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RESEARCH ARTICLE

PARAMETRIC OPTIMIZATION OF MIG WELDING FOR STAINLESS STEEL (SS-304) AND LOW CARBON STEEL USING TAGUCHI DESIGN METHOD

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ABSTRACT

Scope of arc-welding, have increased in the various engineering field like aerospace, nuclear, and underwater industries where complex geometry and hazardous environments necessitate fully automated systems. Even traditional applications of arc welding such as off-highway and automotive manufacturing have increased their demand in quality, cost, accuracy, and volume to stay competitive. As a result, process parameters are needed to improve the existing process of welding. Metal inert gas (MIG) welding process has successfully used for joining similar and dissimilar metals. In this study dissimilar metals, stainless steel (SS-304) and low carbon steel plates are joined by MIG welding successfully. Three parameters of MIG welding viz. current, voltage and travel speed are taken for the analysis. A plan of experiments based on Taguchi technique has been used to acquire the data. The analysis for signal-to-noise ratio was done using MINITAB-13 software for higher-the-better quality characteristics. The significance of each parameter was studied by using the ANOVA (Analysis of variance). Finally the confirmation tests were performed to compare the predicted values with the experimental values which confirm its effectiveness in the analysis of tensile strength of the joint.

INTRODUCTION

The joining of dissimilar metals is generally more challenging than that of similar metals because of difference in the physical, mechanical and metallurgical properties of the parent metals to be joined. In order to take full advantage of the properties of different metals it is necessary to produce high quality joint between them. In this way the designer canuse most suitable material for each part of a given structure.

Dissimilar metal joining offers the potential to utilize the advantages of different materials often providing unique solutions to engineering requirements Taban (2009). The main purpose of dissimilar metal joining are to gain good mechanical properties of one material and either low specific weight or good corrosion resistance or good electrical properties of second material. In recent years the joining processes for dissimilar materials have received considerable attention in many fields. Much of this activity has focused on the transportation industries such as aerospace, aviation, shipbuilding, railway transportation. Although problems involving dissimilar welding are rare, they do exist and some of them are documented, ranging from residual stress problems Joseph *et al.* (2005) to corrosions Pimenta and Jarman (2010). In more specific manner, welding austenitic stainless steels to carbon and low alloy steels are widely practiced in the process and construction industries. Austenitic stainless steel is a high alloy steel. These alloying elements increase its thermal resistance, corrosion resistance and strength, therefore this type of steel is much recommended. Low carbon steels are those which contain carbon less than 0.15% and easily joined by welding. Some industries use these steels for lining process (low carbon steel with stainless steel) especially in pressure vassals industry and metal inert gas welding (MIG) is used extensively for these processes Khuder*et al.*(2011).

LITERATURE REVIEW

The dissimilar metals AISI stainless steel 304L and pure copper plates were joined by Kamal kumarkanaujia [5]. Statistical design of experiment (DOE) was used by him to optimize the Laser beam welding parameters such as laser power, welding speed and pulse duration. Taguchi orthogonal array was used to design the experiment at each factor having four levels.Universal testing machine (UTM) was used to determine the joint strength. Analyses of variance (ANOVA) and the signal-to-noise (S/N) ratio are used to analyze the results for the optimal parameters, and then compared with the base material. Finally the response predicted by fuzzy logic experimentand conclusion has been made that the laser-welded joints are improved successfully by optimizing the input parameters using the Taguchi fuzzy approach, the effect of the focusing position on the response also determined.

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An effect and optimization of welding parameters on the tensile shear strength in the resistance spot welding (RSW) process is investigated by UğurEşme's [6]. The experiment studies were conducted under varyingwelding currents, electrode forces, electrode diameters, and welding times. Taguchi experimental design method was used to settings the welding parameters. Analysis of variance (ANOVA) was used to determine the level of significance of the welding parameters on the tensile shear strength.

The result shows that the analysis of signal-to-noise (S/N) ratio was used to obtain the optimum welding parameters combination. The confirmation tests indicated that Taguchi method is well suitable to increase the tensile shear strength significantly. Finally the experimental results confirmed that Taguchi method is quite valid for optimizing the welding parameters and enhancing the welding performance of the resistance spot welding process.

A. S. Vagh and S. N. Pandya[7]studied the effect of Friction Stir Welding process parameters on the mechanical properties of the AA 2014-T6 alloy joints produced by friction stir welding have been discussed. Effects of tool design, tool rotation speed & tool travels speed on mechanical properties have been analyzed using Taguchi orthogonal array design of experiments technique. The study indicates that Tool design is the main process parameter that has the highest statistical influence on mechanical properties. However, otherparameters such as Tool rotation speed & Tool travel speed has also significant effect on mechanical properties.

S.C. Juang and Y.S. Tarng [8] use Taguchi method to analyze the weld pool geometry in the Tungsten inert gas (TIG) welding of stainless steel. The input parameters were selected are front height, back height, front width, and back width. The modified Taguchi method is adopted tosolve the optimal weld pool geometry with four smaller-the-betterquality characteristics. Experimental results haveshown that the quality characteristics i.e. front height; front width, back height andback width of the weld pool in the TIG welding of stainlesssteel are greatly improved by using this approach.

Taguchi Method

Taguchi design of experiment is one of these techniques which are used widely. The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan who maintained that variation. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning.
The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies.

An orthogonal array is a method of designing experiment that usually requires only a fraction of the full factorial combinations. An orthogonal array means the design is balanced so that factor levels are weighted equally. Because of this, each factor can be evaluated independently of all the other factors, so the effect of one factor does not influence the estimation of another factor.

An L-9 orthogonal array is shown below

	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Signal To Noise Ratio

The signal to noise (S/N) ratios has obtained using Taguchi's methodology. The 'signal' is the desirable value (mean) and the 'noise' is the undesirable value (standard deviation). Thus the S/N ratio represents the amount of variation present in the performance characteristic. Depending upon the objective of the performance characteristic, there can be various types of S/N ratios.There are 3 Signal-to-Noise ratios of common interest for optimization

$$(S/N)_{HB} = -10 \log_{10} \frac{1}{n} \sum_{i=1}^{n} \frac{1}{{y_i}^2}$$

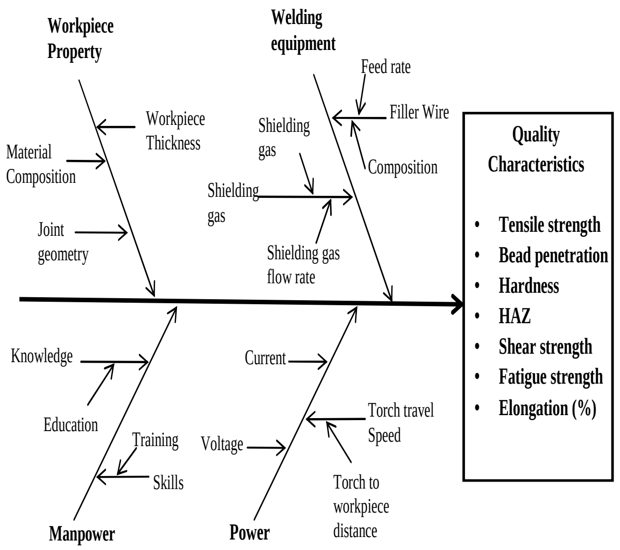
$$(S/N)_{LB} = -10 \log_{10} \frac{1}{n} \sum_{i=1}^{n} {y_i}^2$$

$$(S/N)_{NB} = -10 \log_{10} \frac{1}{n} \sum_{i=1}^{n} (y_i - m)^2$$

Experimentation and data collection

Selection of process parameters

An Ishikawa cause–effect diagram was constructed to identify process parameters which may affect the desired quality characteristics of the final job. These parameters can be listed in four categories as follows:



Ishikawa Cause – Effect Diagram for the MIG Welding Process

The process parameters and their workable range for the experiment were chosen from the hand book O.P. Khanna (1999), and the data available in different literature Anawa E.M. *et al*. (2007), Sapakal S.V. *et al.* (2012), kumar*et al.* (2011). The selected process parameters and their levels are given in the table below:

Process parameters and their values at different levels

Process parameters	Symbol	Level 1	Level 2	Level 3
Variable parameters				
Current (A)	**a**	80	100	120
Voltage (V)	**b**	16	19	22
Speed (cm/min.)	**c**	30	**40**	50
Constant parameters				
Type of workpiece	Joint of stainless steel 304& low carbon steel			
Thickness of workpiece	3 mm			
Gas flow rate	9 l/min.			

Data Analysis

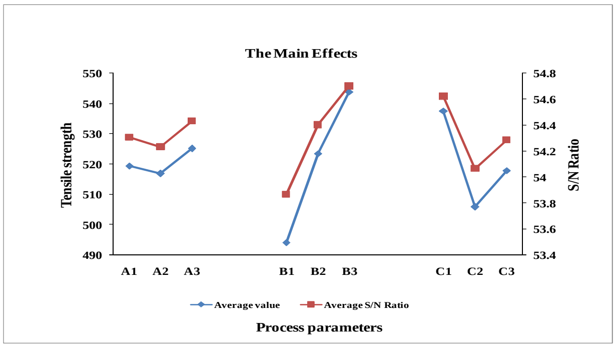
Evaluation of S/N ratios

The S/N ratios were obtained using Taguchi's methodology. Here, the 'signal' is the desirablevalue (mean) and the 'noise' is the undesirable value (standard deviation). Thus the S/N ratiorepresents the amount of variation present in the performance characteristic. Depending upon the objective of the performance characteristic, there can be various types of S/N ratios. Here the desirable objective is higher values of tensile strength. Hence the higher-the-better (HB) typeS/N ratio, as defined below, was used to transform the raw data:

$$(S/N)_{HB} = -10 \log_{10} \frac{1}{n} \sum_{i=1}^{n} \frac{1}{{y_i}^2}$$

where$y_j$is the value of the characteristic in an observation j and$R$ is the number of observationsor the number of repetitions in a trial.

average responses from the raw data help in analyzing the trend of the performance characteristic with respect to thevariation of the factor under study. The level average response plots based on the S/N datahelp in optimizing the objective function under consideration. The peak points of these plotscorrespond to the optimum condition. The main effects on the raw data and of the S/N ratio are shown in figure below.



Main Effect of Process Parameters on the Raw Data and S/N Ratio for the Tensile Strength: A current; B, voltage; C, speed

Analysis Of Variance for Ultimate Tensile Strength

ANOVA is used to estimate the percentage contribution of various process parameters to the selected performance characteristics. This gives the information about how significant the effect of each controlled parameter on the quality characteristics of interest. The total variation in the result is the sum of variation due to various controlled factors and their interactions and due to experimental error. Analysis of variance (ANOVA) for raw data and S/N data has been performed to identify the significant parameters and quantifies their effect on the performance characteristics. The ANOVA based on the raw data identifies the factors which affects the average response rather than reducing variation. However, ANOVA based on the S/N ratio takes both these aspects into account (Jadoun *et. al*. 2007).

Experimental Results for the Ultimate Tensile Strength

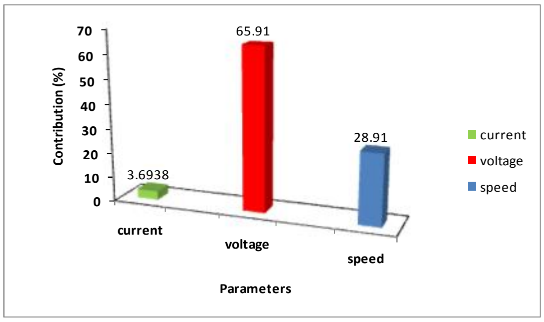
Trial no.	Ultimate tensile strength		[illegible]	S/N Ratio
	$R1$	$R2$	$\frac{R1+R2}{2}$	
1	498.33	502.13	500.23	53.9835
2	526.67	528.21	527.44	54.4435
3	531.67	529.00	530.335	54.4910
4	460.00	472.00	466.00	53.3677
5	506.67	508.33	507.50	54.1087
6	583.33	570.65	576.99	55.2234
7	516.67	515.00	515.835	54.2502
8	543.00	528.00	540.5	54.6559
9	521.67	526.33	524.00	54.3866

S/N Response Table for Ultimate Tensile Strength

Level	Current	Voltage	Speed
1	54.3060	53.8671	54.6209
2	54.2333	54.4027	54.0659
2	54.4309	54.7003	54.2833
Delta	0.1977	0.8332	0.5550
Rank	3	1	2

Main Effects Due To Parameters

The main effects can be studied by the level average response analysis of the raw data orthe S/N data. The analysis is done by averaging the raw and/or S/N data at each level ofeach parameter and plotting the values in graphical form. The level



Bar Graph Showing Percentage Contribution of Each Parameter

ANOVA (without pooling) Raw Data (Ultimate tensile strength)

Source	DOF	SS	Variance	F	P
Current	2	216.46157	108.23079	0.371998	1.486
Voltage	2	7510.149	3755.0745	12.9065	51.507 ††
Speed	2	3653.6834	1826.8417	6.279	25.058 †
Error	11	3200.3901	290.94456		21.949
Total	17	14580.684			100

SS, sum of squares;DOF, Degree of freedom;P, Percentage contribution;†Level of significance at 95% confidence level.

ANOVA (with pooling) S/N Data (Ultimate tensile strength)

Source	DOF	SS	SS'	Variance	F	P
Current	Pooled	…..….	……..	..…….	..…….	..…..
Voltage	2	1.0697294	1.0276936	0.5348647	25.448	63.32 ††
Speed	2	0.4692087	0.4271729	0.23460435	11.1621	26.319 †
Error	4	0.0241207	0.1084367	0.0210179		6.681
Total	8	1.62301				100

SS, sum of squares;DOF, Degree of freedom; P, Percentage contribution; † Significance at 95% confidence level.

The percentage contribution of each factor on performance characteristics is shown in the following figure.

Prediction of the Mean

The optimum condition for each parameter obtained through the raw data analysis and Taguchi method. ANOVA test reveals that voltage and speed significantly affect the response while current is insignificant. So the optimum value for mean is estimated from the significant parameters which are identified by the ANOVA.

The average value of response at the optimum condition is determined as:

$$\mu = \overline{T} + (\overline{B}_3 - \overline{T}) + (\overline{C}_1 - \overline{T}) = 560.923$$

The range of response around the estimated mean at 95% confidence level was found by the confidence interval analysis given in Sec. 5.7.6. Confidence interval obtained for the estimated average of a treatment condition predicted from the experiment is:

CI_2:- $544.253<\mu<577.593$

And confidence interval obtained for the estimated average of a treatment condition used in a confirmation experiment is:

CI_3:- $533.031<\mu<588.815$

Confirmation Experiment

Two confirmation experiments for performance characteristic were performed at optimum settings of the process parameters. The average value of UTS obtained at these levels of parameters is 549.85 N/mm^2, which is within the confidence interval for the predicted UTS at optimum level. The percentage error between the predicted value and the value obtained from the confirmation testis found to be 1.97%.

CONCLUSION

The aim of present work was to optimize the process parameters of MIG welding machine for the dissimilar metal joint for stainless steel (SS- 304) and low carbon steel using Taguchi design method. MIG welding is one of the best welding technique by which we can join two similar and dissimilar materials. The experiment designed by Taguchi method fulfills the desired objective.

Analysis of variance (ANOVA) helps to find out the significance level of the each parameter. The optimum value was predicted using MINITAB-13 software. Based on the investigations following conclusions are drawn.

- MIG welding process is very successful to join stainless steel (SS-304) and low carbon steel.
- Taguchi method can be used to discover the influence of process parameters (current, voltage and welding speed) on the ultimate tensile strength.
- Based on S/N ratio analysis and ANOVA, the process parameters which significantly affects the ultimate tensile strength was voltage and welding speed.
- Confirmation test carried out shows that results coming out at optimum level are under the interval range obtained at 95% confidence level.
- The percentage error between the predicted value and the value obtained from the confirmation testis found to be 1.97%.
- The effect of parameters on the ultimate tensile strength can be ranked in decreasing order as follows: voltage > speed > current.
- Argon as shielding gas has been found to work satisfactorily, very less spatter produce on the weld zone.

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