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Wear Analysis of Surface Composites of AA6063/SIC_p Produced by Friction Stir Processing Using Taguchi Technique

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Abstract

In present study, the taguchi approach was used to optimize the wear analysis result, owing to easiness and low cost requirement which is depend on the concept of orthogonal array. It uses hit and trial approaches to optimize high complex engineering problems. In this experiment, three variables at three levels were used. Using the anova technique for L9 taguchi model, the percentage contribution of each FSP process parameters on the wear rate and frictional force were studied in this present experimental study. Friction Stir Processed (FSP) Aluminum alloy 6063 is modified with SiC ceramic particulate of 400 mesh size. By using pin -ball-on-disk configuration at a rotational speed of 500 rpm and the normal load is 30N, 40N, and 50 N, the wear properties of modified surface is determined. The modification process is done at a constant tool feed rate of 59, 95 and 124 mm/min and tool rotation speed of 1000 rpm. With the help of optical microscopy, microstructure properties of worn surface are determined. A significant improvement has been observed in microstructure and hardness of the surface composite. The Anova analysis justified that the sliding distance followed by weight percentage of SiC are the most significant parameters in minimizing the wear rate.

Keywords: FSP, AA6063, Taguchi Technique, Anova, OM

INTRODUCTION

Al and its alloys are mainly used in the aviation and automobile industry because of their strength to weight ratios is high. [1-3]. Due to their light weight, excellent resistance to corrosion and high strength-to-weight ratio aluminum alloy are very popular for structural application in aerospace, transportation industry and military work. However low strength and low hardness of aluminum alloy reduce its limits, mainly in tribological applications [20] The comparison of unreinforced alloys, the aluminum alloy matrix composite reinforced with ceramic phases shows improvement in tribological properties and also its increase the strength and hardness, and increase in resistance to creep and fatigue. [4]. If we use fusion – welding for joining the aluminum alloy series like 2xxx and 7xxx some problems occurred like formation of cracks were seen in welding process and in welding structure deterioration of mechanical characteristics is occurred. In industrial application surface properties like wear resistance can determine the service life of components. In different applications where aluminum alloys involving surface contact, hardness and wear resistance is mainly influence the life of component. That is why it was strongly required that the surface layer of the component was reinforced with the help hard ceramic particle for the purpose of achieving required hardness and also made the main structure with higher ductility & thermal conductivity [5,6,7]

That is why a new and stronger drive is required to develop new Al- based material with higher resistance to wear and good tribological properties.[8,9].This method is very good for fabrication of hybrid surface metal matrix composites (SMMCs) in aluminum alloy plates. [10, 11, 12]. A rotating tool is used for friction stir processing with pin and shoulder is plunged in a single material. Main purpose of tool is to provide friction heat to that area which is covered by tool for mechanical mixing. The friction and plastic deformation between the tool is the main reason of generation of heat. Due to this heating the material around the tool shoulder and pin become soften. A stirring action is used with tool rotation and transverse speed for the distribution of reinforced particals on the surface of aluminum alloy. The refinement of microstructure of aluminum alloy and improvement of in mechanical properties of material, FSP is more effective than the other conventional method of welding. [13, 14]. Su, J.Q et al. [13] et al. investigate and find that reinfinenemt of grain shows improvement in load bearing capacity and wear resistance. In a work by by, Izadi et al. [15] powder metallurgy on Al/SiC produce by FSP, he found improvement in micro hardness of composite layer by FSP. Flow of material in the stir zone during FSP is successful in uniformly distributing the SiC particles.

Different kind of study and investigation is done for the purpose of producing nano-scale and micro composite by FSP directly by processing a groove filled with reinforcing particles. [1-8]

EXPERIMENTAL PROCEDURE:

Development of friction stir processed al alloy:

The surface of AA6063 Al-alloy is reinforced with SiC using FSP is used for the experiments. The main material is standard AA6063 alloy. Dimensions of the AA6063 blocks were100 mm × 50 mm × 6 mm. A grove was made of 3x2 mm along the longitudinal direction on each specimen to fill the SiC particles. The friction stir processing was carried out on a vertical milling machine and was conducted at rotation speed range of 1000 rpm with tool feed rates of 59 -124 mm/min, respectively. A rotational speed of 1000 rpm produced the best result therefore; the data from this speed were used in this study. The best results were meant that the microstructures had minimum defects. The process was carried out with a tool angle of 2.5º. This angle enables the trailing edge of the tool shoulder to have a forging effect. A conical and untreated tool was used to minimize the wear to the tools during the friction stirring process. This tool was made of AISI 4340 steel and is hardened by quenching. Geometry of specimen with its dimensions as 100x50 and specimen used are shown in fig.1. Fortification particles was placed into a channel in the aluminum block that had a width of 3 mm and a depth of 2 mm. The composite surface layer with agglomerated & circulated SiC particles

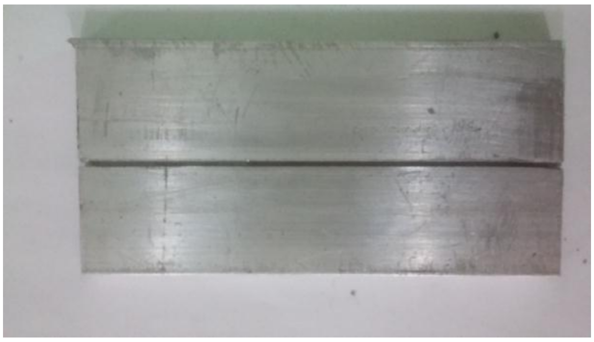
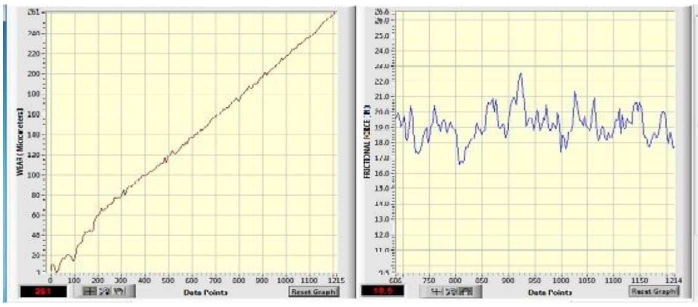


Figure 1: A schematic representation of the specimens used in the experiments.

WEAR TESTING:

A tribometer with rotating disc known as ball-on-disc configuration is used for dry sliding wear testing. The dry wear test is done under normal atmospheric conditions using loads of 30, 40 and 50 N. The size of testing pin was 45mm x 6mm x 6mm.. Wear tests is carried out at a speed of 500rpm. After the wear tests, the worn surfaces were analyzed using OM. The wear volume losses were observed with DUCOM WEAR TESTER at 3 different locations along the wear track, the average of the measured values represented the mean worn area shown in fig 2. After measuring the area, volume of worn area was calculated. Specific wear rate was calculated by Tribometer tester's software. The rectangular pin type wear specimens are shown in fig. 3.



Figurer 2: Showing wear (in micrometer) and frictional force w.r.t time (seconds)

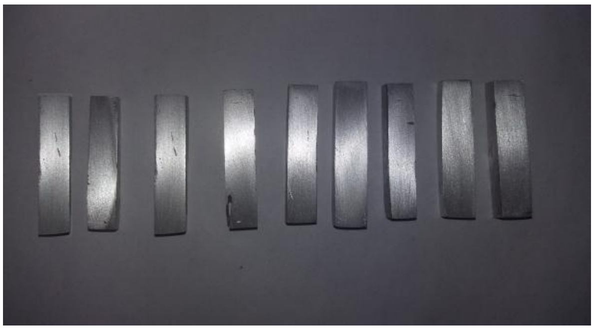


Figure 3: Pin type samples for wear testing

Vicker's microhardness observation

The Vickers microhardness dimensions is conducted 1 mm under the customized material surface as well as at the material interface. The hardness tests is occurred at 0.5 mm intervals with a 100 g load for 15 s per test.

RESULTS AND DISCUSSION:

Friction Stir Processing is used for the purpose of producing surface composite with the help of distributing the reinforcement particle. Different type of processing parameters like tool rotation speed, tilt angle have significant effect on microhardness and material flow pattern. Due to these parameters, reinforcement particles is shown variable distribution.

Wear test:

The wear test is done by using ball-on –disk geometry which has 6 mm in dia. Experiment is started at a sliding speed of 500 rpm and load is 30, 40 and 50 N. The ball on disc apparatus was attached with LVDT to acquire the wear data in a controlled way. The wear rate is calculated by height loss measurement theory. Table 5 shows avg. frictional force and specific wear rate which were done with variation of sliding distance, applied load and weight percentage of SiC. The reinforced SiC ceramic particles resist the plastic liquidity of the material by increasing the resistance and hardness of the material at high temperatures. Additionally, the SiC particles keep the material debris on the surface, and some of this debris accumulates around the particles during wear by remaining stable at the points where they already exist. This is how the wear resistance of the composite material increased. The view of pin on ball tribometer is shown in fig. 4.

Figure. 4: View of wear testing tribometer (DUCOM)

setting up the optimization problem:

The taguchi approach [16] [17] was used to optimize the wear analysis result, owing to easiness and low cost requirement which is depend on the concept of orthogonal array. It uses hit and trial approaches to optimize high complex engineering problems. In this experiment, three variables at three levels were used. The process parameters were chosen at three levels as follows: wear loads have been taken as 30,40 and 50 N, sliding distance as 500,1000 and 1500m respectively and wt. % sic were taken as 0.5,1 and 1.5.

Table 4 shows the wear rate in each nine runs shown in the L9 design, the corresponding frictional force value for every run has also been included in the table 4. According to taguchi model, the minimum value of wear rate is achieved at the minimum value of load =30 N. The maximum value of sliding distance = 1500 and highest value of SiC wt % =1.5. The minimum value of frictional force is achieved at the maximum value of weight percentage of SiC =1.5, the maximum value of sliding distance =1500 and the lowest value of load =30 N. To validate the result two simulation run were performed for wear rate and frictional force, it is shown in the table 5 and table 6 subsequently. It is evident from the response table for wear rate that major contribution was achieved by sliding distance for the lowest wear rate (i.e. shown in the table 5 delta rank 1 is given to the sliding distance). Same for the frictional force, the response table for frictional force, the major contribution is towards to the weight percentage of SiC (i.e. shown in the table 6, delta rank 1 is given to the wt %)

Table 1: Variables for wear test

Control variables	Symbols	Units
Load	L	Newton (N)
Sliding distance	SD	Meter (m)
Wt. % SiC	WT	%

Table 2: Control variables at three levels

Control factors	Level		
	1	2	3
Load	30	40	50
Sliding distance	500	1000	1500
Wt. % SiC	0.5	1	1.5

Table 3: L_9 Orthogonal array

Sr. No.	L	SD	WT%
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	2
9	3	3	1

Table 4: The S/N ratios for wear rate (WR) and frictional force (FF)

Sr. No.	LO	SD	WT%	Wear Rate (WR)	Frictional Force (FF)	S/N ratios (WR)	S/N ratios (FF)
1	30	500	0.5	13.029	14.11	-22.2982	-22.9905
2	30	1000	1.0	6.532	7.75	-16.3009	-17.7860
3	30	1500	1.5	4.625	6.35	-13.3022	-16.0555
4	40	500	1.0	11 .452	8.32	-21.1776	-18.4025
5	40	1000	1.5	7.159	12.17	-17.0970	-21.7058
6	40	1500	0.5	7.259	17.11	-17.2175	-24.6650
7	50	500	1.5	12.245	21.82	-21.6013	-26.7771
8	50	1000	0.5	9.685	23.73	-19.7220	-27.5060
9	50	1500	1.0	7.523	10.12	-17.5278	-20.1036

Table 5: Response table for wear rate (smaller-is-better)

Level	L	SD	WT%
1	-17.30	-21.69	-19.75
2	-18.50	-17.71	-18.34
3	-19.62	-16.02	-17.33
Delta	2.32	5.68	2.41
Rank	3	1	2

Table 6: Response table for frictional force (smaller-is-better)

Level	L	SD	WT%
1	-18.94	-22.72	-25.05
2	-21.59	-22.33	-18.76
3	-24.80	-20.27	-21.51
Delta	5.85	2.45	6.29
Rank	2	3	1

Anova technique:

Using the Anova technique [18][19][21] for L9 taguchi model, the percentage contribution of each FSP process parameters on the wear rate and frictional force were examined in this present experimental study. The analysis of result are tabulated in table 7 and table 8, and graphically shown through pie chart in fig 7 and fig 8. The sliding distance has the largest contribution (i.e. 81.67%) on wear load (6.73%) and weight percentage of SiC (i.e.10.33) which is shown in fig 7. It has been also observed that in another study that weight percentage of SiC has the largest contribution (44.67%) over sliding distance (i.e. 7.69%) and wear load (41.68%) which is shown in fig .8. It suggest that sliding distance play a major role to minimize the wear rate and to minimize the frictional force as well as the mechanical properties such as microhardness and microstructure of friction stir processed Al alloy.

Table 7: ANOVA results for wear rate (x$10^{-3}mm^3/m$)

input Source	DF	Seq SS	Adj SS	Adj MS	F-Value	% Contribution
L	2	4.4010	4.4010	2.2005	5.36	6.73
SD	2	53.3884	53.3884	26.6942	64.98	81.67
% R	2	6.7590	6.7590	3.3795	8.23	10.33
Error	2	0.8216	0.8216	0.4100		1.25
Total	8	65.3700				100

Table 8: ANOVA results for frictional force

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	% Contribution
L	2	129.86	129.86	64.93	6.56	41.68
SD	2	23.96	23.96	11.979	1.21	7.69
% R	2	137.87	137.87	68.934	6.96	44.26
Error	2	19.80	19.80	9.902		6.35
Total	8	311.49				100

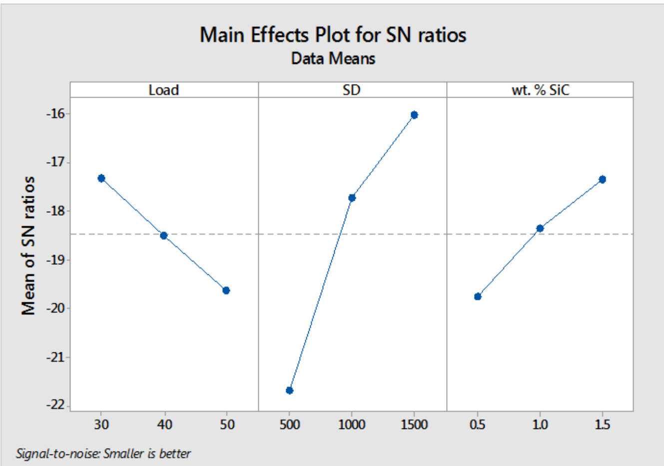


Figure. 5: Main effects plot for S/N ratios (wear rate)

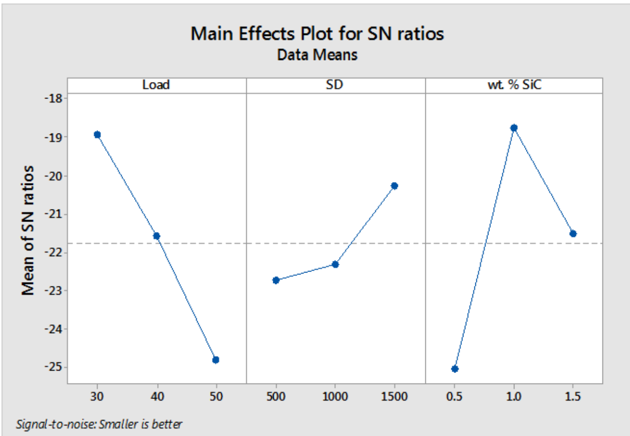


Figure. 6: Main effects plot for S/N ratios (frictional force)

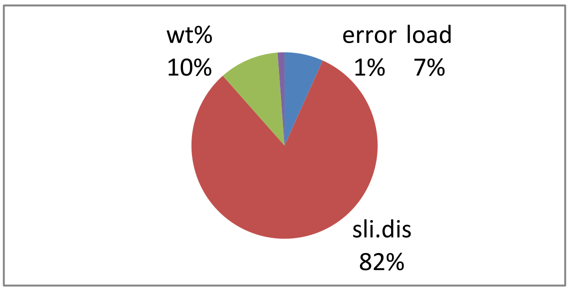


Figure 7: contribution of the process parameter on the wear rate

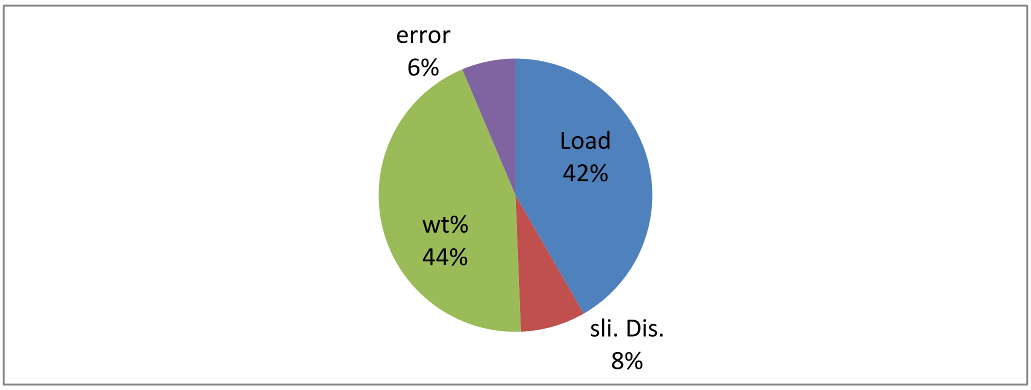


Figure. 8: contribution of process parameters on the frictional force

Micro hardness analysis:

Table shows the During the FSP treatment, the process heat increased due to the friction between the tool shoulder circumference, the pin and the material. When the distribution of the regional hardness after the FSP treatment was examined, it is found that hardness in the shoulder-width zone is lower compared to the main material. It was observed that the distribution of hardness was similar for all feed rates. Although the hardness decreased around the shoulder-width zone of the tool, it increased in the areas closer to the main material. The hardness increased towards the ends of the tool, and hardness values greater than the hardness of the main material were measured in some places.

Aluminum alloys are categorized according to whether heat treatment can or cannot be applied. As a result of FSP treatments conducted in the aluminum alloy that can be heat treated, a softened region occurs in the area and temperature increases. This temperature causes a decrease in the hardness of the structure, and there is a growth in the precipitated grains in the stir zone of the alloy in which precipitation hardening was performed. This finding is similar to those in the literature for FSP applications in studies that were conducted on different Al alloys that were heat treated for precipitation hardening.

Table 9: Vicker's microhardness results for Friction stir processed AA6063+SiC composite.

Material	Vicker's Hardness (at load .05Kgf, dwell time= 10sec)
AA6063+0% SiC	58.60
AA6063+0.5% SiC	62.25
AA6063+1% SiC	69.85
AA6063+1.5% SiC	89.19

CONCLUSIONS:

The aim of this study was to obtain a wear analysis and frictional force analysis with the variation of different process parameters like wear load, sliding distance and wt % of SiC using taguchi optimization model. After the investigation and optimization of friction stir processed al alloy, a significant effect was fond on wear behavior and on friction force due to variation the sliding distance and variation in weight percentage of sic during friction stir processing of al alloy. The sliding distance has the largest contribution(i.e. 81.67%) on wear load (6.73%)and weight percentage of SiC(i.e.10.33) which is shown in fig 8.it has been also observed that in another study that weight percentage of SiC has the largest contribution(44.67%) over sliding distance(i.e. 7.69%) and wear load(41.68%) which is shown in fig .9. It suggest that sliding distance play a major role to minimize the wear rate and to minimize the frictional force as well as the mechanical properties such as microhardness and microstructure of friction stir processed Al alloy.

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