PARAMETRIC OPTIMIZATION OF SUBMERGED ARC WELDING OF DISSIMILAR MILD STEEL AND FERRITIC STAINLESS STEELS USING TAGUCHI METHOD

Ramesh Rudrapati[1], Ranjeet Kumar[2], Pradip Kumar Pal[3], Goutam Nandi[4]
[1]Associate Professor, Mechanical Engineering Department,
G.H. Raisoni College of Engineering & Management, Pune
[2]M.E Student, [3]Professor, [2 3] Mechanical Engineering Department, Jadavpur University, Kolkata
Email:rameshrudrapati@gmail.com[1], ranjeetkumar08sharma@gmail.com[2],
pradippal54@yahoo.com[3], gnandi87@gmail.com[4]

Abstract

The present study is planned to study the significance of welding input parameters on quality of welded joint in submerged arc welding of dissimilar mild and stainless steel materials. Input parameters are current, traverse speed and stick-out; output responses are hardness at weld zone, heat affected zone at mild steel plate side (HAZ at MS) and heat affected zone at stainless steel plate side (HAZ at SS). L_9 orthogonal array of Taguchi method has been constructed to conduct experiments. Output responses have been measured and analyzed by analysis of signal-to-noise ratio to determine the influential factors. The main effect plots of the process parameters have been presented in graphical form that helps in selecting quickly the optimal parametric setting to achieve the desired results. Confirmation analysis has also been done to check the validity of optimum condition.

Index terms: Submerged arc welding, Dissimilar welding, Hardness at weld zone, Heat affected zone, Taguchi method

I. INTRODUCTION

Welding is one of the most popular methods of metal joining processes. The joining of the materials i.e. similar or dissimilar by welding provides a permanent joint of the components [1]. In the present trend, dissimilar welded metal joints are widely using for different applications in many industrial applications to make use of both the materials [2]. The usages of dissimilar metal joints are increasing because of technical and economical reasons [3]: a) provides flexible design of product with the use of properties of the both the materials b) can be used specific properties of the materials economically in functional way. Currently, it is no doubt that steel is a widely used material almost everywhere in industry [4]. However, it is a trend for industry to join dissimilar steel materials together such as stainless steel and mild steel to achieve versatile properties of one part. Stainless steel has distinctive properties which can be taken advantage of in a wide variety of industrial applications such as nuclear structural materials [5], automotive exhaust gas system, chemical industrial applications [6], automobile production [7], etc., because of their excellent mechanical properties and good cost reduction. Mild steels are one of the important materials which used in variety of industrial applications. Joining of dissimilar stainless steel to mild steel is of a great industrial significance for it allows the design engineers to take advantages of the excellent property combined with the both the materials, because manufacturer's demands welded joints with lower cost or / and reduced weight, and enhanced mechanical and thermal properties [8]. Improving the weld bead qualities of dissimilar welded joint (i.e. ferritic stainless steel with mild steel and other materials) are important area of research [9], [10], [11], [12].

Various welding techniques / operations are generally used to join the dissimilar metals / materials those are submerged arc welding, TIG, MIG~~,~~ friction welding process, laser welding etc. Among the other welding processes submerged arc welding is an extremely important welding process, which has tremendous applications in valves manufacturing [13]. Welding quality is strongly characterized by the welding process parameters [14], [15]. Due to that the weld welding factors plays an important role in determining the better mechanical properties of the welded specimen. Therefore, the selection of the optimal welding process parameters combination is very essential for obtaining desired qualities in weldments [14]. The statistical Taguchi design method is widely used to optimize process parameters [13], [16]. Many researches were conducted research investigations on submerged arc welding and other welding operations, to enhance the quality characteristics of a welded joint. The most important input submerged arc welding parameters which would control the welding quality outputs are current, traverse speed and stick-out length[15], [17]. Some of the reported articles in literature are discussed below.

Dissimilar magnesium alloy and mild steel materials had joined by laser-TIG welding in [4]. Microstructure characteristics and mechanical properties of TIG welded austenitic stainless steel and ferritic carbon steel joints had studied in [11]. The thermo-mechanical model was utilized in dissimilar TIG welds of low carbon and ferritic stainless steels to investigate the effects of welding parameters on the distribution of residual stresses [12]. In reference [14] the influence of process parameters and their interactions on joint tensile strength, toughness, fusion zone micro-hardness variation had studied in dissimilar tungsten inert gas welding between austenitic stainless steel AISI 316 and alloy steel AISI 4340 materials. In Reference [15] experimental analysis conducted to optimize submerged arc welding to optimize bead geometry of mild steel welded joints. Dissimilar austenitic stainless-steel with ferritic low carbon steel joint had investigated by using Taguchi approach in laser welding operation [16]. The effects of process parameters on tensile strength of friction welded AISI 1040 grade medium carbon steel and AISI 304 austenitic stainless steel had studied in [18].

In this paper, the ferritic stainless steel (FSS) and mild steel (MS) dissimilar materials have been welded together by tungsten inert welding. The hardness at weld zone and heat affected zone (HAZ) at MS plate side and FSS plate side have been observed and analyzed by means of statistical Taguchi method. The present study is one step towards the study and improves the quality characteristics of FSS/MS submerged arc welded joint, and open a new way to apply FSS/MS dissimilar materials.

II. TAGUCHI METHODOLOGY

Taguchi's philosophy is an efficient tool for determination of optimal values for the different factors involved manufacturing systems or processes. Dr. Genichi Taguchi had conceived and developed a methodology based on orthogonal array of experiments. Taguchi experimental design is an important technique / methodology for robust design. It provides reduced variance for the experiment with optimum parametric setting with minimum number of experimental runs. In Taguchi method, only limited parametric combinations considered instead to check all possible combinations like factorial design [19]. This method allows to determination of factors which most affect product quality with a minimum number of experiments, thus saving time and resources. Orthogonal array provides a set of well-balanced experiments. Taguchi method is very much helpful to analyze the data and prediction of optimal parametric conditions for achieving desired output response. It uses statistical signal-to-noise (S/N) ratio to measure performance of the process or system(s). S/N ratio in Taguchi method uses three different objective functions i.e. larger-the-better (Equation 1) and smaller-the-better (Equation 2) and to analyze and optimize the response variable. In all the criterions (Equations 1-2), optimal level of a process parameter is the level, which results in the highest value of S/N ratio of transformation.

Larger-the-Better: S/N ratio = $-10*\log_{10}(1/n\sum^{n}_{i=1}1/y_i^2)$ (1)

Smaller-the-Better: S/N ratio = $-10*\log_{10}(1/n\sum^{n}_{i=1}y_i^2)$ (2)

where 'n' is the number of replications, "y" is the observed data, 'S' is signal, 'N' is noise, 'μ' is mean, 'd' is standard deviation.

III. EXPERIMENTATION

The main aim of the present investigation is to analyze and optimize the significance of input parameters on output responses: hardness at weld zone, heat affected zone at mild steel (MS) plate side and heat affected zone at ferritic stainless steel (FSS) plate side in submerged arc welding of dissimilar MS and FSS materials. Welding set-up has been prepared, tested and made ready for conducting welding experiments. Thickness of each sample is 8 mm; dimensions of both the materials are: 50 mm x 50 mm x 8 mm. Welding current, traverse speed and stick-out is selected as input parameters. Selected input parameters and their levels are given in Table 1. Welding experiments have been conducted using submerged arc welding machine as per L_9 orthogonal array of experiments of Taguchi method. L_9 orthogonal array design matrix is shown in Table 2. The photographic view of the submerged arc welding is shown in Fig.1. Butt joints are made by welding two pieces; one of AISI 409 ferritic stainless steel and another of AISI 1018 mild steel. Nine welded samples are made, by carrying out welding at different levels of current, traverse speed and stick-out length, as per Taguchi's orthogonal array design of experiments, given in Table 2. Photographic view of a welded specimen (sample number 2) is shown in Fig 2.

Table 1 Process parameters and their levels

Process parameters	Unit	Level 1	Level 2	Level 3
Current	A	250	300	350
Traverse speed	mm/s	37.5	50.0	62.5
Stick-out length	mm	15	20	25

Fig.1 Photographic view of the SAW machine

IV. RESULTS AND ANALYSIS

Experimental runs have been done and butt joints have been made under varied conditions as per L_9 orthogonal array of Taguchi method on submerged arc welding machine. After Welding experiments, output responses hardness at weld zone, heat affected zone at mild steel (MS) plate side and heat affected zone at ferritic stainless steel (FSS) plate side have been measured and tabulated in Table 2. Statistical tool analysis of signal-to-noise ratio has been applied on experimental data study the factor effects on responses. The process parameters have been optimized by Taguchi methodology. Optimization of input parameters helps welding economics in addition to achieving the desire d results [20].

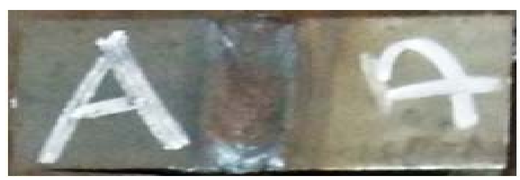

Fig. 2 photographic views of welded sample

A. Analysis of signal-to-noise ratio

Statistical analysis of signal-to-noise ratio technique from MINITAB 16.1 software is applied on experimental data as given in Table 2 to determine the significant welding parameters which have significant effect on output responses i.e. hardness at weld zone, heat affected zone at MS plate side and heat affected zone at FSS plate side.

ANOVA test is performed at 95% confidence level i.e. 5% significance level, details are given in Tables 3-5 for hardness at weld zone, heat affected zone at MS plate side and heat affected zone at FSS plate side respectively.

Table 2 L_9 OA design table and output response

S. No	Current	Traverse Speed	Stick-out leng	Hardness at weld	HAZ at MS plate	HAZ at FSS plate
1	250	37.5	15	339.2	742.	762.
2	250	50	20	366.7	730.	678.
3	250	62.5	25	348.5	624.	744.
4	300	37.5	20	334.4	728.	713.
5	300	50	25	342.3	720.	742.
6	300	62.5	15	305.3	718.	679.
7	350	37.5	25	336.7	612.	567.
8	350	50	15	337.4	617.	560.
9	350	62.5	20	338.1	613.	526.

The correlation coefficient R-square value for the experimental results, are obtained as 0.979 (97.9%) for hardness at weld zone and 0.923 (92.3%) for heat affected zone at MS plate side, 0.976(97.6%) for heat affected zone at FSS plate sideas shown in Tables 3-5, respectively. These indicate good correlation. Significant input parameters can be identified by using P value in the ANOVA table; if P value is less than 0.05 then the corresponding parameters would be treated as significant on the respective response.

ANOVA tables (Tables 3 and 5) of hardness at weld zone, heat affected zone at MS plate side and heat affected zone at FSS plate side depicts that direct effect of welding current is significant on hardness at weld zone and heat affected zone at FSS plate side as their P values are 0.047 and 0.025 respectively. And individual effects of traverse seed and stick-out (C) do not have significant effect as its P values are more than 0.05. Welding parameters traverse speed (B) and stick-out (C) have considerable effects on response hardness at weld zone because P values of these factors very close to 0.05 as found from the Table 3. Results of ANOVA for heat affected zone at MS plate side (Table 4) show that effects of welding factors are not prominent at 95% confidence level as their P values are greater than 0.05.

Main effect plots showing the individual effects of input parameters on output responses: hardness at weld zone, heat affected zone at MS plate side and heat affected zone at FSS plate side drawn and shown in Figs. 3-5 respectively by using MINITAB 16.1 software.

The main effect plots as given in Figs. 3-5 are drawn at mean values of signal-to-noise ratios for respective responses. Main effect plots for hardness at weld zone (Fig. 3) is drawn based on larger the better criterion (i.e. Eq. 1) as larger value desirable. And main effect plots of heat affected zone at MS plate side (Fig. 4) and heat affected zone at FSS plate side (Fig. 5) are made based on smaller the criterion (i.e. Eq. 3) because smaller value desirable.

Table 3 ANOVA for hardness at weld zone

Source	DF	Seq SS	Adj MS	F	P
A	2	0.58662	0.2933	20.39	0.047
B	2	0.34295	0.1714	11.92	0.077
C	2	0.41656	0.2082	14.48	0.065
Residual Error	2	0.02877	0.0143		
Total	8	1.37491	R-Sq = 97.9%;		

Table 4 ANOVA for HAZ at mild steel plate side

Source	DF	Seq SS	Adj MS	F	P
A	2	3.2450	1.6225	9.04	0.100
B	2	0.5244	0.2622	1.46	0.406
C	2	0.5114	0.2557	1.42	0.413
Residual Error	2	0.3591	0.1796		
Total	8	4.6399	R-Sq = 92.3%;		

Individual effects of factors on responses can also be depicted from these main effects plots. If inclination line between the factors levels for each factor is more and then corresponding factors would be treated as significant. From the Fig. 3, it is found that welding current (A) is more significant on hardness at weld zone, next is stick-out (C) and followed by traverse speed (B). Main effect plots of heat affected zone at MS plate side (Fig. 4) depicts that Welding current has more effect on heat affected zone at mild steel plate side, next is traverse speed (B).

Parameter stick-out (C) has lesser effect on heat affected zone at mild steel plate side as found from Fig. 4. Fig. 5 for heat affected zone at FSS plate side show that welding current (A) is more significant, next is stick-out (C) and followed by traverse speed (B).

From the main effect plots, optimal parametric condition(s) for better output response characteristics can found at highest S/N ratio value for each factor for both the conditions i.e. larger the better criterion and smaller the better criterion. From the Fig. 3, it is found that parametric condition: current (A) = 250 A, traverse speed (B) = 50 mm/s, stick-out (C) = 20 mm is optimum for maximizing the hardness at weld zone. The optimal welding parameter combination for heat affected zone at MS plate side found from Fig. 4 is: current (A) = 350 A, traverse speed (B) = 62.5 mm/s, stick-out (C) = 25 mm. Fig. 5 depicts the optimum parametric combination for minimizing the heat affected zone at FSS plate side is: current (A) = 350 A, traverse speed (B) = 62.5 mm/s, stick-out (C) = 20 mm.

V. CONFIRMATORY TEST

Confirmatory experiments are conducted for validate the optimum conditions obtained by Taguchi method for each response characteristic. Improved response values are identified in confirmatory test as compared initial experiments (Table 2), it is thus found that Taguchi method is effective to optimize submerged arc welding of dissimilar mild steel and ferritic stainless steels.

Table 5 ANOVA for HAZ at FSS plate side

Source	DF	Seq SS	Adj MS	F	P
A	2	10.7921	5.3961	38.34	0.025
B	2	0.2752	0.1376	0.98	0.506
C	2	0.5490	0.2745	1.95	0.339
Residual Error	2	0.2815	0.1407		
Total	8	11.8977	R-Sq = 97.6%		

VI. CONCLUSIONS

The following conclusions are drawn from the present analysis as follows:

1. Results of analysis of variance for hardness at weld zone and heat affected zone at ferritic stainless steel plate side shows that welding current is significant for both the responses and other two parameters: traverse speed and stick-out is insignificant at 95% confidence interval.
2. ANOVA results of heat affected zone at mild steel plate side shows that welding parameters do not have significant effect.
3. Optimal parametric conditions for each response separately are obtained by main effect plots made by Taguchi method.
4. Confirmatory test validates the optimization technique used in the present study.

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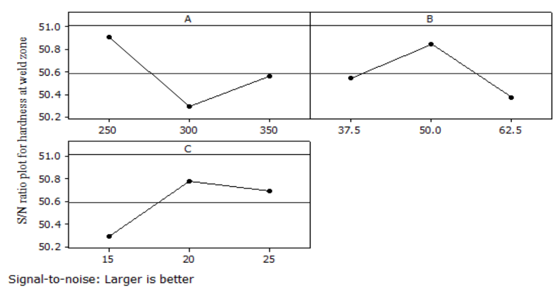

Fig. 3 Main effect plots for hardness at weld zone

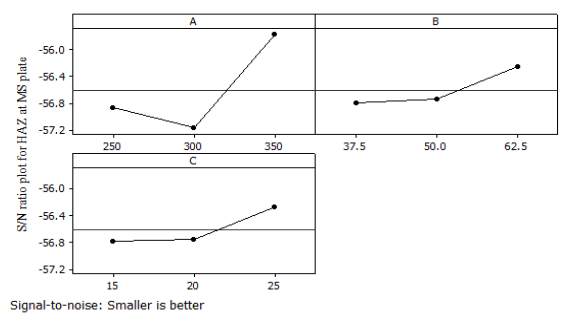

Fig. 4 Main effect plots for HAZ at MS plate side

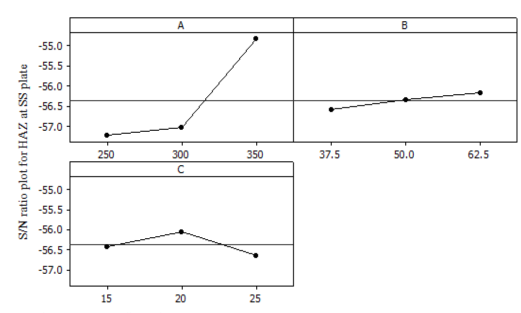

Fig. 5 Main effect plots for HAZ at FSS plate side