Effect Of Rice Husk Ash and Sic Particles on Hardness and Microstructure of Friction Stir Welded Metal Matrix Composites

A.Pradeepraj[1] P.Tamilamudhan[2]
[1]PG Scholar [2]Assistant Professor
[1,2]Department of Mechanical Engineering
[1,2]Sir Issac Newton College of Engineering and Technology, Nagapattinam

Abstract— Metal matrix composites (MMCs) constitute an important class of design and weight efficient structural materials that are encouraging every sphere of engineering applications. Since, there has been an increasing interest in composites containing low density and low cost reinforcements. In the present work, Friction Stir Welding (FSW) has been used to join the AA6061 reinforced with SiC and Rice Husk-Ash metal matrix composites (MMCs). Accordingly, rectangular composite plates were fabricated through stir casting route, then these plates were welded by using FSW. By Taguchi method using L9 orthogonal array, the optimum of process parameters has been determined. ANOVA analysis has been carried out to determine the percentage contribution of each factor on Tensile Strength and Hardness. Micro-structural characterization of the stir zone was carried out through Optical Microscopy (OM). The uniform grain distribution has been observed across the stir zone of AA6061/SiC/Fly-Ash composites after FSW.

Key words: Friction Stir Welding, Hardness, Microstructure, MMCs, Rice Husk-Ash, Silicon Carbide, Taguchi

I. INTRODUCTION

Metal Matrix Composites (MMCs) are fetching very attractive automotive, aerospace, marine and many other applications due to their admirable physical and mechanical properties [1]. Among MMCs the particle reinforced aluminum matrix composites (AMCs) are really attractive because of their low cost, isotropic properties [2].

In order to broaden the wide utilization of AMCs, effective and efficient joining techniques such as solid state welding and fusion welding become of practical importance. However it is difficult to achieve defect free welds by employing conventional fusion welding techniques due to the presence of ceramic particles, problems such as incomplete mixing of parent and filler material and deleterious chemical reaction between reinforcement and parent metal, the presence of porosity, and formation of excess and deleterious phases are difficult to avoid in the joints produced by conventional fusion welding methods [3]. In such cases, solid state welding methods are highly desirable to achieve potentially good AMC joints. As a solid state welding technique, friction stir welding (FSW) is a rapidly developing and has proved to be successful and effective welding method for joining Aluminum alloys.

Friction Stir Welding (FSW) is a solid state welding process first discovered and patented by the Welding Institute of Cambridge U.K. in 1991 by Wayne Thomas et al. FSW process that uses friction generated by a rotating cylindrical tool to heat and plasticize metal on either side of a joint, creating a solid, functional weld. Friction-generated heat is more effective at reorganizing the microstructure of metals and metal alloys than other forms of fusion welding, but FSW can be a much slower process. The process uses a rotating, non-consumable weld tool that plunges into the base material and moves forward. Friction heat caused by the rotating pin creates a plasticized tubular shaft around the pin. Pressure provided by the weld tool forces the plasticized material to the back of the pin, cooling and consolidation. Al alloy is difficult to weld by traditional methods, due to high thermal conductivity, resulting in defects like porosity, cracks etc. Hence FSW is being increasingly used. The process is especially well suited to butt and lap joint in aluminum since aluminum is difficult to weld by arc process, but is very simple to weld by FSW.

In the past few years, joining of AMCs using FSW was attempted and the microstructures and mechanical properties of the FSW joints were studied, including Al2O3p/AA7005 [4], Al2O3p/AA6061 [5], SiCp/AA2009 [6], and B4Cp/AA6061 [7]. FSW has been shown to result in a more homogeneous distribution of the particles and their breakup and bluntness due to the effect of severe plastic deformation and material mixing furthermore, the grain sizes of the matrices were greatly refined due to dynamic recrystallization. Although several studies on FSW of AMCs were reported, a small number of researches are also studied on FSW of hybrid AMCs, but no literature is available to study the effect of low cost reinforcement like Rice Husk-Ash on the welded strength using FSW.

In this study 6mm thick Al6061/SiC/Rice Husk-Ash composite plates produced by stir casting route are welded by Friction Stir Welding and then microstructure, tensile strength and hardness in the nugget zone were examined carefully.

II. EXPERIMENTAL DETAILS

The chemical compositions of Al6061 and Rice Husk-Ash are provided in Table 1 and Table 2 respectively. AA6061-10%*SiC* reinforced with 4% (wt.%) Rice Husk-Ash composite was produced by stir casting process with bottom pouring arrangement. Plates of size 100 mm x 50 mm x 6 mm were prepared from cast composite using machining process. A non-consumable rotating tool made of hot work too steel H13 with straight cylindrical profile pin. Figure 1 represents the straight cylindrical H13 tool.

Fig. 1: Straight cylindrical H13 tool

Element	Weight %
Mg	1.58
Si	0.67
Ti	0.2
Cr	0.2
Mn	0.22
Fe	0.6
Cu	0.27
Zn	0.17
Al	Balance

Table 1: Chemical composition of Al6061

Element	Weight %
SiO_2	94.4
Al_2O_3	0.249
Fe_2O_3	0.136
CaO	0.622
Na_2O	0.023
MgO	0.442
K_2O	2.49
LOI	3.52

Table 2: chemical composition of Rice Husk-Ash

Taguchi's method is a statistical tool for design of experiment for a high quality system. This method is a systematic approach for performance and quality optimization. By this method the number of experiment is reduced 27 to 9 due to the cost of experiment is high. The total degree of freedom must be calculated to choose the correct orthogonal array. The degree of freedom for the orthogonal array should be greater than or at least equal to those for the process parameters. So, L9 orthogonal array was selected which has a degree of freedom of 8. Nine experimental runs were conducted as per Taguchi L9 orthogonal array as shown in table 3.

Ex.No	Tool rotational speed (N) in r.p.m	Welding speed (S) in mm/min	Axial Force (F) in KN
1	900	20	5
2	900	40	6
3	900	60	7
4	1100	20	5
5	1100	40	6
6	1100	60	7
7	1300	20	5
8	1300	40	6
9	1300	60	7

Table 3: L9 orthogonal array

The welding process was carried out on a 10 tons capacity ETA horizontal stir welding machine. The tool was inclined at an angle of 2° backward with respect to normal of the work piece. The rotating tool was plunged into the abutting edges of the plate until the shoulder touches the surface with sufficient plunge force. After a dwell period of 15 seconds, the machine table was moved at a predetermined welding speed. When the plunged tool reaches the other end, the tool was retracted. This process was repeated for different combinations of welding process parameters as shown in Table 4.

S.NO	Parameters	Unit	Level 1	Level 2	Level 3
1	Rotational speed	Rpm	900	1100	1300
2	Traverse speed	mm/min	20	40	60
3	Axial force	KN	5	6	7

Table 4: Process parameters

Figure 2 represents the friction stir welding set up, Figure 3 represents the welded composite plates by FSW. The welded specimens were cross-sectioned perpendicular to the welding direction from joints. These specimens were polished and finally etched with Keller`s reagent. Then using Optical Microscope, microstructures of the welded joints at the nugget zone has been studied. Tensile strength and Vickers hardness was used to measure the strength and hardness of the welded specimen at nugget zones of the weld.

Fig. 2: FSW setup

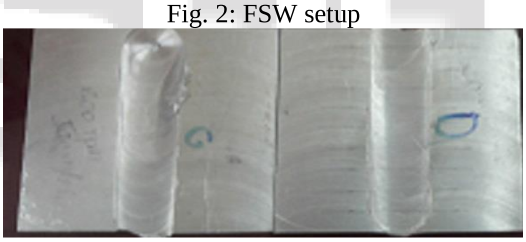

Fig. 3: Welded composite material

III. Results and Discussions

A. Tensile Test and Hardness Test Results

From the tensile test conducted on different specimen prepared as per ASTM E8 standards shown in Fig 4, tensile strength were obtained for each weld joint and from Vickers hardness test, hardness was obtained at three different locations, one along the weld zone and two on the heat affected zones on either side of the weld zone. Only Tensile strength and hardness along the weld zone of each weld joint are considered for optimization. All the values obtained are tabulated in table 4.

Fig. 4: tensile test specimen as per standard

Sl.no	Tool rotational speed (N) in r.p.m	Welding speed (S) in mm/min	Axial Force (F) in KN	Tensile strength N/mm^2	Vickers hardness
1	900	20	5	65.44	66.8
2	900	40	6	87.653	69.8
3	900	60	7	111.29	70.4
4	1100	20	5	98.34	68.0
5	1100	40	6	113.746	71.3
6	1100	60	7	99.0133	69.4
7	1300	20	5	133.74	72.1
8	1300	40	6	98.3466	73.5
9	1300	60	7	79.45	72.3

Table 4: Tensile strength and hardness value for different input parameters

B. *Optimization By Taguchi Method*

In order to optimize FSW process parameters, the tensile strength and hardness were analyzed. To assess the influence of factors on the response, the means and S/N ratios for each control factor can be calculated. In this study, the S/N ratio was chosen according to the criterion of the larger-the-better, in order to maximize the response. The signal to noise ratios (S/N), which are log functions of desired output serve as the objective functions for optimization, help in data analysis. The S/N ratio is calculated using the larger-the-better criterion and is given by [8],

$$\text{S/N ratio} = -10\log\left(\frac{1}{n}\Sigma\frac{1}{y2}\right)$$

Where y is the observed data and n is the number of observations. The obtained tensile strength and hardness were converted into S/N ratio. The experimental results and calculated S/N ratio values are tabulated in table 5.

Ex.No	Tool rotational speed (N) in r.p.m	Welding speed (S) in mm/min	Axial Force (F) in KN	Tensile strength N/mm^2	Vickers hardness
1	900	20	5	65.44	66.8
2	900	40	6	87.65	69.8
3	900	60	7	111.29	70.4
4	1100	20	6	98.34	68.0
5	1100	40	7	113.74	71.3
6	1100	60	5	99.01	69.4
7	1300	20	7	133.74	72.1
8	1300	40	5	98.34	73.5
9	1300	60	6	79.45	72.3

Table 5: Experimental results and corresponding Signal to Noise ratios

Ex.No	Tool rotational speed (N) in r.p.m	Welding speed (S) in mm/min	S/N ratio of tensile strength	S/N ratio of hardness
1	900	20	36.3169	35.4955
2	900	40	38.8553	36.8771
3	900	60	40.9291	36.9515
4	1100	20	39.8546	36.6502
5	1100	40	41.1187	37.0618
6	1100	60	39.9139	36.8272
7	1300	20	42.5252	37.1587
8	1300	40	39.8552	37.3257
9	1300	60	38.0019	37.1828

Table 6:

S/N ratio against the design factors as obtained by the Minitab Software is shown in figure 5&6. Based on the highest values of the S/N ratio and the signal- to- noise ratio of tensile strength plot figure 5, obtained by the Minitab software and with values in table 5, Tensile strength of welded joints increased with increasing in rotational speed from 900rpm to 1100 rpm, Axial force from 5KN to 7KN, traverse speed from 20mm/min to 40mm/min but further increase in the rotational speed from 1100rpm to 1300rpm and welding speed from 40mm/min to 60mm/min decreased the tensile strength of the joints.

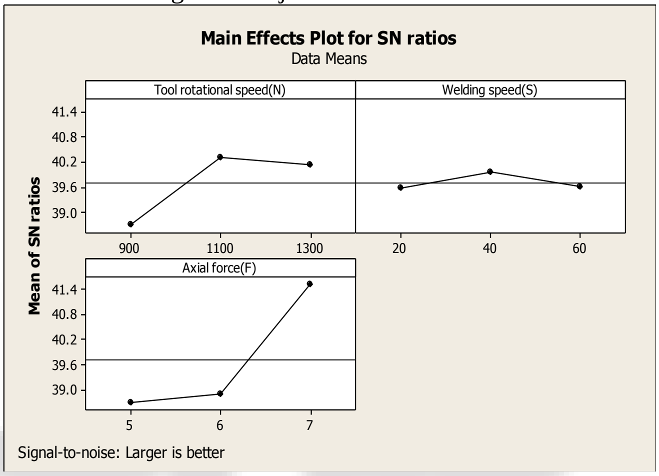

Fig. 5: Mean effect plot for Ultimate tensile strength.

Based on the highest values of the S/N ratio and the signal- to- noise ratio of Vicker's hardness plot fig 6, obtained by the Minitab software and with values in table 5, hardness value increased with increasing in rotational speed from 900rpm to 1300 rpm, Axial force from 5KN to 7KN, traverse speed from 20mm/min to 40mm/min but further increase in the welding speed from 40mm/min to 60mm/min decreased the tensile strength of the joints.

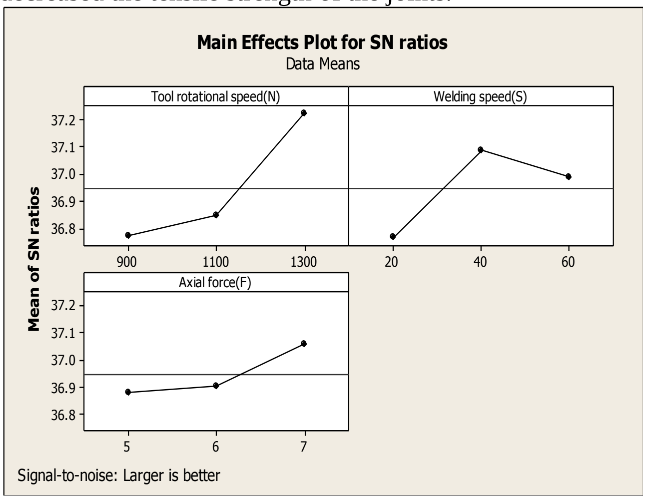

Fig. 6: Mean effect plot for Vicker's Hardness test.

C. Anova Analysis

The main purpose of the ANOVA is the application of a statistical method to identify the effect of individual factors on the process response. The ANOVA table for S/N ratio of Tensile strength is calculated and listed in table 6.

Source	DF	Seq SS	Adj SS	Adj MS
Tool rotational speed	2	4.6096	4.6096	2.304
Welding speed	2	0.2526	0.2526	0.126
Axial force	2	14.9136	14.9136	7.456
Residual error	2	6.8654	6.8654	3.432
Total	8	26.6413	-	-

Table 6: Analysis of Variance for SN ratios of Tensile strength

Source	F	P	% contribution
Tool rotational speed	0.67	0.598	17.5
Welding speed	0.04	0.965	1
Axial force	2.17	0.315	56
Residual error	-	-	25.5

Table 7:

The Taguchi experimental method could not judge the effect of individual parameters on the entire process, thus the percentage of contribution using ANOVA is used to compensate for this effect. Percent contribution indicates the relative power of a factor to reduce variation. For a factor with a high percent contribution, a small variation will have a great influence on the performance. The percentage of contribution (*fi*) is a function of the sum of squares for each significant item and can be calculated as

$$fi = SSfi / SeqSStotal$$

Where *fi* is the *i*th factor, SSfi is the pure sum of squares for *fi*, SeqSStotal is the total mean of sequential sum of squares. From the table 6, we can conclude that the axial force has a contribution of 56% followed by rotational speed which has a contribution of 17.5%. Among these three traverse speed of the welding has the lowest percentage of 1%.

From the table 7 it can conclude that the axial force have the first rank followed by the rotational speed and last as welding speed. From the table 6 it can see that the optimum welding condition to get high tensile strength is tool rotation speed of 1300 r.p.m, welding speed of 20 mm/min and axial force of 7 kN.

Level	Tool rotational speed	Welding speed	Axial force
1	38.70	39.57	38.70
2	40.30	39.94	38.90
3	40.13	39.61	41.52
Delta	1.60	0.38	2.83
Rank	2	3	1

Table 8: Tensile strength Response Table for Signal to Noise Ratios Larger is better

The ANOVA table for S/N ratio of Vicker's hardness is calculated and listed in table 8.

Source	DF	Seq SS	Adj SS	Adj MS
Tool rotational speed	2	0.346	0.346	0.1734
Welding speed	2	0.160	0.160	0.0803
Axial force	2	0.054	0.054	0.0272
Residual error	2	0.006	0.006	0.0030
Total	8	0.566		

Table 9: Analysis of Variance for SN ratios of Vickers micro hardness

Source	F	P	% contribution
Tool rotational speed	57.48	0.017	61
Welding speed	26.61	0.036	28.26
Axial force	9.04	0.100	9.6
Residual error	-	-	1.1

Table 10:

From the table 8, we can conclude that the rotational speed has a contribution of 61% followed by welding speed which has a contribution of 28.26%. Among these three Axial force has the lowest percentage of 1%.

From the table 9 it can conclude that the axial force have the first rank followed by the rotational speed and last as welding speed. From the table 6 it can see that the optimum welding condition to get high tensile strength is tool rotation speed of 1300 r.p.m, welding speed of 40 mm/min and axial force of 5 kN.

Level	Tool rotational speed	Welding speed	Axial force
1	36.77	36.77	36.88
2	36.85	37.09	36.90
3	37.22	36.99	37.06
Delta	0.45	0.32	0.17
Rank	1	2	3

Table 11: Vicker's hardness Response Table for Signal to Noise Ratios Larger is better

D. Microstructure

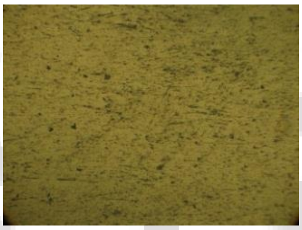

Fig. 6: (a)

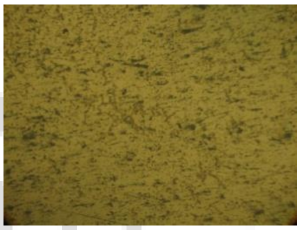

Fig. 6: (b)

Fig. 6: (c)

Fig. 6: (a) Microstructure Image of Parent, (b) Welded AMCs Specimen, (c) Microstructure Image of Welded Region

Optical Microscopy image of AMC parent material microstructure is shown in Fig. 6(a) and the microstructure of AMC after welding with various zones is shown in Fig. 6(b) and Fig. 6(c) shows microstructure of nugget zone. The microstructure of FSW is classified into mainly three regions namely, heat affected zone (HAZ), thermo mechanical affected zone (TMAZ), and weld nugget zone as shown in Fig. 6 (c) [9]. It clearly reveals the different grain sizes in the interfacial boundary between the TMAZ and weld nugget is shown in the figure 7.

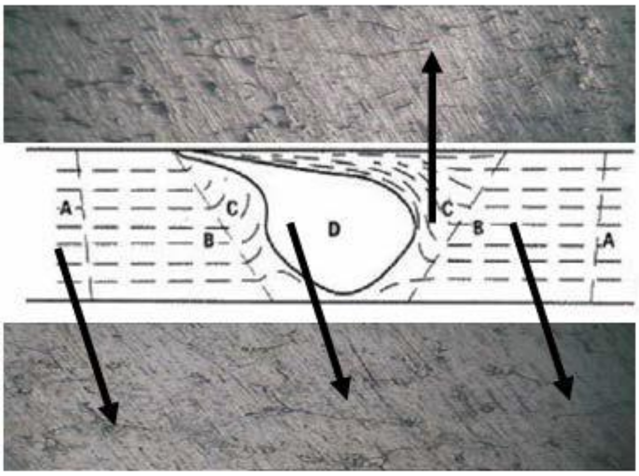

Fig. 7: FSW Weld Showing Four Distinct Zones: (A) Base Metal (B) Heat Affected (C) Thermo mechanically Affected and (D) Stirred (nugget) Zone

The weld nugget zone was a slightly larger than the size of the rotating pin, irrespective of width and height of the pin. On the other hand, the size of the zone will vary with frictional pressure, forging force and friction time. As the friction time is reduced, the large amount of thermal energy is propagated in the direction of work piece which will increase in the size of the nugget zone. The weld nugget surrounded by TMAZ, having well deformed and elongated coarser grain due to the stirring action of the tool. However, in this region plastic deformation and dynamic recrystallization is a bit lesser than weld nugget region. In this study, straight cylindrical pin FSW tool is being used which provides energetic stirring action in the flowing material which results in formation of finer grains.

Microstructure of welded zone at various Rotational speed, Welding speed and Axial force are shown in figure8.

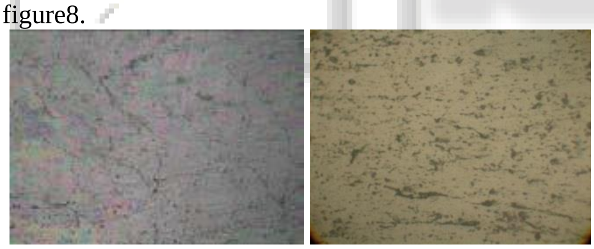

Fig. 8: (a) Fig. 8: (b)

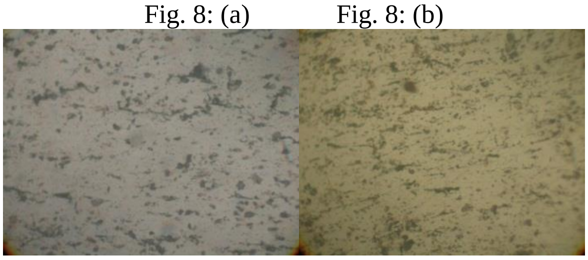

Fig. 8: (c) Fig. 8: (d)

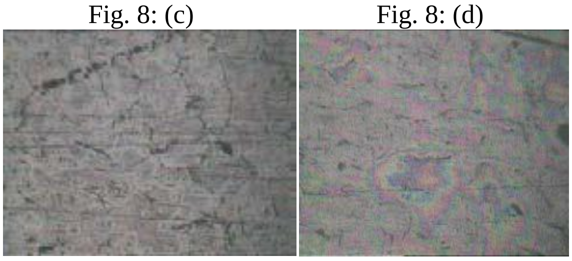

Fig. 8: (e) Fig. 8:(f)

Fig. 8: (g) Fig. 8: (h)

Fig. 8: Microstructure of Welded Zone at Various Rotational Speed, Welding speed, Axial force of (a)600rpm, 20mm/min, 5kN (b)900rpm, 40mm/min, 6kN (c)900rpm, 60mm/min, 7kN (d)1100rpm, 20mm/min, 6kN (e)1100rpm, 40mm/min, 7kN (f)1100rpm, 60mm/min, 5kN (g)1300rpm, 20mm/min, 7kN (h)1300rpm, 40mm/min, 6kN

IV. CONCLUSION

In this study, the Taguchi method was used to obtain optimum conditions for friction Stir Welding (FSW) of Al6061/Sic/Rice Husk-Ash AMCs. Experimental results were evaluated using ANOVA tool. The influence of tool rotation speed, welding speed and tool tilt angle on joint quality in Al6061/Sic/Rice Husk-Ash AMCs has been established. The specimens were subjected to friction stir welding with the rotation rotational speed of 900, 1100 and 1300 rpm and welding speed between 20, 40 and 60 mm/min, providing Axial force of 5, 6 and 7 kN. The welded joints has been tested for tensile strength and hardness.

A maximum tensile strength from the FSW joint fabricated with optimized parameter of 1300rpm rotational speed, 7kN axial force and 20 mm/min welding speed. Tool rotation speed was the major factor contributing to tensile strength and the axial force is found to be the important influential process parameter with 56% contribution followed by rotational speed (17.5) and welding speed (1%) for tensile strength respectively.

A maximum tensile strength from the FSW joint fabricated with optimized parameter of 1300rpm rotational speed, 5kN axial force and 40 mm/min welding speed. Tool rotation speed was the major factor contributing to Vicker's hardness and the rotational speed is found to be the important influential process parameter with 61% contribution followed by welding speed (28.26) and Axial force (1%) for Vicker's hardness respectively.

The microstructure at the nugget zone was characterized by fine and uniform distribution of Sic and Rice Husk-Ash particles.

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