Research Paper Engineering

Optimization Of Process Parameters For Friction Stir Welding Of Aluminium Alloy 6061 Using Anova.

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ABSTRACT

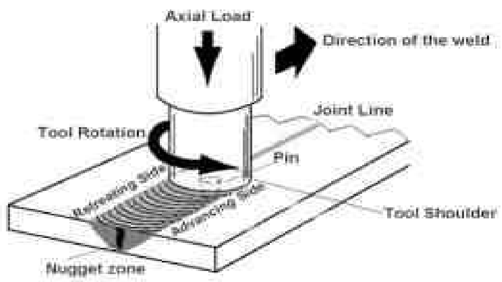
AA6061 aluminium alloy (Al-Mg-Si alloy) has gathered wide acceptance in the fabrication of light weight structures requiring a high strength-to-weight ratio and good corrosion resistance. Fusion welding of aluminum alloys poses certain problems like porosity, distortion due to high thermal conductivity and solidification shrinkage. Compared to the fusion welding processes that are routinely used for joining aluminium alloys, friction stir welding (FSW) process is an emerging solid state joining process in which the material that is being welded does not melt and recast. In the present work an attempt is made to study the feasibility of joining AA 6061 aluminium alloy by friction stir welding (FSW) technique. In addition ANOVA analysis with three factors is performed and results indicate that among the parameters considered (i.e., the tool rotation speed, welding speed, and the axial force), the most significant parameter on the tensile strength is rotational speed, followed by the axial force and welding speed.

Keywords : Friction stir welding, Aluminium Alloy, Rotational Speed, Welding Speed

Introduction

Friction Stir Welding (FSW) was invented at The Welding Institute (TWI) of the United Kingdom in 1991 as a solid-state joining technique and was initially applied to aluminum Alloys (Ref 1,2). The basic concept of FSW is remarkably simple. A non consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and subsequently traversed along the joint line. Figure 1 illustrates process definitions for the tool and work piece.

Figure 1 schematic diagram of friction stir welding



The tool serves three primary functions, that is, heating of the work piece, movement of material to produce the joint, and containment of the hot metal beneath the tool shoulder. Heating is created within the work piece both by friction between the rotating tool pin and shoulder and by severe plastic deformation of the work piece. The localized heating softens material around the pin and, combined with the tool rotation and translation, leads to movement of material from the front to the back of the pin, thus filling the hole in the tool wake as the tool moves forward. The tool shoulder restricts metal flow to a level equivalent to the shoulder position, that is, approximately to the initial work piece top surface. As a result of the tool action and influence on the work piece, when performed properly, a solid-state joint is produced, that is, no melting. In spite of the local micro structural inhomogeneity, one of the significant benefits of this solid-state welding technique is the fully recrystallized, equiaxed, fine grain microstructure created in the nugget by the intense plastic deformation at elevated temperature (Ref36).

Methods

The material used in this investigation was 6.35 mm thick rolled plates of AA6061 aluminum alloy. The aluminium plate dimensions of 50 mm (L) x 150 mm (W) x 6.35 mm (T) was used in the present study. Chemical composition and Mechanical properties are given in Table 1 and Table 2 respectively.

Table 1 chemical composition of Aa6061

Mg	Si	Fe	Cu	Cr	Mn	Zn	Ti	Al
0.8	0.6	0.5	0.3	0.25	0.15	0.2	0.15	bal

Table 2 mechanical properties of AA 6061

Yield strength (Mpa)	Ultimate strength (Mpa)	Elongation(%)	Reduction in cross sectional area(%)	Hardness(VHN)
276	310	18	12.24	105

Three process parameters tool rotation speed(N), welding speed(S), axial force(F),which contribute to heat input and subsequently influence friction stir welded aluminium joints, were selected for this study.

This paper, by using full factorial experimental design (3^3) with taguchi's design concept, analyses effect of tool rotation speed, welding speed and axial force for optimum tensile strength (TS) of friction stir welded joints of AA6061 alloy.

Table.3 process parameters with their range and values at three levels

Process parameters	range	Level 1	Level 2	Level 3
Tool rotational speed (N), rpm	1200 - 2000	1200	1500	2000
Welding speed(S),mm/sec	48 - 72	48	60	72
Axial force(F),kN	2.5 – 3.5	2.5	3	3.5

The initial joint configuration was obtained by securing the plates in position using the mechanical clamps. The direction of the welding was normal to the rolling direction. Figure 2 shows the clamping of specimens. The tool used in this process was made of Tungsten carbide which has a tapered cylindrical pin as shown in the Figure 3.

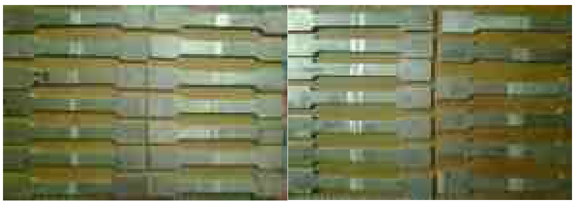
Fig 2 clamping of work pieces

Fig.3 Tool used for friction stir welding

Friction Stir Welding (FSW) was carried out according to the following sequence. Pair of work pieces were abutted along a longitudinal section and rigidly on the thick backing plate, which was Mechanically fixed on the bed of a Vertical Machining Centre (CAMPRO CPV-1100 series VMC). Tool which is shown in Fig.3, rotated anticlockwise and vertically inserted into the work piece. The surface of the work piece came into contact with the shoulder, and the insertion of the rotating tool was stopped. After the generation of frictional heat, tool was moved along the traverse line and welded. Tensile specimens were prepared to required dimensions as per ASTM E8M-04 standards as shown in Figure 4. Tensile test was carried out in universal testing machine and results are presented in

Table 4.

Figure 4 specimens prepared for tensile test.



Results

The experimental results for tensile strength were given in table 4. In the taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value for the output characteristic. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. In this study, S/N ratio was chosen according to criterion larger the better, in order to maximize response.

$$S/N = -10\log\left(\frac{1}{n}\sum\frac{1}{y^2}\right) \quad (1)$$

Where n is the number of measurements and y is the measured value in a run. The S/N ratio values calculated by taking (1) into consideration were listed in Table 4 for tensile strength.

Table 4 experimental values of tensile strength and s/n ratio

TEST	Tool rotational speed N (rpm)	Welding speed S (mm/sec)	Axial force F(kn)	TENSILE STRENGTH (Mpa)	S/N RATIO dB	Means
1.	1200	48	2.5	61.4	35.7634	61.40
2.	1200	48	3	66.7	36.4825	66.70
3.	1200	48	3.5	30.5	29.6860	30.50
4.	1200	60	2.5	58.3	35.3134	58.30
5.	1200	60	3	45.3	33.1220	45.30
6.	1200	60	3.5	31.8	30.0485	31.80
7.	1200	72	2.5	64.6	36.2047	64.60
8.	1200	72	3	65.3	36.2983	65.30
9.	1200	72	3.5	20.8	26.3613	20.80
10.	1500	48	2.5	59.6	35.5049	59.60
11.	1500	48	3	75	37.5012	75.00
12.	1500	48	3.5	79.5	38.0073	79.50
13.	1500	60	2.5	50.7	34.1002	50.70
14.	1500	60	3	65.3	36.2983	65.30
15.	1500	60	3.5	62.9	35.9730	62.90
16.	1500	72	2.5	65.6	36.3381	65.60
17.	1500	72	3	62.7	35.9454	62.70
18.	1500	72	3.5	75.6	37.5704	75.60
19.	2000	48	2.5	97.8	39.8068	97.80
20.	2000	48	3	86.2	38.7101	86.20
21.	2000	48	3.5	75.57	37.5670	75.57
22.	2000	60	2.5	86.08	38.6980	86.08
23.	2000	60	3	73.8	37.3611	73.80
24.	2000	60	3.5	85.71	38.6606	85.71
25.	2000	72	2.5	90.22	39.1061	90.22
26.	2000	72	3	89.5	39.0365	89.50
27.	2000	72	3.5	88.3	38.9192	88.30

Table 5 response table for S/N ratios

LEVEL	N(rpm)	S(mm/sec)	F(kn)
1	33.2533	36.5588	36.7595
2	36.3599	35.5083	36.7506
3	38.6517	36.1978	34.7548
DELTA(MAX -MIN)	5.3984	1.0505	2.0047
RANK	1	3	2

Graph 1 main effects plot for S/N ratios

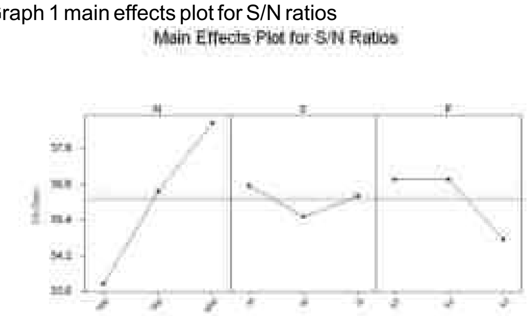
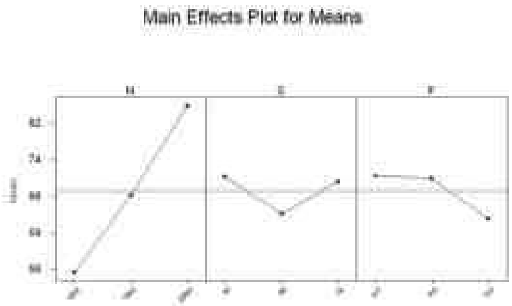


Table 6 response table for means

LEVEL	N(rpm)	S(mm/sec)	F(kn)
1	49.4111	70.2522	70.4778
2	66.3222	62.2100	69.9778
3	85.9089	69.1800	61.1867
DELTA(MAX -MIN)	36.4978	8.0422	9.2911
RANK	1	3	2

Graph 2 main effects plot for means



The experimental results were analyzed with the analysis of variance (ANOVA), which is used to investigation which design parameters significantly affect the characteristic. The contributions of input parameters on tensile strength are identified by ANOVA. Table 7 shows the ANOVA results for tensile stremgth.

Table 7 ANOVA results for tensile strength

Source	Degree Of Freedom	Sum Of Squares	Mean Of Squares	F	% Of Contribution
Tool rotation speed(N)	2	6005.13	3002.565	10.90233	62.57846
Welding speed (S)	2	343.22	171.61	0.623123	3.576675
Axial force(F)	2	491.57	245.785	0.892455	5.12262
NS	4	46.31	11.5775	0.042046	0.482683
NF	4	466.91	116.7275	0.423838	4.865591
SF	4	39.74	9.935	0.036082	0.414219
ERROR	8	2203.25	275.406		22.95975
TOTAL	26	9596.16			100

Conclusions

Tool rotation speed has been found dominant parameter for tensile strength followed by axial load. Welding speed shows minimal effect on tensile strength compared to other parameters. The optimal condition for friction stir welding is tool rotational speed (N) = 2000 (level 3), welding speed (S) = 48 (level 1) and axial force (F) = 2.5 (level 1). Tool rotation speed (N), Welding speed (S), Axial force (F) affect tensile strength by 62.5%, 3.57% and 5.12% respectively.

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