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MULTI-OUTPUT OPTIMIZATION OF MECHANICAL PROPERTIES DURING FRICTION WELDING OF ALUMINIUM 6082 T6 USING TAGUCHI-GREY APPROACH

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Abstract

Friction welding is widely used process in the manufacturing industries such as aerospace and automotive. The performance of friction welding was analyzed from the mechanical properties of welded zone. Many process parameters are influence the mechanical properties of welded zone. Therefore in this research work an attempt has been made to find the influence of process parameters on mechanical properties of welded zone. The spindle speed, forging pressure and time of contact are selected has process parameter. The hardness and surface roughness of welded zone are selected as mechanical properties during the experimentation. The Taguchi design of experiments is chosen to perform the experiments. The outcomes are analyzed by using Grey relational approach. The results indicate that the time of contact has maximum influence on the mechanical properties.

I. INTRODUCTION

Solid state welding is also one of the important type of welding process in which the heat required for the welding purpose is produced by rubbing or by applying hammering operation onto work piece. In this form of welding the material to be welded is heated to a temperature below or just up to the solidus. The coalescence between the parts is achieved under pressure and thus forging or impact action plays an important role in all these processes. Solid state welding are of different types such as friction welding, ultrasonic welding, diffusion and explosive welding.

Friction welding without no doubt, the most successful development in the field of pressure welding has been that of friction welding machine used for this process looks somewhat like large lathe fitted with two chucks one driven by a motor and other is fixed. Two parts to be joined are clamped in the chuck and one part is rotated. This rotating component must be round in cross section but the part held in the fixed chuck can be a matching section or flat. When the rotating chuck reaches the welding speed, parts come into contact under a light axial load, as the force rub two parts friction then generate heat and localized heat plastic zones are produced, with the end load maintained heat continuous to be generated until the whole interface has reached a uniform temperature at the same time. The plastic metal starts to flow outwards towards the periphery, carrying with it any oxides present at the joint face. When adequate heat is formed, the relative rotation of the parts is stopped fast and the end load maybe increased, weld time are short, being around 20-100 seconds. By adjusting power, peripheral speed and the pressure applied time can be reduced to lowest possible value consistent with a good weld. The prepared specimen then can be tested for their mechanical properties, at the welded zone, such as hardness, surface roughness, tensile strength, torsional strength etc.

Many researchers have investigated the effect of input parameters on mechanical properties of friction welded aluminium alloys. Wang and Lin found out that the optimum welding conditions can be established by the application of response surface methodology [1]. Craine and Francis investigated the interface of the joint and gave us an equation of heat generation at the interface by assuming a two dimensional heat transfer model and [2]. Sahin et al. statistically analyzed the affecting parameters on the mechanical properties of the welds prepared and concluded that rpm, friction time and pressure are very influential [3]. Ahmet Sahin et al. focused on the heat transfer mechanism that initiates the friction welding process to mimic the actual process [4]. Faes et al. developed a new welding technique based on friction welding called friex which is used to weld pipelines in a fully automatic way [5]. Samuthiram et al compared the fusion welding technique with friction welding and found out that the mechanical properties exhibited by friction welded alloys were better than welds achieved through the fusion welding technique [6]. Rotundo et al. experimented on the welds formed by aluminium and SiCP composites and found out that the hardness decreased about 10% in the welded zone as compared to the base metal [7].

II. MATERIALAND METHOD

The material used for this experiment is Aluminium 6082 T6 alloy. The chemical composition mainly consists of alloying elements such as Manganese, Iron, Magnesium, Silicon and few other elements as well. The setup consists of a rotating part and a stationary part. The rotating part is held in the chuck while the stationary part is held inside a tool mounted into the tail-post. The chuck is rotated at a certainRPM while the stationary component is brought closer to the rotating component. Both the components are brought in contact with each other while applying the required friction pressure. The procedure consists of two aluminium rods having circular cross section, f 22 mm, and length 8 cm each.

The chemical composition is shown in Table (I).

TABLE I
CHEMICAL COMPOSITION OF 6082 T6 ALUMINIUM ALLOY

Chemical Element	% Present
Manganese	0.40-1.00
Iron	0.00-0.50
Magnesium	0.60-1.20
Silicon	0.70-1.30
Copper	0.00-0.10
Zinc	0.00-0.20
Titanium	0.00-0.10
Chromium	0.00-0.25
Others (Each)	0.00-0.05
Others (Total)	0.00-0.15
Aluminium	Balance

III. PROCESS PARAMETERS

The specimen have equal diameter although for testing the mechanical properties, the input process parameters were varied. The process parameters with ranges are shown in Table (II).

TABLE II
PROCESS PARAMETERS WITH RANGES

Parameters	Level-1	Level-2	Level-3
Spindle Speed (rpm)	750	1000	1250
Forging pressure (Mpa)	25	35	45
Time (s)	45	55	65

The specimens were formed by the variation of the input parameters mentioned above. These parameter variation were obtained through Taguchi's L9 design having three factors and three level of design.

IV. EXPERIMENTAL SETUP

The specimen were welded on a three jaw chuck lathe machine. The setup consists of a self-designed tool that would be mounted into the tailstock to hold the stationary specimen, pressure gauge to measure the forging pressure, stopwatch to find out the time of contact and a tachometer to find out the rpm of chuck. Hardness testing was done on Rockwell hardness testing machine. Surface roughness was measured on a Mitutoyo Surface roughness tester.

V. DESIGN OF EXPERIMENT

A. Taguchi's Design of Experiments

The Taguchi technique from the design of experiments was selected to optimize the process parameters. Taguchi method is a valuable tool for developing the high-quality system. Taguchi uses of orthogonal arrays to conduct small, fractional factorial experiments equal to larger, full factorial experiment. [8]. The L9 orthogonal array was chosen for performing the experimentations.

B. Grey Relation Analysis

The grey relational analysis (GRA) provides a solution to multi-objective problems. The GRA is useful to find the optimal setting of different process variables by relating the entire range of performance parameter values into a single value [9]. The initial step in GRA is to convert the performance of all alternatives into a similarity arrangement between [0, 1], this act is known as normalization. The next step is to define the reference (ideal) order and the calculation of grey relational coefficient (GRC) among actual sequence and ideal sequence. After, then grey relational grade (GRD) is computed between the ideal sequence and every comparability sequences from GRC. The highest GRD is the best choice. For larger-the-better condition, the actual series (experimental results) is normalized by using Eq. (1);

$$yi(k) = \frac{xi(k) - \min xi(k)}{\max xi(k) - \min xi(k)} \quad (1)$$

Where, xi(k) is the actual series, yi(k) series after normalization, max xi(k) and min xi(k) indicate the highest and lowest value of xi(k). For smaller-the-better condition, the actual series is normalized by applying Eq. (2);

$$yi(k) = \frac{\max xi(k) - xi(k)}{\max xi(k) - \min xi(k)} \quad (2)$$

After the normalization of data then grey relational coefficient (GRC) is calculated. The GRC is indicating the correlation among actual and ideal normalized values. The ideal sequence is represented by yo(k) and it is taken as 1. The GRC is calculated from the ideal sequence yo(k) and the actual sequence yi(k). GRC show the correlation between ideal and actual sequence. The larger the GRC closer the yi(k) and yo(k) are. The GRC is calculated by using Eq. (3);

$$\zeta_i = \frac{\Delta\min + \delta\Delta\max}{\Delta ij + \delta\Delta\max} \quad (3)$$

In above Eq. (3), ζi is represented the coefficient of grey relational between yi(k) and yo(k); Δij=│yo(k) – yi(k)│ deviation sequences; Δmin = minimum from Δi(k); Δmax = maximum from Δi(k); δ is the distinctive coefficient, δ□ [0,1]. The role of the distinctive coefficient is to increase or decrease the range of the GRC. The range of distinctive coefficient δ is chosen between [0,1]. Usually, δ =0.5 is used because it offers reasonable distinctive outcome and constancy [10]. The next step after calculating the GRC is to calculate the Grey relational grade (GRD) by using following Eq. (4);

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \zeta i(k) \quad (4)$$

In Eq. (4), i is the GRD between y(ij) and y(oj). The GRD designate the degree of resemblance between the actual and the ideal series. The higher value of GRD indicates that corresponding cutting parameter is closer to optimal. In others words, optimization of the complex multi responses problems is transformed into optimization of a single GRD. The values of GRD are fallen within [0, 1].

VI. RESULT AND DISCUSSION

In this research work the response was optimized under the variation of input parameters based on taguchi's orthogonal array table as shown in table (III).

TABLE III ORTHOGONAL ARRAY L9

Specimen	Rpm	Pressure	Time
1	1000	25	55
2	1000	35	65
3	1000	45	45
4	1250	25	65
5	1250	35	45
6	1250	45	55
7	750	25	45
8	750	35	55
9	750	45	65

The hardness and surface roughness are chosen as process variables. The taguchi design approach was used to perform the experiments. Both the hardness and surface roughness are analyzed to assess the machine performance. The experimental outcomes are shown in the table (IV).

TABLE IV MECHANICAL PROPERTIES

Specimen	Hardness (HB)	Roughness (µM)
1	87.708	0.86
2	95.395	0.68
3	106.08	0.47
4	98.68	0.31
5	97.02	0.49
6	99.78	0.69
7	99.77	1.07
8	92.646	1.00
9	97.847	0.30

The grey relational model is prepared from the results obtained. The experimental data first converted between (0,1), this is known as normalization. For the normalization of Hardness the Eq. (1) and for normalization of surface roughness Eq. (2) is used. The normalized data is represented in Table (V).

TABLE V NORMALIZATION TABLE

Specimen	Hardness	Roughness
1	0.000	0.272
2	0.418	0.506
3	1.000	0.780
4	0.597	0.990
5	0.506	0.753
6	0.657	0.494
7	0.656	0.000
8	0.268	0.091
9	0.552	1.000

The next step is to calculate the grey relational coefficient (GRC) from the normalized data. The estimated value of GRC shows the correlation between the ideal and actual (experimental) data. The Eq. (3) is used to derive the GRC. The calculated GRC is represented in Table (VI).

TABLE VI
GREY RELATION COEFFICIENT (GRC)

Specimen	Hardness	Roughness
1	0.334	0.407
2	0.466	0.527
3	1.000	0.693
4	0.552	0.974
5	0.526	0.669
6	0.593	0.496
7	0.592	0.334
8	0.406	0.355
9	0.527	1.000

Then the last step is to calculate the grey relational grade (GRD). For the calculation of GRD, the significance of all performance characteristics was assumed to be equal. The weights of the two performance characteristics were all the same. The GRD can be calculated by using Eq. (4). The calculated GRD for each run is given in Table (VII).

TABLE VII
GREY RELATION GRADE (GRD)

Specimen	GRD	Rank
1	0.3705	9
2	0.4965	6
3	0.8465	1
4	0.7630	3
5	0.5975	4
6	0.5445	5
7	0.4630	7
8	0.3805	8
9	0.7635	2

Based on the calculated GRD the rank is prepared to recognize the excellent input arrangement. It is observed that specimen no 3 has highest GRD of 0.8465. Higher GRDsignifies the input parameters corresponding to specimen no. 3 provide us with better mechanical properties. To analyze the significance of the process parameters, the analysis of variance (ANOVA) was performed. The Analysis of variance of means table is given in Table (VIII).

TABLE VIII
ANALYSIS OF VARIANCE OF MEANS (ANOVA)

Source	Df	Seq. SS	Adj. SS	Adj. Ms	F	P	Contribution%
Rpm	2	0.01504	0.01504	0.007520	0.38	0.724	6.14
Pressure	2	0.08812	0.08812	0.044062	2.24	0.309	36.0
Time	2	0.10219	0.10219	0.051094	2.59	0.278	41.75
Res. Error	2	0.03941	0.03941	0.019704			16.1
Total	8	0.24476					

From the ANOVA table, it has been observed that Time is the most significant input variable that affects the mechanical properties of the weld. From the grey relational grade, response table is generated to identify the optimum combinations of the parameters.

TABLE IX RESPONSE TABLE

Level	Rpm	Pressure	Time
1	0.5363	0.5322	0.6357
2	0.5712	0.4915	0.4318
3	0.6350	0.7188	0.6749
Delta	0.0987	0.2273	0.2431
Rank	3	2	1

The response table is shown in table (IX). It has been observed from the table that high rotating speed with high pressure and longer duration maximize the grey relational grades which in turn maximize the mechanical properties of the weld

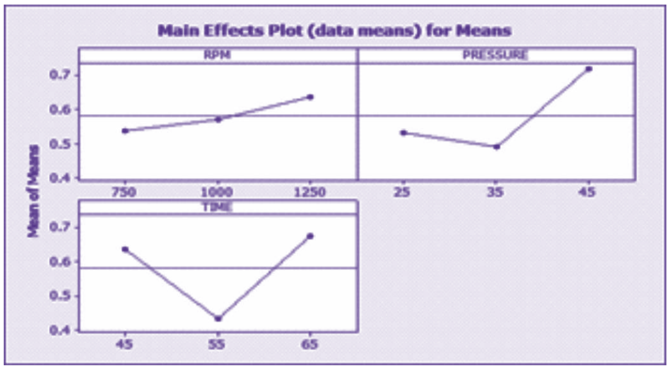

Figure 2. Main effects plot for mean of GRD

Hence we would achieve the best mechanical properties at 1250 rpm speed of the spindle, 45 Mpa pressure and 65 sec time of contact under similar input variables.

Confirmation run:

The confirmation run was carried out to analyze the difference between experimental and predicted values. The table (VII) indicates that run no 3 has maximum values of the grey relational grade. The run no (3) provide the maximum output. The response table (IX) predict that the optimum value of the process parameters are 1250 rpm of spindle, 45 Mpa of forging pressure and 65 Sec time of contact. The experiments was performed at optimum setting of process parameters. It was observed that the hardness was increased form 106.08 HB to 120 HB and the surface roughness was decreased form µm to 0.35µm. Therefore the optimal values which maximize the output are 1250 rpm of spindle speed, 45 Mpa of forging pressure with 65 Sec of contact time.

VII. CONCLUSIONS:

In this research work the experiments were performed to analyze the effects of process parameters on mechanical properties during friction welding of aluminium 6082 T6 alloys. The following conclusion are drawn:

- The optimal value of the process parameters which maximize the output are 1250 rpm of spindle speed, 45 Mpa of forging pressure with 65 Sec of contact time.
- The ANOVA Table shows that the contact time has maximum influence on the mechanical properties.

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