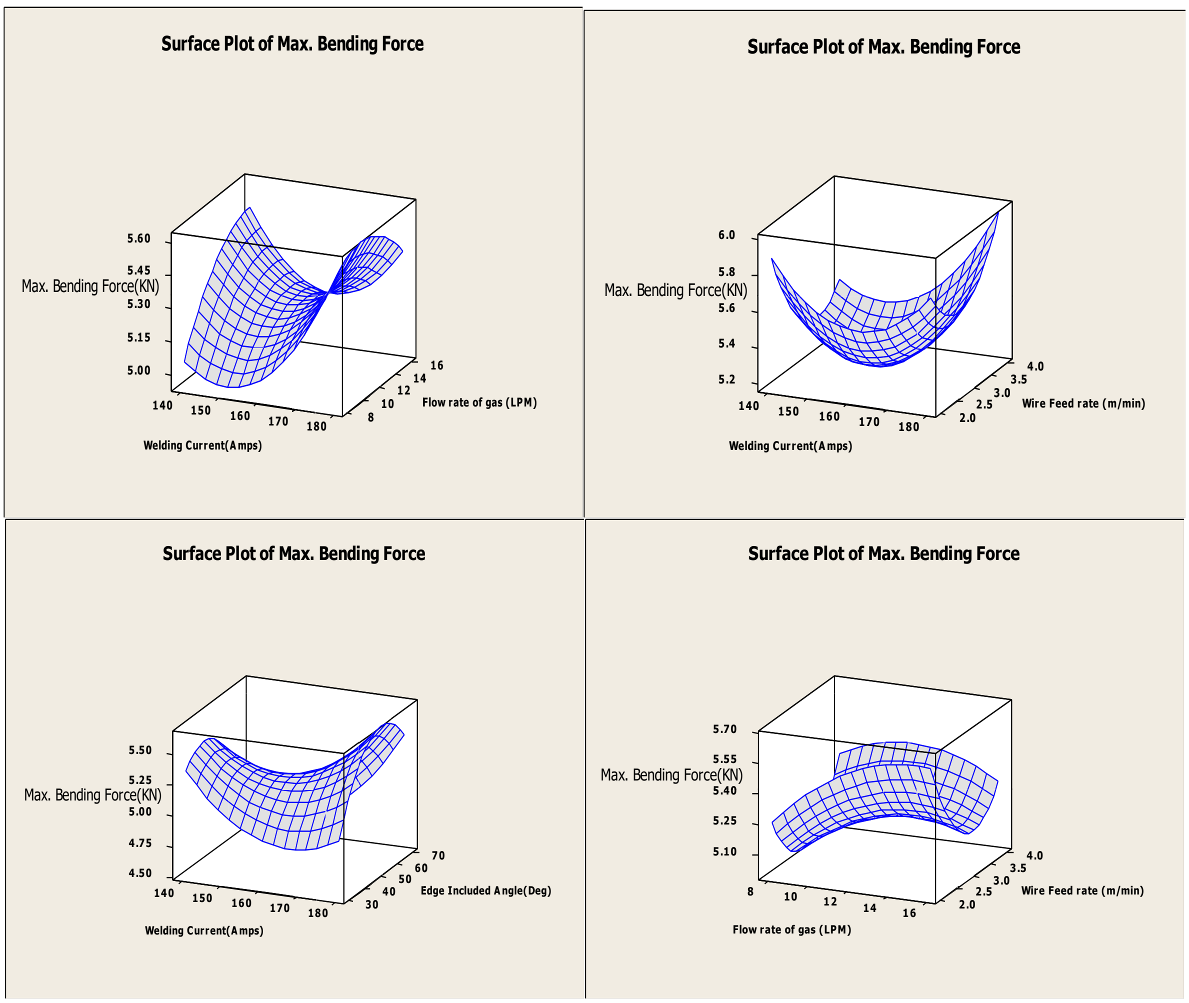


Fig. 12 Surface plots for impact strength.



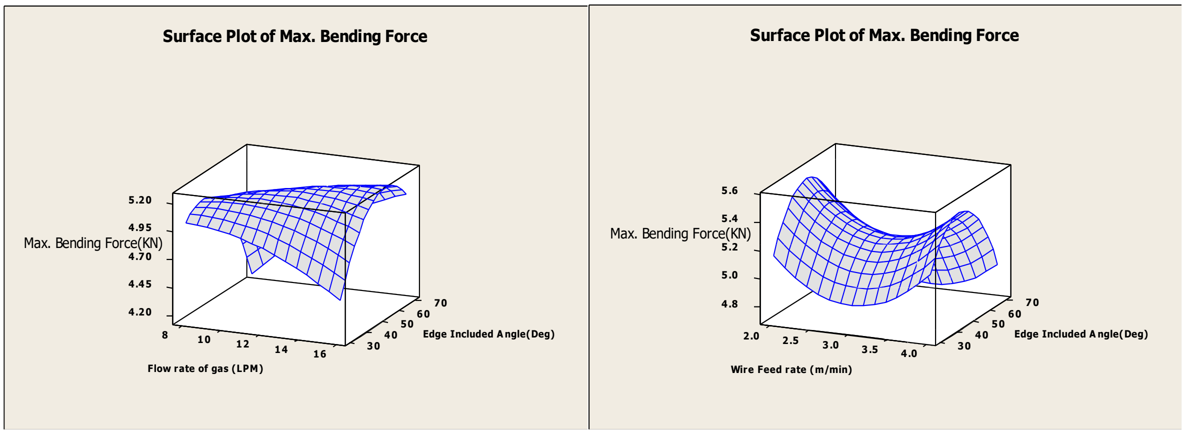


Fig. 13 Surface plots for maximum bending load.

4 OPTIMIZATION

The optimization is carried out using Response optimizer available in MINITAB statistical software. The objective is to maximize tensile strength, impact strength and Max. Bending load. From "Fig. 14", it is understood that at Welding Current of 179.975 Amps, gas flow rate of 12.464 LPM, Wire feed rate of 2.763 m/min and Edge Include Angle of 62.046 Deg, optimal Tensile Strength of 573.566 MPa, Impact Strength of 77.910 Joules and Max. Bending load of 5.607KN are obtained.

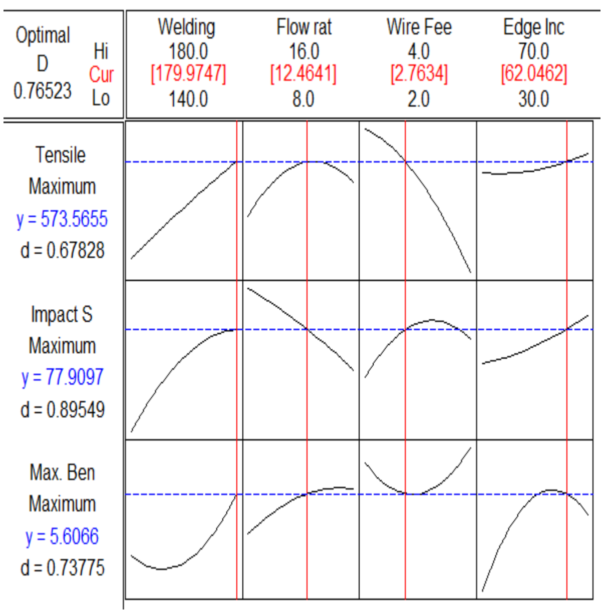


Fig. 14 Optimal solution of Surface Response Method.

5 CONCLUSIONS

Based on the experiments performed the following conclusions are drawn:

1) Empirical mathematical models are developed for tensile strength, impact strength and maximum bending load for MIG weld dissimilar joints of AISI 202 and AISI 316 using statistical software by considering only the significant coefficients.

2) Welding current is the most important parameter which improves the tensile strength, impact strength and maximum bending load; this is due to higher heat input.

3) Higher flow rate of welding gas along with welding current increases the melting rate filler wire there by improves the deposition rate.

4) Filler wire feed rate plays an important role in deposition rate. Low feeds lead to improper penetration and higher feed rate leads to spilling of molten filler wire on the edges of the weld joint.

5) Optimal Edge included angle of the weld joint reducing the welding time and improves the weld joint strength.

6) From the contour plots, it is observed that the most influencing parameter is welding current, followed by flow rate of gas, fire feed rate and edge included angle.

7) From surface plots, we can get optimal combination of two parameters at a time. From overall plots for each output response one may conclude that for maximum tensile strength, impact strength and maximum bending load can be achieved when welding current of 180 Amps, gas flow rate of 14 LPM, Wire feed rate of 3 m/min and Edge Include Angle of 60 Deg.

8) From Response surface optimizer, it is understood that at welding current of 179.975 Amps, gas flow rate of 12.464 LPM, Wire feed rate of 2.763 m/min and Edge Include Angle of 62.046 Deg, optimal Tensile Strength of 573.566 MPa, Impact Strength of 77.910 Joules and Max. Bending load of 5.607KN are obtained. The solution is global solution but within the range of welding parameters.

Although a conclusion may review the main points of the paper, it must not replicate the abstract. A conclusion might elaborate on the importance of the work or suggest applications and extensions. Do not cite references in the conclusion as all points should have been made in the body of the paper. Note that the conclusion section is the last section of the paper to be numbered. The appendix (if present), acknowledgment, and references are listed without numbers.

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