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Experimental Study of Aluminum Based Metal Matrix Composite Fabricated by Friction Stir Processing

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ABSTRACT

FSP Friction stir process was advanced from friction stir welding (FSW) technology, and both FSW process and FSP process use the same process principle of operation. In this research work, the impact of process parameters such as speed, feed, angle of inclination, and number of passes is analysed over mechanical and microstructural attributes ofAl2014 plate reinforced with TiB_2 nanoparticles (60-90 nanometres). Taguchi L9 array design is used to design the experimental matrix. Further Grey Relational Analysis was conjugated with Taguchi to optimize the process parameters such as tensile strength, hardness and grain size. To identify key variables and their contributions to the output response, an analysis of variance (ANOVA) was accomplished. Vickers hardness measurements, and Optical, scan electron microscopy, together with grain analysis, are executed on multiple regions of the machined cross-sections to demonstrate the condition of the machined material properties.

Keywords: FSP Friction stir process, Mechanical Properties, Al2014, hardness, TiB_2

1. Introduction:

The friction stir process evolved from the friction stir welding process. FSP operates by inserting a rotating tool into a slot loaded with reinforcement powder and then spinning the tool along on the interface. The tool's friction heats the materials around the rotating- pin of the FSP tool to temperatures below the melting point of the base metal. The material is "STIRRRED" together as the tool keep rotating, resulting in a combination of the two materials. When done correctly, this method mixes the material without causing phase shift and produces a microstructure with small, equiaxed grains. some alloys can gain super plastic characteristics due to their homogenous crystalline structure separated by high-angle barriers. Adding reinforcement materials to the surface rather than the bulk enhances the surface characteristics and mechanical of the composite. Friction stir processing is a solid- state technique that is used for the purpose of creating surface composites. In comparison to the traditional liquid state processing technique, FSP is a more flexible and energy efficient process for making surface composites. FSP is a friction stir welding (FSW) method that is done at a temp. lower than the melting temp. of the base metal. FSP, one of the several techniques used to create particle reinforced surface composites, has drawn a lot of interest.

2. Review of literature of FSP

(Kadaganchi et al., 2015)describes the creation of a mathematical model using tool geometry, process parameters, and AA 2014-T6 friction weld reactions. Tool rotation and welding speeds, tilting angle, and tool pin shape are the process variables that have the most impact. Regression models were created using the Response Surface Methodology to predict responses using a fourfactor, fivelevel composite design. These findings present that the best tensile strength and elongation are found in AA2014T6 aluminium alloys friction welds welded with a hexagonal tools pin geometry.

(Bharti et al., 2020)authors planned to increase the microhardness and wear rate of the aluminium alloy AA2014. Al2O3 was used as reinforcement in the AA2014 surface composite, which was created utilising the (FSP) friction stir processing method. After FSP, the base materials average grain size that was before 21.9 µm was decreased to 9.2µm in the 1000 rpm FSP and to 3.8µm in the 1400 rpm FSP. The Al2O3 reinforced particles were evenly dispersed in AA2014 following FSP, according to optical microscopy. The microhardness test revealed that the AA2014/Al2O3 surface composite's hardness quality improved following FSP and increased with increasing rotation speed. After FSP, microhardness increased by 30%.

(**Rajendra Prasad et al., 2018)**Examine the impact of tool geometry and volume percentage reinforcements using B4C nanopowder on AA 2014-T6 Alloy 6mm plate thickness. In this study, we plan to investigate the influences of speed of tool rotation and volume% of B4C nanoparticle reinforcement on the mechanical characteristics of surfacebased AA2014T6/B4C nanocomposite through friction utilising a straight cylindrical pin with a concave shoulder radius R of 2.5. Process of Blending (FSP). The surface nanocomposite is created using the hole method. An optical microscope is used to analyse the microstructure. Due to adequate particle distribution and DRX, it was shown that volume% 2 reinforcements led in superior mechanical characteristics at 1600 pm and 20 mm/min.

(Sharma et al., 2015) constant turning and feed speeds of 715 rpm and 110 mm per min, silicon carbide reinforcement nanoparticles were used to create the AA2014 aluminium alloy surface composite. The occurrence of materials dynamic recrystallization while the friction processing led to the development of a recrystallized equiaxed microstructure. The result is a composite with no flaws and evenly distributed SiC particles. During processing, a decrease in the reinforcement's particle size is also seen. But in comparison to the base alloy, the value micro hardness of these alloy produced by friction stirring is lower, showing that precipitation hardening plays a more important role than grain refining. Due to the addition of tougher ceramic particles, the surface metal matrix composite exhibits an increase in micro hardness.

(Pragada et al., 2022) The aluminium alloy AA2014 was treated with FSP to produce a surface metal matrix composite with SiC-CNT hybrid reinforcement. In this work, a total of three FSP passes were employed because the no. of passes affects several properties of produced surface composites.

Then, the micro hardness, coefficient of friction (COF), optical microscopy, and wear resistance of the surface composite was evaluated. It has been demonstrated that altering the FSP pass improves surface composites microhardness uniformity and reinforcement distribution.

(R et al., 2018a)reports on the mechanical performance of a friction-processed surface composite made of aluminium 6061 and boron nitride. In increments of 3% weight, the amount of boron nitride was changed from 0 to 6% by weight. Al6061's microstructure, hardness, and tensile behaviour were investigated in relation to the number of passes and the reinforcing content. The findings indicate that the composites outperformed non - reinforced ones in terms of hardness and tensile strength. As the total number of passes increases, so do the alloy's hardness and tensile strength as well as that of the composite.

(Bharti et al., 2021)created a surface composite using aluminium 5052 as the base material and ZrO2 as the reinforcing material. To examine the variations in the attributes of the produced surface composite, microhardness and wear tests were conducted. On the hardness and wear of the produced composites, the impact of tool rotation and travel speeds was investigated. 56 mm/min and 1400 rpm were determined to be the ideal tool feed and rotational speeds for evenly dispersing the reinforcement throughout the workpiece. After the procedure, the data indicated enhanced microhardness and wear resistance.

3. Pilot experimentation

Prior to the main experimentation process pilot tests were conducted with one factor at a time approach to decide the final process parameters for the main experimentation. Parameters and their range have been given in Table 4.3.

Table 1 Process parameters for pilot experiments

Parameter	**Unit**	**Level 1**	**Level 2**	**Level 3**
RPM	Rev./min	500	1000	1500
Transverse speed	mm/min	30	65	100
Tilt angle	degree	1	2	3
No. of passes	_	1	2	3
Plunge depth	?????????	0.1	0.2	0.3

The combination of above 5 process parameters with 3 levels yielded total 15 experiments. Apart from these we also conducted 2 experiments with each parameter at its highest and lowest value respectively and also 2 experiments with only keeping parameters with highest influence on output at its highest and lowest value of these parameters. That resulted in total 19 of these parameter combinations. Different parametric combinations explored in pilot runs are given in table 2.

Table 2 Coded parametric combination for pilot experimentation

S. No.	**RPM**	**Transverse speed**	**Tilt angle**	**No. of passes**	**Plunge depth**
1	1	2	2	2	2
2	2	2	2	2	2
3	3	2	2	2	2
4	2	1	2	2	2
5	2	2	2	2	2
6	2	3	2	2	2
7	2	2	1	2	2

8	2	2	2	2	2
9	2	2	3	2	2
10	2	2	2	1	2
11	2	2	2	2	2
12	2	2	2	3	2
13	2	2	2	2	1
14	2	2	2	2	2
15	2	2	2	2	3
16	1	1	1	1	1
17	3	3	3	3	3
18	3	1	2	2	2
19	1	3	2	2	2

In Table 2, experiment no. 2, 5, 8, 11 and 14 have the same parameter combination, so these 4 experiments are reduced to single experiment. So the final list of pilot experiments is shown in table 3 with 15 experiments.

Table 3 Final parametric combinations in coded form for pilot experimentation

S. No.	RPM	Transverse speed	Tilt angle	No. of passes	Plunge depth
1	1	2	2	2	2
2	2	2	2	2	2
3	3	2	2	2	2
4	2	1	2	2	2
5	2	3	2	2	2
6	2	2	1	2	2
7	2	2	3	2	2
8	2	2	2	1	2
9	2	2	2	3	2
10	2	2	2	2	1
11	2	2	2	2	3
12	1	1	1	1	1
13	3	3	3	3	3
14	3	1	2	2	2
15	1	3	2	2	2

Putting in the value of different parameters at each level in this table we get the final pilot experimentation parameters list in table 4.

Table 4. Final parametric combinations in actual form for pilot experimentation

S.NO.	RPM	TRANSVERSE SPEED	TILT ANGLE	NO. OF PASSES	PLUNGE DEPTH
1	500	65	2	2	0.2

2	1000	65	2	2	0.2
3	1500	65	2	2	0.2
4	1000	30	2	2	0.2
5	1000	100	2	2	0.2
6	1000	65	1	2	0.2
7	1000	65	3	2	0.2
8	1000	65	2	1	0.2
9	1000	65	2	3	0.2
10	1000	65	2	2	0.1
11	1000	65	2	2	0.3
12	500	30	1	1	0.1
13	1500	100	3	3	0.3
14	1500	30	2	2	0.2
15	500	100	2	2	0.2

Result of these pilot experiments showed various defects like internal or surface defects, onion skin defect, burr defect, cross section reduction etc. in different samples. Mechanical testing of these samples also helps in finding the feasible range of process parameters for main experimentation. Figures 3.1 to 3.6 demonstrate the quality of fabricated composite for experiments no. 3, 4, 9, 11,13 and 14 respectively.

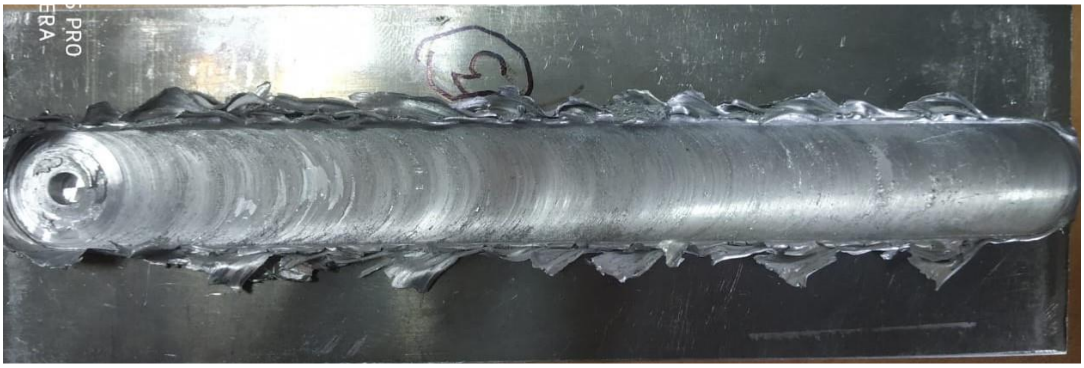

FIGURE 3.1COMPOSITE QUALITY CORRESPONDING TO EXPERIMENT NO. 3

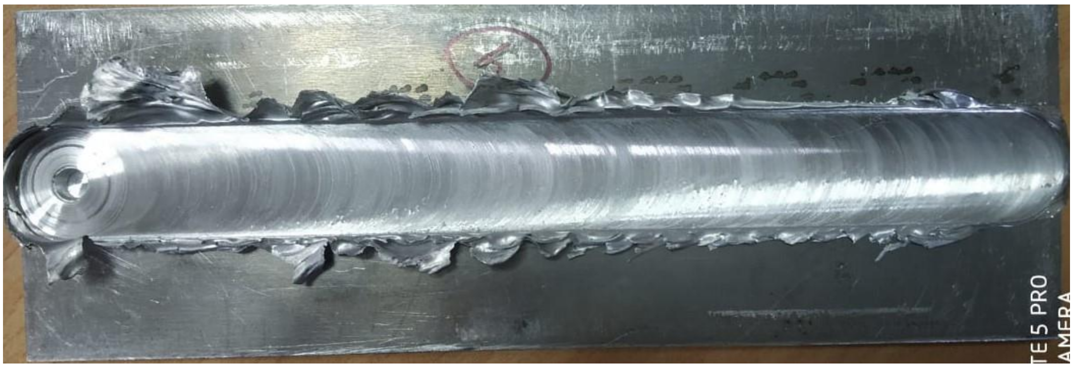

FIGURE 3.2 COMPOSITE QUALITY CORRESPONDING TO EXPERIMENT NO. 4

FIGURE 3.3 COMPOSITE QUALITY CORRESPONDING TO EXPERIMENT NO. 9

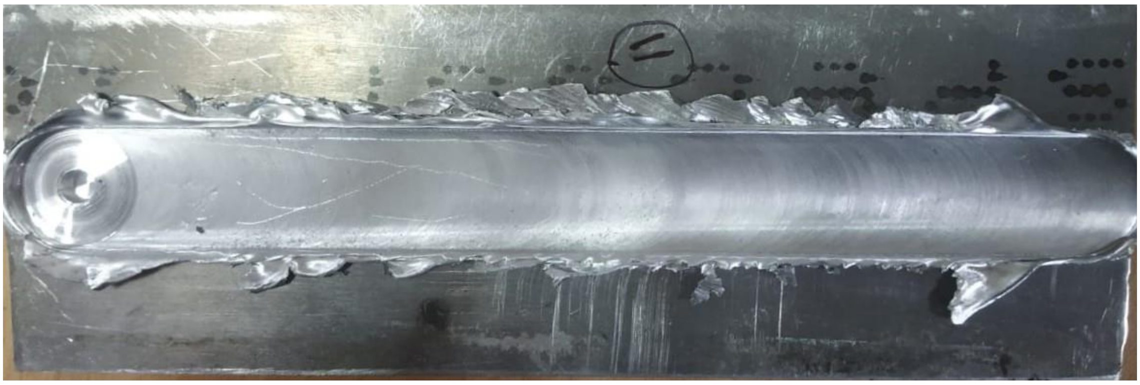

FIGURE 3.4 COMPOSITE QUALITY CORRESPONDING TO EXPERIMENT NO. 11

FIGURE 3.5 COMPOSITE QUALITY CORRESPONDING TO EXPERIMENTNO.13

FIGURE 3.6 COMPOSITE QUALITY CORRESPONDING TO EXPERIMENT NO. 14

After conducting the pilot experimentations, mechanical properties hardness and UTS were measured. Thereafter, grain size was measured using optical microscopy. Results of these characteristics are logged in Table 4.7.

Table 3.7 UTS, Hardness and Grain size values

S. No.	UTS	HARDNESS	GRAIN SIZE
1	378	105	48
2	368	137	29.3
3	326	108	52.3
4	337	101	47.1
5	378	128	38
6	402	143	29.7
7	408	130	36.8
8	398	145	35.7
9	412	140	39.3
10	354	137	46.7

11	345	128	28.5
12	387	98	53.7
13	345	132	36.6
14	350	112	39
15	398	138	53.5

The results of pilot experimentation are as follow:

1. Higher value of plunge depth led to the thinning of the metal plate and excessive chips formation.
2. At lower value of plunge depth tool shoulder might not come in contact with metal plate due to uneven thickness of metal plate, which severely degraded the composite quality.
3. In some experiments the surface finish of the processed zone is better when only 2 passes of fsp tool are which gets affected after the third pass of fsp tool.
4. After single pass of fsp tool in some experiments, improper mixing of reinforcement material was seen. In some cases the reinforcement material can be seen outside processed zone.

4. Results and Discussion

Optimization of process parameters

Tensile strength, Micro hardness, grain sizeisone of the most important mechanical properties. Their data is analysed to determine the optimal levels of parameters which have an important role in deciding the quality of the weld. After selecting welding process parameters, the mean three values of the tensile strength were obtained. The results are shown in Table 5.3.

Table 4.1 test results for various samples

S. No.	RPM	TRANSVERSE SPEED	TILT ANGLE	UTS	HARDNESS	GRAIN SIZE
1	700	40	1	365	101	25.8
2	700	70	2	407	122	31.5
3	700	100	3	401	132	31.5
4	1000	40	2	390	134	24.9
5	1000	70	3	368	129	25.2
6	1000	100	1	372	135	43

Table 5.3 Grey Relational Coefficients for Hardness & Tensile strength

Experiment no.	Gray Relational coefficient		
	UTS	GRAIN SIZE	MICRO HARDNESS
1.	0.3372	0.3502	0.3333
2.	0.6246	0.4532	0.5017
3.	0.5596	0.4532	0.6355
4.	0.4683	0.3333	0.6696
5.	0.3493	0.3333	0.5896
6.	0.3666	1.0000	0.6879

The value of Grey relation Grade Y_i can be calculated from the formula given below. And likewise, we can determine the value of Rank by using rank command in excel for GR grade values.

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} w_k \xi_i(k)$$

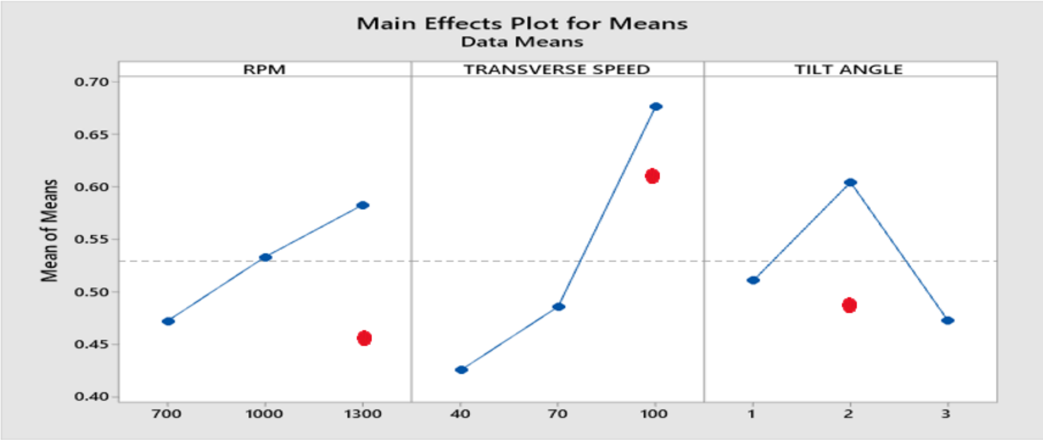

Figure 5.1 Main effect plot for meanGrey Relational Grade

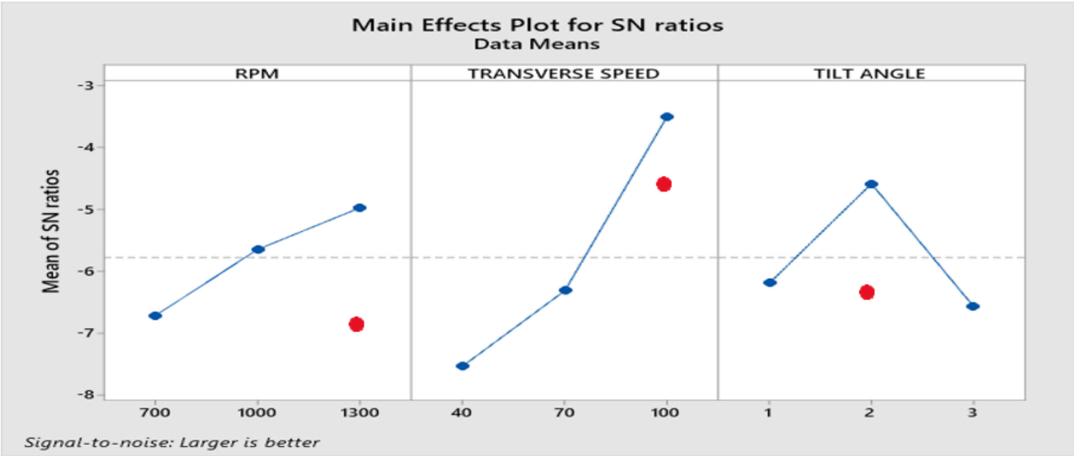

Figure 5.2 Main effect plot for S/N ratios for Grey Relational Grade

Analysing S/N ratio for various process parameters showed higher S/N ratio corresponding to best quality characteristics in larger better and lower ratio corresponding to high quality characteristics in lower is better;theoptimal level of parameters of the processcorresponds to the different S/N ratio and various process parameter can beidentified from the plots as shown in Figures (5.7-5.8) respectively

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