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OPTIMIZATION OF PROCESS PARAMETERS AND CHARACTERIZATION OF FRICTION STIR WELDED ALUMINIUM ALLOYS

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ABSTRACT

The present work is aimed to optimize the process parameters such as rotational speed, traverse speed and axial load for improving mechanical properties like hardness and tensile strength of the friction stir welded joint on aluminium alloys. The process parameters are optimized by MOORA method.

Formation of brittle inter metallic compounds (IMCs) easily occurs, while using conventional fusion welding technique. Therefore, to minimize the formation of brittle IMCs without any melting of base metals under the action of stirring effect and a lower heat input. Box Behnken method is used for finding out the relationship between various responses (tensile strength, hardness and impact test) and welding parameters (tool rotational speed, table traverse speed and axial force).

The application of multi-objective optimization on the basis of ratio analysis (MOORA) method has been applied for solving multiple-criteria (objective) optimization problem in welding. The optimum process parameter found using MOORA method are as follows (i) tool rotational speed of 1000 rpm, (ii) table traverse speed of 25 mm/min and (iii) axial force of 14 kN respectively.

Key words: Friction stir welding, MOORA, Box Behnken

1. INTRODUCTION

Many specific properties of aluminum alloys including light Weight and good structural strength enable them to be applied for structural parts. The demand of aircraft and automotive industries for lightweight materials is met by aluminum alloys. The aluminum alloys AA6XXX and AA5XXX are extensively used in the fabrication of aircraft structures and other structural applications [1]. Dissimilar welding of these two alloys is frequently faced in those structures. Structural parts and frames composed of these aluminum alloys can be welded using sound welding techniques commonly used in industries. But conventional fusion welding of aluminum alloys results in numerous welding defects which includes voids, hot cracking, distortion, precipitates dissolution, loss of work hardening and lack of penetration in the joints [2, 3]. Therefore, solid state bonding technique is highly recommended to solve those problems.

Al alloys; 5052, 5083 and 5086 are used for automotive, marine and other structural applications because of their higher strength to weight ratio and corrosion resistance. Recently, Friction Stir welding (FSW) has engrossed scientists and welders as a proper procedure for dissimilar joining of materials. Friction stir welding (FSW) is an appropriate solid state welding technique to effectively join any combination of dissimilar aluminium alloys [4]. FSW was invented at The Welding Institute (TWI), UK in 1991. A non-consumable rotating tool harder than the base material is plunged into the abutting edges of the plates to be joined under sufficient axial force and advanced along the line of the joint. The tool consists of two parts namely shoulder and pin. The material around the tool pin is softened by the frictional heat generated by the tool rotation. Advancement of the tool pushes plastically deformed material from front to back of the tool and forges to complete the joining process [5].

Recently, high performance tool materials are employed for FSW of high melting temperature materials such as titanium, nickel and steels. The weld surface finish and plastic flow behavior showed that the stirring effect increased and number of defects decreased when the traverse speed was decreased [6].

Decision makers in the manufacturing sector frequently face the problem of assessing a wide range of alternative options and selecting one based on a set of conflicting criteria. It must be noted that in choosing the right alternative, there is not always a single definite criterion of selection, and decision makers have to take into account a large number of criteria. There is a need for simple, systematic, and logical methods or Mathematical tools to guide decision makers in considering a number of selection criteria and their interrelations [7].

The MOORA method is one of the Multi-Criteria Decision-Making (MCDM) methods which use statistical procedure for the selection of the best alternative from the given alternatives. This method generates most suitable alternatives by considering both beneficial (maximization) and non-beneficial (minimization) alternatives and eliminates unsuitable alternatives for strengthening the existing selection procedure. The MOORA method involves lesser computations, comprehensiveness and robustness which can solve multiple numbers of criteria simultaneously [8].

In this paper 3mm, thick aluminium alloys 5052 H32 and 6061 are friction stir welded at different tool rotational speeds, tool travel speed and an axial force. Investigation of mechanical properties are examined and the process parameters are optimized using MOORA method.

2. MATERIAL PREPARATION

Aluminium alloys 5052 H32 and 6061 plates are cut into the required size (150mm×50mm×3mm) by shearing machine and then edge surfaces are milled. The work piece dimensions are shown in the figure 1.

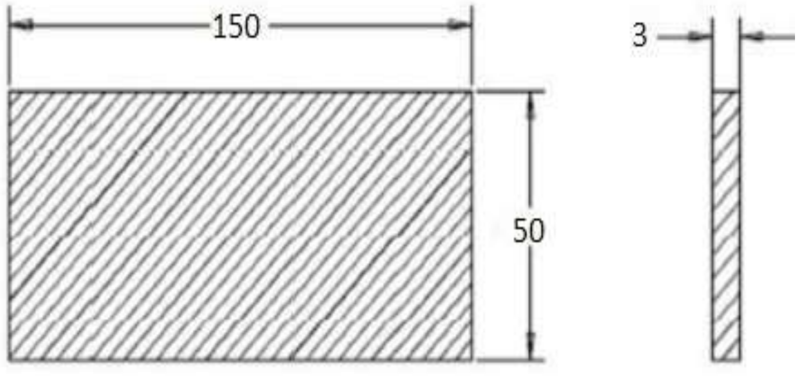

Figure 1 Dimensions of the specimen in mm

2.1 Material Composition

The chemical composition of aluminium alloy 5052 H32 and 6061 are shown in the table 1. The chemical composition for high carbon and high chromium steel (D3 grade) is shown in the tables 2.

Table 1 Composition of Workpiece

Alloy	Aluminium 5052 H32	Aluminium 6061
Element	% weight	
Al	97.05	97.54
Mn	0.018	0.09
Zn	0.034	0.02
Si	0.109	0.468
Fe	0.271	0.219
Cu	0.003	0.238
Cr	0.198	0.102
Mg	2.26	0.926

Table 2 Composition of HCHCR D3 Tool

Element	% weight
C	97.05
Si	0.52
Mn	0.303
Cr	11.2
Fe	85.4
Pb	<0.003
Cu	0.078
Ni	0.072

2.2 Process Parameters

- Tool rotational speed (rpm)
- Table traverse speed (mm/min)
- Axial load (kN)

2.3 Tool Design

The design of the tool greatly influences the uniformity of the welded joint, heat generated during the welding process and the power required. In this design a large amount of heat is generated on the shoulder, preventing the plasticized material from escaping the work piece. While the material flow affects both the shoulder and the tool pin. The tool has hardened to 62 HRC. The dimensions of the FSW tool is shown in the figure 2.

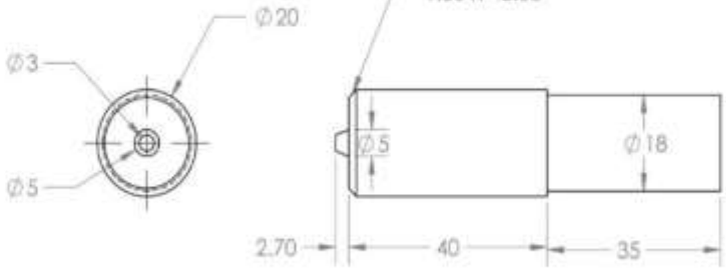

Figure 2 Dimensions of FSW tool in mm

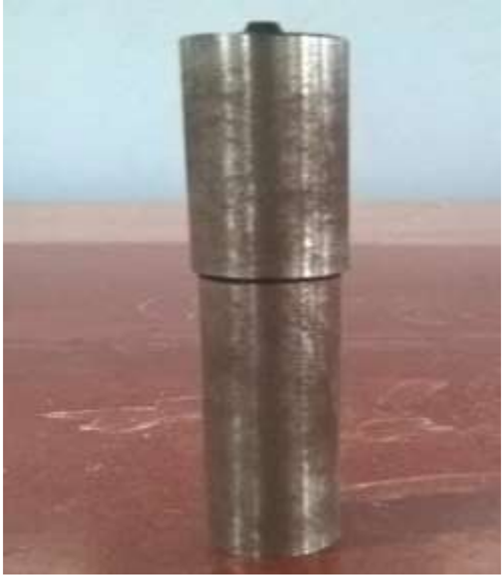

Figure 3 Image of FSW tool

3. THE MOORA METHOD

Multi objective optimization on the basis of the ratio analysis method (MOORA) has been used to eliminate inappropriate alternatives by selecting the most appropriates and also by ordering the selection parameter. It was also a decision making method, where the objectives were measured for every decision of outcomes from a set of available alternatives. The MOORA method was introduced by Brauers [9] and can be applied in various types of complex multi objective optimization problems. In MOORA method the performance of the different output response are arranged in a decision matrix [9] as given in Equation (1).

$$\mathbf{X} = \begin{vmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{vmatrix}$$

where, x_{ij} is the performance measure of i^{th} output on j^{th} objectives, m is the number of alternative or runs, and n is the number of attributes (output).

Then the normalization of the i^{th} alternative over the j^{th} attribute was done by using Equation (2)

$$X^{a}_{ij} = X_{ij} / \sqrt{\sum_{i=j}^{m} x^{2}_{ij}} \qquad (j=1,2,3,\ldots,n)$$

where, X^{a}_{ij} is the normalized dimensionless number which For multi-objective optimization, these normalized performances are added in case of maximization (for beneficial attributes) and subtracted in case of minimization (for non-beneficial attributes). Then the optimization problem becomes in the equation (3)

$$Y_i=\sum_{j=1}^{g} x^{a}_{ij} - \sum_{j=g+1}^{g} x^{a}_{ij}$$

where g is the number of attributes to be maximized, (n−g) is the number of attributes to be minimized, and y_i is the normalized assessment value of ith alternative with respect to all the attributes. Now the ranking of y_i was done from highest to lowest value to know the best alternative among the entire attributes. The ranking of the y_i was the final preference. Thus, the best alternative among the all has the highest y_i value.

4. EXPERIMENTAL PROCEDURE

The materials used for dissimilar Friction Stir Welding (FSW) were 5052 H32 and 6061 aluminium alloys. Figure 4 shows the friction stir welding machine in which the experimental work was carried out. Rolled aluminium alloys plates of 150 mm × 50 mm x 3 mm are clamped tightly in the fixture. Process parameters such as tool rotational speed, table traverse speed and axial load are employed in this work. Table traverse speed (20-30 mm/min), axial load (10-14 kN) and the tool rotational speed (1000 – 2000 rpm) are varied.

Figure 4 shows the step of friction stir welding machine Square butt welding of aluminium alloys are carried out semi automatically on a indigenously build FSW machine (M/s RV Machine Tools, Coimbatore, India). The FSW Tool was made of high carbon and high chromium steel and is shown in figure 3. The tool had a shoulder diameter of 20 mm and pin length of 2.7 mm. The pin profile was tapered cylindrical with a diameter of 5 mm at the shoulder end and 3 mm at the free end.

The rolling directions of the plates was kept parallel to the welding direction. The faying surfaces were thoroughly cleaned with acetone prior to welding.

Figure 4 Set up of Friction Stir Welding Machine

Figure 5 shows the images of joined samples using box behnken design.

Figure 5 Friction stir welded plates

In the present study, the three-level and three-factorial Box– Behnken design was chosen for finding out the relationship between tensile strength, hardness and impact strength. This model has an advantage that permits the use of relatively few combinations of variables for determining the complex response function. The levels of the variables were coded as -1 (low), 0 (central point or middle) and 1 (high) as shown in the table Table 3. A total of 15 experiments are carried out with 3 centre point using the Box–Behnken design. Based on the literature and trial experiment, parameters range was selected and the actual design of matrix is shown in Table 4.

Table 3 Process Parameters and Their Levels

Parameters	Levels		
	-1	0	1
Tool rotational speed (rpm)	1000	1500	2000
Table traverse speed (mm/min)	20	25	30
Axial load (kN)	10	12	14

Table 4 Box Behnken Experimental Design

A	B	C	Total rotational speed (rpm)	Table traverse speed (mm/min)	Axial load (kN)
-1	0	-1	1000	25	12
0	0	0	1500	25	12
0	-1	1	1500	20	14
0	0	0	1500	25	12
0	1	-1	1500	30	10
1	0	-1	2000	25	10
1	0	1	2000	25	14
0	-1	0	1500	20	12
-1	0	1	1000	25	14
0	1	1	1500	30	14
-1	1	0	1000	30	12
0	-1	-1	1500	20	10
1	-1	0	2000	20	12
1	1	0	2000	30	12
-1	-1	0	1000	20	12
-1	0	1	1000	25	14

5. RESULT AND DISCUSSIONS

The output responses data for the tensile strength, hardness and impact are given in Table 5. MOORA optimization method is applied to find out the optimal process parameters. The normalization of the output responses is done according to the Equation 2. After that the normalized assessment values were calculated. The MOORA index of the assessment values is calculated and ranked according to the highest value of the MOORA index. Table 6 shows the normalized assessment values and its ranking.

Table 5 Experimentally Measured Data of Output Responses

Total rotational speed (rpm)	Table traverse speed (mm/ min)	Axial load (kN)	Tensile strength (MPa)	Hardness (HV)	Impact (J)
1000	25	12	220.4	115.1	2
1500	25	12	155.6	123.2	3
1500	20	14	138.9	115.53	3
1500	25	12	107.5	113.75	2
1500	30	10	134.5	116.7	3
2000	25	10	161.3	125.06	3
2000	25	14	109.4	127.2	2
1500	20	12	194.4	129.16	2
1000	25	14	234.9	138.96	3
1500	30	14	158.7	115.8	3
1000	30	12	222.2	116.7	1
1500	20	10	250.1	127.7	2
2000	20	12	109.3	121.16	2
2000	30	12	161.3	124.23	3
1000	20	12	218.6	135.23	2

Table 6 Normalized Assessment Values and Its Ranking

Total rotational speed (rpm)	Table traverse speed (mm/ min)	Axial load (kN)	MOORA Index (y_i)	Rank
0.3196	0.2411	0.2085	0.7692	8
0.2256	0.2581	0.3128	0.7965	6
0.2014	0.2420	0.3128	0.7562	10
0.1559	0.2383	0.2085	0.6027	15
0.1950	0.2445	0.3128	0.7523	11
0.2339	0.2620	0.3128	0.8087	4
0.1586	0.2665	0.2085	0.6336	13
0.2819	0.2706	0.2085	0.7610	9
0.3406	0.2911	0.3128	0.9445	1
0.2301	0.2426	0.3128	0.7855	7
0.3222	0.2445	0.1043	0.6709	12
0.3627	0.2675	0.2085	0.8387	2
0.1585	0.2538	0.2085	0.6208	14
0.2339	0.2602	0.3128	0.8069	5
0.3170	0.2833	0.2085	0.8088	3

The optimal process parameters using multi objective MOORA based method is found to be at tool rotational speed of 1000 rpm, table traverse speed of 25 mm/min and Axial load of 14 mm respectively.

6. CONCLUSION

In the present work aluminium alloys 5052 H32 and 6061 are successfully joined using friction stir welding. The effect of tool rotational speed, table traverse speed and axial load were investigated. The experiments are conducted based on the box behnken design. The optimum process parameters were predicted using the Multi-objective optimization on the basis of ratio analysis (MOORA) method.

The following conclusions were made based on the series of experiments and analysis of the results:

- The optimum process parameter found using MOORA method are as follows (i) tool rotational speed of 1000 rpm, (ii) table traverse speed of 25 mm/min and (iii) axial force of 14 kN respectively.
- The tensile strength, hardness and impact strength of the optimized parameters are 234.9 MPa, 138.96 HV and 3 J respectively

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