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Effect of Shielding Gases on Micro Hardness of FE 410 (AISI 1024) Steel Welded Joint in GMAW Process

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ABSTRACT: Gas Metal Arc Welding (GMAW) process is a leading arc welding process which has higher productivity and good in quality. Quality of welded joint of GMAW process depends on number of influences, like welding current, shielding gas, arc travel speed, welding position, joint angle etc., but the proper selection of welding parameters is also very important. In this study, the process parameters are optimized by using the Taguchi technique based on Taguchi's L_9 orthogonal array. Experiments have been conducted based on three process parameters, namely, the three shielding gases, welding current and arc travel speed and three levels of each parameters were carefully selected. Micro hardness has been predicted for the optimum welding parameters and parameters percentage of contribution in producing a better joint is calculated, by applying the effect of the signal-to-noise ratio and analysis of variance. Based on the study, shielding gas was found to be the most significant variable over the other process parameters while the welding current and arc travel speed took the second and third rank respectively.

Keywords: GMAW, welding parameters, micro hardness, Taguchi method, SN ratio.

I. INTRODUCTION

The gas metal arc (GMA) welding process is a welding process that yields coalescence of metals by heating with a welding arc between continuous filler metal (consumable) electrode and the work piece. Molten weld pool and electrode wire are protected from contaminants in the atmosphere by a shielding gas obtained from various combinations (Kim *et al.*, 2003). The quality, efficiency and overall operating acceptance of the welding operation are strongly dependent on the shielding gas, since it dominates the mode of metal transfer. The shielding gas not only affects the properties of the weld but also determines the shape and penetration pattern as well. The shielding gas also affects the residual contents of hydrogen, nitrogen and oxygen dissolved in the weld metal (Liao *et al*., 2007). Various techniques such as gas, slag, gas and slag, vacuum and self-protection can be used to protect the weld pool during the fusion welding. Obviously, different protection techniques provide different degrees of weld pool protection (Kacar *et al.,* 2005). The composition of a shielding mixture in arc welding depends mostly on the kind of material to be welded. The selection of the shielding gas should, by all means, take into account chemical–metallurgical processes between the gases and the molten pool that occur during welding (Ates *et al.,* 2007). The neural networks can be used as an alternative way for calculating the gas mixture according to the presented conventional calculation method. Gas mixtures (Ar, O_2 and CO_2) were used in the input layer and, tensile strength, impact strength and elongation of the weld metal hardness were used in the output layer (Karadeniz *et al.,* 2007). From the previous study with an MIG or GMAW process, it observed that the depth of penetration increased when the welding current is increased but decreased with decrease in voltage and the penetration increased when arc travel rate decreased until it attained a minimum value depends on the arc power (Ibrahim *et al*., 2012).The experimental results showed that activating flux aided GMAW increased the weld area and penetration and tended to reduce the angular distortion of the weldment. The $MgCO_3$ flux produced the most noticeable effect. Furthermore, the welded joint presented better tensile strength and hardness (Huang *et al.,* 2005). The development of shielding gases for welding applications has been of increasing interest for two main reasons: to improve the productivity and the operating characteristics of the process and to reduce the healthy and safety problems due to fume and particle emissions. The author outlines some of the most important features of seven shielding gas mixtures used and gives information about the influence of these mixtures on the process characteristics, namely on the metal transfer modes and fume emissions (Pires *et al.,* 2007). Gas metal arc welding of high strength low alloy (HSLA) steel with solid- and flux-cored arc welding wires using different shielding gas compositions was performed. The composition of filler wire and shielding gas in gas metal arc welds of HSLA steel determines the inclusion characteristics, microstructure and mechanical properties.

Thus, acceptable weld metal properties in HSLA steel using gas metal arc welding (GMAW) process could be achieved with the proper combination of filler wire and shielding gas composition (Mukhopadhyay *et al.*, 2006). The effects of different parameters on welding penetration, microstructural and hardness measurement in mild steel that having the 6mm thickness of base metal by using the robotic gas metal arc welding are investigated. The variables that choose in this study are arc voltage, welding current and welding speed. Increasing the parameters value of welding current increased the value of depth of penetration (Ebrahimnia *et al*., 2009).

After going through the literature, it was decided to investigate the effects of different welding parameters on micro hardness of FE 410 (AISI 1024) steel welded joint in GMAW process. The process parameters are optimized by using the Taguchi technique based on Taguchi's L_9 orthogonal array. Experiments have been conducted based on three process parameters, namely, the three shielding gases, welding current and arc travel speed and three levels of each parameters were carefully selected.

II. MATERIALS AND METHOD

A. Materials

Due to high industry importance and wider level applications, FE 410 (AISI 1024) HR steel having thickness 8mm and ER 70S-6 (filler material) were selected in this research.

Table 1. Chemical compositions of FE 410 (AISI 1024).

Designat-ion	Chemical Composition, max wt%				
	%C	%Mn	%P	%S	%Fe
AISI 1024	0.2	1.3	0.045	0.045	Balance

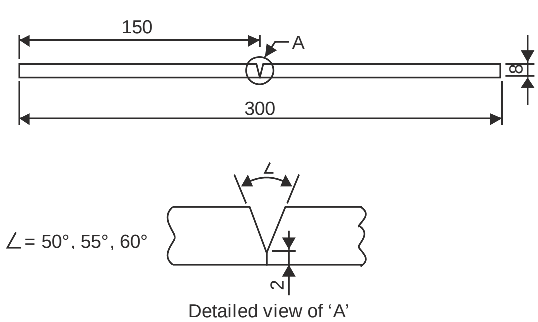

Fig. 1. Preparation of Single 'V' Groove.

The chemical composition of base material and filler material is shown in table 1 and table 2 respectively. Here, for reducing the possibility of defects formation in the weld metal, the rusts and other combinations were removed from plate and after that these parts were prepared for providing a single 'V' groove butt joint with 60^o groove angle as shown in Fig. 1.

Table 2. Chemical compositions of ER 70S-6.

Designa t-ion	Chemical Composition, max wt%				
	%C	**%Mn**	**%Si**	**%P**	**%S**
ER 70S-6	0.06-0.15	1.40-1.85	0.80-1.15	0.025 max	0.035 max
	%Ni	**%Cr**	**Mo**	**V**	**Cu**
	0.15 max	0.15 Max	0.15 max	0.03 max	0.5 max

B. Taguchi Method

The Taguchi method is very effective, because it is simple to carry on the experimental design and its approach is very systematic to provide good quality and low cost in manufacturing (Demirci *et al.*, 2011). The main aim of the Taguchi method is to analyze the statistical data, which has been given as an input function to produce an optimum result. The effect of the combination of the input functions as a result is produced by the S/N ratio and mean response (Wu *et al.*, 2002).

The micro hardness of the weld is varied by the parameters such as the welding current, shielding gases and an arc travel speed. The input parameters are entered in the array table with the output characteristics as the average micro hardness.

MINITAB Release 15 is the software that gives the statistical analysis of how to form a combination of input parameters and to find out the most significant combination. Process parameters are control factors, and the factors which initiate variability in the process are the noise factors. In a Taguchi designed experiment, the noise factors are manipulated for the variability to occur and from the results optimal control factors that make the process robust, can be identified.

The Signal to Noise ratio (S/N) indicates the control factors settings that minimize the effects of the noise factors. The Taguchi experiments are carried out in a two step optimization process.

Step 1: Use the S/N ratio to identify those control factors that reduce variability.

Step 2: Identify the control factors that bring the mean to target and have little or no effect on the S/N ratio.

Usually, the calculation of the main effect of the S/N ratio and mean response is done by three categories of quality characteristics, as listed below.

(i) The smaller the better: The Smaller the better criterion is applied to the problems, when a minimization of the response is required for the output characteristics data; (i.e.) if the output result needs to be the minimum in value and the data are non-negative with a target value of zero.

Here, in this optimization, maximum toughness is required and hence the "larger the better" criterion is applied.

S/N ratio (η) = -10 log10 ((1/n) Σ $(Y_{ij})^2$) ...(1)

where *n* is the number of replications, Y_{ij} is the observed response value.

i = 1, 2, 3….n; j = 1, 2, 3…k

(ii) The Larger the better: The Larger the better criterion is applied to the problems, when the maximization of the response is required for the output characteristics data. The data of the target value is positive. Here the optimized result needed is higher toughness, and hence this criterion is selected to find out the optimum process parameter, which can give high toughness. The following formula is used to find the optimum result,

$$S/N \text{ ratio } (\eta) = -10 \log_{10} ((1/n) \Sigma (1/ (Y_{ij})^2)) \quad ...(2)$$

(The value of the response table for the mean and S/N ratio given by the MINITAB software is verified, using this equation manually)

(iii) The Nominal the best: The Nominal the best criterion is applied to target the response, and base the S/N ratio on the mean and standard deviations. The data are non-negative with an absolute zero, in which the standard deviation is zero when the mean is zero.

$$S/N \text{ ratio } (\eta) = -10 \log_{10} (\mu^2/\sigma^2) \quad ...(3)$$

Where, $\mu = (Y_1+Y_2+Y_3+.......+Y_1) / n$,

$\sigma = ((Y_i-Y)^2 / (n-1))$

The Taguchi method has been implemented using MINITAB software, which includes the S/N ratio and ANOVA. Through ANOVA the contribution of the individual parameter in making better welds can be identified. The response for the signal to noise ratio gives the most influencing parameter. Through the mean plots of the S/N ratio and mean response, the optimum parameter has been identified (Pradeep *et al.*, 2013).

C. Experimental Method

According to the L_9 orthogonal array, there are 9 trial conditions. The three factors used in this experiment are the shielding gases, welding current and arc travel speed. Three levels were selected as low, medium and high for both of the parameters except shielding gases which are given in the table 3 and level of these parameters were taken on the basis of literature, industrial practice and trial welding using the GMAW process on the same steel. The experiment's notation is also included in the L_9 orthogonal array which results in an additional column in order to represent the parameters as presented in Table 4.

Table 3: Selected GMAW variables and their levels.

Variables	Level 1	Level 2	Level 3
Welding Current (Amp)	140	160	180
Arc Travel Speed (cm/min)	20	25	26
Shielding Gas	CO_2	Ar + CO_2	Ar + O_2

Table 4: Experimental layout using the L_9.

Experiment Number	Process variables used		
	Shielding gas used	**Welding current**	**Arc travel speed**
1	CO_2	175	22
2	CO_2	190	24
3	CO_2	205	26
4	Ar+CO_2	175	24
5	Ar+CO_2	190	26
6	Ar+CO_2	205	22
7	Ar+O_2	175	26
8	Ar+O_2	190	22
9	Ar+O_2	205	24

As with other arc welding procedures, a good GMAW welding procedure starts with the correct edge preparation and joint fit-up. The joint surfaces must be free from rust, scale, grease, oil, paint and other foreign materials. For making good weldment, it is necessary to tack weld the sample. The welding equipment must be assembled and welding parameters set according to the data given in the table for a specific sample. All gas and other connections must be absolutely leak-proof. If the shielding gas gets contaminated with air or water, the arc becomes erratic and pores appear on the weld.

The gun nozzle size and the shielding gas flow rate must be correctly set according to the material being welded and joint design. The experiments were performed on a GMAW machine with CV characteristics as per experimental layout of L_9 orthogonal array (Table 4) and after completion of welding the reinforcement from all the plates were flushed out using a portable grinding machine and all the specimens after reinforcement grinding is shown in the fig 2.Micro hardness measurements were taken with a load of 200 gram for 20 seconds at fusion zone on one side of the weld metal.

The distance between two successive readings was made 1mm. Three readings were taken for the fusion zone at a successive distance of 1mm. This measurement procedure was carried out for all the samples numbered from sample 1 to sample 9. The average of the three readings were calculated and recorded in the appropriate column of the table.

III. RESULTS AND DISCUSSION

After conducting the experimentation according to the orthogonal array L_9 with input parameters namely shielding gases, welding current and arc travel speed resulted 9 trial conditions. All the experiments were carried out at random order. The output parameters was micro hardness and all the testing specimens were prepared according to the ASTM standards and tested according to the standard procedure of ASTM. In order to evaluate the influence of each selected factor on the responses, the S/N ratios for each control factor has calculated.

In this study, the S/N ratio was selected according to the criterion the bigger-the better, in order to maximize the responses. The S/N ratio for ‘‘bigger is better’’ target for all the responses were calculated.

Fig. 2. Sample No. 1-9 after reinforcement grinding.

After completion of welding, reinforcement was grinded with a portable grinder and is shown in Fig. 2.

Table 5: Observation with S/N ratio for micro hardness.

Trial Number	Output (Micro Hardness)				S/N ratio
	R 1	R 2	R 3	Mean	
1	363	362	361	362	51.1742
2	372	366	363	367	51.2933
3	363	360	360	361	51.1501
4	364	361	358	361	51.1501
5	407	404	401	404	52.1276
6	418	415	412	415	52.3610
7	332	331	327	330	50.3703
8	357	358	353	356	51.0290
9	338	336	331	335	50.5009

According to Taguchi design of experiment for above three factors, each at three levels, an orthogonal array of L_9 was used to do experimentation. The three factors used in this experiment are the shielding gases, welding current medium and high for both of the parameters except shielding gases and these parameters were taken on the basis of literature, industrial practice and trials.

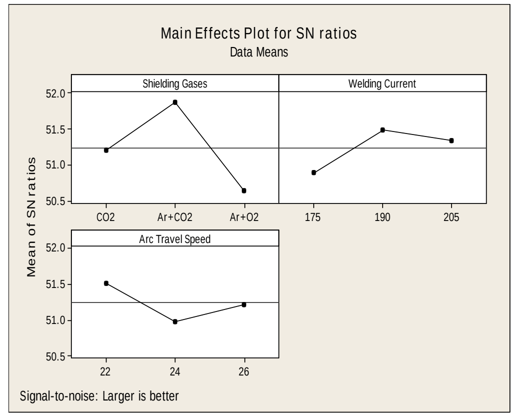

Fig. 3. Main Effects Plot for SN ratios.

The value of micro hardness depends on the three process parameters namely shielding gases, welding current and arc travel speed. Before taking micro hardness reading from specimens, it is necessary to ground flat on both of the side of the specimens. Flattening of the surface from both side of the specimens were produced by surface grinder. The weld zone lies at the centre on all of the specimens.

To find S/N ratio, three readings of hardness of fusion zone of the welded joint were evaluated and recorded in the appropriate column in the table 5. Then the average of three readings was calculated and recorded in the same table. The S/N ratio of the average output was calculated against each trial conditions and recorded.

A. Mean and Signal to Noise ratio

The Mean and signal to noise ratio are the two effects which influence the response of the factors. The influencing level of each selected welding parameter can be identified.

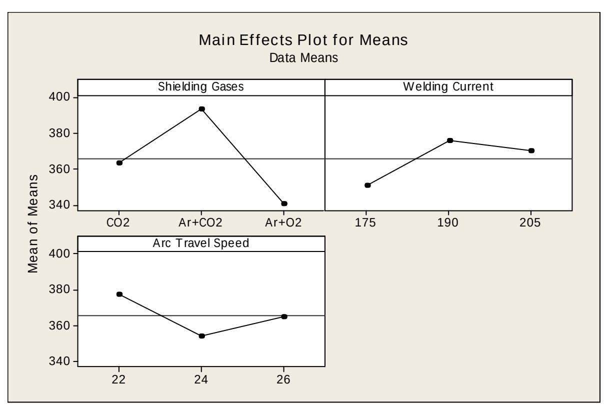

Fig. 4. Main effects plot for Means.

The micro hardness of the fusion zone was taken as the output characteristic. The table 6 response table for the Signal to Noise ratio shows that the shielding gas ranks first in the contribution of high hardness of the fusion zone while welding current and arc travel speed take the second and third ranks respectively. The same trend has been observed in the response table of the mean which is presented in Table 7. The responses for the plot of the S/N ratio and mean are shown in Fig. 3 and Fig. 4 respectively. The micro hardness was high for Ar+CO_2 shielding gas blend, at 190 amp current and at 22 cm/min arc travel speed; which was optimal from the plots obtained.
The cooling rate is the direct function of the of heat input.

Table 6: S/N ratios response table for micro hardness.

Level	Shielding Gases	Welding Current	Arc Travel Speed
1	51.21	50.90	51.52
2	51.88	51.48	50.98
3	50.63	51.34	51.22
Delta	1.25	0.59	0.54
Rank	1	2	3

When the welding operation is performed at high current and slow travel speed, temperature of the arc plasma in the arc will be higher, so the heat in the weld pool increases and it increases the micro hardness due to fine grain structure.
The Ar+CO_2 gas has lower potential of oxidation compared to the CO_2 and Ar + O_2 for inclusion, thereby more amount of pearlite phase is formed and giving high value of micro hardness.

Table 7: Response table for Means for micro hardness.

Level	Shielding Gases	Welding Current	Arc Travel
1	363.3	351.0	377.7
2	393.3	375.7	354.3
3	340.3	370.3	365.0
Delta	53.0	24.7	23.3
Rank	1	2	3

B. Analysis of variance
ANOVA was done on MINITAB 15 software. The main aim of the analysis is to estimate the percentage of the individual contribution of the welding parameter on the micro hardness of the fusion zone of the weld. Individual optimal values for the process parameters and their specified performance characteristics can be obtained.

Table 8: Analysis of variance for SN ratios (ANOVA) for micro hardness.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage Contribution
Shielding Gases	2	2.33459	2.33459	1.16730	27.77	0.035	68.36%
Welding Current	2	0.55651	0.55651	0.27826	6.62	0.131	16.30%
Arc Travel Speed	2	0.43978	0.43978	0.21989	5.23	0.161	12.88%
Residual Error	2	0.08408	0.08408	0.04204			
Total	8	3.41497					

The relative importance of the welding parameters is presented in the table 8. The abbreviation used in the table are DF-Degree of Freedom, Seq SS- Sequential Sum of Squares, Adj SS- Adjusted Sum of Squares, Adj MS– Adjusted Mean Square, F test of hypothesis and P value of hypothesis. The analysis of variance for micro hardness shows that shielding gas is the most influential parameter with a percentage of 68.36 %, followed by the welding current of 16.30 %n and arc travel speed of 12.88 %.

The optimum parameter obtained can be due to the following possibilities; either the combination of the process parameters as prescribed may be present in the experimental combination or may not be present in the combination. The optimum parameter for the high micro hardness obtained by the Taguchi method is presented in the table 9. The combination of the process parameters of Ar+CO_2 shielding gas, 190 Amp welding current and 22 cm/min arc travel speed has been predicted.

Table 9: Optimized result obtained from ANOVA.

	Shielding gas	Welding current Amp	Arc travel speed cm/min	Micro hardness HV
Factors	Ar+CO_2	190	22	432

The micro hardness value obtained from the optimized study is verified by conducting experiments using the optimal combination of the process parameters. Three experiments were conducted with the optimum combination and the average micro hardness of the fusion zone of the weld obtained with these process parameters was found 432. The average value micro hardness of the base metal was found 232 HV. Therefore the optimized weld has given better hardness value. Shielding gas has shown a greatest effect on the micro hardness of the fusion zone compared to welding current and arc travel speed. The value of micro hardness depends on the amount of pearlite phase present in the microstructure. The shielding gas $Ar+CO_2$ has provided minimum amount of inclusion which promotes a base for pearlite and thereby more amount of pearlite phase was formed which gave high value of hardness. The welding current and arc travel speed has an influence on micro hardness but not as much as of shielding gases.

IV. CONCLUSION

1. The optimum parameter for the high micro hardness obtained through the Taguchi is the combination of process parameters of $Ar+CO_2$ shielding gas, 190 Amp welding current and 22cm/min arc travel speed.
2. Maximum hardness, in terms of optimum value of 432 HV is achieved.
3. Shielding gas ($Ar+CO_2$) was most significant with 68.36% contribution, followed by the welding current of 16.30% and arc travel speed of 12.88%.

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