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Investigation of friction stir welding parameters of 6063-7075 Aluminum alloys by Taguchi method

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Abstract

In this work, effect of some welding parameters such as rotational speed, travel speed and plates' position on microstructure and mechanical properties of Friction Stir Welded joint of 6063 and 7075 alloys was predicted via Taguchi method. Signal to Noise ratio (S/N) analysis indicated that maximum tensile strength achieved when rotational and travel speeds, and plates' position were chosen as 1600 rpm, 120 mm/min and Al7075 in advancing side (AS-7075), respectively. According to ANOVA analysis, it was observed that rotational, travel speed and plates' position have 59, 30 and 7 percent influence on tensile strength of joint respectively. Finally a model for tensile strength values based on FSW parameters was calculated which was also confirmed by experimental results.

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Keywords: 6063 and 7075 Al alloys; Friction stir welding; Taguchi; ANOVA.

1. Introduction

Parameters of friction stir welding process (FSW) such as geometry of tool and joint design have major influence on heat distribution, material flow pattern and created structures, which finally affects the quality of welded joints, Cavaliere et al. (2006). Lots of researches have been done about the effect of FSW parameters on mechanical and metallurgical properties of similar and dissimilar aluminum alloys joints ,Nansaarng and Chaivanich (2007), Azimzadegan and Serajzadeh (2010). But, few investigations ,Jayaraman et al. (2009), Lakshminarayanan and

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Balasubramanian (2008), Nourani et al. (2011) have been performed on formulization and optimization of effects of FSW parameters on mechanical and metallurgical properties. Taguchi is a useful method which, specify effectiveness of involved parameters on the main purpose of process. Taguchi method, have been used for optimization of metallurgical processes in past, Karnyabi-Gol and Sheikh-Amiri (2010), Anawa and Olabi (2008), Saigal and Leisk (1992). For example, Jayaraman et al. (2009) showed that vertical force has maximum influence on tensile strength of joint rather than other effective parameters of FSW process of A319 cast alloy, which are rotational speed, travel speed and vertical axis force. Their results illustrated that total effect of rotational and speed travel parameters on tensile strength of welded joint, is less than effect of vertical force. Whereas, Lashminarayanan and Balasubramanian (2008) showed that rotational speed plays more important role than travel speed and vertical force in increasing tensile strength of friction stir welded RDE-40 aluminum alloy joints. A performed investigation on dimensions of heat affected zone (HAZ) created in friction stir welded 6061 alloy joints, indicated that effectiveness of rotational speed, travel speed and vertical force on dimensions of HAZ are 47%, 14% and 38% respectively, Nourani et al. (2011). Beside time saving, costs of performed experiments will be reduced a lot by optimization and formulization of welding parameters for distinct alloys. Therefore, in this study, it has been tried to investigate the effect of rotational speed, travel speed and plates' position parameters on properties of dissimilar 6063-7075 alloys joint, so that the effectiveness of each parameter on tensile strength and optimal condition of friction stir welding process for 6063-7075 joints, could be determined.

2. Experimental design and procedure

Taguchi design with L9 orthogonal array which composed of 3 columns and 3 rows were employed to optimize the FSP parameters (Table 1). The selected FSW parameters for this study were: rotational speed (W), travel speed (V), plates' position (L). The Taguchi method was applied to the experimental data and the signal to noise ratio (S/N) for each level of process parameters is measured based on the S/N analysis. Regardless of the category of the quality characteristic, a higher S/N ratio corresponds to a better quality characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio, Roy (1990). A detailed ANOVA framework for assessing the significance of the process parameters is also provided. The optimal combination of the process parameters can be then predicted.

5 mm thickness 6063-T6 Al and 7075-T6 alloys plates was used as base material. A welding tool including a shoulder and a pin with diameters of 18 mm and 5 mm, respectively, was made from H13 steel. The tensile test samples were prepared in a perpendicular direction to the welding direction according to ASTM-E8-04 standard. The room temperature tensile tests were performed using a MTS-316 tensile machine with a strain rate of 1×10^{-3} s^{-1}.

Table 1. FSW parameters and design levels.

Parameters	Code	Unit	Level 1	Level 2	Level 3
A: Rotational speed	W	rpm	800	1200	1600
B: Travel speed	V	mm/min	80	120	160
C: Plates' position	L	AS or RS	AS-7075	AS-6063	-
AS: Advancing side, RS: Retreating side					

3. Results

3.1. Signal to noise ratio (S/N) analysis

In this study, tensile strength had been investigated as main parameter in order to achieve a joint with proper quality. Signal to noise analysis was used to minimize fluctuations in ultimate tensile strength values. Therefor final results of strength values were more applicable and comparable. Proper ratio of S/N was considered based on experiment, knowledge and perception of whole process. Purpose of this study was to achieve maximum tensile strength of joints for mentioned alloys. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio and for "higher the better" quality characteristics the S/N ratio is calculated using the formula 1, Roy (1990):

$$\frac{S}{N} = -10Log\ (1/n \sum_{i=1}^{R} \frac{1}{Y_{Hi}^2}) \quad (1)$$

Where n is the numbers of replicates of each experiment at same conditions and Y_{Hi} is the tensile strength of each sample in test number i.

According to Table 2, 9 main values for tensile strength and 9 corresponding values of S/N (orthogonal array OA) were obtained. Optimal combination of factors and levels were obtained by analyzing each calculated main values, in order to achieve the maximum tensile strength. The main value of tensile strength in Table 2 for each experiment was calculated by averaging three values of measured tensile strengths. Also, main and average values of tensile strength and S/N ratio in all levels were calculated and listed in Table 3. As its clear, higher values of S/N ratio of an experiment, corresponds to better quality of welded joint, Darwin et al. (2008). Therefore the optimal condition is a condition with maximum S/N ratio. Values of S/N ratio of tensile strength in different levels of used parameters are shown in Fig. 1. As shown in Fig. 1, value of tensile strength is maximum when rotational speed, travel speed and plates' position were in 3, 2 and 1 levels respectively, because, values of S/N ratios in these levels are maximum. Investigation of friction stir welded A319 alloy joint also has declared that maximum values of S/N ratio were obtained when rotational speed and travel speed values are 1200 rpm and 40 mm/min respectively, Jayaraman et al. (2009).

Table 2. Standard orthogonal arrays of 9 different groups following Taguchi's suggestion.

Test number	W (rpm)	V (mm/min)	L (AS or RS)	UTS (MPa)			S/N
1	800	80	AS-7075	98	95	100	39.780
2	800	120	AS-6063	102	97	94	39.789
3	800	160	AS-7075	88	91	84	38.842
4	1000	80	AS-7075	120	118	123	41.603
5	1000	120	AS-7075	106	108	103	40.473
6	1000	160	AS-6063	98	90	95	39.477
7	1600	80	AS-6063	115	113	121	41.303
8	1600	120	AS-7075	157	147	150	43.588
9	1600	160	AS-7075	139	140	145	43.000

Table 3. Main effects of the process parameters.

Process Parameter	Level	Mean			S/N ratio		
		W	V	L	W	V	L
	1	94.333	111.444	117.333	39.470	40.898	41.216
Average value	2	106.777	114.888	102.777	40.518	41.084	40.186
	3	136.333	111.111	-	42.630	40.636	-
Main effects	2 – 1	12.444	3.444	-14.556	1.048	0.185	-1.031
	3 – 1	42	-0.333	n/a	3.160	-0.262	n/a
	3 – 2	29.556	-3.777	n/a	2.112	-0.449	n/a

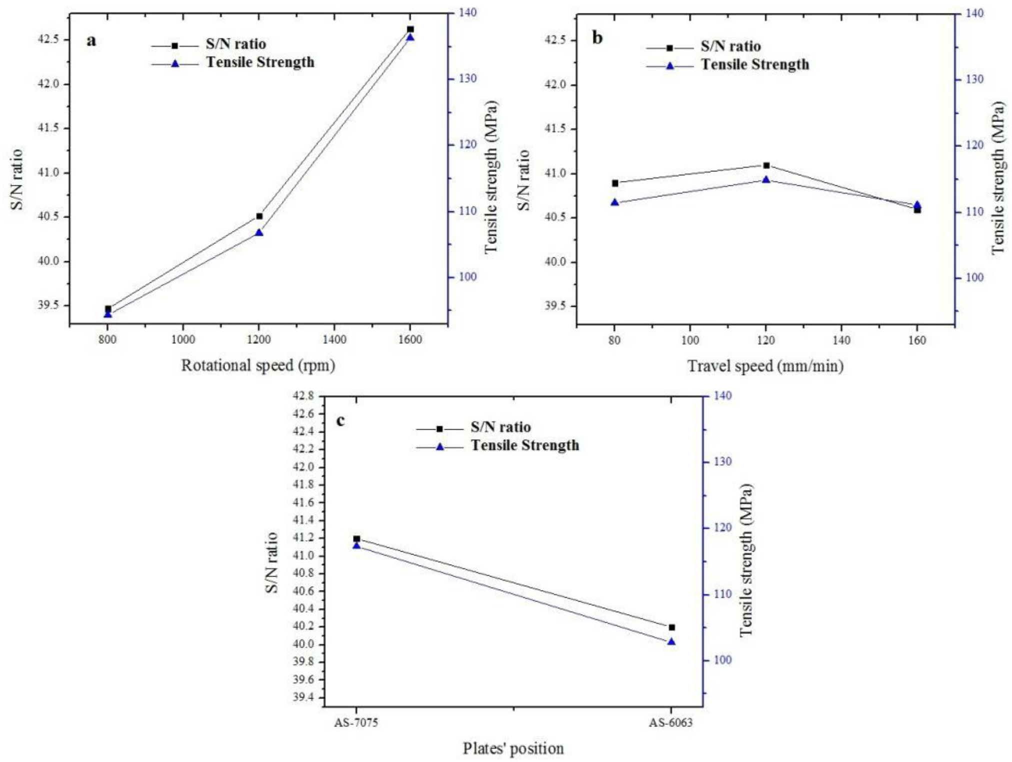

Fig. 1. The effect of parameters (a) W, (b) V and (c) L on tensile strength and S/N ratio of the responses.

3.2. ANOVA analysis of variance

Calculating the effectiveness of each parameter is possible by using variance analysis, Roy (1990). Main purpose of ANOVA analysis is to determine the most effective parameter on tensile strength of friction stir welded 6063-7075 alloys joint. Results of ANOVA analysis for S/N ratios and also main ratios are mentioned in Table 4. The value of F in Table 4 shows the effectiveness of each parameter on tensile strength of joint. How much the value of F is higher, and then higher fluctuations of that parameter will lead to higher effect on quality of joints properties. According to values of F, it's obvious that rotational speed, travel speed and plates' position have the most effect on tensile strength of joint, respectively. Percentage of distribution coefficient (P) is part of total changes observed in experiments which is attributed to effect of each parameter on results of strength. In fact, this factor (P) shows the capability of each parameter in reducing the variance. So, by optimum controlling of each parameter according to achieved value of P for that parameter, value of variance of whole process could be reduced. As shown in Table 4, values of Percentage of distribution coefficient (%P) for rotational speed, travel speed and plates' position parameters are 59, 30 and 7, respectively. As reported in previous studies, Jayaraman et al. (2009), Lakshminarayanan and Balasubramanian (2008), Nourani et al. (2011) rotational speed which owns maximum value of P, is the most effective parameter on tensile strength of joint. After rotational speed, travel speed and plates' position have most effect on strength of welded joint.

Table 4. ANOVA for tensile strength (S/N ratio and means).

Source	DOF	SS		V		SS'		F		P%	
		S/N ratio	Means	S/N ratio	Means	S/N ratio	Means	S/N ratio	Means	S/N ratio	Means
W	2	14.548	8377.187	7.774	4188.593	12.383	8181.408	56.183	55.452	59.069	58.435
V	2	5.245	2055.574	3.152	1141.372	5.113	2213.639	25.96	24.231	30.035	29.608
L	1	1.121	1271.141	0.637	1271.141	1.039	1173.252	4.14	5.101	6.705	7.225
Error	2	0.304	87.745	-	-	-	-	-	-	4.191	4.702
Total	7	21.220	11782.749	-	-	-	-	-	-	100	100

DOF: Degree of freedom, SS: Sum of squares, V: Variance, SS: Pure sum of square, F: Fisher distribution, P%: Percentage contribution

3.3. Estimation of best condition

The main purpose of this study is to identify important parameters and their effects on tensile strength of 6063-7075 alloys joint, created by FSW welding process. And according to maximum values of S/N ratio for each parameter as shown in Fig.1 and Table 2, optimal values for rotational speed, travel speed and plates' position were 1600 rpm, 120 mm/min and AS-7075 respectively. The optimal value of tensile strength will be achieved in such a condition that effective parameters positioned in their own effective levels. According to equation 2, Value of tensile strength for 6063 and 7075 FSW joint was estimated to be 143.59 MPa.

$$TS = RS3 + TS2 + PS1 - 2T \quad (2)$$

RS3 is the mean value of tensile strength for rotational speed in level 3, TS2 is the mean value of tensile strength for travel speed in level, PS1 is the mean value of tensile strength for plates' position in level 1 and T is the mean value of tensile strength of all experiments. Three samples have welded in optimum conditions for each parameter In order to investigate the exactness of estimations in this work. Resulting mean value of tensile strength for mentioned samples was 154 MPa which was so close to estimated value.

4. Conclusions

In this study, the effect of rotational speed, travel speed and plates positions on strength of dissimilar 6063-7075 joint was investigated by using Taguchi method and ANOVA analysis. Results of S/N analysis indicated that the optimal condition for dissimilar 6063-7075 joint is achieved when values of rotational speed, travel speed and plates' positions were 1600 rpm, 120 mm/min and AS-7075 respectively. In such condition, tensile strength of joint was 143.59 MPa. Finally ANOVA analysis indicated that effectiveness of rotational speed, travel speed and plates' position parameters on tensile strength of joint were 59%, 30% and 7% respectively.

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