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ANALYSIS ON MULTIPLE RESPONSE OPTIMIZATION OF FRICTION STIR WELDING PARAMETERS AA7075-T6 ALLOYS USING PCA AND GRA

M.VISHNU, SHABANA AZMI

Sree Dattha Institute of Engineering and Science Hyderabad Telangana

Abstract

Friction Stir Welding is a variation of friction welding method. Accomplishing the optimal processing parameters for the best probable design is still a challenging task. This paper presents a novel methodology for the optimization of welding parameters on dissimilar friction stir welded joints between AA7075-T6 aluminum alloys with multiple responses. In this study, welding parameters namely rotational speed, welding speed and pin profiles are optimized with the considerations of multi responses such as Ultimate Tensile Strength (UTS) and Hardness (H). L27 Orthogonal array was taken to conduct the experiments with the range 700 – 1100 revolutions per minute (rpm) for rotational speed and with welding speed from 20, 40 & 60 millimetre/minute (mm/min). These methods show a good convergence with the trial and the optimum process parameters combinations, where the maximum Ultimate Tensile Strength and the Hardness are obtained.

Keywords

Friction Stir Welding (FSW); Grey relational analysis (GRA),Principle compotent anaysis (PCA),AA7075.

1. INTRODUCTION

Friction Stir Welding (FSW) was introduced in 1992 as a safe, state-of-the-art welding process by The Welding Institute (TWI) in the United Kingdom (Mishra et al. 2013). The spinning and passing cylindrical tool with a profile pin in FSW "moves" the connected surfaces using frictional and adiabatic heat. Figure 1.1 depicts the friction stir welding process schemes. The rotary tool performs two main functions: (a) heating the work piece and (b) moving the plasticized result to the junction. The heating process is accomplished through friction between the tool and the work piece. This localized heating softens the material around the moving pin, and the combination of tool rotation and motion results in the front-to-back plasticization of the pin. It is shown schematically in the below image.

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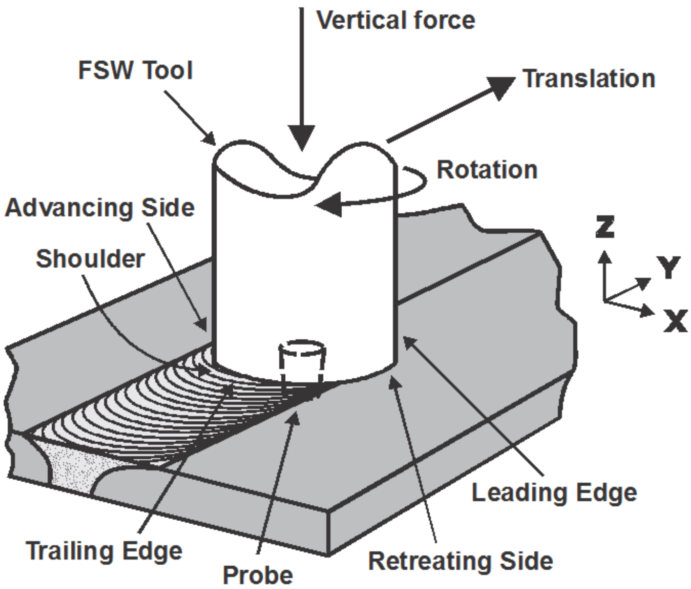

Fig 1. Friction Stir Welding Schematic Representation

Engineering judgment has been used until recently to optimize the multi-response problem. Aluminum alloys have low weldability by conventional fusion welding processes. Friction stir welding (FSW) is a promising alternative to traditional fusion welding techniques for producing high quality aluminum joints. A new hybrid artificial neural network (ANN) approach has been proposed in which Henry Gas Solubility Optimization (HGSO) algorithm has been incorporated to improve the performance of Random Vector Functional Link (RVFL) network. The HGSO-RVFL model was constructed with four parameters; rotational speed, welding speed, tilt angle, and pin profile [1]. [2]Conducted the experimental investigation, modelling, and optimization of friction stir welding process (FSW) to reach desirable mechanical properties of aluminum 7075 plates. Main factors of process were tool pin profile, tool rotary speed, welding speed, and welding axial force. Four factors and five levels of central composite design have been utilized to minimize the number of experimental observations. Results indicated that the tool with square pin profile, rotary speed of 1,400 RPM, welding speed of 1.75 mm/s, and axial force of 7.5 KN resulted in desirable mechanical properties in both cases of single response and multiresponse optimization. This paper deals with the selection of the optimal process parameters for the FSW of the AA6082 aluminum alloy. Three welding parameters, namely tool plunging, rotational speed and welding speed, have been handled as independent variables for developing two mathematical models by means of a non-linear regression-based approach, with the aim of predicting both ultimate tensile strength and ultimate elongation of the welded joints [3]. The de-coupled thermo-mechanical model of the FSW process used in this work which consists of a transient thermal model and a quasi-static Elasto-plastic mechanical model, is simulated by utilizing the commercial finite element software ANSYS. In order to facilitate the automation of the optimization procedure both the models are implemented by means of the Parametric Design Language (APDL) of ANSYS. The model represents the welding of two flat plates by considering the bead on plate. The dimension of the workpiece is 300 mm x 100 mm x 3 mm [4]. In this study, a previously developed and validated three-dimensional steady state thermal model of FS welding of AA2024 – T3 plates has been used for evaluating the quality of the candidate solutions. It should be noted that this is a computationally expensive model and closed form formulations (i.e. analytical equations) for the underlying physics are not available, which forces us to use them sparingly during the optimization procedure. A mathematical correlation model, a surrogate in other words, is iteratively constructed to replace the FSW simulations and guide the search towards feasible and promising regions [5]. [6] Developed response surface methodology (RSM) to predict the tensile strength of friction stir welded AA7039 and compared with the ANN model. Considering central composite face centred design full replications technique a mathematical model was developed and three factors each at three levels were considered for experimentation.[7] proposed the hybrid RSM based Genetic Algorithm (GA) technique to optimize the FS welding process parameters on the tensile strength and micro-structural properties of dissimilar AISI 1020-ASTM A536 joints.To optimize the process parameter to achieve the better mechanical properties of FS welded AM20 magnesium alloy Taguchi - Grey relational analysis (GRA) was utilized by [8]. Welding speed, tool rotation speed, shoulder diameter and plunging depth were considered to design the experiment. Eight weld quality parameters, namely UTS, YS, % E, CS, bending angle, average hardness at the NZ, TMAZ and HAZ were measured.FS welded AA2219 alloys was fabricated to develop a mathematical model to predict the corrosion resistance by [9]. The welding parameters, such as tool pin profile, rotational speed, welding speed and axial force, were used to conduct the welding process.Reverse dual-rotation of FS welded high-strength 2219-T6 aluminum alloy was optimized by [10]. The authors reported that, better relationship was achieved between the process variables and the obtained tensile strength was obviously higher than the optimum tensile strength compared to conventional FSW and approaches the optimum tensile strength obtained by the underwater FSW.FS welded process were optimized for the aluminum alloys of AA6351 - AA5083 to maximize UTS also to develop an empirical model using RSM was investigated by [11]. The process parameters such as tool pin profile, tool rotational speed welding speed and axial force were

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considered mainly in the present study. Response surface graphs and contour plots were drawn to study the effect of FSW parameters on the UTS. [12]Proposed central composite design (CCD) and a mathematical was developed using RSM on FS welding of AA6061 - T6 aluminum alloy. The welding parameters such as tool rotational speed, welding speed and axial force were used to investigate the joint characteristics of FS welded AA6061 - T6 aluminum alloys.

2. MATERIAL TESTING & SPECIFICATIONS

Aluminium alloys AA7075 – T6 selected to fabricate dissimilar joints using the FSW process; where T6 refers to temper as solution heat treated, stretched and artificially aged. The friction stir welding machine from CIT(Coimbatore Institute of Technology) Coimbatore was used for welding of the plates. Both plates are 6.35mm in thickness. Chemical compositions and the mechanical properties of AA 7075 are shown in Tables 1 and 2 respectively. The following process parameters with each of three levels are considered for friction Stir Welding of Aluminum 7075-T6 alloy plates of 150 mm X 75 mm X 4 mm. Three different pin profiles Triangular, Circular and Rectangular tools were used, which were machined from EN31 & H13 tool steel.

Table 1. AA7075 Composition

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Percentage	0.04	0.17	1.4	0.04	2.4	0.20 – 0.21	5.7	0.04 – 0.05	Bal

Table 2. Mechanical Properties of AA7075

Yield strength	412 MPa
Ultimate tensile strength	488 MPa
% elongation at break	13.3
Fracture toughness	22.8 Mpa-m1/2
Brinell hardness	104
Young’s modulus	717x102Mpa
Poisson’s ratio	0.3
Strength to weight ratio	196 KN-m/kg

Experimental Work

The friction stir welding is carried out by placing the high strength aluminium alloy AA7075 at the retreating side (RS), and by keeping the T6 at the advancing side (AS); since, if the weaker alloy is placed at the RS, the fabricated weld will become weaker than when the weaker alloy is at the RS [5]. The transverse tensile specimens are prepared with reference to ASTM E8M-04 standard from the weldments.Previous research revealed that the Rotational Speed, Welding Speed, and Pin Diameter were major influencing aspects in FSW. As a result, the best working conditions for optimal joint preparation must be identified. For friction Stir Welding of Aluminum 7075-T6 alloy plates 150 mm X 75 mm X 4 mm, the following process parameters with each of three levels are examined. As a result, speed ranges of 700, 900, and 1100 rpm are chosen.

Fig 1. FSW Machine

Fig 2. Tools Used

Fig 3. FSW Welding of AA 7075 – T6

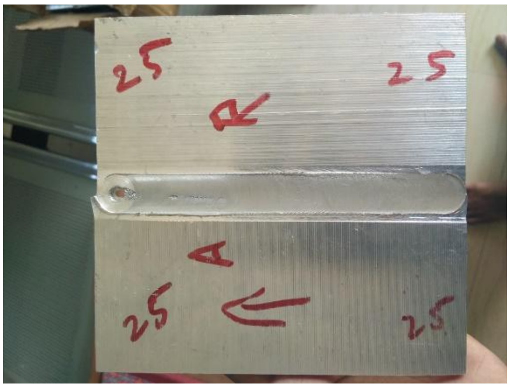

Fig 4. FS Welded Specimen

The ultimate tensile strength and the hardness are measured from the averages of the three specimens. The levels, the factors and the various parameters used are given in Table 3. Taguchi's L27 orthogonal array was used to design the experiments with three factors and three levels and the experiments conducted. Taguchi advocates use of orthogonal array designs to assign the factors chosen for experiment. The advantage of Taguchi method is that it uses a special design of orthogonal arrays to study the entire parameters space with only a small number of experiments. The experimental results for L27 orthogonal array are given in Table 4. Figure 1 & 3 represents the experimental setup and a welded plate during the experimentation.

Table 3. Dissimilar friction stir welding parameters with selected levels

S. No	Operating parameter	Symbol	Unit	Level		
				1	2	3
1	Tool rotational speed	R	rpm	700	900	1100
2	Welding speed	W	mm/ min	20	40	60
3	Tool pin profile	P	-	Trian gular	Squar e	Hexag on

Table 4. Experimental results for 27 orthogonal array (actual values)

S.No	Rotational Speed (rpm)	Weld speed (mm/min)	Tool pin profile	Tensile strength (MPa)	BHN
1	700	20	Triangle	172.065	90.73
2	700	20	Square	137.041	93.9
3	700	20	Hexagon	193.952	87.7
4	700	40	Triangle	257.496	95.73
5	700	40	Square	277.446	98.33
6	700	40	Hexagon	378.555	96.53
7	700	60	Triangle	267.602	105.67
8	700	60	Square	187.628	109.33
9	700	60	Hexagon	243.487	85.93
10	900	20	Triangle	327.679	104.67
11	900	20	Square	297.772	99.6
12	900	20	Hexagon	268.008	86.63
13	900	40	Triangle	259.145	103.67

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14	900	40	Square	368.917	93
15	900	40	Hexagon	267.619	92.83
16	900	60	Triangle	244.241	96.47
17	900	60	Square	264.797	104.67
18	900	60	Hexagon	113.857	93.9
19	1100	20	Triangle	317.387	97.2
20	1100	20	Square	266.277	86.77
21	1100	20	Hexagon	280.208	84.8
22	1100	40	Triangle	133.493	93.9
23	1100	40	Square	213.036	96.2
24	1100	40	Hexagon	55.176	105
25	1100	60	Triangle	382.243	106.67
26	1100	60	Square	286.453	100.5
27	1100	60	Hexagon	209.879	102.67

L27 Orthogonal Array was considered for number of experiments to be conducted with the help of Mini TAB Software to optimize the process parameters. Six variables (process parameters) with three levels have been taken. These values are displayed in table 5.

Table 5. Design of Data Matrix Values

Exp.No	A	B	C	D	E	F
1	1	1	1	1	1	1
2	1	1	1	1	2	2
3	1	1	1	1	3	3
4	1	2	2	2	1	1
5	1	2	2	2	2	2
6	1	2	2	2	3	3
7	1	3	3	3	1	1
8	1	3	3	3	2	2
9	1	3	3	3	3	3
10	2	1	2	3	1	2
11	2	1	2	3	2	3
12	2	1	2	3	3	1
13	2	2	3	1	1	2
14	2	2	3	1	2	3
15	2	2	3	1	3	1
16	2	3	1	2	1	2

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17	2	3	1	2	2	3
18	2	3	1	2	3	1
19	3	1	3	2	1	3
20	3	1	3	2	2	1
21	3	1	3	2	3	2
22	3	2	1	3	1	3
23	3	2	1	3	2	1
24	3	2	1	3	3	2
25	3	3	2	1	1	3
26	3	3	2	1	2	1
27	3	3	2	1	3	2

3. MECHANICAL CHARACTERIZATION (SEM)

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the surface topography and composition of the sample. The electron beam is scanned in a raster scan pattern, and the position of the beam is combined with the intensity of the detected signal to produce an image.

Specimens are observed in high vacuum in a conventional SEM in a variable pressure or elevated temperatures with specialized instruments. Morphological analysis was carried out at the room temperature to understand the microstructural interface and mechanism of failure of the new material AA 7075 – T6 using SEM. The samples having maximum and minimum values of tensile strength were selected for SEM analysis. Before taking the micrographs, selected samples were coated to enhance the conductivity. The SEM equipment is shown in the below figure 5.

Fig 5. Scanning Electron Microscope

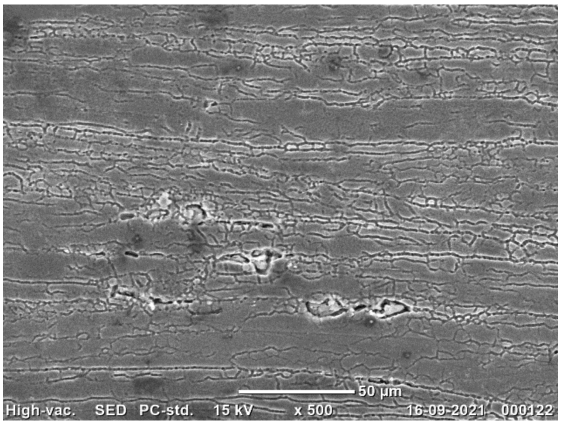

Fig 6. Microstructure at 500X

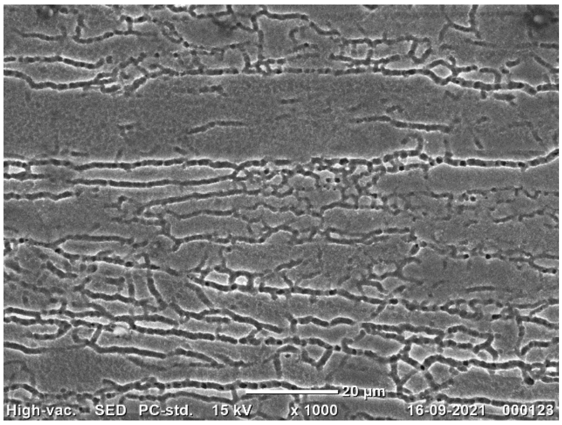

Fig 7. Microstructure at 1000X

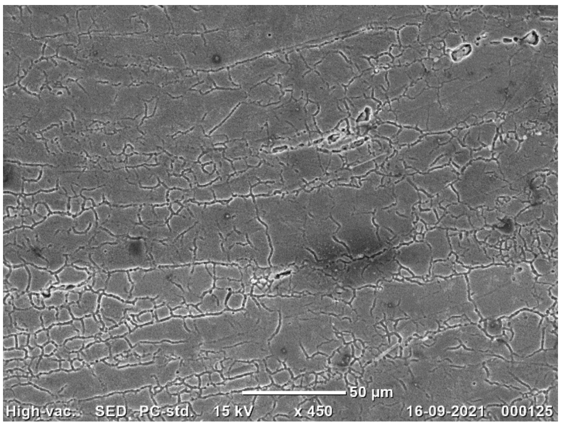

Fig 8. HAZ & TMAZ at 500X

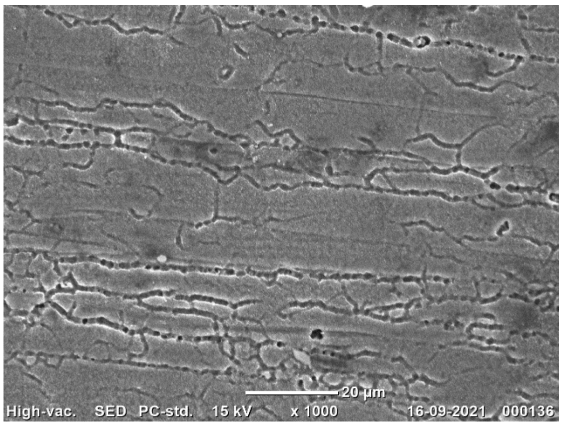

Fig 9. HAZ & TMAZ at 1000X

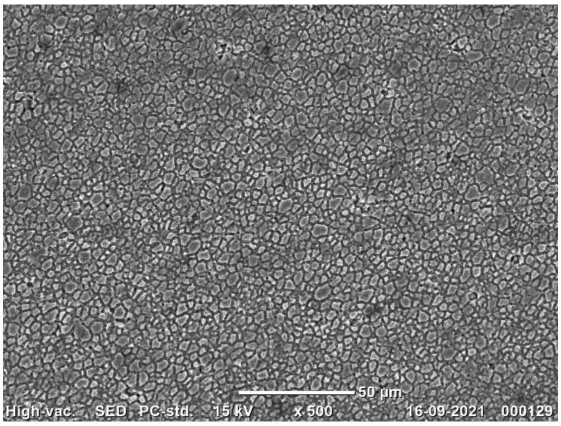	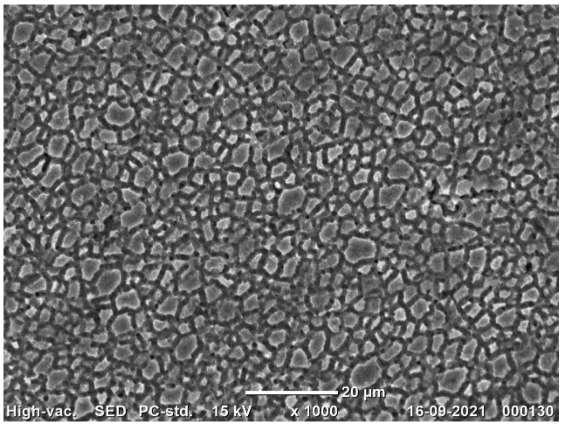
Fig 10. Stir Zone at 500X	Fig 11. Stir Zone at 1000X

The above figures shows the microstrucral representation of AA 7075 – T6 friction stir welded material. The figure 6 shows the microstructure at 500X and in fig 7 shows the microstructures at 1000X. The microstructures of the welded material shows voids and defects fig 6. The number of defects found in fig 6 are 4. But when we check the fig 7, it indicated clear microstructures of the welded specimen. After the welding, the upper zone has a very smooth contours whereas the lower regions is followed by larger cracks.

The figures 8 & 9 shows the microstructures at HAZ (Heat Affected Zone) & TMAZ (Thermo – Mechanical Affected Zone) of the welded specimens. The fig 8. Represents HAZ & TMAZ of the welded specimen which indicates 5 – 6 black spots and medium cracks followed from upper to lower regions at 500X. The fig. 9 represents HAZ and TMAZ of the specimen indicating only 1 black spot in the heat affecting zones with clear and good microstructures and this is found at 1000X.

The figures 10 & 11 shows the microstructures of the stir zones at 500 & 1000X. Where the fig 10. Shows the clear microstructures of the welded specimen with good flow of grains and there are 3 black spots found which are more reacted to Heat. The fig 11. Represents the clear microstructures of the welded specimen having semi coarse grains in its structure.

Conclusion

- In this work, a multiple response problem taken with three independent variables, and it was formulated by Grey Relational analysis method, Principal Component Analysis method, DEA Rank based method are compared by their own procedure using FSW experimental data. These methods can be used to predict the welding parameters within the experimental design

- The rotational speed, tool pin profiles are prominent factors which affect the welding of aluminium alloys.
- The tool pin profile is the most influencing factor in determining the multiple performance characteristics followed by rotational speed and welding speed.
- The best multiple performance characteristics was obtained from all methods with when friction stir welding of dissimilar aluminium alloys with the rotational speed 1100 rpm, welding speed 60 mm/min and the tool pin profile Hexagon.
- Different microstructures were obtained for the welded specimen at two different heat zones at a magnification of 500 & 1000X.
- Compared to 1000X magnification, 500X shows black spots, voids and crack defects in the heat affected zones.

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