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Design of TIG welding experiments to optimize the hardness and Toughness of weld bead formed between Cu alloys

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Abstract- Tungsten Inert gas (TIG) welding process is mostly used in industries to join either similar or dissimilar materials. Particularly it is used to achieve a high strength joint among metals and alloys. In this project, effects of welding current, welding speed and gas flow rate on hardness and toughness of weld bead, formed between Brass and Bronze is analyzed and optimized. Based upon these parameters, L9 orthogonal array is constructed and subsequently 9 experiments are carried out. These experiments are tested for hardness and toughness. Results of hardness and toughness are analyzed in MINITAB software and optimized by using Grey Relational analysis. Form results it is found that higher values of aforementioned parameters are desirable for optimum hardness and toughness. Finally Analysis of variance (ANOVA) reveals that gas flow rate is the most effective parameter for this optimization.

Keywords- TIG, Brass, Bronze, Toughness, hardness, Design of experiment (DOE), MINITAB, Grey relational analysis, Optimum, ANOVA.

1. INTRODUCTION

Welding is a permanent joining process used to join various ferrous and nonferrous materials by the application of heat and or pressure. In few cases filler material is required to form a weld pool of molten metal which gives a strong bond after solidification. Weldability of a material is influenced by many parameters: melting point, thermal conductivity, thermal expansion, electrical resistance, surface conditions etc.

In TIG welding process straight polarity i.e tungsten (non consumable) electrode connects with negative terminal and work pieces connect with positive terminal except for reactive materials. Mostly argon or helium is used as shielding gas to prevent the interaction of atmospheric gases with welding area and to transfer the heat during welding. Shielding gas also facilitates to maintain a stable. Today, the applications of TIG welding has been extended to variety of ferrous materials like MS, SS, HSS as well as non ferrous materials like Cu alloys, Al alloys etc. to give high quality weld. **Fig. 1** exhibits the view of Automatic TIG welding machine used in the present experimental work with following objectives:

1. Analyze the effects of process parameters on hardness and toughness of weld bead
2. Optimize the hardness and toughness of weld bead**.**

9 experiments are carried out to create butt joints between Brass and Bronze pieces at various levels of process parameters: welding current, welding speed and gas flow rate in TIG welding process.

Figure 1**:** Automatic TIG welding Machine

Effects of welding process

Welding Current: The higher current damages the work pieces during the welding and limiting current facilitates to prevent spatter.

Welding speed: Too higher welding speed may results in to lack of penetration while too slow may results in to excessive deposition rate. Therefore a balanced welding speed should be maintained.

Gas flow rate: The purpose of gas flow rate is to protect the weld zone from atmospheric contamination otherwise oxidation will results in to defect. Therefore, a certain amount of gas flow rate is required to be maintained.

After welding, weldments are tested for hardness and toughness in Rockwell hardness tester (**Fig. 2**) and impact test (**Fig. 3**) respectively. L 9 orthogonal array is constructed to design the experiments and optimized using Taguchi technique.

Figure 2: Rockwell hardness Tester

Figure 3: Impact test to measure toughness

Optimization

In the present work optimization is carried out using Grey relational analysis for which analysis of S/N ratios is required.

Analysis of S/N ratio:

In Taguchi technique, desirable value for the output characteristic is represented by the term 'signal' and undesirable value for the output characteristic is represented by the term 'noise'. S/N ratios for different conditions are calculated from following equations:

1. Nominal is the best characteristic

$$S / N = 10 \log_{10}\left(\frac{\bar{Y}}{S_y^2}\right) \ldots(1)$$

2. Smaller is the best characteristic

$$S / N = - 10 \log_{10}\left(\frac{\sum y^2}{n}\right) \ldots(2)$$

3. Larger the better characteristics

$$S / N = -10 \log_{10}\left(\frac{1}{n}\sum\frac{1}{y^2}\right) \ldots(3)$$

Where; n is the number experiments performed and y is the output response obtained by the experiment.

Grey Relational Analysis (GRA):

This technique transforms the multiple performance characteristics into single characteristics. The following steps are followed in GRA

- Experimental data are normalized in the range between zero and one.
- The grey relational coefficients are calculated from the normalized experimental data.
- The Grey relational gradeare computed by averaging the weighted grey relational coefficients corresponding to each performance characteristic.
- Then optimal levels of process parameters are selected.

In the analysis of grey relation for 'higher is better' response normalization done by equation (4) and for 'lower is better', normalization done by equation (5).

$$X_i^*(k) = \frac{X_i(k) - \dot{X}_i \min(k)}{X_i max(k) - X_i \min(k)} \ldots(4)$$

$$X_i^*(k) = \frac{X_i max(\dot{k}) - X_i(k)}{X_i max(k) - X_i \min(k)} \ldots(5)$$

Where;

Xi* (k) and Xi (k) are the normalized data and observed data, respectively, for i^{th} experiment using K^{th} response. The smallest and largest values $X_i(k)$ in the K^{th} response are $X_i$min(k) and Xi max(k), respectively.

After pre-processing the data, the grey relation coefficient (GRC) $\zeta_i(k)$ for the K^{th} response characteristics in the i^{th} experiment can be expressed as following:

$$\zeta i\ (k) = \frac{\Delta \min + \zeta\Delta\max}{\Delta i\ (k) + \zeta\Delta\max} \ldots(6)$$

where;

X_0^i (k) = denotes reference sequence , $X^*_j(k)$ = denotes the comparability sequence ς Є [0,1], is the distinguishing factor; 0.5 is widely accepted.

$\Delta_i = |X_0^*(k)-X_j^*(k)|$ = differnece in absolute value between $X_0^*(k)$ and $X_j^*(k)$

$\Delta_{min}=\min_{(j\epsilon i)}\min_{(k)}|X_0^*(k)-X_j^*(k)|$ = smallest value of$\Delta_{i.}$

$\Delta_{max}=\max_{(j\epsilon i)}\max_{(k)}|X_0^*(k)-X_j^*(k)|$ = largest value of$\Delta_{i.}$

After calculating GRC, the grey relational grade (GRG) is obtained as:

$$\gamma_i=\left(\frac{\sum w\times \zeta i\ (k)}{m}\right) \ldots(7)$$

where;

γ_i is the Grey Relational Grade, n is the number of responses, m is the number of run and w is the weight factor. Amount of influence of a response can be controlled in deciding the optimum machining parameters varying the value of w keeping in mind $\sum_1^n w$ should be equal to 1.

Verma1 et al. [1] Optimized TIG Welding parameters on mechanical properties of aluminum 6061 alloy.

Khatter et al. [2] constructed L9 orthogonal array with welding current, welding voltage and gas flow rate and found optimal parameters setting.

Esme1 et al. [3] employed Taguchi method and grey relational analysis in TIG welding. It was also observed that essential requirements for welding are deeper penetration with higher tensile load and lower heat affected zone.

Prakash et al. [4] found that welding Current has the greatest influence on Tensile and Hardness in the welded sample of ASTM A29 in TIG welding.

Narwar and Jain [5] studied the outcome of conventional and nonconventional optimization techniques on TIG welding process to select a suitable approach.

Ravinder and Jarial [6] Optimized the welding process parameters for Tensile and Hardness of the welding joints by constructing L9 orthogonal array.

Kumar and Patel [7] found that tensile strength and hardness at various combination of process parameter and suggested a suitable solution for hardness.

Patil and Kharate [8] designed a TIG welding process and observed that for tensile strength and hardness, voltage is main affecting factor.

Patel and Patel [9] carried out literature survey to study welding process parameters like welding current, welding speed, depth to width ratio on different materials like mild steel , titanium alloy, brass, carbon, stainless steel etc.

Gohel et al. [10] Optimized the combination of welding process parameters for Tensile strength and hardness in TIG welding. From the ANOVA it is conclude that the welding current and gas flow rate are most significant parameter for Tensile strength and Hardness respectively.

Ansari and Quazi [11] observed the effects of parameters on impact strength of butt weld joint with different groove angles and proposed the best suitable parameters for maximum tensile strength, fatigue strength, hardness and heat effected zone.

Yadav et al. [12] observed that voltage is the most significant factor for the hardness of weld bead in TIG welding process.

Bahar [13] optimized the bending strength of a butt joint on the basis of welding process parameters: current, welding speed and gas flow rate in tungsten inert gas (TIG) welding.

2. MATERIALS AND METHODS

Two plates are butt welded at different combination of process parameters by TIG welding. Details pertaining to material of plates, welding conditions etc are explained in this section. material of plates to be welded taken as Brass and Bronze, each plate having dimension as 50mm×47mm×8mm. Brass is a metallic alloy that is made of Copper and Zinc. The proportions of zinc and copper can vary to create different types of brass alloys with varying mechanical and electrical properties. Bronze is one of the earliest metals known man.It is defined as an alloy made of copper and another metal, usually tin, composition may vary, but most modern bronze is 88%copper and 12% tin. Chemical compositions of Brass and Bronze is given in **Table 1**.

Table 1: Chemical composition of Brass and Bronze

	Copper	Zinc	Tin
Brass	67%	33%	-
Bronze	88	-	12

Material used for filler: No

Shielding gas used: Argon

Electrode used: Ball shape Non consumable tungsten electrode having 3mm diameter is used.

Varied Parameters: Welding current, Welding speed and Gas flow rate have been varied for 3 levels as shown in **Table 2**. On the basis of these levels factors relationship, 9 combinations of these factors are considered (shown in **Table 3**) to construct L9 orthogonal array.

Table 2: Levels of varying parameters

Parameters	Levels		
	L1	L2	L3
Welding current, I (Amp)	170	180	190
Welding speed, S (mm/min)	60	80	100
Gas flow rate, GFR (mm^3/min)	21	22	23

Table 3: L9 orthogonal array and respective Results

Exp.	I	S	GFR	Hardness	Toughness
No				(C-scale)	(Joules)
1	170	60	21	53	18
2	170	80	22	60.5	82
3	170	100	23	70.5	16
4	180	60	22	54.75	22
5	180	80	23	55	106
6	180	100	21	70	78
7	190	60	23	74.75	72
8	190	80	21	53.5	24
9	190	100	22	54.75	

Corresponding to L 9 orthogonal array (given in Table 3) 9 welding experiments are performed (shown in Fig. 4) and subsequently tested for hardness and toughness (values are given in Table 3).

Figure4a: 170A/60mm/min21L/min

Figure 4b:170A/80mm/min22L/min

Figure 4c:170A/100mm/min23L/min

Figure 4d: 180A/60mm/min22L/min

Figure 4e: 180A/80mm/min23L/min

Figure 4f:180A/100mm/min21L/min

Figure 4g:190A/60mm/min23L/min

Figure 4h:190A/80mm/min21L/min

Figure4i: 190A/100mm/min22L/min

Figure 4: welded specimen in 9 experiments are shown

3. RESULTS AND DISCUSSIONS

In order to optimize hardness as well as toughness, multi response optimization i.e Grey relational analysis is employed for which grey relational coefficients (GRC) and grey relational grades (GRG) are calculated and presented in **Table 4**.

Table 4: Grey relational coefficients for hardness & bending strength and grey relational grades

Exp. No	**GRC (Hardness)**	**GRC (Toughness)**	**GRG**
1	0.3515474	0.39110499	0.3713261
2	0.472893	0.8844326	0.6786628
3	0.786785	0.37486266	0.580823
4	0.3751799	0.4222761	0.797940
5	0.3787529	1.124588	0.7516585
6	0.7632224	0.8491086	0.5061655
7	1.0546422	0.798087	0.926364
8	0.3580692	0.437390	0.397729
9	0.37518012	0.814846	0.595013

Grey relational grades from Table 4 are analyzed in MINTAB for multi response optimization. **Fig. 5** shows the main effect plot for S/N ratios and **Table 5** presents the analysis of variance.

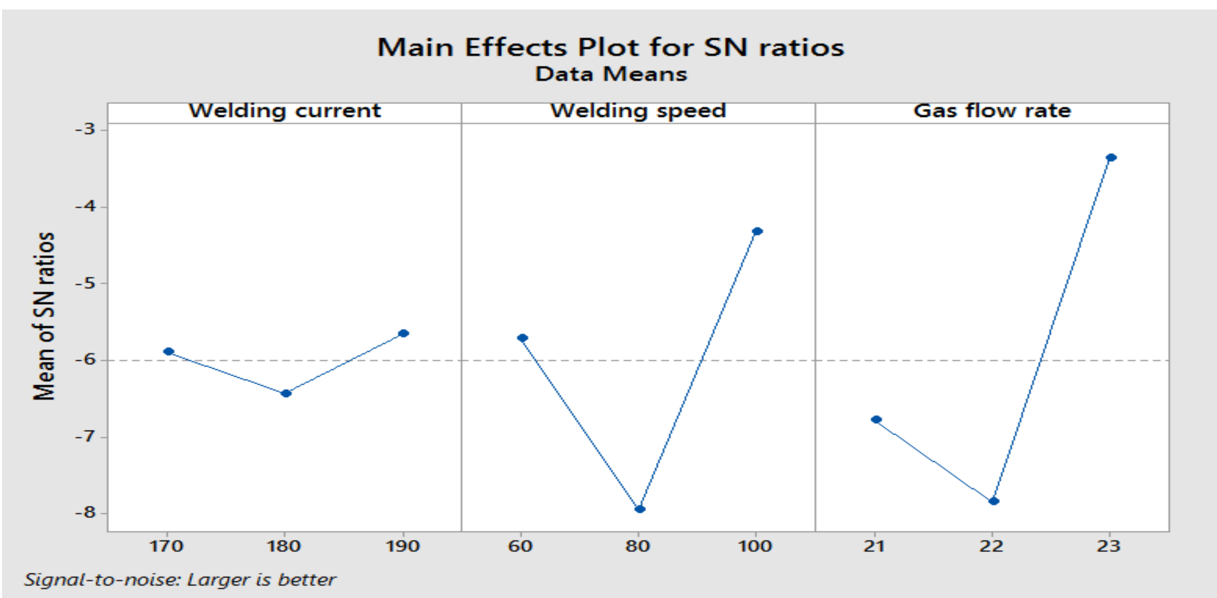

Figure 5: Main effect plot for SN ratios in multi response

Table 5: ANOVA for multi transformed response

Analysis of Variance for Transformed Response

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Welding current	2	0.012948	11.55%	0.012948	0.006474	1.07	0.483
Welding speed	2	0.008330	7.43%	0.008330	0.004165	0.69	0.592
Gas flow rate	2	0.078746	70.24%	0.078746	0.039373	6.51	0.133
Error	2	0.012088	10.78%	0.012088	0.006044		
Total	8	0.112112	100.00%				

Since higher values of hardness and toughness are desired therefore corresponding optimal process parameters for multi response are evaluated from Fig. 5 and presented in **Table 6**. From Table 5, it is also clear that contribution of gas flow rate is higher (70.24 %) and of welding speed is lower (7.43 %).

Table 6: Optimal parameters for multi response

Parameter	Levels	values
welding current, I (A)	3	190
welding speed, S (mm/min)	3	100
Gas flow rate (mm^3/min)	3	23

From Table 6, it can be pointed out that for multi response optimization i.e optimization of hardness as well as toughness, welding current, welding speed as well as gas flow rate should be higher.

4. CONCLUSIONS

From this communication it is concluded that optimum parameter setting for multi response optimization (i.e optimization of hardness with toughness) of weld bead is obtained at 190 A of welding current, 100 mm/min of welding speed and 23 mm^3/min of gas flow rate. From this study it is also clear that when it's the matter of toughness as well as hardness then gas flow rate would be most influential parameter among aforementioned parameters.

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