B. MALLICK
K. HALDER
A. S. HAMEED
M.S. JAFAR AL SUAIDY
and
A.K. BANDAPADDAYYA

Experimental investigation for multi characteristics optimization of MIG welding on 304 stainless steel using desirability function analysis

Metal Inert Gas (MIG) welding is an advanced type of welding process where a fusion of gas welding and arc welding is used with shielding component (CO_2) at welding zone and brass coated stainless-steel wire is used as electrode and the feed for joining material (304 stainless steel) is automated which can mostly utilized in mines and metals industries for specific uses. This paper includes parametric influences like applied voltage (V), current (I) and gas flow rate (lit./min) on surface roughness (R_z), width of bed thickness (WOBT) and hardness. The article also consists of the development of mathematical models and analysis of variances (ANOVA) for validation to fit of experimental data and developed models. To find out the single as well as multi objective optimization for minimum surface roughness (R_z), minimum width of bed thickness (WOBT) and maximum hardness through desirability function analysis using response surface methodology (RSM) during welding of 304 stainless-steel thin plate by MIG process. This paper also validated the test results at optimal conditions of 26V, 120amp and 21 litter/min gas flow rate and achieved maximum hardness of 97, WOBT of 5.57mm and minimum surface roughness (R_z) of 7.65μm.

Keywords: *MIG, 304 stainless steel, width of bed thickness (WOBT), surface roughness (R_z) desirability function analysis, optimization.*

1. Introduction

Welding is a permanent joining process for hard ductile material. MIG is a fusion of gas welding as well as arc welding. It is essential for small fabrications or repairs as well as large structures like shipbuilding and robotic welding in modern industrial field. MIG can be used on a long range of materials and thicknesses. A shielding gas (CO_2) prevents oxidation forming and some flux-cored wires avoids the necessary shielding of gas. It is far quicker to lay down weld metal with MIG than other welding process. MIG welding also utilized in automotive sub-assemblies and bodywork and MIG brazing is used at low current on thin-gauge, high-strength steels and wind turbine towers. MIG welding produces high quality welds much faster without producing slag. Minor weld spatter is produced by MIG welding process. But MIG welding cannot be used in the vertical or overhead welding positions. Bhakthavatchalam et.al. [1] used low power pulsed laser MIG (L-M) based AM system and fabricated metal products which had been verified. Timothy J. Horn et.al [2] produced complex by progressive consolidation of feedstock, such as powder or wire, in a layer-by-layer. Md. Samir Khan et. al. [3] proposed too much of gas flow rate caused turbulence and hinders a quality weld. B. Mishra et. al. [4] used Taguchi optimization to find the optimal process parameters for penetration. JvedKazi et. al. [5] explained hardness of MIG welding is greater than TIG welding. JavedKazi et. al.[6] used microscopic study for measuring bead width, bead height, bead penetration and percentage. Dilution. Monika et. al. [7] found that the welding current, voltage, GFR increased, the tensile strength decreased, but when welding speed increased, the tensile strength also increased. D.Bahar et. al. [8] showed in optimization of hardness of the welding joint, contribution of gas flow rate was higher and apart from gas flow rate other parameters should be low. Jigar Shah et. al. [9] found that MIG welding precise output with high production can be obtained. Vikas Chauhan et. al. [10] obtained the best welding techniques by which join two similar and dissimilar materials. C. Labeshkumar et. al.[11] used Taguchi's orthogonal array method for optimization of MIG welding parameters. Aniket Narwadkar et. al.[12] performed ANOVA test used for optimizing angular distortion of butt-welded joints. Sharmistha Singh et. al. [13] obtained that the weld joint had

Messrs. B. Mallick, K. Halder, Mechanical Engineering Department, Techno International Batanagar, Maulana Abul Kalam Azad University of Technology, Kolkata 700141, India, e-mail: bijan.ju@gmail.com. and joy.2016.halder@gmail.com., A. S. Hameed, M.S. Jafar Al Suaidy, Mechanical Engineering Department, College of Engineering, Wasit University, IRAQ, e-mail: azzam@uowasit.edu.iq and mohanedsalah@uowasit.edu.iq and A.K. Bandapaddayya, Mechanical Engineering Department, Jadavpur University, Kolkata-32, India.

more strength than mild steel. S. V. Sapakal et. al.[14] used Taguchi optimization method to find the optimal process parameters for penetration. Gejendhiran Set. al. [15] told TIG welding produced the less hardness value than the MIG welding. Mohd. Shoeb et. al. [16] showed gas flow rate had no significant effect on penetrations. Jigar Shah et. al. [17] found that gas pressure and current were most influenced parameter for tensile strength and hardness. Ajit Hooda et. al. [18] explained that the longitudinal yield strength was greater than the transverse yield strength. Y. T. Ic.et. al. [19] used design of experiment (DOE) and goal programming (GP) methods for determination of critical MIG parameter for optimization. Abbasi. K et. al. [20] used automatic robotic welding machine and a mixture of argon and carbon dioxide as shielding gas used for finding the effect of pressure on MIG welding. So, some research gap is still found out and present research objective has been lay out to reach the goal.

2. Experimentalmethods and materials

For doing the experimentation of 304 stainless steel thin plates has been used in typical set up of MIG welding machine. Carbon dioxide is used as a shielding gas and SS wire as joining material. Circuit diagram of typical MIG welding set up is shown in Fig.1. Also, the 3D model of MIG welding set up is shown in Fig.2. That set up contains shielding gas cylinder, MIG welding machine, electrode wire spool, control box, electrode wire automatic feed. Welding spot with wire feed is shown in Fig.3.

Experimental planning and design of experiment (DOE) has been using Minitab software based on central composite design method (CCDM).

TABLE 1: PROPERTIES AND CHEMICAL COMPOSITION OF 304 STAINLESS STEEL

Physical properties	
Density	8.03g/cm^3
Electrical resistivity	72 microhm-cm (20C)
Specific heat	500 J/kg °K (0-100°C)
Thermal conductivity	16.3 W/m-k (100°C)
Modulus of elasticity (MPa)	193 x 103 in tension
Melting range	2550-2650°F (1399-1454°C)
Chemical composition	
Carbon	0.08 %
Manganese	2.00%
Phosphorus	0.045%
Sulphur	0.03%
Silicon	0.75%
Chromium	18.00-20.00%
Nickel	8.00-10.50%
Nitrogen	0.10 %
Iron	Balance

3. Experimentation and results analysis

The coded and encoded process parameters are shown in Tables 3 and 4 with the effective parameters and maximum results at different conditions. The range of parameters is selected using trial and error method. Fig.4 shows the solid model of welded job. Fig.5 shows drafting model of welded job.

3.1 DEVELOPMENT OF MATHEMATICAL MODELS AND ANOVA TEST

Using response surface methodology as desirability function analysis, co-relating with the co-efficient of

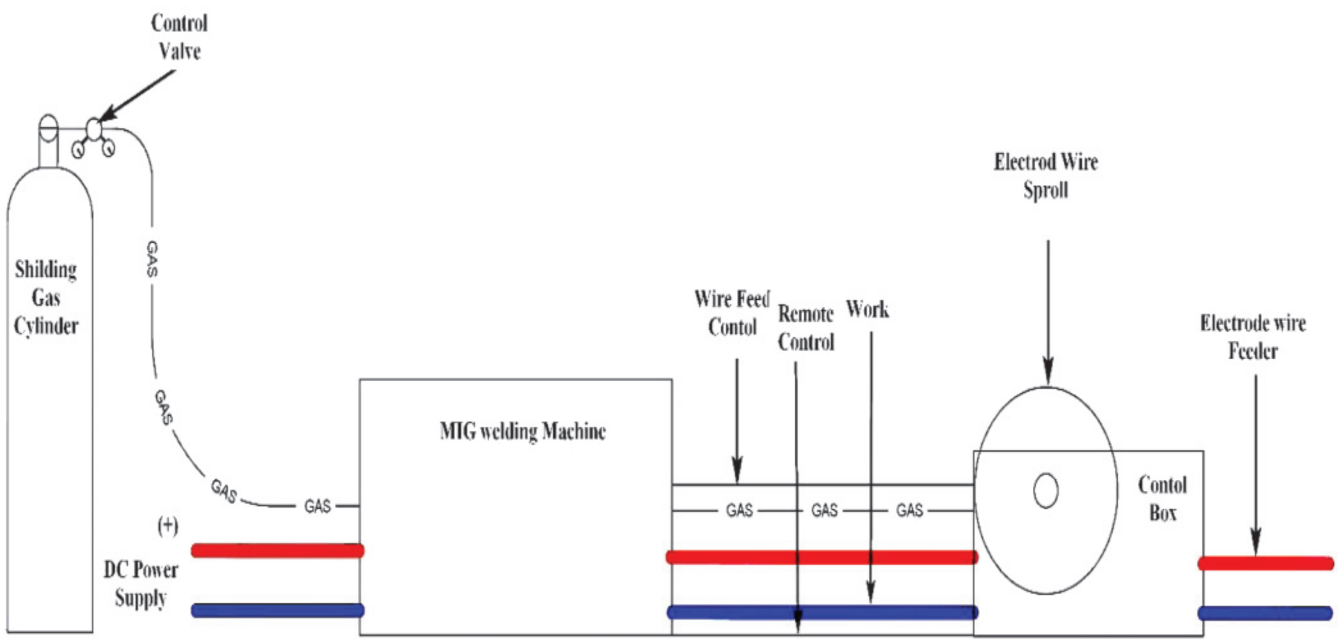

Fig.1 Schematic diagram of MIG welding machine

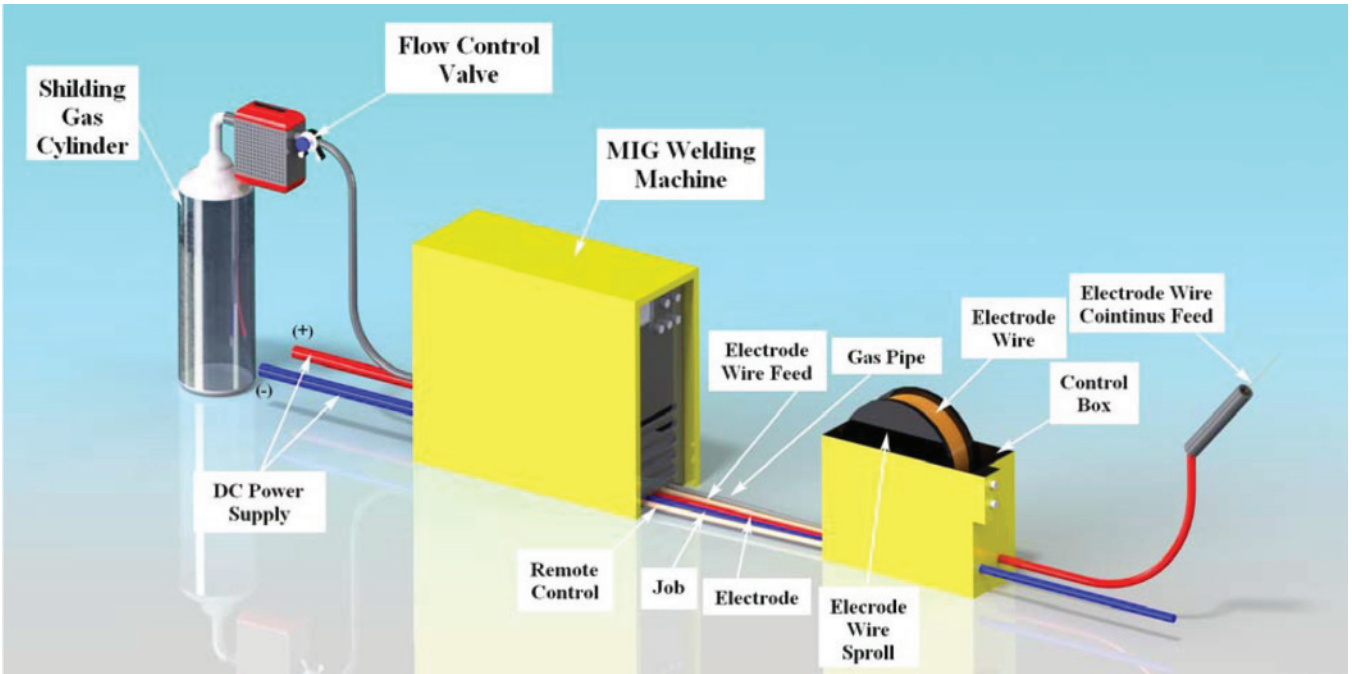

Fig.2 3D model of MIG welding machine

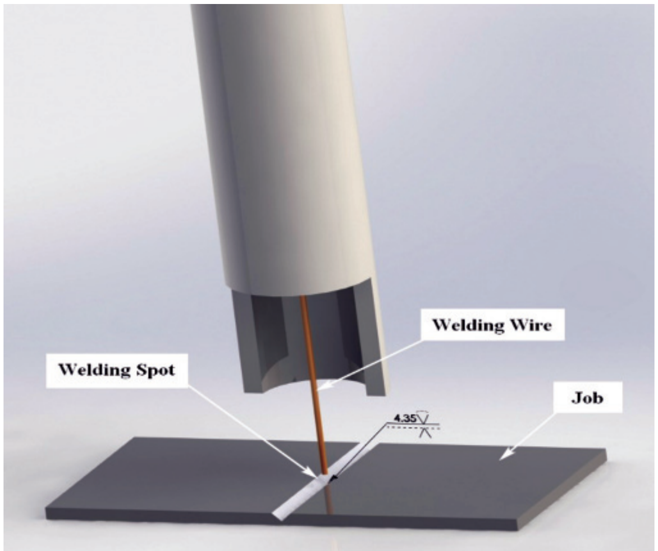

Fig.3 3D model of welding spot with welding wire

performances with process variables, the non-linear mathematical models have been developed and optimized the test results for achieving the optimal results during MIG welding process.

Equation (1) is for hardness and Table 4 shows the ANOVA test analysis of hardness. Standard F ratio value is 4.06 and p value is near about 0.05 also the adjR^2 value is near about 95% which shows the goodness of the model.

$$Y(H) = 92.5818 + 1.8000x_1 - 1.3000x_2 + 0.7000x_3 + 0.5455x_1^2 - 0.9545x_2^2 + 3.0455x_3^2 + 1.7500x_1x_2 - 0.7500x_1x_3 + 0.7500x_2x_3 \quad \text{... (1)}$$

TABLE 2: PROCESS PARAMETERS LEVELS

	–1	0	+1
Voltage, V(Volt) (X_1)	26	30	34
Current, I(Amp.) (X_2)	120	150	180
Gas flow rate, $\dot{m}$ (Lit./min) (X_3)	15	18	21

$R^2 = 95.37\%$ adj $R^2 = 91.21\%$

Equation (2) is for WOBT and Table 5 shows the ANOVA test analysis of WOBT. Standard F ratio value is 4.06 and p value is near about 0.05 also the adjR^2 value is near about 95%.

$$Y(WOBT) = 6.41891 + 2.74400x_1 + 0.60900x_2 - 0.14300x_3 + 1.12273x_1^2 + 2.87773x_2^2 - 0.75227x_3^2 - 0.06875x_1x_2 - 0.74375x_1x_3 - 0.39125x_2x_3 \quad \text{... (2)}$$

$R^2 = 95.76\%$ adj $R^2 = 91.94\%$

Equation (3) is for surface roughness and Table 6 shows the ANOVA test analysis of surface roughness. Standard F ratio value is 4.06 and p value is near about 0.05 also the adjR^2 value is near about 95%.

$$Y(Rz) = 15.6523 + 4.9437x_1 + 1.9195x_2 + 1.0066x_3 - 0.5045x_1^2 + 2.0155x_2^2 - 3.3170x_3^2 - 1.2546x_1x_2 - 1.5014x_1x_3 + 0.5824x_2x_3 \quad \text{... (3)}$$

$R^2 = 93.08\%$ adj $R^2 = 86.85\%$

3.2 PARAMETRIC INFLUENCES ON MACHINING PERFORMANCES

3.2.1 Influence of applied voltage, current and gas flow rate on hardness

From the Fig.6 it is clear that if applied voltage is increased, hardness of stainless steel is increased and from the Fig.7 it

TABLE 3: EXPERIMENTAL RESULTS AND CONDITIONS

	Applied voltage (V)	Current(amp.)	Gas flow rate (lit./min)	Hardness (H)	WOBT (mm)	Surface roughness (R_Z)(μm)
1	26	120	15	96	6.08	3.959
2	34	120	15	98	11.12	19.853
3	26	180	15	88	9.50	9.650
4	34	180	15	97	12.10	19.980
5	26	120	21	97	6.11	7.870
6	34	120	21	96	11.96	17.213
7	26	180	21	92	5.80	15.345
8	34	180	21	98	13.54	20.215
9	26	150	18	92	5.00	8.990
10	34	150	18	94	11.21	17.990
11	30	120	18	92	9.65	14.560
12	30	180	18	91	10.07	17.460
13	30	150	15	94	6.25	9.245
14	30	150	21	97	6.21	12.110
15	30	150	18	93	6.21	16.560
16	30	150	18	93	5.98	16.870
17	30	150	18	92	6.09	16.345
18	30	150	18	93	5.97	17.000
19	30	150	18	93	5.99	16.890
20	30	150	18	92	6.02	16.880

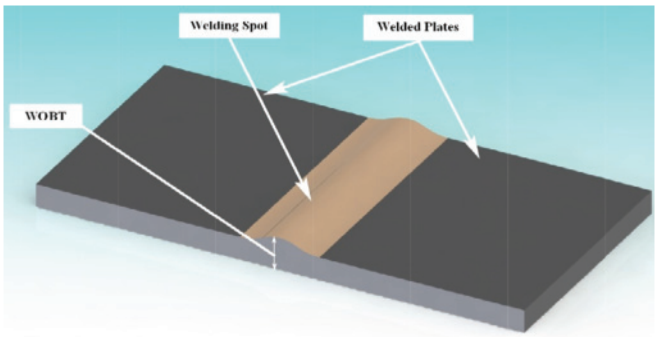

Fig.4 3D solid model of welding spot

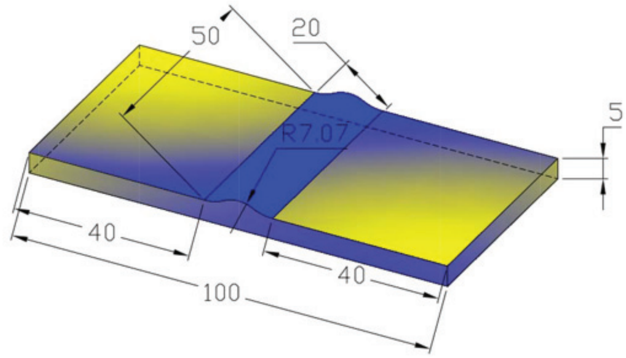

Fig.5 3D drafting model of welding spot

TABLE 4: ANALYSIS OF VARIANCES (ANOVA) TABLE FOR HARDNESS

Source	DOF	SS	MS	F	P
Regression	9	129.518	14.3909	22.91	0
Linear	3	54.2	18.0667	28.76	0
Square	3	41.818	13.9394	22.19	0
Interaction	3	33.5	11.1667	17.78	0
Residual error	10	6.282	0.6282		
Lack – of - fit	5	4.948	0.9897	3.71	0.088
Pure error	5	1.333			
Total	19	135.8	0.2667		

TABLE 5: ANALYSIS OF VARIANCES (ANOVA) TEST FOR WOBT

Source	DOF	SS	MS	F	P
Regression	9	136.764	15.196	25.09	0
Linear	3	79.209	26.4029	43.59	0
Square	3	51.868	17.2892	28.54	0
Interaction	3	5.688	1.8959	3.13	0.074
Residual error	10	6.057	0.6057		
Lack – of - fit	5	6.015	1.2029	140.75	0
Pure error	5	0.043	0.0085		
Total	19	142.821			

is clear that if gas flow rate is initially increased, hardness is increased but at 17.5 lit/min of gas flow rate it decreases and after that increasing of gas flow rate hardness of stainless steel is increased after welding by MIG process.

3.2.2 Influence of applied voltage, current and gas flow rate on WOBT

From the Fig.7 it is found that if applied voltage is increased, width of bed thickness increases and when gas

Table 6: Analysis of variances (ANOVA) table for surface roughness (R_z)(μm)

Source	DOF	SS	MS	F	P
Regression	9	365.143	40.571	14.94	0.000
Linear	3	291.379	97.126	35.77	0.000
Square	3	40.425	13.475	4.96	0.023
Interaction	3	33.339	11.113	4.09	0.039
Residual error	10	27.151	2.715		
Lack – of - fit	5	26.837	5.367	85.69	0.000
Pure error	5	0.313	0.063		
Total	19	392.294			

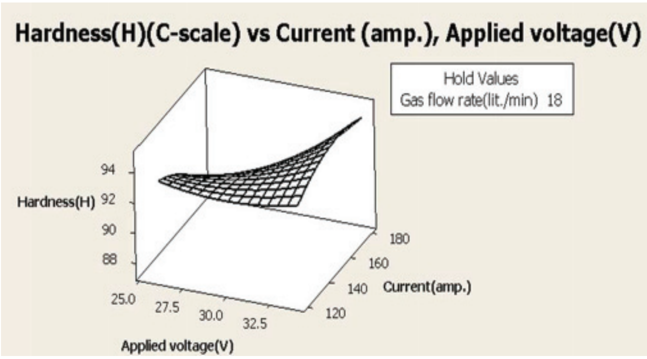

Fig.6 Effects of applied voltage and current on hardness

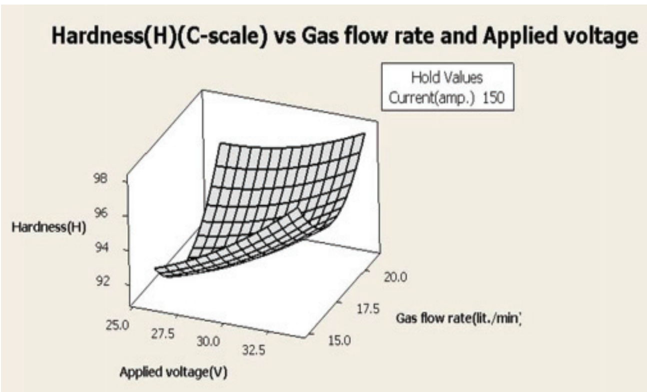

Fig.7 Effects of applied voltage and gas flow rate on hardness

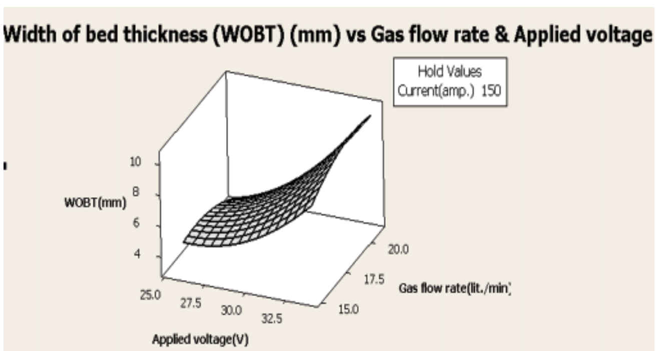

Fig.8 Effects of applied voltage and gas flow rate on WOBT

flow rate also increases, width of bed thickness gradually increases, when current has been kept fixed at 150 amps.

From the Fig.8 it is propounded that width of bed thickness is increased with the varying of applied voltage, keeping gas flow rate constant at 18 lit./min and if current is increased, width of bed thickness is increased and it is observed that at lower current intensity induces better welding zone and increased the quality of welded portion.

3.2.3 Influence of applied voltage, gas flow rate and current on SR

From the Fig.9 it is clear that surface roughness is increased as applied voltage and current is increased, keeping other parameters constant and from Fig.10 it is also obvious to find out that gas flow rate at higher rate decreases the surface roughness, though initially it increases when current is kept fixed at 150 amps.

3.3 Sigle objective optimization for maximum hardness and minimum surface roughness, WOBT

By single objective optimization of hardness through Minitab software it is found from the Fig.11, parametric combination for maximum hardness is found applied voltage 34V, current 169.09amp, gas flow rate 21lit/min and it is reach at C, scale hardness of 98.

By single objective optimization of WOBT through

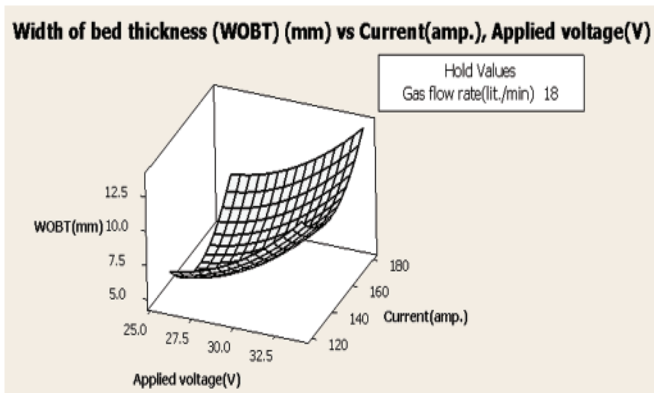

Fig.9 Effects of applied voltage and current on WOBT

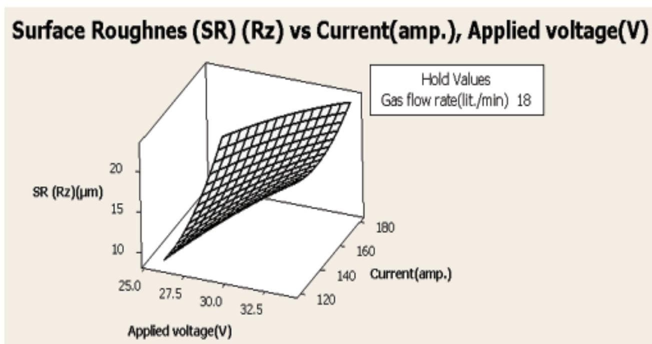

Fig.10 Effects of applied voltage and current on SR

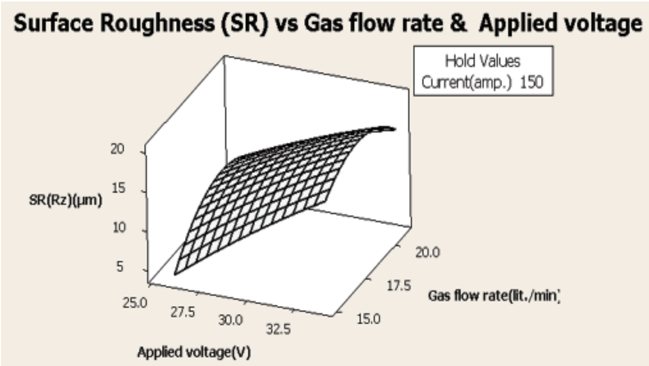

Fig.11 Effects of applied voltage and gas flow rate on SR

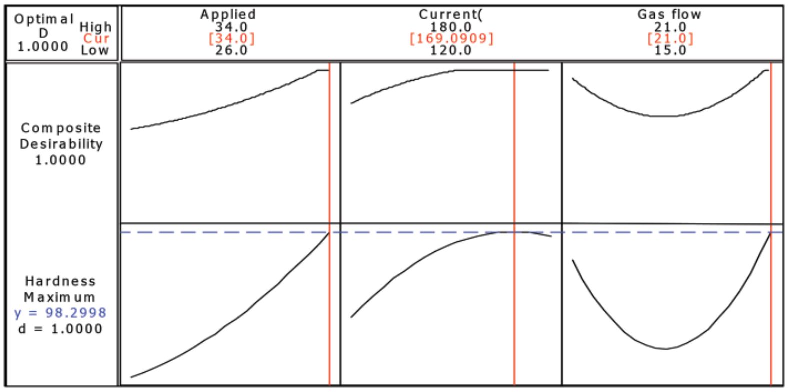

Fig.12 Single objective optimization of hardness

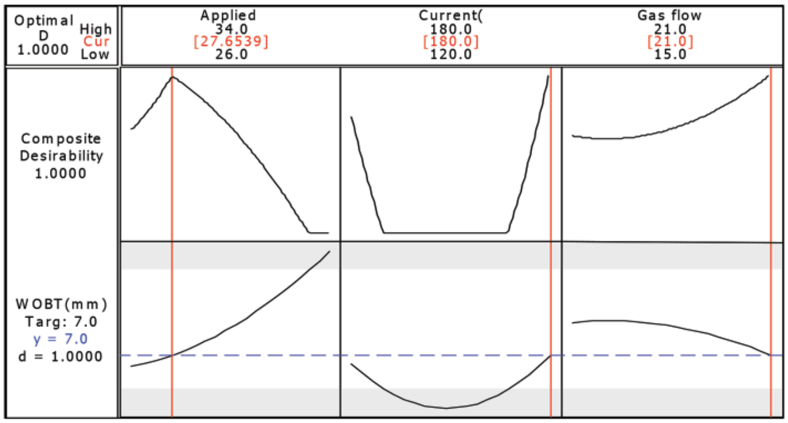

Fig.13 Single objective optimization of WOBT

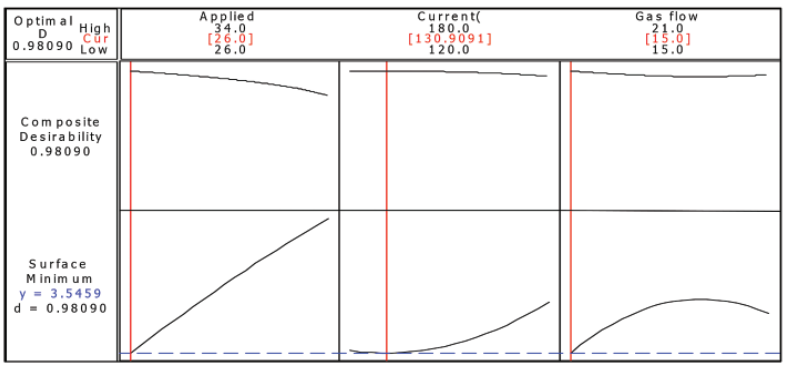

Fig.14 Single objective optimization of SR

Minitab software it is found from the Fig.12 at the parametric combination of applied voltage 27.6V, current 180amp, gas flow rate 21lit/min WOBT becomes minimum of 7 mm.

From the Fig.14 for single objective optimization of surface roughness through Minitab software it has been observed that at the parametric combination of applied voltage 26V, current 130.91amp, gas flow rate 15lit/min minimum surface roughness (R_z) has been achieved, 3.545 µm.

3.4 Multi-criteria optimization for max. hardness and min. WOBT and SR

From the Fig.15 it is found that multi objective optimization of hardness, WOBT, surface roughness through

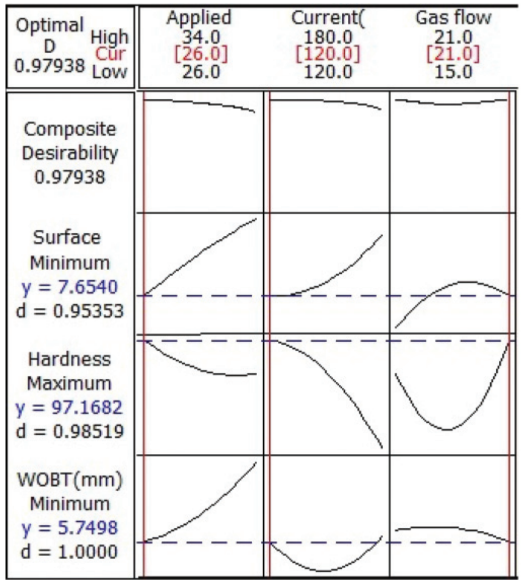

Fig.15: Multi objective optimization of hardness, WOBT and SR

desirability function analysis for maximum hardness, minimum SR and WOBT, the parametric combination has been achieved applied voltage 26V/current 120amp,/gas flow rate 21 lit/min and desired value of those machining criteria are found hardness = 97.168, surface roughness (R_z) = 7.654µm and width of bed thickness = 5.745 mm, that is experimentally validated.

4. Conclusions

To reach the goal and to fulfil the objective of the present research the following conclusions can be withdrawn:

- Applied voltage and current have dominating role on machining criteria of MIG welding process. Lower current with moderate gas flow rate provides better weld ability by MIG process.
- Desirability function analysis can be used successfully as voluntary optimization of

process parameters to achieve the optimal results.

- The developed mathematical models are validated using analysis of variances (ANOVA) and show the adequacy of test results.
- The maximum hardness and minimum surface roughness with width of bed thickness is found at the parametric combination of applied voltage 26V/ current 120amp,/gas flow rate 21 lit/min.

References

[1] U. Bhakthavatchalam, K. Ganeshmurthy, A. Jaisooriyan(208): "Additive Manufacturing Using MIG Welding". *International Journal of Research in Engineering*, Science and Management, 1, 10.

[2] Timothy J. Horn, Dr Ola L. A. Harrysson (2012): "Overview of Current Additive Manufacturing Technologies and Selected Applications" *sage journals*, 1.

[3] Khan, Md. Samir, Kumar, Vishwajeet, Mandal, Prosun and Mondal, Subhas Chandra(2018): "Experimental Investigation of Combined TIG-MIG Welding for304 Stainless Steel Plates" International Conference on Mechanical, Materials and Renewable Energy,2.

[4] Mishra, B., Panda, R.R. and Mohants, D. K. (2014): "Metal Inert Gas (Mig) Welding Parameters Optimization, *International Journal of Multi-disciplinary and Current Research*, 2.

[5] Javed Kazi, Syed Zaid, Syed Mohd. Talha, Mukri Yasir, Dakhwe Akib (2015): , "A Review on Various Welding Techniques", *International Journal of Modern Engineering Research* (IJMER),5,2.

[6] Valluru, Srivani, Aruna, K, Dr. Hema, P. (2017): "Investigation of Process Parameters during MIG Welding of AISI1010Mild Steel Plates", *International Research Journal of Engineering and Technology* (IRJET), 04, 04.

[7] Monika, Chuhan, Jagdip (2017): "A review paper on gas metal arc welding(GMAW) of mild steel 1018 by using Taguchi technique", *International journal of current engineering and scientific research* (IJCESR),4, 7.

[8] Bahar, D., Sharif, Md. Nawaz, Shravan Kumar, K, and Reddy, D(2018): "Optimization of MIG welding process parameters for hardnessand strength of welding joint using Grey relational analysis", *International Journal of Research in Advent Technology*, 6, 5.

[9] Shah, Jigar, Patel, Gaurav, Makwana,Jatin(2017): "A Review on Optimization and Prediction of MIGWelding Process Parameters Using ANN", *International Journal of Engineering Development and Research*, 5, 1.

[10] Chauhan, Vikas, and Jadum, Dr. R. S.(2015): "Parametric optimization of mig welding for stainless steel (SS-304) and low carbon steel using taguchi design method", *International Journal of Recent Scientific Research*, 6, 2.

[11] Labeshkumar, C., Vanaja, T., Murti, Dr. KGK, and Prasad, VVSH (2017): "Optimization of Mig Welding Process Parameters for Improving Welding Strength of Steel", *International Journal of Engineering Trends and Technology* (IJETT),50, 1..

[12] Narwadkar, Aniket, Bhosle, Santosh (2016): "Optimization of MIG Welding Parameters to Control the Angular Distortion in Fe410WA Steel",Materials and Manufacturing Processes,08 17.

[13] Singh, Sharmistha, Gupta. Neha(2016): "Analysis of Hardness in Metal Inert Gas Welding of Two Dissimilar Metals, Mild Steel & Stainless Steel", *IOSR Journal of Mechanical and Civil Engineering* (IOSR-JMCE), 13, 3, I.

[14] Sapakal, S.V., Telsang,mM.T. (2012): "Parametric optimization of MIG welding usingtaguchi design method", *International Journal of Advanced Engineering Research and Studies*, IJAERS, I, IV.

[15] Gejendhiran S., Satheesh Kumar K V., Dr. Sivakumar A.(2014): "a study of welding parameters on mechanicalproperties of gas metal arc welding and gastungsten arc welding: a review", *International Journal of Advanced Engineering Research*, III/II.

[16] Shoeb, Mohd., Prof. Mohd. Parvez, Prof. Pratibha Kumari(1013): "Effect of Mig Welding Input Process Parameters on Weld Bead Geometry on Hsla Steel", *International Journal of Engineering Science and Technology* (IJEST),5 0.

[17] Shah, Jigar, Patel, Gaurav, Makwana, Jatin (2017): "Optimization and Prediction of MIG Welding Process Parameters Using ANN", *International Journal of Engineering Development and Research*, 5, 2.

[18] Hooda, Ajit, Dhingra, Ashwani and Sharm, Satpal (2012): "Optimization of Mig Welding Process Parameters to Predict Maximum Yield Strength inAisi 1040", *Int. J. Mech. Eng. & Rob. Res.*, 1, 3.

[19] Y. T. Ic., F. Elaldi, F. Pakdil And N. E. Ipek (2012): "Design of Experiment and Goal Programming Application for the GMAW Process", *Welding Journal Research,* 91.

[20] Abbasi. K, Alam. S, Khan. M.I (2011): "An experimental study on the effect of increased pressure on MIG welding arc", *International Journal of Applied Engineering Research*, 21.

Printed by Pradip Kumar Chanda at The Indian Press Pvt. Ltd. 93A Lenin Sarani, Kolkata 700 013 and published by him for Books & Journals Pvt. Ltd. from 62 Lenin Sarani, Kolkata 700 013.