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Parametric Optimization of MIG Welding by Using Taguchi Orthogonal Array

S Anand Paul[1], B Sai Baba[2], B Naveen[3], VHS Kumar[4], P Gopi Chand[5], V. Harikiran[6*]

[1,2,3,4,5]*Student, Department of Mechanical Engineering, Avanthi Institute of Engineering and Technology, Makavarapalem (V), Visakhapatnam, Andhra Pradesh, India.*

[6]*Associate Professor, Department of Mechanical Engineering, Avanthi Institute of Engineering and Technology, Makavarapalem (V), Visakhapatnam, Andhra Pradesh, India.*

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ABSTRACT: These days one of the most important welding processes in industries is Metal Inert Gas Welding (MIG). MIG welding is affected by many factors such as the torch velocity, torch gap, voltage, current, gas flow rate, nozzle to plate distance, torch angle, wire feed rate, Welding speed, weld deposit area etc., which are input parameters in this project work. In this process, input variables are voltage, current and welding speed with tensile properties and hardness as responses such as tensile properties, hardness and penetration of low carbon steel (ASTM A29). The design of experiments based on Taguchi orthogonal array [L_9], acquire Analysis of variance (ANOVA) to determine the influence of parameters with optimal condition. Finally, the confirmation test has been carried out to compare the predicted value of tensile strength and hardness with the experimental value.

KEYWORDS: MIG Welding, Mild Steel, Taguchi Approach, Hardness, Tensile strength.

I. INTRODUCTION

Welding is a process of joining metal parts or we can say it is fabrication process, in which by heating the surfaces of the work piece with the help of arc (may be mechanical or electrical) or by other means and uniting them by hammering or pressing, etc. We know that MIG welding is one of most versatile technique till now in modern production technology and most importantly, it is suitable for both either for thin sheet or thick section components. Basically, in this process an electric arc is produced between consumable wire electrode and the workpiece, due to this heat work piece metal melts and join. Now in order to protect weld pool from contamination from the atmosphere, i.e. Moisture or oxygen, we are using inert gases like argon, helium or a mixture of argon-helium or by a mixture of argon-carbon dioxide. While compared to other welding process in this method we are not providing any external filler metal because the wire electrode provides the arc as well act as a filler metal [1].

Park et al., [2] conducted an experiments on optimization of the wire feed rate during pulse MIG welding of AL sheets. In this experiment they conducted various wire feed speeds range from 0.5m/min to 1.5m/min and also the bead characteristics were evaluated and shape factors of the bead width, back bead width, weld bead and bead cross section area are measured. According to their weld quality the wire speed is optimized by varying welding speed. After the experiments they found that wire feed speed are optimized at welding speeds of 0.50m/min, a. 0m/min, and 1.5m/min

Chavda et al., [3] conducted experiments on a review on optimization of MIG welding parameters using Taguchi's DOE Method. They have chosen medium carbon steel material and optimize the welding parameters. Finally, conduct the test to compare with the predicted values with the experimental values to confirm its results in the analysis of weld strength and depth of penetration.

Kanwal et al., [4] conducted an experiments on optimization of MIG welding parameters for the hardness of aluminium alloys using Taguchi method. The materials used for this experiment are aluminium alloys of grade 6061 and 5083 having a dimension of (75x60x6) mm. In this experiment Argon gas used as shielding gas. Finally, they found that both aluminium alloys 5083 and 6061 having great hardness, and most important that welding current has major effects on hardness of welded joints.

Abhishek et al., [5] conducted an experiment on parametric optimization of MIG welding with the help of Taguchi method. In this paper represent the investigation at the optimization

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of welding parameters and effect on the hardening effect at heat effected zone and determine tensile strength of MIG welded steel.

Verma et al. [6] conducted an investigation on optimization of process parameters of metal inert gas welding by Taguchi method on CRC steel is 513 Grade-D. In this experiment they obtain better bead height and bead width separately

Bataineh et al. [7] conducted an experiment on optimizing process conditions in MIG welding of aluminum alloys through factorial design experiments. After the experiment they set, a conclusion that at voltage 24 V and filler rate is 7 in/s, respectively, at which the mean weld strength is maximized.

Faseeulla et al. [8] conducted an experiment on a response surface model to study the effects of process parameters of weld-bolding on tensile shear strength of the weld-bond of 2mm thick aluminium alloy 6061 T651 sheets. Finally, using this model they get the maximum tensile shear strength of the weld bond.

Malik et al., [9] conducted an experiment on parameter optimization for tensile strength & hardness of MIG welding joint of HSS & mild steel by using Taguchi technique. In this experiment, they are using high speed steel of grade M2 and low carbon steel under varying parameters. They finally conclude that Taguchi parametric design process is best suitable for cost of operation.

In this study, the author performed MIG welding experiments on low carbon steel (ASTM A29). A Taguchi OA [L9] is used to design the experiments The process variables such as voltage (V), current (A) and wire speed (S) whereas tensile strength (TS) and Hardness at HAZ are responses

II. MATERIALS AND METHODOLOGY

Figure 1 Front View of MIG welding Setup and Sample Preparation for Butt Welding Joint

The sample of size 200x100x90mm has cut with help of Power Hacksaw. We made as groove of 60 degrees on each sample with the help of Power Grinder. the chemical composition of Low Carbon steel ASTM A29 is shown in Table 1. Low-carbon steel is the most widely used form of carbon steel. These steels usually have a carbon content of less than 0.25 wt.%. They cannot be hardened by heat treatment (to form martensite) so this is usually achieved by cold work. Low carbon steels are often used in automobile body components, structural shapes (I-beams, channel and angle iron), pipes, construction and bridge components, and food cans. Where, the material property chart (Figure 2) for against in the materials selection and design process. The Ashby charts are interactive with technical data upon selected material. The features of butt welding as shown in Figure 3.

Table 1 ASTM A29 chemical composition

Element	%
Carbon	0.70-0.80
Iron, Fe	98
Manganese, Mn	0.40-0.70
Sulphur, S	0.05
Phosphorous, P	0.04

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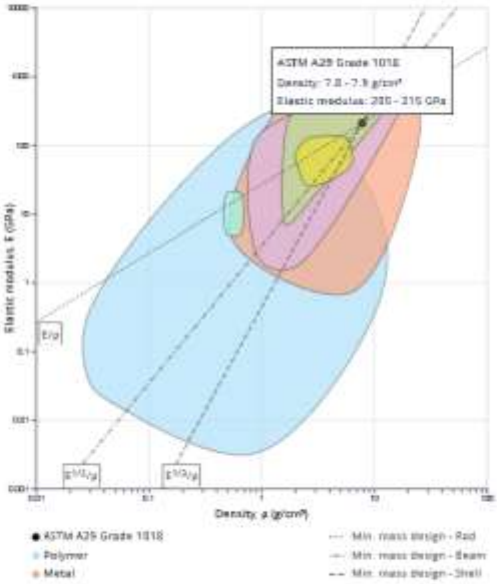

Figure 2 Ashby charts are interactive with materials

The experimental work employs parametric optimization to attain welds joint quality. Taguchi's method of Design of Experiments was adopted to carry out the first stage of experiments for this study. This design method involves selecting a pre-determined orthogonal array that is derived from a selection of chosen factors and levels. This orthogonal array selection allowed for the efficient combination of varied parameters. The experimental design has followed by a signal-to-noise ratio analysis and then the analysis of variance (ANOVA) to determine the significance of mild steel joints if any. The experiments were carried out on butt joint weld joint configuration shown in Figure 3.

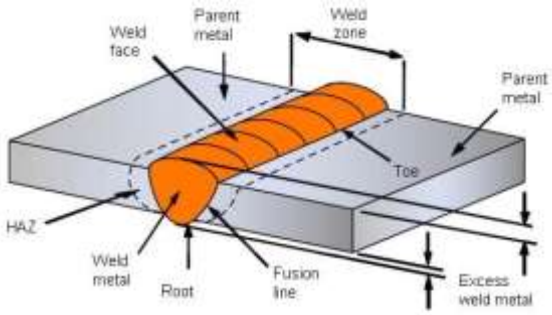

Figure 3 Features of butt welding

A Japanese scientist i.e. Genichi Taguchi, develop a technique on an orthogonal array. This method is widely used in manufacturing industries. The main objective of this method is to provide a high-quality product at very low cost to the producer (manufacturer). Taguchi developed an array for predict how different parameters affect the mean and variance of the process parameters. He made the method in such a way that each factor have equally weighted because each factor is evaluated independently of other factors, so that's why the effect of one factor does not affect the value of other factors or we can it is statistically technique that allows us to improve the consistency of production. Taguchi method recognizes that not all factors that cause variability can be controlled [10]. These uncontrollable factors are called noise. Taguchi designs try to identify controllable factors to evaluate variability that occurs and then determines optimal factor setting that minimize the process variability. A process designed with this goal will produce more consistent output and performance regardless of the environment in which it is used.

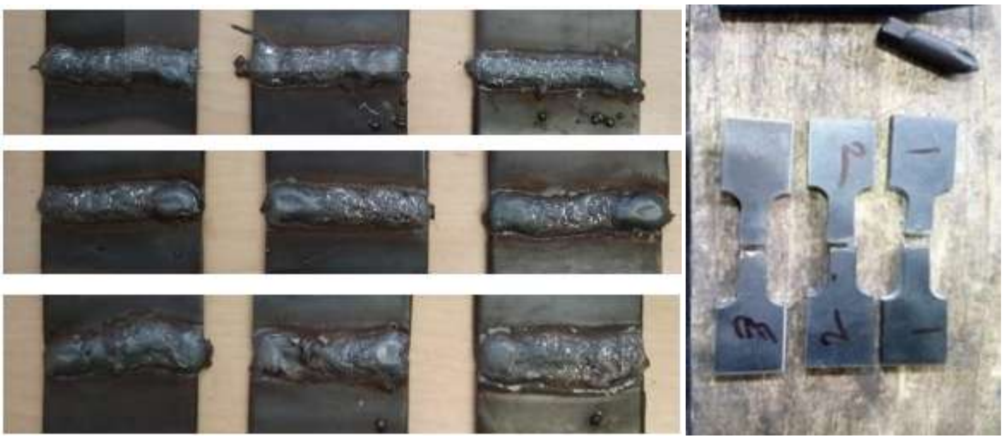

Figure 4 Prepared MIG Welded Samples based on Taguchi OA[L9] and Tested Tensile samples

III. EXPERIMENTATION

In this project work, based on the design the welded samples are prepared shown in Figure 4. The welded samples for measuring micro-hardness first rubbed with emery paper size of 1/0, 2/0 & 4/0 and then clean with the help of acetone solution. The tensile samples are prepared and shown in Figure 4.

Table 2 Design of Experiment with Taguchi Orthogonal Array [L9]

Run	V	A	S
1	20	200	2.2
2	20	215	2.65
3	20	230	3.1
4	22	200	2.2
5	22	215	2.65
6	22	230	3.1
7	24	200	2.2
8	24	215	2.65
9	24	230	3.1

Based on design conducted total nine experiments were done based on orthogonal array (L_9) shown in Table 2. The main effect of different parameters such as welding voltage, current and wire speed of low carbon steel ASTM A29 was analysed and observed the hardness and tensile strength of all nine-weld metal and observed the value of hardness and tensile strength with its S/N ratios are predicted in Table 3.

Table 3 Response of Tensile and Hardness with S/N ratio

Run	TS	HAZ	TS - SNRA	HAZ-SNRA
1	351.20	168.50	50.91	-44.53
2	325.20	147.50	50.24	-43.38
3	315.10	156.50	49.97	-43.89

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4	481.20	247.00	53.65	-47.85
5	382.50	189.00	51.65	-45.53
6	325.60	166.50	50.25	-44.43
7	425.10	219.00	52.57	-46.81
8	352.20	153.50	50.94	-43.72
9	342.10	179.50	50.68	-45.08

IV. OBESERVATIONS FROM THE WELD TESTS CONDUCTED

In this experiment, Tensile strength has obtained experimentally and Taguchi method is used for the analysis with the help of ANOVA (L9). According to data are found, we get a graph of the signal-to-noise (S/N) ratio is shown in Figure 5. The calculated S/N ratio is shown in Table 4, determined response table by considering S/N ratio as larger – is- the – better. Analysis of variance (ANOVA) is a statistical tool used to analyse the S/N ratios. We also know that the term "signal" represents the desirable mean value, and the "noise"- undesirable value. Hence, we can say that S/N ratio show the amount of variation, which is presented in the performance characteristics.

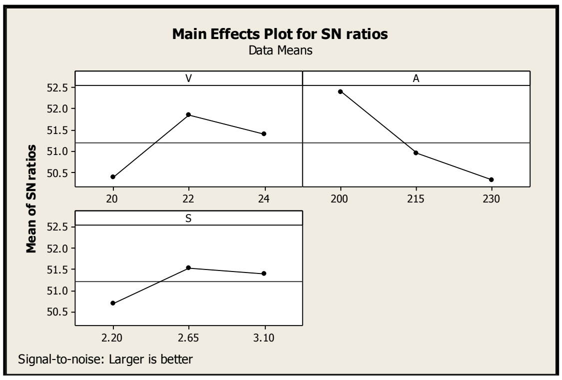

Figure 5 Main Effects plot of process parameters on tensile strength for S/N ratio

From the response graph, the optimal condition for Tensile strength as the welding current (A) is a dominant parameter on the tested specimens, followed by welding voltage (V) and wire speed (S). This refers the optimal condition of Tensile strength as V2A1S2, the same also reflected in Figure 5.

Table 4 Analysis of Variance for S/N Ratio of tensile strength

Source	DF	Seq Ss	Adj MS	F	P
V	2	3.4313	1.7156	7.84	0.113
A	2	6.7637	3.3819	15.46	0.061
S	2	1.1809	0.5904	2.70	0.270
Error	2	0.4376	0.2188		
Total	8	11.8135			

The ANOVA is one of the most widely used methods for portioning variability into an identifiable source of variation and the associated DOF in an experiment. F-test for analyze the significant effects of the process parameters, which form quality characteristics. In Table 4 show, the result of ANOVA analysis of S/N ratio of low carbon steel ASTM A29. The ANOVA obtained R^2 and R_{adj}^2 as 96.3 and 85.2%. The ANOVA revealed the influence of process parameters with a response. Welding current, (A) is the most influencing parameter (57.25%) and followed by the welding voltage (V) as (29.05%) and wire speed as 10%.

ANOVA of Hardness at HAZ

From Figure 6 it was observed that the welding voltage (20 volts), welding current (215 amp), and wire speed (2.2) gives an optimal Hardness at HAZ. We know that the S/N ratio for each parameter was determined by averaging the S/N ratios at the corresponding level.

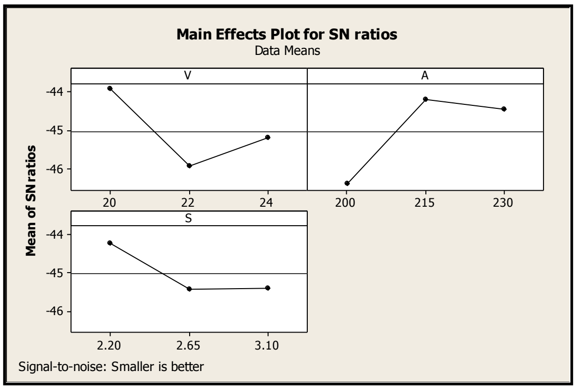

Figure 1 Effects of process parameter on hardness at HAZ for S/N ratio

The ANOVA (Table 5) obtained R^2 and R_{adj}^2 as 99.3 and 97.2%. The ANOVA revealed the influence of process parameters with a response. Welding current, (A) is the most influencing parameter (48.14%) and followed by the welding voltage (V) as (34.78%) and wire speed as 16.12%.

Table 5 Analysis of Variance for S/N Ratio of Hardness

Source	DF	Seq Ss	Adj MS	F	P
V	2	6.1716	3.08581	49.88	0.020
A	2	8.5902	4.29509	69.43	0.014
S	2	2.8608	1.43042	23.12	0.041
Residual	2	0.1237	0.06186		
Total	8	17.7463			

Multiple Linear Regression Models

Multiple linear regression equations were developing a relation between the process variables and response. The value of regression coefficient R^2 (0.963) is in good agreement with the adjusted R^2 (0.852) for the Tensile strength of the ASTM A29. R^2 (0.993) is in good agreement with the adjusted R^2 (0.972) for the Hardness of the ASTM A29. Considering that both values are close to unity, this model gives a good result between the independent parameters and responses.

The regression equation developed for the surface roughness of the Tensile strength is as follows:

TS = 696 + 10.7 v - 3.05 A + 34.7 S ----- (1)

The regression equation developed for the Hardness of ASTM A29 is as follows:

HS = 276 + 6.62 v - 1.47 A + 28.1 S ---- (2)

We can predict from Equations. (1) & (2) that the Welding Current (A) plays a greater role on Tensile and Hardness, followed by welding voltage (V) and wire speed (S). The coefficient associated with welding current (A) is negative, thus indicating that the Tensile and hardness as decreases with increasing welding current. Conversely, the Tensile and hardness increase with increasing welding voltage and wire speed because the coefficients of these factors are positive. Wire speed has a greater effect on Tensile and hardness as compared with other parameters according to its coefficient value in the welding of MIG.

V. CONFIRMATION TEST

The confirmation test is the last step in the experiment. The confirmation test is shown in Table 6. The confirmation test is the final step in the design of the experiment process. Confirmation tests were conducted to validate the statistical analysis by selecting experimental conditions that are different from those employed in the analysis. The parameters used in the confirmation test are presented in Table 6.

Experimental results were compared with the computed values developed from the regression models. Table 6 shows that the experimental values and calculated values from the regression equation are nearly the same with the least error (±5%). The resulting equations are capable of predicting the surface roughness to an acceptable level of accuracy. The % of error determined with ratio of the difference of actual and predicted to actual once. As shown in Table 6, the % of error less than (±5%) which is significant.

Table 6 Confirmation Test

	T S			HS		
Exp Run	Cal.	Exp.	Error	Cal.	Exp.	Error
1	376.3	351.2	-7.16	176.2	168.5	4.38
3	316.1	315.1	-0.31	157.4	156.5	0.58
5	367.6	382.5	3.89	180.1	189.0	-4.97
6	337.5	325.6	-3.65	170.7	166.5	2.43
9	358.9	342.1	-4.90	183.9	179.5	2.39

VI. CONCLUSION

The present study on ASTM A29 using Tungsten inert gas welding process.The Welding Current has the greatest influence on Tensile and Hardness in the Weldability of ASTM A29 followed by welding voltage and wire speed. The optimal conditional for Tensile strength as the welding current (250) is a dominant parameter on the tested specimens, followed by welding voltage (20) and wire speed (2.2). The ANOVA obtained R^2 and R_{adj}^2 as 96.3 and 85.2%. The ANOVA revealed the influence of process parameters with a response. Welding current, (A) is the most influencing parameter (57.25%) and followed by the welding voltage (V) as (29.05%) and wire speed as 10%. The optimal condition of Hardness, such as the welding voltage (20 volts), welding current (215 amp), and wire speed (2.2) can be used to achieve better hardness in ASTM A29. The ANOVA of hardness at HAZ obtained R^2 and R_{adj}^2 as 99.3 and 97.2%. The ANOVA revealed the influence of process parameters with a response. Welding current, (A) is the most influencing parameter (48.14%) and followed by the welding voltage (V) as (34.78%) and wire speed as 16.12%. The regression equation developed mathematical expression for Tensile strength and hardness at HAZ of ASTM A29 welded samples Confirmation tests conducted and validate the statistical analysis, which revealed % of error less than (±5%) which is significant.

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