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Investigation on properties of sic reinforced friction stir welded joint in aluminium alloy

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ABSTRACT

This study attempts to incorporate SiC particles in the weld zone during friction stir welding of Al 6061-T6 alloy. SiC particles of micro size were added during friction stir welding within the weld zone through a special arrangement, and joined Al 6061-T6 alloy plates were evaluated for their mechanical and microstructural properties under two different conditions, i.e. without incorporating SiC particles and after incorporating SiC particles in weld zone. The results of the study reveal that the mechanical properties of the SiC particle reinforced Al 6061-T6 alloy welded joints are superior compared to plain Al6061-T6 alloy welded joints. Tensile strength and hardness values are significantly increased. Microstructural examinations of the welded joints were conducted using Optical microscope. It reveals that the distribution of reinforcement particles is uniform in most cases and in some cases non uniformity occurred because of some defects and improper welding. Pinning effect of grain coarsening occurs on account of addition of SiC particles in the weld region. Based on the obtained results, incorporation of SiC hard particles in the microstructure of weld zone produced by FSW is recommended. Ceramic particles reinforced welded joint using Friction stir welding method can improve mechanical and tribological properties of the joint.

Keywords: Aluminium alloys, Friction stir welding, Grain coarsening, Improved Mechanical properties.

1 INTRODUCTION

. Friction stir welding (FSW) is a widely used solid state joining process (the metal is not melted) for soft materials such as aluminium alloys because it avoids many of the common problems of fusion welding and is used when the original metal properties must remain unchanged as much as possible. Aluminium has property of low weight with high strength, comparable to that of structural steels. High tensile strength in relation to density (referred to as specific strength) as well as high corrosion resistance make aluminium alloys the primary structural material used for various structural elements of critical importance in aviation, automotive, transport, military, ship-building, civil engineering and other industries.

The frictional heat generated by rotating the tool, stirring action of the pin plasticizes the material and the joint is produced by plastic deformation of the material. The pin turns as well as traverses along the weld's length, empowering to weld the two plates [1]. An investigation on effect of tool shape and welding parameters on the mechanical properties of a 5mm thick aluminium plates was done by Three shapes (triangle, square and round shapes) were utilized to weld the aluminium plates with diverse welding conditions. Three distinct zones can be recognized in the friction stir welding process namely, the stirred zone (SZ), the thermo mechanically affected zone (TMAZ) and the heat affected zone (HAZ) [2]. The stirred zone is the region through which the tool's pin passes, and thus intense plastic deformation and frictional heating during FSW occur, which result in the generation of a recrystallized microstructure[3]. It has been found that increasing the rotational speed increase the quality of joint [4]. The hardness of the aluminium plates were observed to be higher when utilizing the square shape tool than other shapes. The thermo mechanically affected zone is a transition zone between base metal zone and stirred zone and it usually refers to as (TMAZ). This zone experiences both temperature and plastic deformation but the deformation strain is insufficient to induce recrystalisation, the heat affected zone (HAZ) is a zone experience a temperature rise and it usually has approximately the same grain structure as the parent material [5].

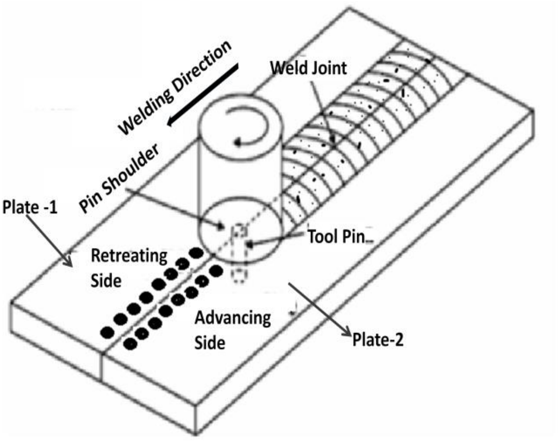

Fig.1. Friction Stir Welding

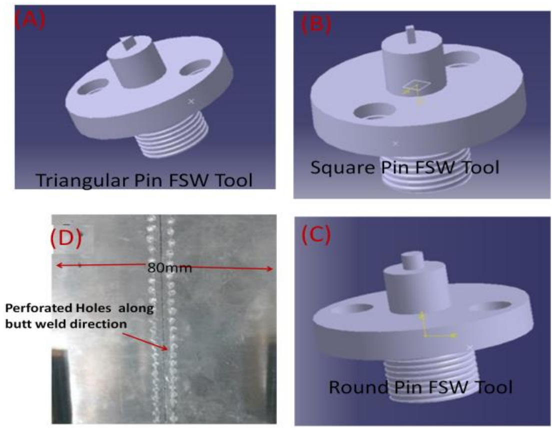

Fig.2. Types of tools and Workpiece (a) Triangular Pin (b) rectangular pin (d) round pin FSW tool (d) Workpiece with perforated holes along weld direction

2 EXPERIMENTAL PROCEDURE

2.1 FSW Process Parameters

There are a lot of welding parameters to consider when using FSW as a machining process. But it’s important to examine these factors to determine if FSW is right for our application. The FSW process parameters that may influence the quality of FSW joint are tool rotational speed, welding Speed and tool pin geometry. In the present investigation, three levels of these process parameters were considered after conducting trial runs. The FSW process parameters and their levels are given in Table 1.

Table.1. FSW Process Parameters and Their Levels

Welding parameter	Tool pin geometry	Rotational speed(rpm)	Travel speed(mm/min)
Level 1	Triangular	400	25
Level 2	Square	1000	40
Level 3	Circular	1600	63

2.2 Material, Equipment and Experiment detail.

The experiments were conducted on the aluminium alloy AA- 6061, its chemical composition is shown in Tables 2 and H13 Tool Steel is selected for tool material. The chemical composition of tool is presented in Table 3

Table.2. Chemical Composition Of Al6061

Elements	Si	Mg	Cu	Al	Other
Contents (%)	0.60	1.00	0.28	97.9	0.22

Table.3. Chemical Composition Of H13 Tool Steel

Elements	Cr	Mo	Si	V	C	Ni	Cu	Mn	P	S	Fe
	4.75-5.50	1.10-1.75	0.80-1.20	0.80-1.20	0.32-0.45	0.30	0.25	0.20-0.50	0.03	0.03	Balance

The welding was carried out in a modified vertical milling machine. Three different tools of pin geometry triangular, square, and circular cross section, were used to fabricate the joints. A row of 2mm diameter blind hole of 4mm depth at centre to cetre distance of 4mm were made to fill the SiC particles. Based on the previous research with availability of speeds on the machine, three different rotational speed and travel speeds were selected to carry out the experiment.

Table.4. Specification of tool geometry

1.Pin length (mm)	4.5	3.Pin diameter (mm)	6
2.Shoulder diameter (mm)	18	4. Shoulder diameter/pin diameter ratio	3

2.3 Design of experiments

In order to examine the effect of process parameters on mechanical properties of the joints, the statistical techniques of Taguchi method and analysis of variance (ANOVA) were selected. It reduces the number of experiment. Taguchi has simplified their use by providing tabulated sets of standard Orthogonal Array and corresponding linear graphs to fit specific projects [6]. For conducting experiment L-9 orthogonal array is selected.

Three stages of Taguchi approach to design the experiments are as follows:

1. Planning a matrix experiment to determine the effect of the control factors
2. Conducting the matrix experiment
3. Analysing and verifying the results.

In this work, three factors at three levels were selected based on the literature and trial experiments. The matrix experiment was designed according to the Taguchi parameter design methodology, L9 Orthogonal Array as shown in Table 5 to investigate the effect of three controllable factors (rotational speed, welding speed, tool pin geometry) on the tensile shear strength. Each row of the OA represents a run, which is a specific set of factors.

2.4 Tensile strength and hardness test specimen preparation

The tensile shear strength test specimens with the dimensions given in Figure 4 were prepared after welding according to ASTM E8 standard from the middle of the welded plates to eliminate the start and end effects of the welding process as shown in fig.4. Tensile shear strength tests were conducted using a Servo controlled universal testing machine keeping the cross-head speed at 20 mm/min during the loading conditions.

Samples were prepared in the size of 10mm X 25mm X 5mm from the weld zone such that it may contain all zones i.e. Stir zone, Thermally Mechanically Affected Zone (TMAZ) and Heat Affected Zone (HAZ). Before conducting hardness test samples were polished by different sand paper to get smooth surface.

Samples were also prepared for Optical Microscopy test and Scanning Electron Microscopy test. Sand papers of different grades were used for primary polishing and cloth polishing with water emulsion was used as liquid media. Samples were etched with Killer's Reagent for better result in optical microscopy test.

3 RESULTS AND DISCUSSIONS

3.1 Optical microscopy test and SEM of Fracture Surface

Optical Microscopy tests of few samples were studied which are shown in fig.3. Fig. 3(A) shows the grain distribution of as received metal plates. It reveals that the grains are coarser in size because as received plates are hot rolled AA-6061-T6 plates. When these plates are welded using friction stir welding, grain refinement takes place and fine grains were formed which is shown in fig.3 (B). Again when these plates were welded by friction stir welding along with incorporating SiC as reinforcement powders, again grain refinement will take place and ultra fine grains will formed. The formation of ultrafine grains is the result of combined effect of Dynamic recrystalisation and pinning effect in presence of SiC particles which can be observed in Optical Microscopy image of weld zone shown in fig. 3(C).

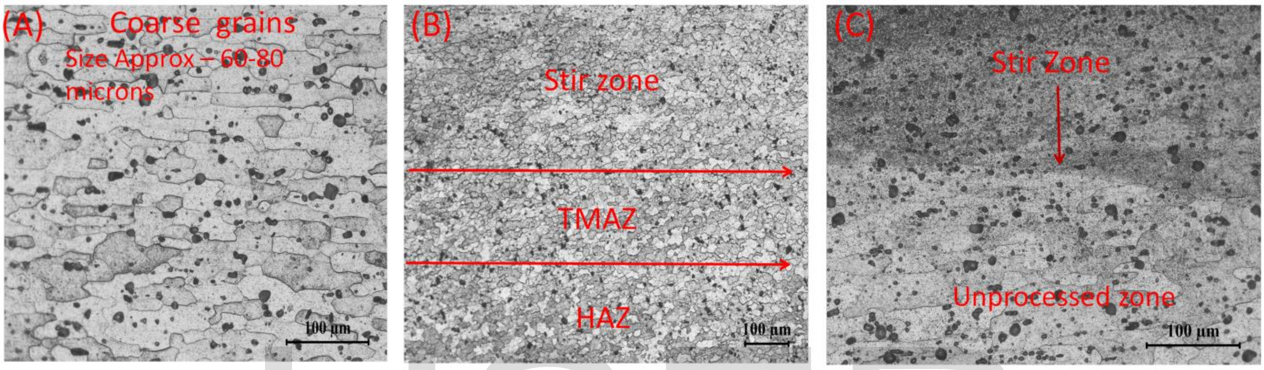

Fig.3 Optical Images of Fabricated samples

The tensile test specimens were further examined to know the mechanism of failure in the failure zone. Few samples were selected and prepared for the Scanning Electron Microscopy (SEM) test. The SEM examination of fracture surface of as received sample shows that the failure took place due to tensile fracture which can be observed in fig.4(A). when sample were welded by friction stir welding, grain refinement takes place in the weld zone and material will get strengthen and ductility will decrease. So failure mechanism appears like ductile failure but sallow crust and short valleys can be observed as shown in fig.4(B). When butt weld were welded by FWS along with incorporating reinforcement particles, the tensile fracture appears to be brittle fracture as appeared in fig.4(C). The weld zone becomes moderate brittle or more strength compared to the As received and only friction stirred sample.

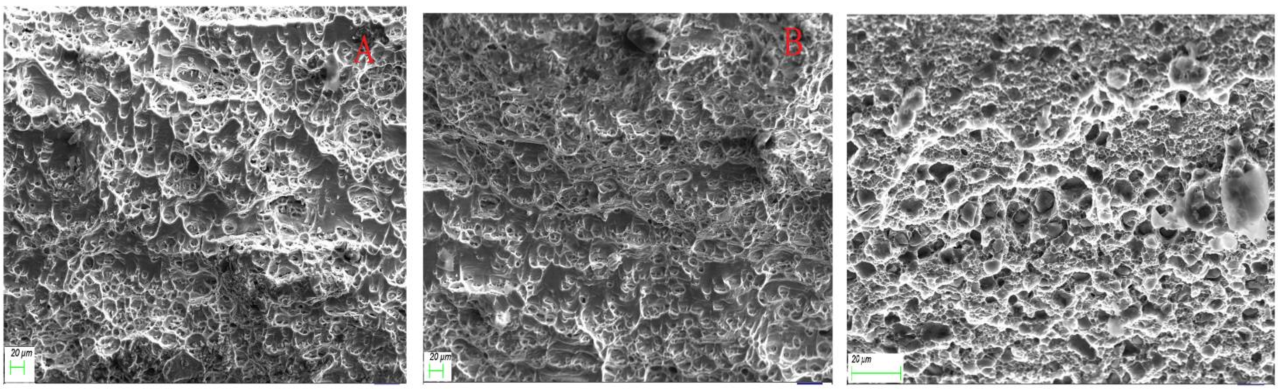

Fig. 4 SEM images of Tensile fracture surfaces (A) As received metal (B) Friction Stirred Welded without Reinforcement (C) Friction Stirred Welded with Reinforcement of SiC particles.

3.2 Signal to Noise ratio for tensile strength

Taguchi method uses a statistical measure of performance called signal-to-noise (S/N) ratio to analyse the results. In its simplest form, the S/N ratio is the ratio of the mean response (signal) to the standard deviation (noise). S/N parameter is gained by minimizing the loss function and defined in three different conditions: lower-the-better, larger-the-better, and nominal-the-better. Applying this method, it can be guaranteed that the effect of noise factors (which are not controllable or are unidentified to be controlled) such as stirring machine and environmental condition will be the minimum in comparison to the main factors, and it means that the final result shows the least sensitivity to noise factors. For the friction stir weld strength, the larger-the-better quality characteristic is taken [7-8].

In this work, 9 signals to noise (S/N) ratios were calculated and the estimated tensile shear strength and S/N ratio are given in Table 5.

Table.5.Orthogonal array for 9 with response (Ultimate tensile strength)

RUN	Profile Shape	Rotational Speed (rpm)	Travel speed (mm/min)	UTS (as weld) (M Pa)	Signal/Noise	UTS (Welded with SiC) (Mpa)	Signal/Noise
1	Triangular(1)	400	25	196	39.6454	209	40.7485
2	Triangular(1)	1000	40	213	41.0616	236	42.6708
3	Triangular(1)	1600	63	221	41.6557	227	42.0761
4	Square (2)	400	40	224	41.8684	223	41.7981
5	Square(2)	1000	63	209	40.7485	229	42.2118
6	Square(2)	1600	25	231	42.3454	243	43.1067
7	Circular(3)	400	63	217	41.3637	219	41.5109
8	Circular(3)	1000	25	188	38.8897	249	43.4637
9	Circular(3)	1600	40	222	41.7272	228	42.1442

Table.6.Optimization Response Table (As weld condition)

LEVEL	Pin Profile	Rotational Speed (rpm)	Travel speed (mm/mim)
1	40.79	40.96	40.29
2	41.65	40.23	41.55
3	40.66	41.91	41.26
DELTA	0.99	1.68	1.26
RANK	3	1	2

S/N ratio for tensile shear strength calculated by Minitab statistical software indicate that the tensile shear strength was maximum when rotational speed, welding speed and Tool profile were 1600 rev/min, 25 mm/min and Square tool From the results of Table 6, diagrams were drawn to display the welding parameters effects on weld strength. These diagrams are shown in Figures 5.

Table 7 Optimized Response Table (Welded with SiC nano-particles)

Level	Pin profile	Rotational speed (rpm)	Travel speed (mm/min)
1	41.83	41.35	42.44
2	42.37	42.78	42.20
3	42.37	42.44	41.93
Delta	0.54	1.43	0.51
Rank	2	1	3

3.3 Signal to Noise ratio for micro hardness

The S/N ratios have been calculated to identify the major contributing factors that cause variation in Micro hardness. Table 5 shows the ANOVA results for S/N ratio of Micro hardness of samples. In this table ranking has done which indicate, how much factor affects the output response. Rank 1 indicates that it affects the most. It is calculated by Delta, the highest value of delta is given rank 1 and so on. Delta is calculated by subtracting lowest value from the highest value as shown in Table7and higher is better selected for optimization technique.

Table 8. Orthogonal array for 9 with response (Micro hardness)

Shoulder pin shape	Speed (rpm)	Feed rate (mm/min)	Micro hardness (As weld) (Avg.at SZ) (As Weld)	S-N ratio	Micro hardness (weld with SiC particles) (Avg. at SZ)	S-N Ratio
Triangular	400	25	73	37.26	103.50	40.29
Triangular	1000	40	69.27	36.81	108.80	40.73
Triangular	1600	63	76.45	37.66	89.28	39.01
Square	400	40	75.18	37.52	95.70	39.61
Square	1000	63	81.18	38.18	99.35	39.94
Square	1600	25	81.81	38.25	113.50	41.09
Circular	400	63	76.36	37.65	93.45	39.41
Circular	1000	25	73.18	37.28	116.20	41.30
Circular	1600	40	76.09	37.62	104.00	40.34

Table.9.Optimization Response Table (As weld condition)

LEVEL	Profile Shape	Rotational Speed	Travel speed
1	37.85	38.04	38.13
2	38.42	37.97	37.89
3	38.05	38.31	38.31
DELTA	0.57	0.35	0.42
RANK	1	3	2

Table 10. Optimization Response Table (welded with SIC nano-particles)

Level	Pin profile	Rotational speed	Travel speed
1	40.02	39.78	40.90
2	40.22	40.66	40.23
3	40.35	40.15	39.46
Delta	0.34	0.88	1.44
Rank	3	2	1

3.4 Graphical Representation

Main effect plots for SN ratio of Tensile strength and Microhardness are shown fig 6 and fig.5. Main effect plot for tensile strength shows that square pin contributes more with respect to triangular and round pin FSW tool. The Square shaped pin profile stirred effectively along weld direction due to more number of stirring edges. Similarly highest rotational speed and medium tool travel rate i.e. 40mm/min contribute more in strength of but weld with respect to other levels. The medium tool travel speed provides sufficient frictional heat at the weld zone thus contributes in enhancing strength of weld.

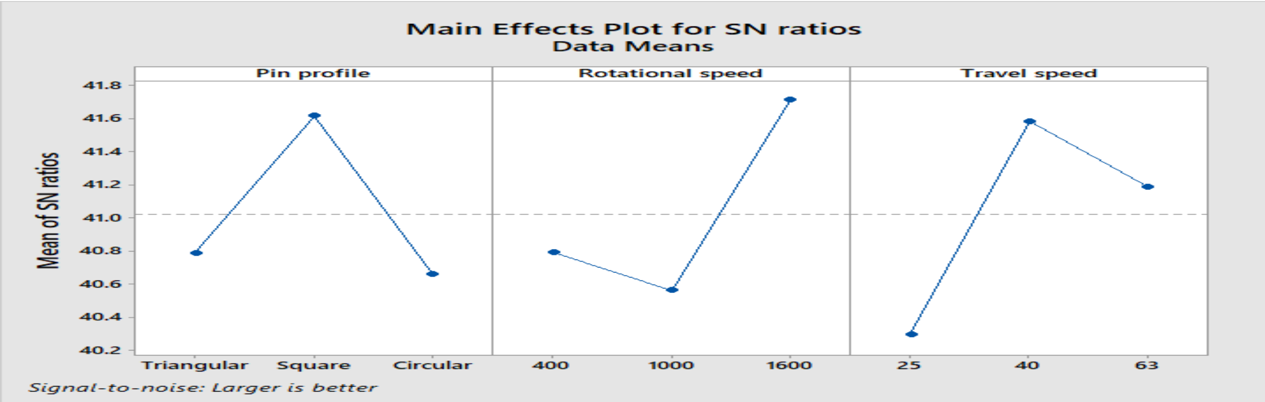

Fig. 5.Main effect Plots for SN ratio for Tensile strength

Fig . 6 Shows the main effect plots for vicker's microhardness of welded samples. Here also square pin profiled FSW tool contributes more in enhancing microhardness of weld zone. Proper stirring of weld zone with four edges of square tool is the reason behind increase in hardness. Similarly high rotational speed and high traverse speed contribute more in enhancing microhardness of weld zone. Highest traverse speed aid in the dynamic recrystalisation and fast cooling of processed zone.

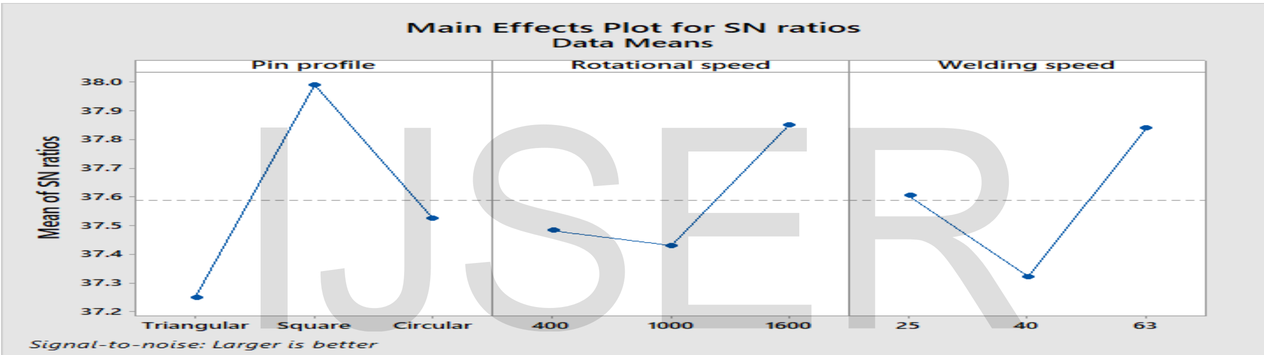

Fig. 6 Main effect Plots for SN ratio for Micro hardness (a) As weld (b) Welded with SiC

4 CONCLUSION

For solving welding optimization problems, various conventional techniques had been used so far, but they are not robust and have problems when applied to the welding process, which involves a number of variables and constraints. To overcome the above problems, Taguchi method is used in this work. Since Taguchi method is experimental method and it is realistic in nature. The present study is carried out to study the effect of input parameters on the tensile strength and micro hardness of friction stirred solid state joining process.

The method of addition of SiC particles during friction stir welding of Al 6061 plates is found to be a viable technique. Depositing the SiC reinforcement powder in perforated holes along both side of butt weld, proves a best method of fixing reinforcement before processing. Tensile strength value increased nearly by 15% compared to as stir weld condition. Maximum value in as weld condition is 231 MPa and in case of welding with SiC particles 249 MPa is the maximum value. With increasing number of FSW passes, the dispersion of SiC particles becomes more uniform. Good bonding of reinforcement with the matrix is the reason behind improvement in strength and hardness [18-19]. Optical microscopy study reveals near uniform distribution of SiC particles in the weld zone which is an indication that correct proportion of SiC particles has been added in the weld zone. Thus this research shows that the Friction Stir Welding along with incorporating reinforcement powder in weld zone can be employed to enhance strength and hardness of joint. Same time wear properties of joint can be improved by incorporating suitable reinforcement in weld zone.

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