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Multi Response Optimization of process parameters of friction stir welded AA6061 T6 and AA 7075 T651 Using Response Surface Methodology

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In this work friction stir welding of AAA 6061 T6 with 7075-T651 of 6mm thickness was carried out. A 31 run Central composite design was adopted to run the experiments. The process parameter ranges were identified based on trial runs. The optimization of the process parameters was done based on the results and plots obtained from Design Expert 10.0 software and the mathematical model was developed for the same. The microhardness tests were also studied. The advancing side was 6061 T6 due to its formability properties. Interference of each process parameters on the Tensile strength was obtained from the contour plots. The fitness was justified by Anova.

Keywords: Ultimate Tensile Strength, Anova, Mathematical Model, Response Surface Methodology

Introduction

The friction stir welding process has received worldwide attention and is being used for commercial purposes for joining aluminum alloys. A Farzadi *et al*[1] studied the joining of AA2024 and AA6061 Aluminum plates of 5 mm thickness. The change in process parameters produced defect-free welded joints. The ratio of the tool shoulder diameter and pin diameter was a primary factor. D. Venkateswarlu *et al*[2] analyzed that the good mechanical properties of FS weld joints were achieved by using Artificial bee colony algorithm to identify the process parameters. Kalemba-Rec *et al*[3] studied tool tilt angle and tool geometry using the response surface methodology (RSM) with central composite design (CCD) for dissimilar AA7075-AA6061 aluminum alloys. The metal at the advancing side effects temperature and strain rate during FSW A considerable quantity of work has been carried in various dissimilar Aluminum Alloy combinations. Since the tempering conditions have changed the Aluminum series used in this work has produced varying results thus making it a unique study from the already done work. And a systematic experimental design was built to get results that will help the industry to set process parameters to obtain better weldments and improve the quality of joints produced. And till now micro hardness analysis has not been reported.

Materials and methods

Aluminum alloy 7075 T651 is solution heat-treated and artificially aged. It is zinc-based alloy. Due to which the alloy has high impact strength thus used for ballistic applications. But has low toughness. The parameter range is as shown in Table 1.The tensile test specimens were cut as per ASTME standards. The specimen required was cut into 30*20 mm for the microstructure analysis. Then it was polished in the belt grinder. Further polishing was done using emery papers of the grade 4/0 3/0 2/0 1/0. Then after that fine polishing using twin disk polisher was done, which was followed by etching. And finally the microstructure was analyzed using the metallurgical microscope and the following microstructures were found. The indentation was made up to 10 mm (one indentation/mm) on either side of weld line of specimens at a load of 500 gms and for 15 seconds.

Development of the mathematical model

DESIGN EXPERT 10 software package was employed for the purpose of finding the various co-

Table 1 — Process parameters range used for DOE

Parameters	Units	Notations	Level				
			-2	-1	0	1	2
Tool pin profile	-	P	HEX	C	CT	S	TC
Tool rotational speed	rpm	N	3	4	5	6	7
Welding speed	mm/min	S	1400	1475	1550	1625	1700
Axial force	ton	F	3	4	5	6	7

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Table 2 — Anova for response surface quadratic model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Model	10272.79	14	733.77	2.94	0.0208	significant
A-tool profile	15.07	1	15.07	0.060	0.8090	
B-rotating speed	0.55	1	0.55	2.188E-003	0.9633	
C-traversing speed	119.97	1	119.97	0.48	0.4980	
D-axial load	646.47	1	646.47	2.59	0.1271	
AB	69.39	1	69.39	0.28	0.6052	
AC	161.93	1	161.93	0.65	0.4323	
AD	264.39	1	264.39	1.06	0.3187	
BC	1.85	1	1.85	7.411E-003	0.9325	
BD	0.66	1	0.66	2.662E-003	0.9595	
CD	0.94	1	0.94	3.770E-003	0.9518	
A^2	4752.16	1	4752.16	19.04	0.0005	
B^2	3927.87	1	3927.87	15.74	0.0011	
C^2	1975.30	1	1975.30	7.92	0.0125	
D^2	665.38	1	665.38	2.67	0.1220	
Residual	3993.03	16	249.56			
Lack of Fit	3396.06	10	339.61	3.41	0.0732	not significant
Pure Error	596.97	6	99.50			
Cor Total	14265.82	30				

Table 3 — Coefficient of R square

Std. Dev.	15.80	R-Squared	0.7201
Mean	170.20	Adj R-Squared	0.4752
C.V. %	9.28	Pred R-Squared	-0.4282
PRESS	20373.84	Adeq Precision	4.837

efficient for the response. The Anova Table 2 and 3 represent not significant factors. The coefficients' found to be insignificant were eliminated for the same. In RSM, the natural variables are transformed into coded variables which are dimensionless. The final mathematical model is given in the equation below.

$$YT\Sigma=+199.42-0.79* A-0.15* B-2.24* X+5.19* \Delta-2.08* AB+3.18* AX+4.07* A\Delta\chi-0.34* BX+0.20* B\Delta+0.24* X\Delta-12.89* A\perp 2-11.72* B\perp 2-8.31* X\perp 2-4.82* \Delta\perp 2$$

Results and Discussion

The contour plots display a discrete hill shape for indicating the possible interference of process parameters with responses. Locating the immobile point involves characterizing the response, whether it is maximum, minimum or a saddle point.The response surfaces of tensile behavior from Figure 1 a, b and c were analyzed. K.S. Anil Kumar *et al*[4] analyzed weld configuration and heat generation during friction stir welding of AA 7075 and AA 5083. M.M. Hasan *et al*[5] studied in A413 the base metal displayed tensile specimens failure. P. Sadeesh *et al*[6] studied that the rotational and traverse speeds and the penetration depth affected the microstructure and thus the properties. The corresponding FSW parameters for maximum UTS are Threaded cylindrical pin profile, tool rotational speed of 1550 rpm, traverse speed of 35 mm/min and axial force of 5 ton. P.S. Effertz *et al*[7] R.S.S. Prasanth *et al*[8] and Z.-J *et al*[9] H Aydin *et al*[10] reported that the increase in traverse speed and increase in rotational speed lead to reduction in heat generation and consecutively decrease in tensile strength due to improper material flow.

Hardness test

The Brinell's hardness for the specimen 1,4 and 5 was carried out and the following results were obtained. Run 10 specimen which used a cylindrical tool profile with a rotational speed of 1500 rpm and a travel speed of 18mm/min was found to have a hardness value around 106.8. Run 23 specimen which used a square tool profile with a rotational speed of 1600 rpm and a travel speed of 20mm/min was found to have a hardness value around 123.5.Run 11 specimen which used a threaded cylindrical tool profile with a rotational speed of 1700 rpm and a travel speed of 18mm/min was found to have a hardness value around 94.8 BHN.

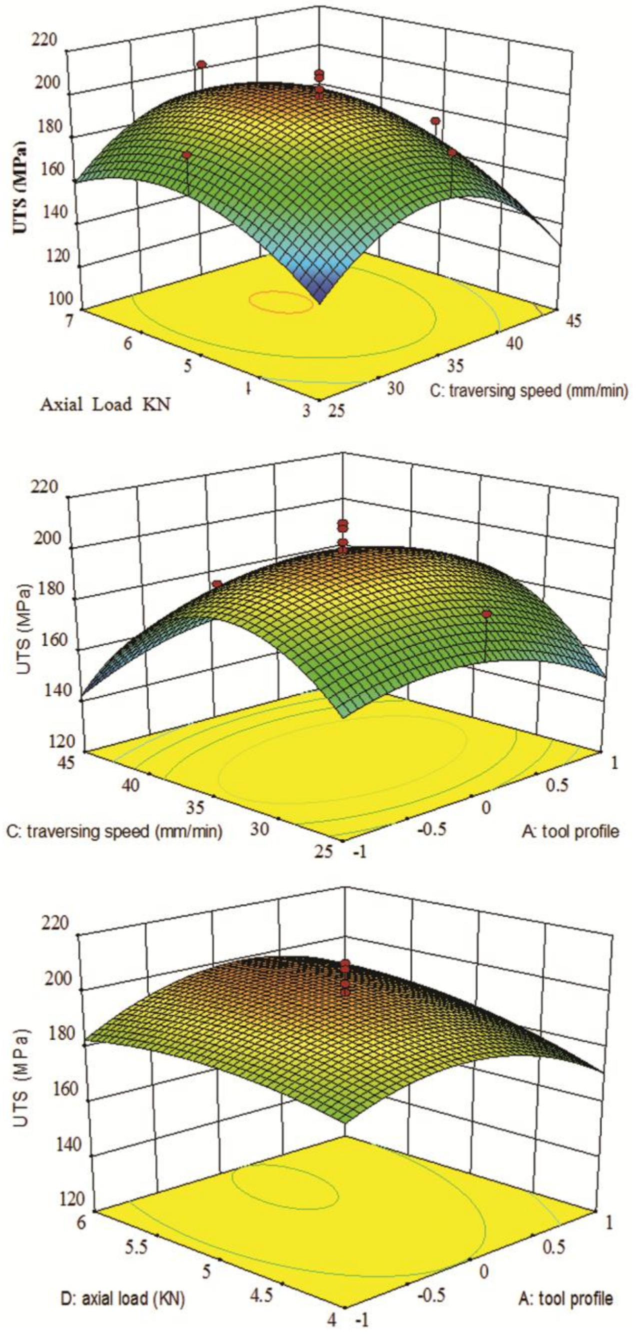

Fig. 1 — Response surface graph of a) axial load and traversing speed on UTS b) traversing speed and tool pin profile c)axial load and tool pin profile

Conclusion

Run 11 which used a threaded tool using the parameters rotational speed of 1700 rpm and travel speed of 18 mm/min showed the maximum tensile strength. Since onion rings were observed in the microstructure of run 11 which used the threaded tool, the material mixing was done perfectly in that set of parameters. Since the hardness test shows lower value for this specimen the better tensile strength is thus proved.For lower and higher rotational speed and traversing speed the tensile strength was found to be low due to higher and insufficient heat generation respectively.

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