Proceedings of the International Conference on Applied Mechanical Engineering Research (IC-AMER2019)
NIT Warangal, India – May 02-05, 2019
Paper No. XXX (The number assigned when the papaer is accepted)

INVESTIGATION ON WEAR BEHAVIOUR OF AA5052/SiC/Al_2O_3 HYBRID COMPOSITE FABRICATED USING STIR CASTING PROCESS

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This project aims to increase the wear resistance of Aluminium Alloy 5052 (AA5052), which has very good corrosion resistance, ductility, excellent thermal and electrical conductivity. It is commonly used in marine applications like ship hulls, underwater natural gas tanks and pipelines. Composites were fabricated using AA5052 reinforced with Silicon Carbide 3% and Alumina 3 & 4% by weight of the matrix, melting temperature 700 & 750°C, and stirring time 3 & 5 min. The composites were tested for Micro-hardness and Tensile strength. The average values of Micro-hardness and Tensile Strength was 88 HV and 237 N/mm^2 respectively. Maximum Micro-hardness and Tensile Strength was achieved for the combination of Silicon Carbide-3%, Alumina–4%, melting temperature–750°C and stirring time–3 min. Composite fabricated for the above said condition is used for wear analysis. The design of experiments was planned in full factorial method with load, speed, time and track diameter as input factors and wear as the response or output factor. The test was performed in Pin-on-disc tribometer as per design of experiments. Microstructural study of the wear surface was done in Inverted Microscope and it showed the different mechanisms associated with the wear. The process parameter combination of 2 kg load, 500 rpm speed, 5 min time and 70 cm track diameter was found to be the optimum condition for minimum wear of the fabricated hybrid composite. Wear resistance was increased by 51%. Speed has the maximum influence with 45.42% contribution whereas time has the least influence with 7.02% contribution.
Keywords: stir casting, hybrid composite, pin-on-disc apparatus, full factorial method

1. Introduction

Aluminium based Metal Matrix Composites are being extensively used in various fields owing to their superior mechanical properties like low weight, high strength-to-weight and stiffness-to-weight ratio and good corrosion resistance. Among the various methods available to process Metal Matrix Composites (MMC) like Powder metallurgy, Diffusion bonding, Deformation bonding, Squeeze casting etc., Stir casting is the most commonly used and economic method. Composite materials have become a significant part of engineering materials that find applications starting from day-to-day applications to advanced technologies.

Saravanan et. al[1]., made a detailed review of the effect of particulate reinforcements on Aluminium metal matrix composites and their different fabrication techniques. They have also provided guidelines and criteria for selection of process parameters like stirring speed, time, melt temperature, reinforcements and die preheat temperature etc., in stir casting process. B Prabu et. al[2]., concluded that particle clustering occurred when stirring speed and stirring time were less. Homogenous distribution of SiC in the matrix was reported when the stirring speed and time was increased to 600 rpm and 10 min respectively. N. Natarajan et. al[3]., suggested that for a sliding speed of 4.5 m/s, applied load of 10 N, sliding time of 5 min and reinforcement content of 15% both coefficient of friction and the wear rate was optimum.

2. Experimental Work

2. 1. Composite Fabrication

The composites were fabricated in Bottom pouring type Stir casting machine supplied by SwamEquip, Chennai. The experimental setup consists of an electric resistance type furnace and a mechanical stirrer. The furnace has a crucible capacity of 2 kg. The maximum temperature that can be achieved during operation is 1000°C. The current rating of the furnace is single phase 230V AC, 50Hz. AA5052 rods of the required weight were heated in the crucible until they were completely molten and maintained at 700 & 750°C. Reinforcement powders Silicon Carbide (3%) and Alumina (3 & 4%) were preheated externally to a temperature of 250°C to remove surface impurities that ensures proper mixing and were introduced into the melt pool and stirred at 600 rpm for 3 & 5 minutes. Argon gas was passed in to the molten metal to remove the soluble gases present in the liquid state metal. The completely molten hybrid composite was poured into the die of required length and diameter.

2. 2. Design of Experiments

Design of experiment is a suitable tool to model and analyse the effect of process variables or factors on a specific variable or response, which is an unknown function of the process variables. Design of Experiments was planned in full factorial design method. It is a multi-factor design that not only tests the individual effect of factors, but also the combined effect or interaction of the factors on response. The number of experiments required in a factorial design is higher than that in a Taguchi design or fractional design, but it delivers accurate results. The parameters chosen for analysis were load, speed, time and track diameter and the response parameter is wear. Table 1 shows the parameters, their levels and the number of experimental runs conducted.

2. 3. Wear Test

All the fabricated hybrid composites were tested for Micro-hardness and Tensile strength. The average Micro-hardness and Tensile strength was 88 HV and 237 N/mm^2 respectively. Maximum Tensile Strength and Micro-hardness was achieved for the combination Silicon Carbide-3%, Alumina–4%, Melting temperature–750°C and Stirring time–3 min. This composite was selected for wear analysis. A Pin-on-disc test tribometer supplied by Ducom Instruments, was used to study the dry sliding wear behaviour of the composites in accordance to ASTM G99-95 standards. Pins of 20 mm height and 10 mm diameter were cut from the samples and polished. All these tests were conducted at room temperature. The wear test was carried out for 2 & 3 kg load, 500 & 600 rpm speed, 5 & 7 min time and 70 & 80 cm track diameter as per the design of experiments. The pin is held and loaded vertically into the rotating steel disc of material EN32 and hardness 65 HRC by an arm. Once the specimen has run for the specified time, it is removed, cleaned and the process is repeated.

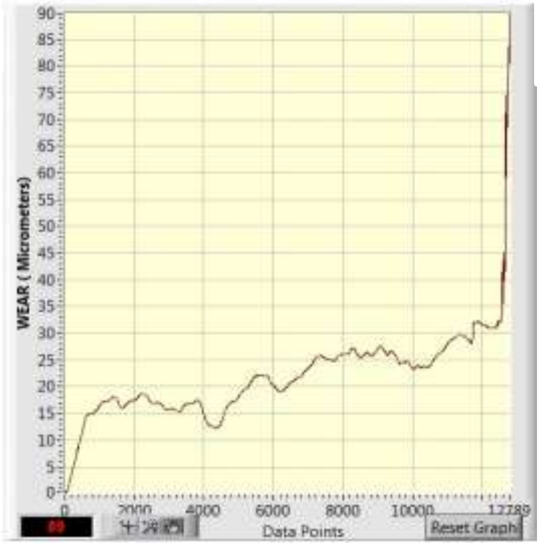
2. 4. Microstructural study of Wear surface

Morphological feature of worn surface is an important quantitative aspect of wear surface analysis. Wear measurement depends on tribological features at interspaces. The worn specimen was removed from the tribometer and studied in an Inverted microscope supplied by Mitutoyo. The workpiece mounted on the stage can be moved in X and Y directions with the help of concentric knobs which facilitate coarse and fine adjustments. The objective lens extends and retracts along the vertical direction to provide the necessary focussing.

3. Results and Discussion

The wear value for each run was noted from the data acquisition system. The results of the test are given in the Table 1 where the wear values for each specimen is entered against its parameter combination. The wear graphs of the samples 1 & 16 are shown in the figure 1. Samples 1 and 16 showed a wear of 89 μm and 165 μm respectively which are the minimum and maximum values in the entire set. This difference was attributed to the changes in the wear conditions. The higher the load and speed the higher was the wear.

a)



b)

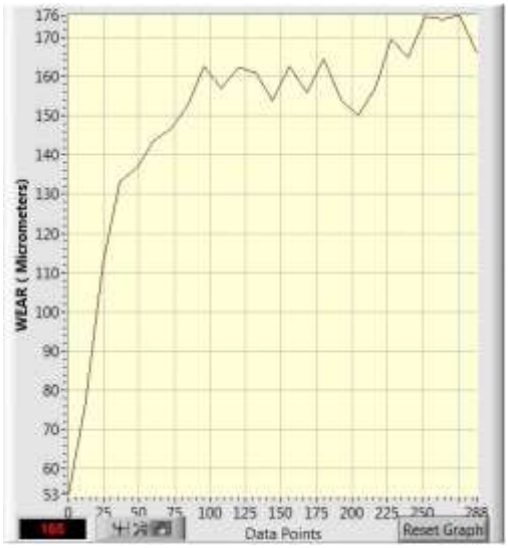


Fig. 1 Wear graphs of samples a) Sample 1, load-2kg, speed-500 rpm, time-5min, track diameter-70cm
b) Sample 16, load-3kg, speed – 600 rpm, time-7 min, track diameter – 70cm

Table. 1. Wear Test results

S.No.	**Load (kg)**	**Speed (rpm)**	**Time (min)**	**Track diameter (cm)**	**Wear (µm)**
1	2	500	5	70	89
2	3	500	5	70	113
3	2	600	5	70	122
4	3	600	5	70	142
5	2	500	7	70	103
6	3	500	7	70	122
7	2	600	7	70	125
8	3	600	7	70	153
9	2	500	5	80	103
10	3	500	5	80	129
11	2	600	5	80	129
12	3	600	5	80	158
13	2	500	7	80	109
14	3	500	7	80	146
15	2	600	7	80	154
16	3	600	7	80	165

3. 1. Optimization

The results obtained from wear test were optimized for minimum wear. Figure 2 depicts the main effects plot for Wear, which shows the individual influence of the chosen factors on the response wear. The mean of wear has a linear relation with the factors. The rotational speed of the disc decides the relative motion between the tribo-pairs. The higher the speed, the higher will be the relative motion between the tribo-pairs in the given time and hence higher wear. Load decides the force applied on the specimen, higher the load the higher is the coefficient of friction and wear. Track diameter controls the sliding distance and time the duration for which the specimen is in contact with the rotating disc. Increase in both the factors have similar effect as the other factors, the final result is the increase in wear. The slope of the curves obtained shows the influence of the corresponding parameter. Speed has maximum influence and time the minimum. The minimum value of wear occurred for the condition load - 2 kg, speed – 500 rpm, time – 5 min and track diameter – 70 cm.

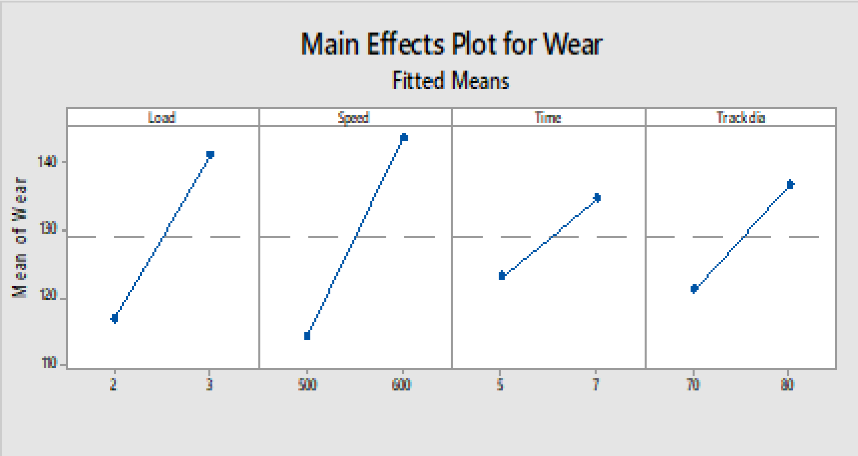


Fig. 2 Main Effects Plot for Wear

3. 2. ANOVA (Analysis of Variance)

ANOVA test gives the statistical significance of the model. The confidence limits are taken as 95% for all the factors. Factors with P-value less than 0.05 are considered to be significant. The Table 2 shows the values obtained for ANOVA test and it can be seen that all the factors are significant. Speed has the maximum influence on wear at 45.52% followed by Load at 31.29%, Track diameter at 12.78 % and Time at 7.04%.

Table. 2. ANOVA Test for Wear Analysis

Source	**DF**	**Seq SS**	**Contribution (%)**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Load	1	2352.3	31.29	2352.3	2352.25	102.17	0.000
Speed	1	3422.3	45.52	3422.3	3422.25	148.65	0.000
Time	1	529.0	7.04	529.0	529.00	22.98	0.001
Track dia	1	961.0	12.78	961.0	961.00	41.74	0.000
Error	1	253.3	3.37	253.3	23.02		
Total	5	7517.8	100.00				

3. 3. Multiple Linear Regression Model

The data adequacy and analysis of the model designed in full factorial model can be evaluated using multiple linear regression model. Regression test also gives the regression equation which is a generalised equation corresponding to the effects of all the factors on the responses. Substituting the optimum conditions namely load – 2 kg, speed – 500 rpm, time – 5 min and track diameter – 70 cm in the regression equation the optimum value of wear obtained is 88.6 µm

$$\text{Wear} = -243.4 + 24.25\ \text{Load} + 0.2925\ \text{Speed} + 5.75\ \text{Time} + 1.550\ \text{Track dia}$$

3. 4. Worn Surface Microstructural Study

Figure 3 shows the micrographs of the worn surface of the samples studied. The mechanism of the wear that occurred on the specimens can be understood from the micrographs. Sample 1 shows Ploughing – removal or displacement of material in chunks and sample 7 shows Grooves – linear cuts on the surface of the specimen. Both are characteristics of abrasive wear that occurs between a soft and comparatively hard surface. In this case, the hardened steel disc removed material from the samples. In sample 1 due to low speed and load the material displaces sideways from the hard surface and causes cavities. In sample 7 due to high speed and load the material gets removed in the form of chips or debris. The presence of reinforcement particles over the worn surface act as a resistance to the material's wear.

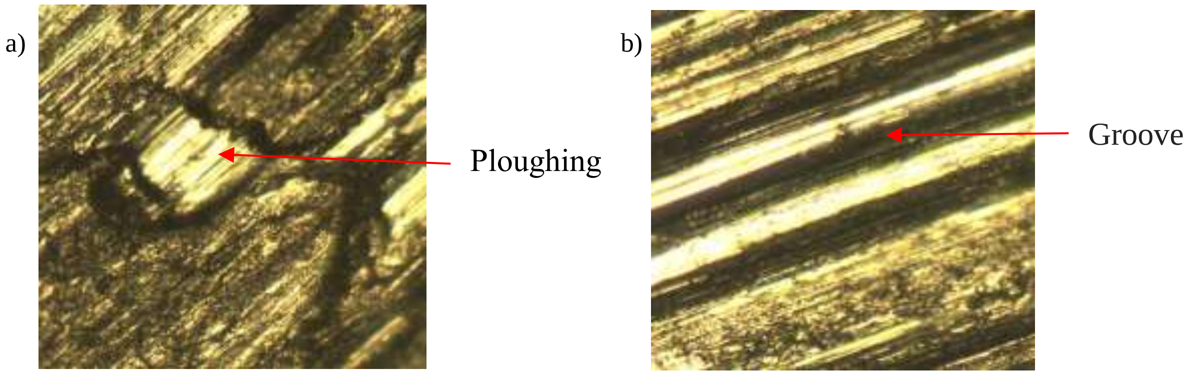


Fig. 3 Worn Surface Micrograph of Samples a) Sample 1, load-3kg, speed – 600 rpm, time-7 min, track diameter – 70cm b) Sample 7, load-2kg, speed – 600 rpm, time-7 min, track diameter – 70cm

4. Conclusion

The hybrid composite samples of AA5052 as matrix, and SiC and Alumina as reinforcements were successfully fabricated using stir casting process. The wear behaviour and worn surface microstructure were investigated for the fabricated samples. From the results it is observed that the dual particulate reinforcements have shown an impact in the wear properties of the composite.

- The minimum wear obtained is 89 µm, in other words the wear resistance has increased by 51%.
- The process parameter combination of 2 kg load, 500 rpm speed, 5 min time and 70 cm track diameter was found to be the optimum condition for minimum wear of the fabricated hybrid composite.
- Speed is the most significant factor for wear with 45.42% contribution followed by load at 31.29%, track diameter at 12.78% and time at 7.04%.
- This hybrid composite can be explored for use in marine applications like ship hulls, underwater natural gas tanks and pipelines.

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