Experimental Investigation on Wear Behaviour of AA6082 Aluminium Alloy, Tungsten Carbide and Graphite Hybrid Composites

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Abstract - In this experimental study, Aluminium alloy (AA) 6082 was strengthened with Tungsten Carbide and graphite through stir casting technique. Scanning Electron Microscope (SEM) was employed to study the wear performance of the Al/WC/Gr composites. Wear tests were carried out using a pin-on-disc apparatus. The input parameters in this study are the load applied (4, 8, 12, 16, and 20 kg), speed of sliding (1, 1.5, 2, 2.5 and 3 m/s) and distance slides (1000, 1500, 2000 and 2500 m). Response Surface Methodology (RSM) has been carried out using MINITAB 14 software program to examine the rate of wear and frictional behaviour of the hybrid composites.

Keywords - Hybrid Composites, Wear, Microstructure, Response Surface Methodology

1. Introduction

Studies conducted in aerospace and automotive industries reveal that the materials used for fabricating items need to showcase good mechanical properties with higher resistance [1]. Composite elements are a choice of materials exclusively in utilizations like dry sliding areas to elevate the Tribological performance of the material. In several applications, Metal Model Composites (MMCs) with aluminium as the model material plays a vital in enhancing these properties [2]. The properties like environmental resistance strength to weight ratio and stiffness are the potential benefits of Al composites. On the other hand, they have low resistant to wear; especially at boundary or partial lubricating situations. Stir casting technique is the most commonly used method for fabricating aluminium composites because of it is economical compared to other processes. The statistical relation between the input and output variables and its influence on parameters can be estimated by using statistical modelling techniques like Response Surface Methodology (RSM). The application of RSM in various optimization problems were investigated by different authors [15–19]. Allwyn Kingsly Gladstonaa et al. [21] reported that RSM is one of the primary technique that deals by multi-variables problems that influences the responses. This technique optimizes processes and determines the best combination. This idea considerably minimizes the trials required for the model to determine the optimal parameters. Although researcher studied on the various properties of wear in numerous aluminium alloys in dry conditions and wear behaviour of hybrid aluminium composite is limited. Dry sliding wear properties of materials depend on the parameters like load, speed of sliding and distance of sliding [25].

2.1.2 Tungsten carbide

Addition of Tungsten Carbide in aluminium enhances the mechanical and tribological behaviour of the composites [5–9]. WC is considered as one of potential high strength materials because of its high strength, high hardness and better chemical stability. Addition of Tungsten Carbide in aluminium alloy (AA) 6082 improves the wear resistance of the aluminium composites. Addition of hard particles like WC in Al alloy reduces the rate of wear, and it is influenced by parameters like speed of sliding, load applied and distance slides [13–17].

2.1.3 Graphite

Graphite is one among the mostly used lubricant of solid type due to its positive properties of combinations such as chemical inertness, low friction, film forming ability, lack of intrinsic abrasiveness etc. Inclusion of suitable composition of the graphite in Aluminium alloy decreases the rate of wear of hybrid composites. Addition of graphite...
particle in aluminium model, hardness of the composites and reduces the flexural strength [3,4].

**Table 1. Chemical composition of AA6082 aluminium alloy**

| Element | Mn | Cu | Cr | Mg | Si | Fe | Zn | Ti | Balance |
|---------|----|----|----|----|----|----|----|----|---------|
| Wt.%    | 0.5| 9  | 3  | 0.7| 1.0| 0.2| 0.0| 0.0| 1       |

**2.2. Wear test**

Dry sliding wear tests have been conducted as per ASTM: G99 standard using a pin on disc apparatus as shown in Fig. 2. The wear tests have been conducted on room temperature against hardened nickel steel of hardness of 62 HRC. Wear tests were carried by varying the load applied of 4, 8, 12, 16 and 20 N and with speed of sliding of 1, 1.5, 2, 2.5 and 3 m/s. The distance slides has been varied from 500 to 2500 m in intervals of 500 m. The diameter of pin used in this study is 6 mm and height of the specimen is kept as 15 mm. The sliding track diameter in the hardened disc is fixed at 27 mm. Specimen is removed after each test, cleaned and dried and the specimen is weighed to determine the weight loss. The losses in weight is estimated using an electronic weighing machine of an accuracy of 0.1 mg in Fig 2.

![Fig. 2. Pin-on-Disc wear tester.](image)

**Table 2. Input levels of wear parameters**

| S. No | Parameters | Levels |
|-------|------------|--------|
| 1     | Load (kg)  | -2, -1, 0, 1, 2 |
| 2     | Speed of sliding (m/s) | 1, 1.5, 2, 2.5, 3 |
| 3     | Distance slides(m) | 500, 1000, 1500, 2000, 2500 |
| 4     | Reinforcement % | 2, 4, 6, 8, 10 |

**2.3. Response Surface Methodology (RSM)**

Optimization involves study based on response with a set of combinations, and predicting the response of the variables. In this study speed of sliding, load applied and distance of sliding have been considered as a separate variable. The mass of wear loss is considered for response variable. The speed of sliding is changed over five levels (1.0 and 3.0 m/s) relative to the centre point 2.0 m/s. The process parameter and their variable along with the coded values are represented in Table.2. Based on the response surface variable a set of 30 experiments were conducted and their responses and variables are represented in Table.3.

**Table 3. Response values for dry and lubricated wear for the experiments.**

| S.No | Velocity | Distance | Load | Reinforcement | Wear mm/m | Friction |
|------|----------|----------|------|---------------|-----------|----------|
| 1    | 2.5      | 2000     | 8    | 4             | 0.0233    | 0.108    |
| 2    | 2        | 1500     | 12   | 6             | 0.0598    | 0.3105   |
| 3    | 2        | 1500     | 4    | 6             | 0.0690    | 0.0075   |
| 4    | 2        | 1500     | 12   | 6             | 0.0801    | 0.0179   |
| 5    | 2        | 500      | 12   | 6             | 0.3115    | 0.0102   |
| 6    | 1.5      | 2000     | 8    | 8             | 0.1022    | 0.1428   |
| 7    | 1.5      | 1000     | 16   | 8             | 0.1569    | 0.0054   |
| 8    | 2.5      | 1000     | 8    | 4             | 0.1757    | 0.0312   |
| 9    | 1.5      | 1000     | 8    | 4             | 0.101     | 0.0702   |
| 10   | 2        | 1500     | 12   | 6             | 0.0052    | 0.0639   |
| 11   | 2        | 1500     | 20   | 6             | 0.1019    | 0.1042   |
| 12   | 2.5      | 2000     | 16   | 8             | 0.077     | 0.0347   |
| 13   | 1.5      | 2000     | 8    | 4             | 0.0865    | 0.0212   |
| 14   | 2.5      | 2000     | 8    | 8             | 0.1042    | 0.1848   |
| 15   | 2        | 1500     | 12   | 2             | 0.0678    | 0.2702   |
| 16   | 2.5      | 1000     | 8    | 8             | 0.0471    | 0.2641   |
| 17   | 2        | 1500     | 12   | 6             | 0.0993    | 0.0407   |
| 18   | 2        | 1500     | 12   | 10            | 0.0837    | 0.0025   |
| 19   | 2        | 1500     | 12   | 6             | 0.0865    | 0.0980   |
| 20   | 2.5      | 1000     | 16   | 4             | 0.1372    | 0.0054   |
| 21   | 1.5      | 2000     | 16   | 4             | 0.0788    | 0.0062   |
| 22   | 3        | 1500     | 12   | 6             | 0.1018    | 0.0141   |
| 23   | 2.5      | 2000     | 16   | 4             | 0.0229    | 0.0429   |
| 24   | 1.5      | 1000     | 16   | 4             | 0.0378    | 0.0688   |
| 25   | 1.5      | 1000     | 8    | 8             | 0.0785    | 0.0513   |
| 26   | 2.5      | 1000     | 16   | 8             | 0.0132    | 0.0069   |
| 27   | 1        | 1500     | 12   | 6             | 0.0707    | 0.0702   |
| 28   | 2        | 1500     | 12   | 6             | 0.0410    | 0.0466   |
| 29   | 1.5      | 2000     | 16   | 8             | 0.015     | 0.2449   |
| 30   | 2        | 2500     | 12   | 6             | 0.0370    | 0.3083   |

**3. Results and discussion**

**3.1. Sliding wear behavior of AA6082/WC/Graphite hybrid composites**

**3.1.1. Effect of rate of wear on load**

The distinction of rate of wear in to the load applied is represented in Fig. 3. The load applied influences the rate of wear in aluminium alloy and its composites of hybrid properties considerably. The rate of wear of composites...
varies with changes in load applied and it significantly reduces the rate of wear of the hybrid composites. The rate of wear of Al/WC/Gr increases based on load applied and the influences in hybrid composite is less compared to base AA 6082 alloy. This phenomenon is largely due to the Mg particles of AA 6082 availability. At various load conditions the resistance of wear in the hybrid composites has been better to the AA 6082 alloy model alloy [16,17,18] in Fig 3.

3.1.2. Effect of rate of wear in distance slides
The variation of rate of wear with variation in distance slides is represented in Fig.3. An increase in distance slides decreases the rate of wear of Al/WC/Gr hybrid composites. At higher distance slides the temperature along the sliding surface increases thereby softening the composite materials and increases the deformation at elevated distance slides. The increase in hardness of the hybrid composite results in enhancement of seizure and wear resistance of the Al/WC/Gr hybrid composites. WC and graphite particles reinforced in hybrid composite improve the plastic formability than the base AA3082 model alloy. Presence of graphite particles in hybrid composite acts as an efficient protecting layer between the two friction surfaces that reduces the rate of wear [21].

3.1.3. Effect of rate of wear on speed of sliding
The influence of rate of wear with respect to the variation in speed of sliding is exposed in Fig.4. The distance slides are kept at 2000 m and a load of 16 kg. An increase in speed increases the rate of wear of the base Al alloy (AA 6082) and its hybrid composites to a certain extend. Increasing the speed of sliding increases the temperature along the sliding surfaces and softens the pin surfaces. The rate of wear of hybrid composites are less compared to the wear of AA 6082 alloy. This is probably due to the improvement in the hardness. The increase in hardness of hybrid composite results in enhancement of wear resistance. Addition of graphite and WC particles in Al alloy (AA 6082) will reduce the rate of wear of composites [20].

3.2. Microstructure of AA6082/WC/Graphite hybrid composites
The behaviour of composites based on the microstructure characteristics and the interface between the model and reinforcements. The scanning electron microstructure of the worn out specimen made of Al/WC/Gr hybrid composites is represented in Fig.5. Clustering along with non-homogeneous distribution of the WC and Graphite in the Al alloy were observed in few samples. This might be probably due to the difference of contact time between the WC and Graphite particles with respect to the base alloy [6]. The failure in composite sample containing less amount of reinforcement particles were characterised by delamination and adhesive wear. This mode of failure is primarily ductile in nature. An increase in reinforcement is characterised by ploughing, protrusion, particle breakup and even tearing of particles. There is predominantly brittle kind of wear influenced due to the higher hardness of the composites.

![Fig.3 Influence of distance slides and load on Wear](image)

![Fig.4 Influence of speed of sliding and percentage reinforcement on Wear](image)

![Fig. 5. SEM micrographs of AA6061/RHA AMCs containing RHA; (a) 2 wt.%, (b) 4 wt.%, (c) 6 wt.%, (d) 8 wt.% and (e) 10 wt.%](image)
4. Conclusions
The Al alloy (AA3082) reinforced with WC and Graphite composites were fabricated by stir cast technique with different weight fractions of reinforcements. The following observations are made from the study The AA 6082 hybrid composites reinforced with WC and Graphite was effectively produced by stir casting. The wear resistance of Al/WC/Gr hybrid composites increased with the addition WC and Gr particles. The rate of wear of composites are considerably compared to base Al alloy (AA3082) model. Rate of wear of the composites increases with load and decreases with increase in addition of WC. An increase in speed increases the rate of wear of the base Al alloy (AA 6082) and its hybrid composites to a certain extend. An increase in distance slides decreases the rate of wear of Al/WC/Gr hybrid composites. The wear of the composite specimen is characterised by delamination, ploughing, protrusion, particle breakup and tearing of particles.

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