Enhancing mechanical properties of friction stir welded Al alloy joints by adding magnesium particles

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ABSTRACT

Keywords:
Friction Stir Welding,
Tensile Strength,
Yield Strength,
Hardness,
Different Joint Profiles,
Magnesium Particles

Friction stir welding (FSW), a solid-State welding technique, is being extensively used in similar as well as dissimilar joining of Al Mg, Cu, Ti, and their alloys. In the present study, the two aluminum plates are joined by adding Magnesium particles of 60 mesh were the welding zone before the welding was carried. The variable parameters that affect much are taken as input parameters. They are tool rotation speed, tool traverse speed and three different joint profiles like (straight, inclined, semicircle) and with and without magnesium the paper discuss the influence of hardness, tensile strength, impact strength. The work material conducted AA6061 T6. Taguchi method based on L_{18} so used as DOE.

1. Introduction

Aluminium alloys with a wide range of properties. Among all aluminum alloys, AA 6061 alloy plays major role in the aerospace industry in which magnesium and silicon (0.3-1.5 w%, Si, Mg) are the principal alloying elements. It is widely used in the aerospace applications because it has good formability, weldability, machinability, corrosion resistance, and good strength compared to other aluminum alloys. Aluminum alloys are generally classified as non-weldable because of the poor solidification microstructure and porosity in the fusion zone. Also, the loss in mechanical properties as compared to the base material is very significant. These factors make the joining of these alloys by conventional welding processes unattractive. Some aluminum alloys can be resistance welded, but the surface preparation is expensive, with surface oxide being a major problem. The Welding Institute (TWI) of UK in 1991 as a solid-state joining technique, and it was initially applied to aluminium alloys. The basic concept of FSW is 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.

Till the shoulder contact the top surface of workpiece and traversed along the line of joint to produce the weld (Fig. 1). The tool serves primary functions: (a) heating of workpiece, (b) deform the material (c) movement of deform material to produce the joint. The heating is accomplished by friction between the rotating tool and the workpiece and plastic deformation of workpiece. The localized heating softens the material around the pin and combination of tool rotation and translation leads to movement of material from the front of the pin to the back of the pin. Because of this process a joint is produced in solid state.

Friction Stir Welding is the most significant development in metal joining in a decade. In Friction Stir Welding no cover gas or flux is used, thereby making the process environmentally friendly, energy efficiency and versatility or it is a ‘green technology’. The joining does not involve any use of filler metal and therefore any aluminium alloy can be joined without concern

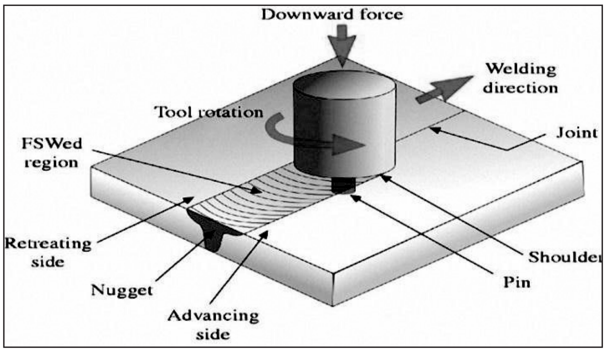

Fig. 1. Schematic drawing of FSW process.

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for the compatibility of composition, which is an issue in fusion welding. In FSW no cover gas or flux is used and does not involve any use of filler metal so that the properties of the joints are improving compare to the parent metal. Friction stir welding can be applied to various types of joints like butt joints, lap joints, T butt joints, pipes and fillet joints with different thickness and different profile. FSW technique was initially developed for Al Alloys, it also has great potential for welding of Mg, Cu, Ti, Al alloy matrix composites, lead, some steels, stainless steels, and different material combinations, particularly those with close melting temperatures and similar behaviour such as hot workability. However, cost effective stirring tools are needed for welding some of these materials such as metal matrix composites and those with high melting temperatures, i.e. steels and titanium alloys. In this process, a specially consider important parameters, tool material, tool design, tool rotation, downward force and weld speed along the joint line, generating frictional heating that softens a material underneath the tool. The softened material flows around the tool through extensive plastic deformation and is consolidated behind the tool to form a solid-state continuous joint.

2. Literature Review

A brief literature review on Al-materials is presented in the following. To start with, the metallic and metallurgical properties of materials for Al joining by FSW have been studied Tashkandi et al., [1] it has been reported that the volume fraction of alumina particles incorporated in this study were 2, 4, 6, 8 and 10% were added on both sides of welding line. Also, the alumina particles were pre-mixed with magnesium particles prior being added to the welding zone. Magnesium particles were used to enhance the bonding between the alumina particles and the matrix of 6061 aluminum alloy. Friction stir welded joints containing alumina particles were successfully obtained and it was observed that the strength of these joints was better than that of base metal. Golden Renjith Nimal et al., [2] it has been reported that Here, two Aluminum 7020 plates were welded with Mg as interlayer, using friction stir welding method. The joints were produced using same welding parameters only the variation is done in the traveling speed of the tool. Tensile strength of the joint is determined using a universal testing machine. Hardness of the joint is found out by Rockwell hardness test. To validate the results Scanning Electron Microscope (SEM) and Energy Dispersive X-ray spectroscopy (EDX) testing where done. By analyzing the test result we found that joints with 10mm/ min travel speed have comparatively high strength than other joints. Analysis found that even in the 10mm/min travel speed weld contain small defects and it is found that defect plays a vital role in the strength of the material. Hema Pothur et al., [3] have experimental study on the Friction Stir Welding Parameters on The Micro Structural and Mechanical Properties of Aluminum Alloy 6061. The authors also developed empirical relationships to predict the grain size and hardness of the weld nugget of the friction stir welded AA7075-T6 Aluminum alloy joints. Six factors, five levels, central composite, rotatable design matrix is used for optimization of the experimental conditions. The empirical relationships are developed by response surface methodology incorporating tool and process parameters. A linear regression relationship is also established between grain size and hardness of the weld nugget of friction stir welded joints. The welded nugget grain size is related with hardness of the joint. The developed relationships are effectively used to predict the weld nugget grain size of the joint non-destructively by measuring the weld nugget hardness. P Jagadeesh. Chandra Prasad et al., [3] have says in FSW minimum defects were observed for the highest tool rotation speed. An analysis of defects is studied. Tensile Test values and bend test values were also studied. Koilraj et al., [4] optimized FSW process with respect to tensile strength of the dissimilar welds AA2219 and AA5083 using five different tool profiles. The process parameters chosen were rotational speed, Transverse speed and D/d ratio where D= shoulder diameter and d= tool pin diameter respectively. The optimum values obtained were 700 rpm, 15 mm/min and 3 respectively for the cylindrical threaded pin tool profile. Bidasi, et al., [5] have investigated the effects of FSW process parameters including rotational and welding speed on the micro-structure and mechanical properties of aluminium 5083 alloy in lap joint welding and different joint defects were analysed. It was observed that the nugget area had the best grain size and higher hardness in compared with other welding areas. Also, the best rotational speed is obtained at 825 rpm and 32 mm/min. Peel et al., [6] uses AA5083 aluminium alloy for friction stir welding by varying the welding conditions like tool design, rotation speed and translation speed. The results of microstructural, mechanical property and residual stress investigations of four aluminium

AA5083 friction stir welds produced under varying conditions are stated. It is found that the weld properties are dominated by the thermal input rather than the mechanical deformation by the tool. Sundaram et al., [7] analyse the friction stir welded AA2024-T6 and AA5083-H321 using five different pin profiles. He reported that cylindrical tool with tapered pin diameter gives better tensile strength results among triangular, flat cylindrical, cylindrical threaded tool profiles. Defect free welds were reported for the range of 300 to 700 rpm, 15 to 35 mm/min and axial force of 4 to 8 kN. Also, tool rotational speed is found to be the most significant factor determining the tensile strength of the joint. Jun-Won Kwon et al., [8] have study the Influence of tool plunge depth and welding distance on friction stir lap welding of AA5454-O aluminium alloy plates with different Thicknesses taken the thin sheets and studied the thickness of the tool plunge depth and welding distance on surface appearance, and observed that defect-free FSW weld zones were successfully obtained in all the tool plunge depths and welding distances, the maximum tensile shear load of the FSW weld plates was much higher than that of the adhesive-bonded aluminium alloy plate. Ali et al., [9] characterization of 2024-T351 Friction Stir Welding Joints Characterization of macrostructure, microstructure, hardness, precipitate distribution, residual stress, and cyclic deformation behaviour of 2024-T351 friction stir welded joints has been studied. Nandan et al., [10] have conducted Tensile and Fatigue Behavior of Friction-Stir Welded Tailor-Welded Blank of Al Alloy 5754. It was observed that the yield and tensile strengths of friction stir welded specimens with weld located 900 to the tensile direction are close to the base material values, but its elongation is nearly half the elongation for the base material. The friction stir welded joints had relatively high-fatigue strength, and was even superior to that of the base aluminum alloy in the high-cycle region.

It is concluded from the literature survey that a few studies have been carried out on the usage of magnesium particles added in welding zone. However, there is no information regarding usage of different weld joint profiles.

To address the above-mentioned research gaps addition of magnesium particles to the weld pool was considered. Various weld joint profiles were also considered to study their effect on weld joint.

3. Process Perameters

The table - 1 shows that the parameter considered on the Tool Rotational Speed-A which is 1000-1400 Rpm. The second parameter considered is the Welding Speed-B which is 40-60mm/min. Joint Profiles-D is also considered as one of the parameters for the analysis. Magnesium-C particles also considered 5 grams for each joint.

By Taguchi method, L18 are designed. These are mixed levels as they are obtained from the input parameters which have four factors with three levels and one factor with two levels.

Table 1
Process parameters.

Process parameters	Level 1	Level 2	Level 3
A	1000	1200	1400
B	40	50	60
C	without	With	---
D	Straight	Inclined	Semi-circular

4. Experimental Setup

AA 6061 aluminum was made into cast rectangular plates (100 x 100 x 4). Square butt joint configuration was prepared to fabricate FSW joint. A non-consumable, rotating tool made of high carbon steel, was used to fabricate FSW joints and J55 CNC vertical milling machine was used to fabricate joints. The machine setup is shown in fig. 2 and the joined three profile weldings are shown in fig. 3.

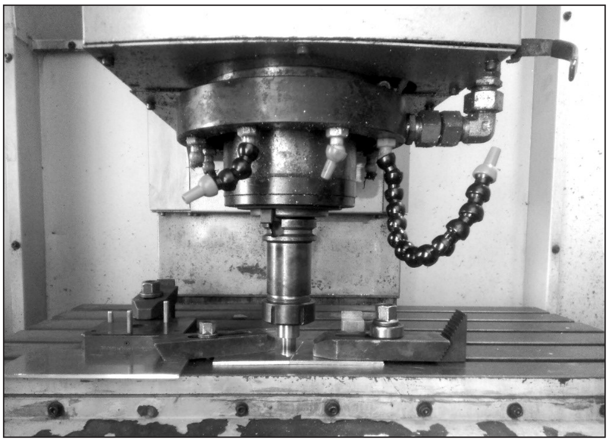


Fig. 2. CNC J55 Vertical milling Machine FSW setup.

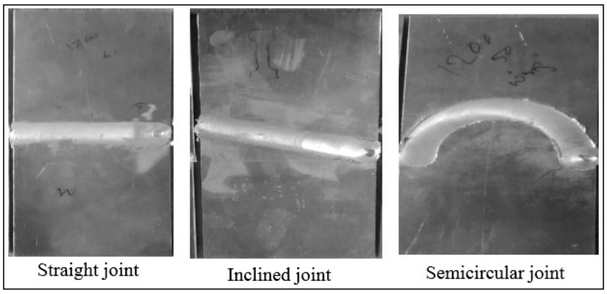
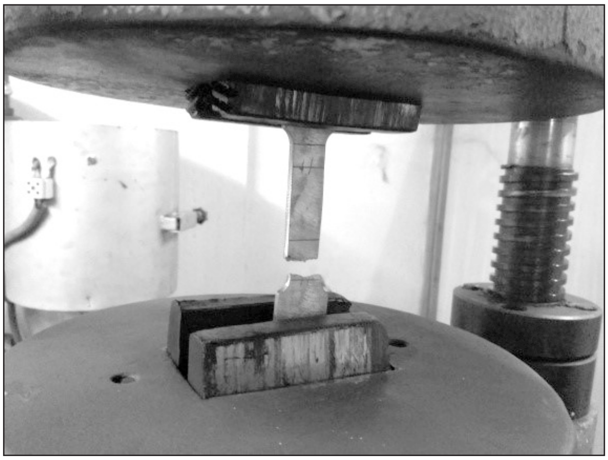
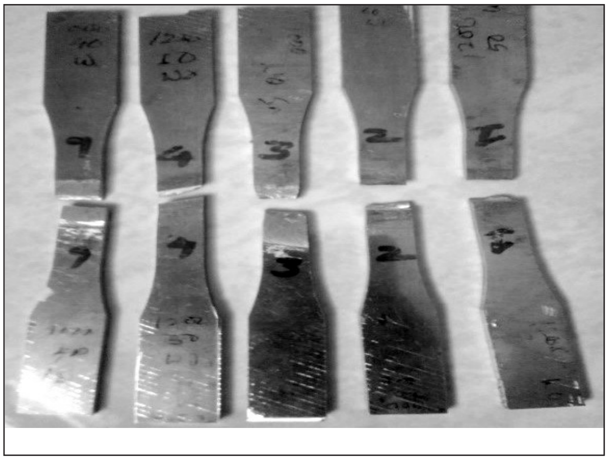


Fig. 3. Different weld joint profiles.



(a) UTM machine with sample



b) Tested Samples

Fig. 4. Tensile test machine and tested specimens.

5. Mechanical Testing

(a) Tensile Test

Tensile test specimens were prepared to required dimensions as per ASTM E8M-04. One tensile specimen was prepared from each joint. Tensile test was carried out in 100kN servo controlled Universal Testing Machine and tested samples is shown in Fig. 4 and results is presented in Table-2.

Fig. 5. Hardness testing machine.

From the graph it can be concluded that experiment number 14 having highest tensile strength the parameters are with magnesium, semi-circular joint profile, speed 1200rpm, feed 40mm/min. From the above graph we can say that by adding magnesium particles to the weld pool, it has tensile strength of weld join is increased.

(b) Rock Hardness Test

The Rockwell Hardness test makes use of indentation to measure the hardness of the different specimens. The machine generally has different types of scales to get the readings but here C scale was used to check readings. The specimen is first loaded with the help of minor load then after that major load is applied with the minor load still applied. The indentation on the specimen is done by the indenter then reading is noted on the B scale and a dimensionless number of hardness is got in the form of HRC number. If the penetration of indenter is more the hardness will be less and vice-versa. Reading of the test is given in the Table-2.

From the graph it can be concluded that experiment number 14 having highest tensile strength the parameters are With Magnesium, Straight Joint Profile, Speed 1200rpm, Feed 50mm/Min. From the above graph we can say that by adding magnesium particles to the weld pool, it has Hardness of weld join is increased.

(a) Charpy Impact Test Machine

(b) After Impact Test

Fig. 6. Impact test mechanical testing result.

Table 2
Experimental result table.

S.no	Magnesium	Speed (rpm)	Feed (mm/min)	Joint Profile	Hardness (HRC)	Impact Strength J/mm^2	Tensile Strength N/mm^2
1	With out	1000	40	Straight	42.00	3903.23	170.00
2	With out	1000	50	Inclined	43.50	4096.77	172.00
3	With out	1000	60	Semicircle	45.00	4245.25	168.00
4	With out	1200	40	Straight	43.00	3709.68	171.00
5	With out	1200	50	Inclined	45.96	4174.63	172.00
6	With out	1200	60	Semicircle	46.38	4215.36	178.00
7	With out	1400	40	Inclined	45.00	4193.55	173.00
8	With out	1400	50	Semicircle	47.00	4274.19	175.00
9	With out	1400	60	Straight	40.00	4129.03	153.00
10	With	1000	40	Semicircle	45.92	4290.32	177.00
11	With	1000	50	Straight	48.00	4258.06	179.00
12	With	1000	60	Inclined	48.35	4274.19	176.00
13	With	1200	40	Inclined	48.63	4253.28	180.00
14	With	1200	50	Semicircle	49.00	4258.06	184.00
15	With	1200	60	Straight	48.00	4274.19	176.00
16	With	1400	40	Semicircle	47.83	4290.32	179.00
17	With	1400	50	Straight	42.00	4290.32	170.00
18	With	1400	60	Inclined	46.00	4256.55	176.00

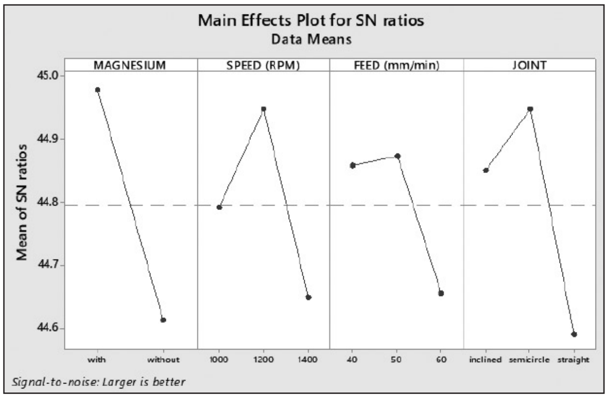


Fig. 7. Graph of main effects of S/N ratios effects of tensile strength.

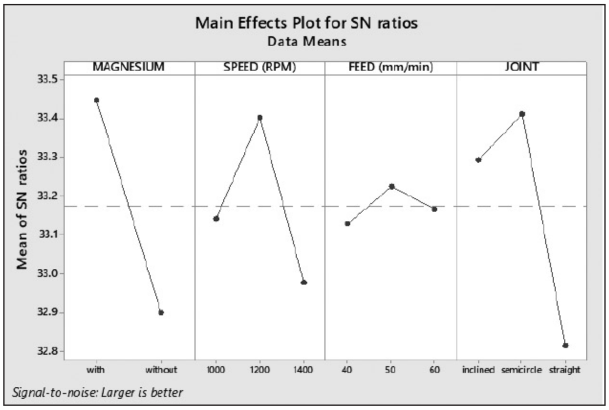


Fig. 8. Graph of main effects of S/N ratios effects of hardness.

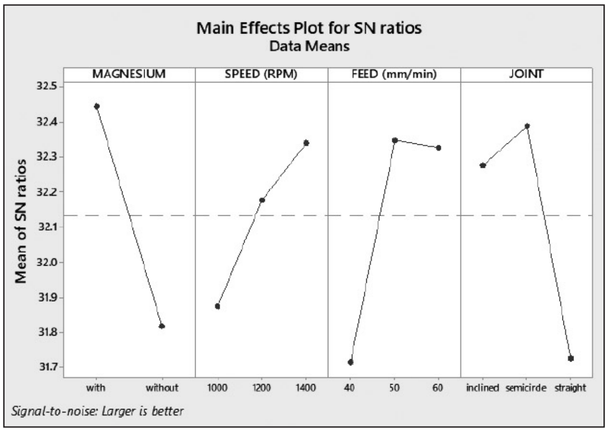


Fig. 9. Graph of main effects of S/N ratios effects of Impact strength.

(c) Impact Test

Charpy impact strength testing is a method of determining impact strength. A notched sample is generally used to determine impact strength. An arm held at a specific height (constant potential energy) is released. The arm hits the sample and breaks it. From the energy absorbed by the sample, its impact strength is determined.

Table 3
Response table for S/N ratios for tensile strength.

Factor	DOF	SS	MS	% of Contribution
Mg	1	234.72	234.72	31.29
Speed (rpm)	2	102.33	51.17	13.63
Feed (mm/ min)	2	64.33	32.17	8.52
Joint	2	156.00	78.00	20.78
Error	10	193.11	19.31	25.77
Total	17	750.50		100

Table 4
Response table for S/N ratios for hardness.

Factor	DOF	SS	MS	% of Contribution
Mg	1	37.238	37.2384	31.85
Speed (rpm)	2	14.684	7.3418	12.56
Feed (mm/ min)	2	0.795	0.3973	0.68
Joint	2	30.601	15.3007	26.17
Error	10	33.576	3.3576	28.75
Total	17	116.894		100

The dimensions of a standard specimen are 75mm x 10mm x 4mm. Reading of the test is given below in the table-2.

From the graph it can be concluded that experiment number 10 having highest impact strength the parameters are With Magnesium, Semi-circular Joint Profile, Speed 1000rpm, Feed 40mm/min. From the above graph we can say that by adding magnesium particles to the weld pool, it has Impact strength of weld join is increased.

6. Taguchi Analysis

Response table for S/N Ratios (larger is better) for Tensile Strength, Hardness, and Impact Strength.

Table 5
Response table for S/N ratios for impact strength.

Factor	DOF	SS	MS	% of Contribution
Mg	1	33.87	33.87	24.00
Speed (rpm)	2	11.30	5.64	8.00
Feed (mm/ min)	2	27.19	13.59	19.27
Joint	2	26.67	13.33	18.90
Error	10	42.08	4.208	29.82
Total	17	141.10	----	100

Analyzing the experimental data to determine the effect of each variable on the output, the S/N ratio is plotted as follows.

From the above response, Table-3 represents S/N ratios for Tensile Stress and the results show that magnesium is most influencing and followed by Feed, joint profile, speed. The Hardness induced to be maximum in Rockwell hardness of the Al6061 alloy, larger is better is considered for analysis and S/N ratios and mean effective plots are obtained and are shown in Table-4 The results show that the first four influence parameters are magnesium, Feed, joint profile and the most influence is magnesium. The response Table-5 shows S/N ratios and means for Maximum Impact strength. The results show that magnesium is most influencing and least influenced by Speed.

7. Conclusion

The parameters identified for the fabrication of the Friction Stir Butt joint weld profiles are Speed, Welding speed, Joint profiles and magnesium particles (with and without). These parameters are analyzed by Design of experiments using Taguchi; to optimize the geometry of the weld joint.

- The Analysis of Taguchi for L18 orthogonal array shows that, for the Tensile Strength of Tensile test, Magnesium is most influence parameter while the Feed (welding speed) is the least influence parameter. The remaining parameters have a moderate effect.
- For Hardness, Magnesium is highly influenced while Feed (welding speed) least influence. The remaining parameters have a moderate effect.
- For Impact strength, the high influenced parameter is Magnesium and least influence parameter is Speed rpm.
- From the S/N ratio plots, the optimal geometry of FSBW is Rotational speed 1200rpm, Feed 50mm/min, Semicircular joint profile with Magnesium. The FSBW are fabricated based on this result.

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