Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Wear Analysis of Al6061 Hybrid Metal Matrix B4C/Zro2 /Sic Composites

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This paper presents the microstructural wear analysis of Aluminium based hybrid metal matrix composites. Aluminium 6061 alloy was reinforced with 2% B4C, ZrO2(2%,4%,6%), SiC (4%, 6%,8%) by stir casting method. The specimens were prepared as per ASTM standards and tested. The wear test carried on pin on disc apparatus. Wear surface morphology was characterized by scanning electron microscopy. By using scanning electron microscopy, deep groves and debris were evaluated. This investigation explains the detection of abrasive wear and fatigue wear. Worn surface morphology was examined for different load conditions. Additionally, this paper addresses the microstructural properties of Hybrid Aluminium Matrix Composites (HAMCs). Wear surface morphology was characterized After and before testing. Crack, pores, fatigue of materials were evaluated for the effect of reinforcements.

Keywords: Aluminium hybrid metal matrix composites, microstructural analysis of wear surface, worn surface morphology, deep grooves and debris. Microstructural analysis.

1. Introduction

Wear is a common cause of composite or other material failure and must be replaced in many applications. Directly or indirectly, it causes several thousand dollars in economic damage. Suits are the separation of movable and immovable goods. Frictional destruction of the material, flexural and mechanical deformation and machining technique can be used to characterize the wear. Hybrids have a wide variety of applications including gears, magnetized bearings, multi-row roller bearings, seals, camshafts and journal bearings. Surface deformation results from complex dynamic loading occurring sequentially on the faces of the contacting couple. Applications of physical system dynamics can be found in aviation industry, nuclear power plants, manufacturing operations etc. The sliding velocity, distance and load components of the wear parameter have a significant effect on the surface interface.

The goal of wear evaluation is to optimize the wear variables for appropriate applications by considering the wear characteristics of the hybrid materials. Under load conditions, the wear effect of circumferential displacement is greater than 100 μm [i]. The different types of wear mechanism are Adhesive wear, Abrasive Wear, Delamination, Erosive wear, Fretting Wear, Cavitation, Corrosive wear [ii].

Wear properties of metal matrix composites

Metal matrix composites (MMC) are essential because of their high levels of efficiency, including their structural applications, density, and elastic modulus. Hybrid metal matrix composites (HMMCs) are ideal for applications that require combining high resistance properties, heat transfer, acoustic properties and toughness [iii iv v vi]. HMMCs are widely used for special automotive applications including brakes, piston, braking systems and cylinder blocks [vii]. In the past few years, hard ceramic materials such as aluminum and silicon carbide have been used to strengthen HMMCs made of Al, Ti, Cu, Mg and related alloys [viii]. By forming a barrier between the pin and the gray cast iron (GCI) face, the addition of graphite as primary reinforcement improves the abrasion resilience of lightweight materials. The addition of aluminum as a reinforcing material also significantly affects the wear behavior. As composite materials are commonly used in autos, soft stabilizers such as talcum are used in automobiles [ix]. Compared to the Al6061 alloy, the hybrids had higher compressive and yield strengths. Both the improvement in displacement and the increase in aging response are attributed to the increased strength of the composites [x xi].

By increasing the weight percentage of reinforcement in all realistic conditions, the friction and wear properties of HMMCs are further improved. The wear rate of the prepared samples increases with load and sliding distance, while SiC and Al_2O_3 metal particles containing up to 25 percent by weight of SiC and Al_2O_3 reduce the wear rate at room temperature. As the ratio of reinforcement rises, the coefficient of friction (CoF) decreases slightly, and the micro-hardness of the composite material test specimens increases as the volume concentration of particulate reinforcements increases. According to Umanath et al [xii] results of wear resistance of Al6061 alloy and composites, Al6061/3%alumina/15% SiC exhibits higher abrasion resistance than its alloy under all loading conditions [xiii]. By adding moderate amounts of SiC and B_4C particles, the wear resistance of the hybrid composite was improved [xiv]. Due to its superior wear performance and relative affordability, Al-SiC MMC braking drum can replace conventional gray cast iron (CI) brake drum in vehicles. CoF evaluated and discussed the dry slide wear properties of hybrids made of aluminum, silicon carbide and graphene [xv xvi].

According to the researcher, the CoF of friction coupling (disc and pad) should be very high and stable [xvii xviii]. The friction coefficient of drum brakes of any combination was found to be higher than that of the CI brake pedal, and it hardly changed with the imposed braking speed and load to obtain the correct brake friction pair performance [xix]. Metals and alloys are used extensively in the aerospace and automotive sectors for gearboxes, engine parts, and other elements. The revolving and moving parts that were designed to function in moisturizing environments can ultimately operate in semi-lubricated or dry environments. As a result, working temperatures increase, wear accelerates, and equipment replacements occur more quickly. Therefore, abrasion is one of the main issues that need to be addressed to extend product life.

In dry working conditions, composite materials represent potential alternatives to metals. The focus of current research is on developing hybrid reinforced nanocomposites to increase the wear resistance of a component. In the past, the addition of reinforcement has significantly improved interface properties. However, in some cases, it has exhibited deterioration in mechanical properties.

2. Research Methodology

The tribological analysis were carried out by Pin-disc-apparatus reciprocating mechanism with tribometer PLINT-TE67/R to evaluate the wear performance of hybrid metal matrix composites (AA6061/B_4C/ZrO_2/SiC) and interaction with GCI counterpart disc plates. The specimen was prepared from the fabricated composites as per the standard dimensions (ASTM G99-95), as shows in Figure 1. It has radius of curvature 40 mm, arc length 20 mm and thickness of the specimen is 35 mm. The GCI plates consists of 338HV hardness, flat plates with a dimension of 40x18x5 mm. The chemical properties and surface morphology of GCI plates shows in Figure 1 and Table 1 respectively.

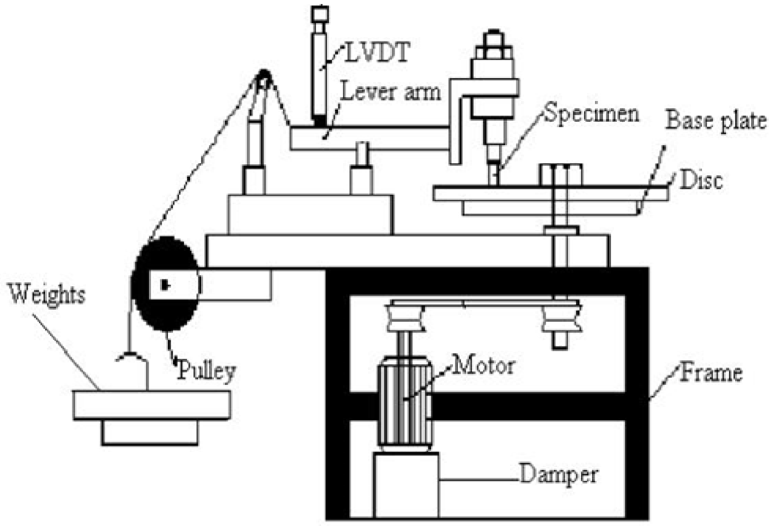

Figure 1. Wear test Pin-on-disc Setup

Table 1. GCI plates chemical composition

Chemical	Percentage
C	3.59
Mn	0.392
Si	2.37
P	0.624
Ni	1.52
Fe	90.4
Cu	0.28
S	0.023
Mu	0.007
Others	0.545

The experiment setup pin-on-disc mechanism is shown in Figure 1. The lower tool's surfaces are metallically polished with emery sheets in sizes 1/1000, 2/1000, and 3/1000. The wear tests were carried out with a standard time of 30 minutes and a standard ratio of $1m/s^{-}1$. The test conducted with the following parameters is the sliding distance (1000, 2000 and 3000 m), the sliding load (20, 40 and 60 N) and the sliding speed (1.5, 3.0 and 4.5 m/s). During the test, compressed air was used to expel small abrasive particles from the interface. All wear tests were carried out under laboratory atmospheric conditions and the reciprocating motion of the frequency range is 1Hz. The average readings are taken from each combination of wear parameters.

The tribometer integrated with data acquisition system to record the different responses including coefficient of friction and wear loss with respect to the wear parameters. Before and after the test, both pin and flat samples were ultrasonically polished with alcohol. The composite materials wear rate was estimated using the weight loss method and the amount of degraded material (mm^3) per unit load (N) per unit sliding distance (m). Scanning electron microscopy (SEM) and X-ray energy dysfunctional spectroscopy (EDS) studies were used to evaluate primary wear patterns.

3. Result and Discussion:

Surface Morphology

Addressing a uniform distribution of reinforcement particles throughout the matrix composition is a significant process in fabricating hybrid composites. It is also important to avoid particle segregation or agglomeration during solidification development. According to Chawla[xx], the cohesive properties of hybrids can be significantly influenced by the morphology, type and concentration of reinforcement particles. The solubility of nanoparticles in the melt, the type of reinforcement, the crystallization rate and the flow of the molten metal are the factors that control the dispersing of the particles. In addition, a uniform dispersion of reinforcing particles can be achieved by mechanically stirring a semi-solid material. Evaluation of the distribution of reinforcement particles in matrix alloys can be done by studying morphology. Research observations addressing the micro-structural properties of HAMCs are summarized below.

Analysis of wear surfaces A significant wear process parameter that can determine the wear severity of composite samples is debris degradation. In order to identify wear debris in mechanical properties, applications for debris analysis were first developed in the 1940s. This investigation before and after wear surface morphology were characterized by Scanning Electron Microscope (SEM). During the wear analysis, crack, delamination, porosity, plastic deformations of materials were evaluated for the effect of reinforcements 2% B_4C and ZrO_2 (2%, 4% and 6%) and SiC (4%, 6%, and 12%). Fatigue wear and shear particle permanent deformation are the terms of the wear process that define the spherical distribution of wear on the interfaces. Fatigue wear and shear particle permanent deformation are the terms of the wear process that define the spherical distribution of wear on the interfaces and abrasive wear was detected using OEM and scanning electron microscopy (SEM).

Due to the effective thermal advance of the stir casting process, current tests show minimal porosity and significant complications are neglected. In contrast, the SEM study showed that both matrix dispersion and particle dispersion were similar. Spherical morphology has been demonstrated through observations as the surface morphology of cast materials. As a result of various periodic loading conditions throughout the casting, abrasive wear materials have replaced fatigue wear.

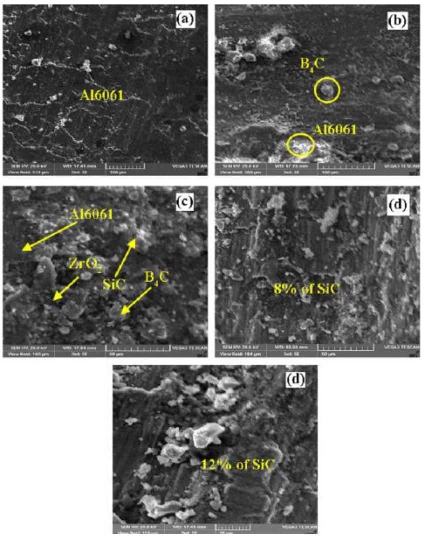

Figure 2. SEM micrographs of AA6061 alloy and their composites at before wear

As can be seen in the Figure 3 (a-b), the wear surfaces of the hybrid composites show a high amount of wear and localized adhesion between the composite pin surface and the counter disc, and the combined wear of narrow grooves (dark layers) and material flow in the sliding direction are clearly observed. The worn surface composite appeared similar to the pure material and was distinguished mainly by plastic deformation with less ploughing defects and cutting impacts. Morphological analysis of the composites revealed that ploughing the worn surface was the most dominant wear mechanism.

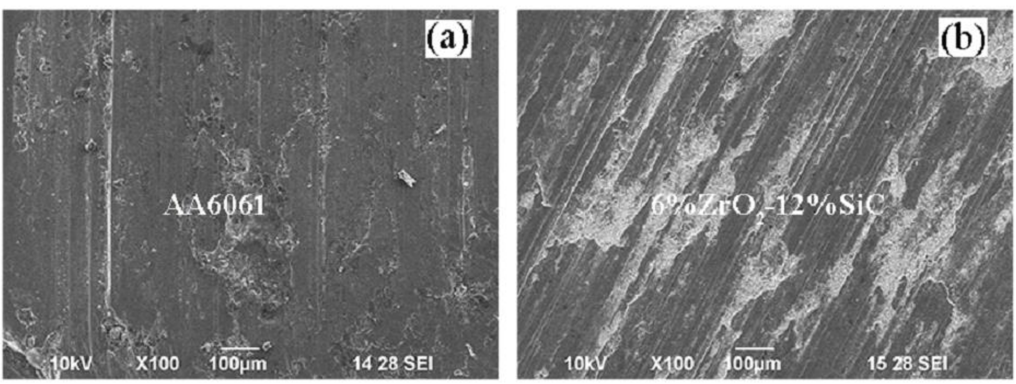

Figure 3. Illustrations of Worn surface morphology

SEM morphology of the reinforcement distributions indicate that it is not uniform, which may be caused by different densities of the reinforcing elements and aluminum matrices. Figure 4 shows the worn surfaces of pure Al6061 alloys and Al6061- B_4C-ZrO_2-SiC under different wear parameters. The wear patterns and wear directions are readily visible in the SEM photographs, as can be observed. In addition, nanoparticle-reinforced materials have higher wear patterns compared to pure composites. The surface morphology of pure alloys is moderately soft, and adhesive associated with some grove formations, while compared to high reinforced hybrid composites (Al6061-2% B_4C-6%ZrO_2-12%SiC) are rough surface with detached fragments and strong wear patterns. Also, the light region in the SEM images shows unidirectional flow of heavy materials, indicating high levels of wear and localized adhesion between material surfaces and counter body. Also, stronger wear grooves are observed in the hybrid composites increasing with higher load.

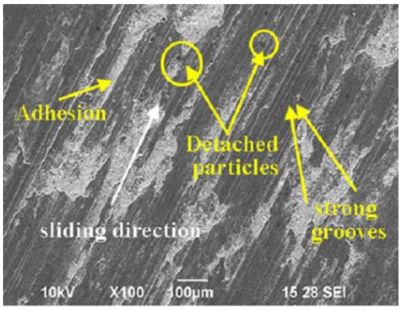

Figure 4. SEM morphology of worn surfaces at load 30 N Al6061-2% B_4C-6%ZrO_2-12%SiC

The composition of Al6061-2% B_4C-6%ZrO_2-12%SiC hybrid composites achieved the better wear resistance. To identify the wear processes, the worn surfaces of Al6061-2% B_4C-6%ZrO_2-12%SiC composites were investigated by Scanning Electron Microscope (SEM). It is clear that wear mechanisms might vary depending on wear conditions (Sliding velocity, load and sliding distance). The evolution of wear analysis can access the delamination wear, ploughing defects, adhesives, abrasion, and abrasives wear (Idusuyi et al 2019). The addition of 2% B_4C and 12% SiC reinforcements leads to an increase in debris and segregated particles, thus increasing the wear resistance compared to pure aluminum alloy and 2% B_4C reinforcement.

The movement of aluminum from the pin surface to the worn surface is indicated by the availability of aluminum in the dark layer, and the oxidation reaction is indicated by the presence of oxygen. According to these observations, there is a material transfer and mechanical mixing between two friction surfaces, resulting in a surface Mechanically Mixed Layer (MML). According to these observations, there is mechanical mixing of materials between the two moving interfaces, and a MML has developed in the darkened regions on the wear surface. Therefore, it indicates that the increase in wear rate of all hybrid composites is due to physical change with oxidation reaction (Das et al 2016).

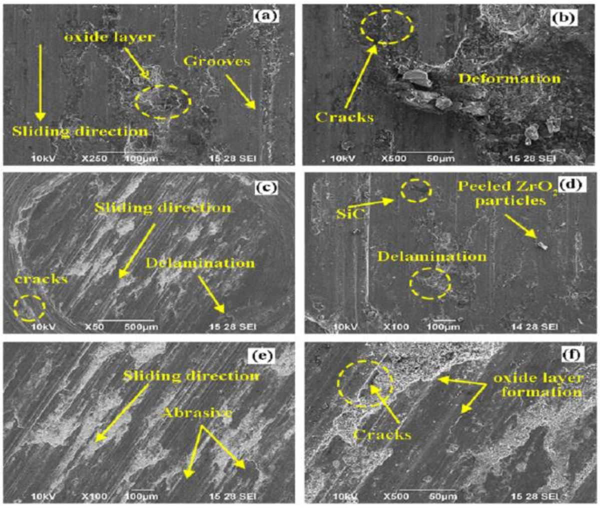

Figure 5. SEM image of various compositions of worn surfaces

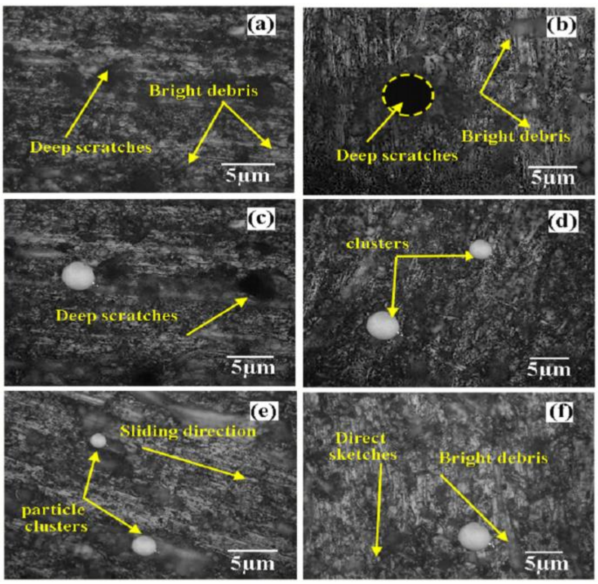

Figure 6. Microstructure of various compositions of deep grooves and debris analysis

Furthermore, demonstrating that the significant wear mechanism is scratches with minimal oxidation by magnified scanning electron microscopy (SEM) shows deep scratches and bright debris on the worn surface of Al 6061 and Al6061+B_4C samples. Abrasive elements are composed of hard ceramic particles that are removed by friction on the surface. The Figure shows oxidation, adhesive and abrasive surfaces on the worn surface at high sliding speeds as observed by the evolution of the wear track. Most of the area was covered by oxide layers, but abrasion residues were still visible, and small areas of particle ablation were found in the surface morphology. Abrasive particles are smoothed by friction, and oxidation covers the surface and excessive wear is reduced. Once the intensity of the abrasion scratches decreases, a few faces are well worn, and the speed settles at 1.5 m/s at minimum load level, further oxidation becomes noticeable. As oxidation progresses, abrasive wear weakens and eventually disappears completely with increased load; This type of damage is the result of both adhesion and oxidation mechanisms. Depending on the global temperature intensity during the sliding wear, the variations in the loads changed from abrasion to adhesion and oxidation. Finally, it is clearly seen that oxidation and frictional heat play an important role during the wear analysis for the increase in wear resistance of hybrid composites.

4. Conclusion:

1. The surface morphology was examined using a scanning electron microscope (SEM). Chemical constituents were also measured using Energy Dispersive Spectroscopy (EDS). The worn surfaces were examined for different load conditions were examined by using scanning electron microscope (SEM). Evaluation of the distribution of reinforcement particles in matrix alloys can be done by studying morphology. Research observations addressing the micro-structural properties of HAMCs are summarized.

2. Abrasive wear was detected using OEM and SEM. After and before wear surface morphology were characterized by SEM.

3. During the wear analysis, crack, delamination, porosity, plastic deformations of materials were evaluated for the effect of reinforcements 2% B_4C and ZrO_2 (2%, 4% and 6%) and SiC (4%, 6%, and 12%).

4. As a result of various periodic loading conditions throughout the casting, abrasive wear materials have replaced fatigue wear. Stronger wear grooves are observed in the hybrid composites increasing with higher load.

5. Morphological analysis of the composites revealed that ploughing the worn surface was the most dominant wear mechanism.

6. The addition of 2% B_4C and 12% SiC reinforcements leads to an increase in debris and segregated particles, thus increasing the wear resistance compared to pure aluminum alloy and 2% B_4C reinforcement.

7. Finally, it is clearly seen that oxidation and frictional heat play an important role during the wear analysis for the increase in wear resistance of hybrid composites.

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