Optimization of Friction Stir Welding Process of Dissimilar Aluminium Alloy using Multi Criteria Decision making Approach

Urmila H. Dakave[1], Sachin K. Patil[2]

[1]PG Student, Dept. of Mechanical Engineering, RIT, Islampur, Maharashtra, India
[2]Professor, Dept. of Mechanical Engineering, RIT, Islampur, Maharashtra, India

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Abstract - *Friction stir welding is a newly developed welding technique which can be used for joining of similar and dissimilar metal joining. This technique produces the high quality weld. In this experimental work dissimilar aluminium alloy AA6082 –AA1100 series joined by friction stir welding process. The FSW tool geometry and process variables perform an important role in governing the joint strength. Process parameters selected such as Rotational speed, welding speed, shoulder diameter and responses as tensile strength, microhardness. For optimization Multi criteria decision making approach used as for calculating weighting method Criteria Importance through Inter-criteria Correlation (CRITIC) method is attempted along with TOPSIS approach.*

Key Words: FSW, Aluminium alloy, Process parameters, MCDM, TOPSIS

1. INTRODUCTION

Welding is a joining process of two or more workpieces of the similar or dissimilar materials which are heated and consequently melted together by the application of heat or pressure or both and with or without addition of filler material between gaps of workpieces to obtain uniform closer to base material like structures [1]. Friction stir welding (FSW) a new metal joining process was originally developed in UK in 1991 at The Welding Institute (TWI) as a solid-state joining technique, and which was initiated by applied to aluminum alloys [2] [3].

The uniqueness of FSW welding process is a non-consumable rotating tool which is specifically designed pin and shoulder get plunged into the adjoining edges of sheets or plates to be joined and movement of this tool traversed lengthwise the line of joint. The tool performance based upon two primary functions start with heating of workpiece as well as movement of material to produce the joint. The heating is generated by friction between the tool and the workpiece and plastic deformation at the involved joining faces zone of workpiece [4]. The heating of specified area the material around the pin and process of combination of tools rotary and translator motion leads to movement of material from the front side of the pin to behind the pin. Overall result of this process a joint produced during this action is a 'solid state' with limited melting at the contacting zone. Due to the variant geometrical features of the tool, the material movement nearby the pin can be relatively intricate [5].

Various fusion welding techniques or processes like TIG and MIG are used to weld aluminium, but the maximum joint efficiency observed between the ranges of 50–60 % of the base metal strength. Many researchers have successfully worked with weld combination of Al–steel using FSW [6– 8]. Researchers have obtained a weld efficiency increased up to 80–85 % of the strength of aluminium. For the manufacturer the working interesting challenge is to select appropriate welding process parameters along with tool geometry for getting good quality of weld [9, 10].

Solution to this problem has been taken up by many researchers who have investigated and optimized process parameters using the Taguchi method [11–14] and response surface methodology (RSM) [15–17] concepts for improving the quality of weld. These different techniques are furthermost suitable for single-response optimization problem, but most of industries situations faces the multi-response problem.

S. Sudhagar have worked on A Multi Criteria Decision Making approach for process improvement in Friction Stir Welding of Aluminium Alloy Grey Relational Analysis and Technique for Order Preference by Similarity to Ideal Solution apply to find out the optimal solution process parameter which will provides maximum value of all focused responses. Result is obtained through both techniques and the optimum conditions are tool rotational speed of 1000rpm, welding speed of 80mm/min and tool offset at 0mm [18].

D.Vijayan1, V. Seshagiri Rao has studied Optimization of friction stir welding process parameters using RSM based Grey–Fuzzy approach. The results indicate a RSM based fuzzy grey relational approach improving tensile properties of FS welded AA2024 and AA6061 aluminum alloys when comparing to conventional grey relational approach. A quadratic relationship was also established between the process parameters and fuzzy grey relational grade [19].

Subramanya R Prabhu used Multi Response Optimization of Friction Stir Welding Process Variables using TOPSIS approach. Process variables such as tool revolving speed, tool traverse speed and the tool pin profile are optimized with multiple responses such as % elongation, tensile strength and hardness. In the present study a technique for order preference by similarity to ideal solution (TOPSIS). The optimal solution reveals that the multiple response characteristics of the FS welded AMCs can be improved through the TOPSIS approach [20].

Therefore, there are several researches done on decision making methods available in the Multi criteria decision making methods (MCDM) such as grey relation analysis (GRA), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), FUZZY TOPSIS, involved in solving engineering problems [21, 22]. Among these methods, TOPSIS and GRA have been found to be highly effectiveness in solving MCDM problems, as it offers a simple calculation that involves less calculation time and the values are close to the process parameters [23]. TOPSIS is MCDM method found to be the most successful in obtaining optimum solutions. TOPSIS system has advantages that include easy understand ability, and as a simple computational technique with easy implementation. TOPSIS method was applied in various fields such as charging stations, computer networks, solar farms and process parameter selection in manufacturing [24].

Numerous studies defines the TOPSIS approach for optimal solution but the less work was observed on using a weight defining criteria methods which can be combined with the TOPSIS to get the closely observed weighting and applying the TOPSIS approach to find out the process output parameters based on optimal referencing as a multi response optimization [25]. Weighting Methods for Multi-Criteria Decision Making Technique which are based upon many divisional work criteria considerations as subjective methods, objective methods, The present work emphasized on the use of these weighting methods in determining the criteria preference of each criterion to bring about desirable properties and in order to establish and satisfy a multiple measure of performance across all the criteria selected by identifying the best options possible [26].

In this present work is an attempt to select the optimum process parameters of experimentation on friction stir welding of dissimilar aluminium alloy AA6082 and AA1100 based Weighting Methods for Multi-Criteria Decision Making approach. In this study, three parameters namely, rotation speed, welding speed and shoulder diameter have been considered for the present study. Ultimate tensile strength, hardness and percentage of elongation have been considered as important issues in weld joint formation. In optimization Criteria Importance through Inter-criteria Correlation (CRITIC) method is attempted through TOPSIS approach.

2. MATERIALS AND METHODS

2.1 Material

For dissimilar welding joint of aluminium alloys selected materials are AA 1100 Aluminium is 1000 series aluminium alloy. It is pure aluminium with a minimum 99% aluminium content. AA 1100 is widely used in the chemical and food processing industries also used for electrical bus bars and bus bar supports. It is non heat treatable aluminium alloy. Another material is the AA 6082 aluminium alloy is an alloy in the wrought aluminium-magnesium-silicon family 6000 or 6xxx series. Typically, the 6xxx alloys have good formability and good weldability. Chemical composition of both base metal is shown in following Table 1

Table 1 Composition of AA1100 aluminium alloy of 1000 series

Element	AA1100 content %	Element	AA6082 content %
Al	99	Al	95.2-98.39
Si+Fe	0.68	Si	0.7 - 1.3
Cu	0.2	Fe	0.5max
Mg	0	Cu	0.1
Mn	0.001	Mg	0.6 - 1.2
Zn	0.02	Mn	0.4 -1.2
Ti	0.02	Zn	0.2
Ca	0.02	Ti	0.1
Pb	0.02	Cr	0.25
Zr	0.003	Residuals	0.15

Plates were cut and sizing into size of 100 × 50 × 5 mm for experimentation. Tool material selected was AISI H13. It is a chromium-molybdenum hot-worked air hardening steel and is known for good elevated-temperature strength, thermal fatigue resistance, and wear resistance [27]. In addition to friction stir welding aluminum alloys, H13 tools have been used to friction stir welding due to its better performance even at high temperatures. Hardness of the tool is between 45 to 55 HRC. The geometry of tool is fabricated of pin shape straight cylindrical. The tool geometry variation kept at shoulder diameters. The dimensions are Shank dia. = 16 mm

Pin length =4.7 Pin dia: 5mm, Shoulder dia: D1-20, D2-22, and D3-24 as shown in Fig.1

Fig.1 Straight cylindrical probe FSW Tool

For experimentation fixture used is of M.S. plate provided with groove slot that hold the materials to the backing plate should be placed as close to the joint as possible to ensure that the work pieces are held in place during the welding procedure.

2.2 Experimentation

The design of experimentation was done by using the Taguchi L9 orthogonal array with the help of MINITAB 19 software. Using the process parameters and levels as shown in Table 2

Table 2: Process parameters and levels

Parameters	Levels		
	1	2	3
Rotational speed (RPM)	900	1200	1500
Welding speed (mm/min)	25	35	45
Tool Shoulder Diameter(mm)	20	22	24

Experimentation were preformed according to L9 array. By changing the process parametric values. Tensile test specimens are prepared from welded joints and the FS welded part as per the ASTM E8 standard. From each FS welded joint three specimens were taken in a direction perpendicular to the joint line. Tests are conducted using universal testing machine shown in Figure 2 and their UTS and % of elongation were measured. The geometry of the tensile test specimen is depicted in Figure 3. The hardness of the FS welded joint was measured using Vickers macro hardness tester with an indentation load of 0.5 kg for 12 sec. Test was carried out at the middle region across the weld at 3mm interval on both side of the weld line.

Figure 2 computerized Universal testing machine

Figure 3 ASTM standard sample

2.3 Optimization Method

2.3.1 Criteria Importance through Inter-criteria Correlation (CRITIC) Method

The criteria importance through inter criteria correlation (CRITIC) method is based on the standard deviation proposed by Diakoulaki et al. (1995) [28] which uses correlation analysis to measure the value of each criterion.

Step 1 : Calculate the normalized matrix

For benefit criterion Pij= ((y_ij)-y_j min)/(yj max- yj min) ,i=1....m, j=1......m ....(Eq.1)

For minimization criterion Pij= (yi max-yij)/(yj max- yj min) ,i=1....m, j=1......m ......(Eq.2)

Step 2 Compute a linear correlation coefficient between the criteria values in the matrix

$$Vjk = \frac{\sum_{i=1}^{m}(\text{pij}-\overline{\text{pj}})(\text{pik}-\overline{\text{pk}})}{\sqrt{\sum_{i=1}^{m}(\text{pij}-\overline{\text{pj}})^2 \sum_{i=1}^{m}(\text{pik}-\overline{\text{pk}})^2}} \;, j = 1 \ldots \ldots n \text{ ......(Eq.3)}$$

Step 3 Calculate the weight of the criteria

$$\beta j = \sigma j \sum_{K=1}^{n}(1 - Vjk) \;;\; j = 1 \ldots \ldots . n \text{ .....(Eq.4)}$$

$$wj = \frac{\beta j}{\sum_{k=1}^{n} \beta k} \text{ ......(Eq.5)}$$

Step 4 Calculate the weighted matrix

wj * pij ......(Eq.6)

2.3.2 TOPSIS: Technique for order preference by similarity to ideal solution

The TOPSIS method used for optimizing the process parameters was broken down into steps as presented herein-under and adopted by Wang [29].

Step 5: Calculating positive A+ and Negative A- ideal solutions

To calculate the optimal value from the weighted matrix no Positive-Ideal solution (A+) and Negative-Ideal solution (A−) for each parameter of the weighted normalized matrix calculated using the below expressions

$$A^{+} = \begin{cases} (\tilde{v}_1^{+}, \tilde{v}_2^{+}, \dots\dots, \tilde{v}_n^{+}) = \{(\mathrm{Max}_i\, v_{ij} \mid i = 1 \dots m, j = 1 \dots n)\} = \text{for maximization} \\ (\tilde{v}_1^{-}, \tilde{v}_2^{-}, \dots\dots, \tilde{v}_n^{-}) = \{(\mathrm{Max}_i\, v_{ij} \mid i = 1 \dots m, j = 1 \dots n)\} = \text{for minimization} \end{cases}$$
....(Eq.7)

$$A^{-} = \begin{cases} (\tilde{v}_1^{+}, \tilde{v}_2^{+}, \dots\dots, \tilde{v}_n^{+}) = \{(\mathrm{Max}_I\, v_{ij} \mid i = 1 \dots m, j = 1 \dots n)\} = \text{for maximization} \\ (\tilde{v}_1^{-}, \tilde{v}_2^{-}, \dots\dots, \tilde{v}_n^{-}) = \{(\mathrm{Max}_I\, v_{ij} \mid i = 1 \dots m, j = 1 \dots n)\} = \text{for minimization} \end{cases}$$
....(Eq.8)

Step 6: Calculating differences for each alternative from A+ and A- and closeness coefficient CCi using following formulas and applied TOPSIS

Distance from A+ $si^{+} = \sqrt{\sum_{j=1}^{m}\left(v_{ij} - v_i^{+}\right)^2}$, $i = 1 \dots . n$ ....(Eq.9)

Distance from A− $si^{-} = \sqrt{\sum_{j=1}^{m}\left(v_{ij} - v_i^{-}\right)^2}$, $i = 1 \dots . n$ ..(Eq.10)

The similarities or closeness coefficient $CC_i = \frac{S_i^{-}}{S_i^{+} - S_i^{-}}$

..(Eq.11)

Step 7 Rank the preference order– A set of alternatives can now be preference ranked according to the descending order of CCi

3. RESULT

After performing designed experiments and testing the weld joint there corresponding result shown in Table 5 where

Rs- Rotational speed(RPM), Ws- Weld speed(mm/min), Sd- Shoulder dia. (mm), Ts- Tensile strength N/mm², MH- Microhardness no, E%- percentage of elongation

Table-3: Process parameter and resulted mechanical properties

Exp. No.	Rs	Ws	Sd	Ts	MH	E%
1	900	25	20	66	34	27
2	900	35	22	78	96	31
3	900	45	24	90	58	19
4	1200	25	22	113	94	38
5	1200	35	24	88	49	19
6	1200	45	20	109	59	33
7	1500	25	24	89	66	41
8	1500	35	20	103	45	40
9	1500	45	22	111	78	35

As resulted data of responsive parameter first of all critic method was applied as per the procedure given in the section 2.3.1 which gives proper resulted matrix that it weighted matrix of responsive parameters as shown in table 4. It was calculated by applying the weightages to each normalized matrix resulted data to get the particular weightage of each responsive parameter corresponding to result of responsive parameter. According to calculations weighted matrix this matrix the applied with the TOPSIS approach to get the positive and the negative Ideal solutions, where the responsive parameters maximization or minimization was considered and ideal solutions was calculated as shown in table 5

Table -4: Weighted matrix by CRITIC method

Exp. No.	Ts	MH	E%
1	0.00000	0.00000	0.26148
2	0.07534	0.28157	0.18677
3	0.15068	0.10739	0.42335
4	0.29508	0.27255	0.06848
5	0.13812	0.06723	0.41713
6	0.26996	0.11191	0.14942
7	0.14440	0.14394	0.00000
8	0.23229	0.05054	0.02490
9	0.28252	0.19945	0.11829

Table-5: Positive and negative ideal solutions of similarity

Responses	Positive Ideal solution A+	negative Ideal solution A-
Tensile strength	0.29508	0.00000
Microhardness	0.28157	0.00000
Elongation %	0.00000	0.42335

Using ideal solutions and the weighted matrix , distance from Positive and negative solution Si+, Si- ,Calculation of Closeness coefficient CCi and alternatives preference ranking was done as per values as shown in table 6

Table-6: TOPSIS applied on each Weighted value

Experiment no	Si+ (Distance from A+)	Si (Distance from A-)	closeness coefficient (cci)	Rank
1	0.48448	0.16187	0.25043	8
2	0.28839	0.37540	0.56554	6
3	0.48002	0.18503	0.27822	7
4	**0.06908**	**0.53599**	**0.88584**	**1**
5	0.49454	0.15374	0.23715	9
6	0.22747	0.40055	0.63780	5
7	0.20407	0.46989	0.69721	3
8	0.24070	0.46398	0.65842	4
9	0.14455	0.46115	0.76135	2

From above table results of optimized responsive parameters it was found that 4th no experiment was ranked first It means that it was the optimal solution of process parameters as it gives the closeness coefficient value nearer to less than one. And this result shows process parameters levels as per 4^{th} experiment gives better responsive parameters.

Confirmation Test:

As per 4th experiment parameters confirmation test was carried out rotational speed 1200rpm, weld speed 25 mm/min and shoulder dia. as 22 mm. the specimen prepared was tested for parameters was tensile strength, microhardness and elongation %. According to it result found as Tensile strength as 115 mpa, microhardness 82 Hv and elongation as 35%. The results found were closer to the optimal solutions of the responsive parameters.

4. DISCUSSION

1st rank was obtained to experiment no. 4 Weldment has the best weld properties of Vickers microhardness Number of 94 HV, Ultimate Tensile Strength of 113 MPa closer and maximum than the base metal strength, and Percent Elongation of 38 % with corresponding process parameters of Rotational of 1200 rpm , weld speed of 25 mm/ min, and the shoulder diameter 22mm. This indicates that to produce weld of an acceptable quality, the process parameters of weldment 4th should be applied. According to the conformation test result found was closer to optimal solution. The method adopted was CRITIC which gives result Criteria Importance Through Inter-criteria Correlation when weights are calculated and used through TOPSIS. This combination of method gives better result based on correlation coefficient.

5. CONCLUSION

In this work the FSW welding of dissimilar aluminium alloy process was optimized for multi responses parameters. The main aim was to apply a weight calculating objective method approach CRITIC which gives result Criteria Importance Through Inter-criteria Correlation based weights which gives the optimal levels of parameters when applied within the TOPSIS. For multi-response optimization of focused responses tensile strength, hardness and percentage elongation, optimum values were found out to be 1200 rpm rotational speed, 25 mm/min weld speed and 22 mm shoulder diameter for AA6082 and AA1100 Materials FSW welding. It is the recommended levels with the controllable parameters of FSW welding process as the minimization of the percentage of elongation and maximization of ultimate tensile strength and hardness of the weld.

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BIOGRAPHIES

Miss. Urmila Harish Dakave.
PG, Rajarambapu Institute of Technology,
Research interests:
PLC programming, Manufacturing processes, welding techniques, material handling equipments

Dr. Sachin K. Patil
HOD, Mechanical Engg., RIT, Rajaramnagar Islampur
Ph.D. (2015)SVNIT, Surat
Research Area Production and Operation Management Decision Support Models Planning, Scheduling and Control Problems of Manufacturing System MCDM in Fuzzy Environment Logistics and Supply Chain Analysis Computational Intelligence in Manufacturing and Logistics Knowledge Management Computer Integrated Manufacturing“