USING THE ORTHOGONAL ARRAY WITH GREY RELATIONAL ANALYSIS TO OPTIMIZE TIG WELDING OF AISI 310 AUSTENITIC STAINLESS STEELS

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ABSTRACT-The present work is planned to study some aspects of tungsten inert gas welding (TIG) of AISI 310 austenitic stainless steels. Emphasis has been given to identify the effect of welding parameters on the quality of butt-welded joints. TIG welding has been carried out as per L_9 orthogonal array of Taguchi method. After welding, ultimate tensile stress and percentage elongation have been measured. Grey based Taguchi methodology has been used to analyze and optimize the multi responses: ultimate tensile stress and percentage elongation. Statistical technique analysis of signal-to-noise ratio has been used to identify the significance of welding variables on output responses. The optimal combination of processing welding parameters for simultaneous optimization of both the responses has been obtained by Taguchi method. The confirmatory test has been conducted to validate the predicted welding results.
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Keywords-TIG welding, austenitic stainless steel, Taguchi method, Grey-relational analysis, Analysis of variance

INTRODUCTION

Stainless steel is a complex group of iron based alloys with at least 10.5% chromium and a maximum of 1.5% carbon, usually along with nickel. Selvaraj et al. [1] mentioned that applications of stainless steels have been increased enormously in variety of engineering fields. The combination of good corrosion resistance, wide range of strength levels, fair formability, aesthetically pleasing appearance have made stainless steel materials as a good choice for many industrial applications like automobile, marine, naval, etc. In many of the mentioned applications needs joining of stainless steel materials to make complex parts or desired combinations for usage of different industrial applications.

Stainless steel can be welded by most of the common arc welding processes includes flux cored arc welding, gas metal arc welding, gas tungsten arc welding, shielded metal arc welding with coated electrodes and submerged arc welding [2].TIG welding has become an important industrial process because of its advantages over the other widely used joining techniques. TIG welding is very often used to weld stainless steels. The cost of stainless steel materials are very high compared to other conventional materials like mild steel, aluminum etc., TIG welding setup requires high initial equipment cost. A typical schematic diagram of TIG welding is shown in Fig. 1. In TIG welding operation, selection process parameters plays very important role to obtain the desired weld qualities and welding performance. So, it is necessary to select the optimum welding parametric condition to improve the mechanical and surface properties of weldments and to enhance the efficiency of the welding process by minimize the rework or scrap loses due to faulty welds. In the present work, significance of welding process parameters on multi-responses: ultimate tensile stress and percentage elongation of TIG welding of AISI 310 austenitic stainless steels have been investigated by using design of experiments.

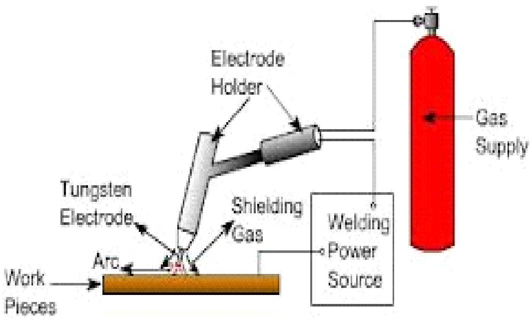

Fig. 1:A typical schematic diagram of TIG welding

Design of experiments which includes a set of techniques used to study of the significance of various factors on the outcome of a controlled experiment [3]. DOE's Taguchi methodology defines the quality of the part produced in terms of loss imparted by the product. But, Taguchi is an intelligent tool for designing, analyzing and optimizing the process / system only for single performance characteristics. Traditional Taguchi method cannotsolve the multi-objective optimization problem [4, 5]. The Grey system theory, was proposed by Deng in 1982, is mostly used to study uncertainties in system models, analyze relations between systems, establish models and make forecasts and decisions [6]. In recent years, the grey relational analysis has become a powerful tool for multi-objective problems during research and development so that multiple response characteristics can be optimized combinedly. Singh et al., [2]analyzed the shot peening process of welded AISI 304 austenitic stainless steel to optimize multi-response characteristics including tensile strength, surface hardness and surface roughness, using integrated grey relational analysis (GRA) based on Taguchi orthogonal array approach. Tamrin et al., [7]analyzed the joint characteristics weld strength, weld width and kerf width in CO_2 laser lap joining of dissimilar materials by using GRA. Researchers utilized statistical ANOVA to ascertain the relative influence of process parameters on the joint characteristics. Tarng et al.,[8]optimized multiple weld qualities in submerged arc welding (SAW) process parameters in hardfacing with the application of grey-based Taguchi methods. Datta et al., [9] presented the grey-based Taguchi methodology for searching an optimal parametric combination, capable of producing desired quality weld by considering multi-response characteristics in SAW. Nikhil et al., [10] studied and optimized the process parameters of through transmission laser welding process by grey-Taguchi method to maximize joint strength and minimize weld width of welded samples simultaneously. Acherjee et al., [11] used the applications of grey-based Taguchi method for simultaneous optimization of multiple quality characteristics in laser transmission welding process when welding of thermoplastic materials.

From the literature, it is found that reported articles on TIG welding of austenitic stainless steels are not found to be rich. Several aspects of TIG welding process needs to be explored to enhance the response characteristics of welded specimens and to develop sound knowledge base on TIG welding of austenitic stainless steels. Present work is one step forward for that. Taking into the some of the aspects into consideration the present work is planned to investigate the significances of TIG welding process variables of on multi response characteristics of austenitic stainless steel weldments by using integrated Taguchi-grey relational analysis.

TAGUCHI METHOD AND GREY RELATIONAL ANALYSIS

Taguchi's philosophy is an efficient tool for design and produce high quality manufacturing systems as well products [12]. Dr. Genichi Taguchi had developed a methodology based on orthogonal array of experiments. It provides reduced variance for the experiment with optimum parametric setting with minimum number of experiments. With integration of the Taguchi method with design of experiments, parametric optimization of the process obtained to enhance the system / process efficiency. Orthogonal array provides a set of well-balanced experiments and signal-to-noise ratio in Taguchi method are logarithmic functions of desired output serve as objective functions for process optimization [12]. 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 ratio to measure performance of process or system(s). S/N ratio in Taguchi method uses three different objective functions i.e. larger-the-better, smaller-the-better and nominal-the better to analyze and optimize the response variable. Larger-the-better objective function is given in Eq. 1; in this criterion, optimal level of a process parameter is the level, which results in the highest value of S/N ratio of transformation.

Larger-the-Better: $\frac{S}{N} ratio = -10 log10 \left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right)$(1)

where, n = number of parameters; y = output response

The Grey theory has been first developed since 1982 to construct the system uncertainty for relation analysis, modeling, forecasting, decision and control. GRA is mainly utilized in finding the major relations in the system to access the alternatives before multi-attribute decision making, and it considers simultaneously the overall relational rating regarding each alternative and also selects the most valuable degrees as the best alternative. Data pre- processing steps of GRA can be expressed as:

Step 1: In the grey relational analysis, when the range of the sequence is large or the standard value is enormous, the function of factors is neglected. However, if the factors goals and directions are different, the grey relational analysis might also produce incorrect results. Therefore, one has to preprocess the data which are related to a group of sequences, which is called "grey theory relational generation [13]".

For higher-the-better quality characteristics data preprocessing are calculated by Eq.2:

$$Xi\ (k) = \frac{Yi\ (k) - \text{Min}\, Yi\ (k)}{maxYi\ (k) - minYi(k)} \qquad (2)$$

where Xi (k) is the value after grey relational generation while min Yi (k) and max Yi (k) are respectively the smallest and largest values of Yi (k) for the k^{th} response.

Step 2: Grey relation co-efficient

By normalizing, grey relational co-efficient (GRC) is calculated by using Eq.3 which is given below

$$\xi\text{i(k)} = \frac{\Delta \min + r\Delta max}{\Delta 0ik + r\Delta max} \qquad (3)$$

where Δoi = ‖x0(k) _ xi(k)‖ = difference of the absolute value between x0(k) and xi(k) and here 'r' is distinguishing co efficient which is used to adjust the difference of the relational coefficient, usually 'r' is within the set {0, 1}. $\xi_i(k)$ is grey relation co-efficient.

Step 3: determination of the grey relational grade for each experiment combination

$$\alpha i = \sum_{k=1}^{n} \xi i(k) / n \qquad (4)$$

Where 'n' is the number of performance characteristics.

Step 4: Grey relational ordering: In relational analysis, the practical meaning of the numerical values of grey relational grades between elements is not absolutely important, while the grey relational ordering between them yields more subtle information. The combination yielding the highest grey relational grade is assigned an order of 1 while the combinationyielding the minimum grade is assigned the lowest order. The ordering of the present grey grades is shown in the last column.

EXPERIMENTATION

As already mentioned above that main aim of the present study is to analyze and optimize the input parameters of TIG welding operation when welding of austenitic stainless steel (AISI 310) material. Welding set-up has been prepared, tested and made ready for doing welding. Each workpiece has the dimension 80 mm x 40 mm x 3 mm. Experiments have been conducted using TIG welding, independently to acknowledge the effects of welding process parameters, i.e. current, gas flow rate and arc gap on ultimate tensile stress and percentage elongation of welded austenitic stainless steel specimens. Selected input parameters and their levels are given in Table 1. Orthogonal array design has been adopted for planning the experiments. L_9 orthogonal array design matrix is shown in Table 2. Butt joints are made by welding two such pieces. Nine welded samples are thus made, by carrying out welding at different levels of input parameters. Photographic view of a welded specimen (sample number 2) is shown in Fig 2.

After welding, Photographic view of a tensile test specimen is shown in Fig 3. The dimensions of each of the tensile tests specimens are given in Fig.4. Tensile test specimens are tested on Instron universal testing machine, housed at fatigue fracture damage analysis (FFDA) Laboratory, Mechanical Engineering Department, Jadavpur University and observations are made. A hydraulic jaw is used during testing for gripping the samples. Measured responses i.e. ultimate tensile strength (UTS) and percentage elongation (PE) are shown in Table 2.

Table 1 Input parameters and their levels

Process Parameters	Level I	Level II	Level III
Current (A)	90	12	2
Gas flow rate (B)	100	14	3
Arc gap (C)	110	16	4

Fig 2: Photographic view of sample number 2 after welding

Table 2. L_9 orthogonal array and output responses

S.No	Input Parameters			Output responses	
	A	B	C	UTS	PE
	90	12	2	551.40	35.38
2	90	14	3	520.11	30.21
3	90	16	4	560.68	41.06
4	10	12	3	533.30	27.87
5	10	14	4	538.03	34.20
6	10	16	2	559.83	40.10
7	11	12	4	554.35	32.55
8	11	14	2	542.85	34.14
9	11	16	3	549.12	35.44

Fig 3:Photographic view of the tensile test specimen number 9

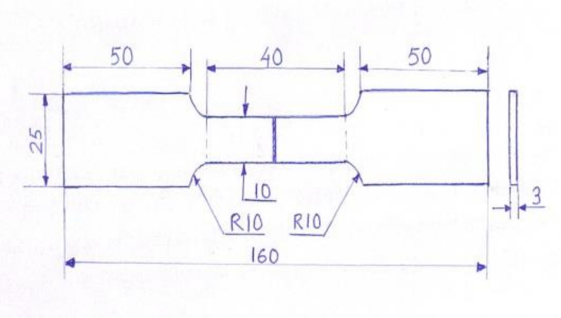

Fig 4:Dimensions of the specimen prepared for tensile test

RESULTS ANDANALYSIS

In the present investigation, the effects of welding process parameters on quality characteristics i.e. UTS and PE, of welded specimen has been investigated, as already mentioned above. Multi response (UTS and PE) problem has been converted into single response problem using Taguchi method cum grey relational analysis. Then the statistical analysis has been carried out on the grey relational grade (which corresponds both the responses) using analysis of signal-to-noise ratio to identify the influential process parameters which has significant effect on both the responses.

Grey relational analysis

Higher values of UTS and PE indicate the better quality of the welded specimen, so Eq. 2 is used to normalize the experimental data. Grey relational generation values for UTS and PEare shown in Table 3. Grey-relational coefficient is calculated by using Eq.3. The value of 'r' is taken as 0.5 since both the output parameters are considered to be equal importance. The grey relational grade can be calculated by using Eq. 4. The data relating to grey relation co-efficient and grey relation grades are shown in Table 4. Higher value of grey relational grade yields the optimal parametric setting among the other conditions [14].From the Table 4, it is found that experiment number 3 has generated the highest grey relational grade.

Table 3. Grey relational generation and values of Δ_{0i}

S.No	Grey relational generation		Values of Δ_{0i}	
	UTS	PE	UTS	PE
1	0.7714	0.6101	0.2286	0.3899
2	0.0000	0.1901	1.0000	0.8099
3	1.0000	0.9391	0.0000	0.0609
4	0.3250	0.0000	0.6750	1.0000
5	0.4416	0.5142	0.5584	0.4858
6	0.9299	1.0000	0.0701	0.0000
7	0.8442	0.3802	0.1558	0.6198
8	0.5607	0.5093	0.4393	0.4907
9	0.7152	0.6149	0.2848	0.3851

Table 4. Grey relational coefficient and grade

S. No	Grey relational		Grey relational grade	Order
	UTS	PE		
	0.6863	0.5618	0.6241	3
2	0.3333	0.3817	0.3575	9
3	1.0000	0.8914	0.9457	1
4	0.4255	0.3333	0.3794	8
5	0.4724	0.5072	0.4898	7
6	0.8771	1.0000	0.9386	2
7	0.7624	0.4465	0.6045	4
8	0.5323	0.5047	0.5185	6
9	0.6371	0.5649	0.6010	5

Analysis of signal-to-noise ratio

Statistical analysis of signal-to-noise ratio technique from MINITAB 16.1 software is applied on grey relational grade to determine the influential welding processes parameters which have significant effect on UTS and PE. ANOVA is performed at 95% confidence level i.e. 5% significance level, details are given in Table 5. 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 variables would be treated as significant on the respective response. ANOVA table (Table 5) of grey relational grade depicts that direct effects of gas flow rate and arc gap are significant on both the responses i.e. UTS and PE, as their P values are 0.003 and 0.005 respectively. Individual effect of current is insignificant at 95% confidence levels, because its P value is more than 0.05, as found from Table 5.

Table 5.Analysis of variance for GRG

Source	DF	Seq SS	Adj MS	F	P
A	2	0.4614	0.2307	3.16	0.24
B	2	42.533	21.2667	290.93	0.00
C	2	27.323	13.6615	186.89	0.00
Residual Error	2	0.1462	0.0731		
Total	8	70.464 0	R-Sq = 99.8% & R-Sq(adj) = 99.2%		

Response table for signal to noise ratio under the larger-the-better criterion for grey relational grade is obtained from Taguchi method and given in Table 6. It is evident from the Table 6 that gas flow rate (B) is the most significant parameter for both the responses, next is arc gap (C) and followed by current (A).

Table 6.Response table signal-to-noise ratio of GRG

Level	A	B	C
1	-4.505	-5.628	-3.450
2	-5.056	-6.946	-7.258
3	-4.833	-1.819	-3.686
Delta Value	0.551	5.127	3.808
Rank	3	1	2

Main effect plots for grey relational grade is drawn and shown in Fig.5. Optimal parametric setting can determined from the main effect plots for maximizing both the response characteristics.Parametric condition at higher value of signal-to-noise ratio indicates the close to optimal. Fig. 5 depicts the optimum parametric combination is: current (A) = 90 A, gas flow rate (B) = 16 l/min and arc gap (C) = 4 mm.

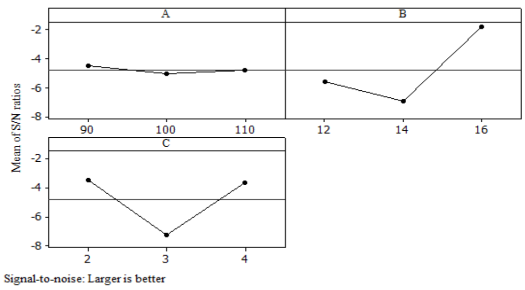

Fig 5: Main effect plots for GRG

CONFIRMATORY TEST

A confirmation experiment has to be conductedto validate the optimal condition [15], predicted by the optimization methodology i.e. Taguchi method combined with grey relations analysis, used in the present study. Two confirmatory experiments are performed at optimum welding parametric condition. The average values of responses (UTS and PE) are higher than those obtained in initial experiments (Table2).

CONCLUSIONS

The welding process parameters that affect the TIG welding of AISI 310 austenitic stainless steels have been studied using grey based Taguchi methodology. Multi-response problem of ultimate tensile strength (UTS) and percentage elongation (PE) is transformed into single problem of grey relational grade using grey relational analysis. The variables affecting the UTS and PE according to their relative significance are the gas flow rate, arc gap and current respectively. The optimum welding condition is said to be at current (A) = 90 A, gas flow rate (B) = 16 l/min and arc gap (C) = 4 mm. It has been shown that, welding process parameters set at their optimum levels can ensure significant improvement in the response variables. Grey based Taguchi method is efficient tool for optimizing multi responses in TIG welding operation.

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