Tribological Suitability of aluminium hybrid composite above atmospheric temperature

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Abstract. Industries are facing problems with light weight alloys due to tribological impediments in which utmost complicated problem is wear. As a consequence, endeavour has been made to fabricate increased wear resistance materials. In 2014, 2.87 million tons of aluminium was used by the global automotive industry (excluding China). By 2020, an annual demand of 4.49 million tons of aluminium is projected. Key factors of this growth include both increased production of automobiles and broader use of aluminium alloys in modern automobiles. The main advantage of spacecraft aluminium alloys is their ability to withstand high and low temperatures, vibration loads, and radiation. Additionally, aluminium alloys exhibit outstanding strength and durability in cryogenic environments as the temperature drops. In the present investigation Al2618 is used as a Matrix and hard ceramic boron carbide, with amorphous graphite is used as reinforcement. Stir casting is used to synthesis the hybrid composite. Statistical model taguchi is used to assess the dry sliding wear properties of the hybrid Metal matrix composite at different temperature (50°C, 100°C, 150°C). Evaluation of particle distribution of reinforcement in the matrix and worn surface morphology is studied by SEM. Wear resistance of the hybrid composite (reinforced with B4C & Gr) is enhanced at 150°C than conventional alloy. Glazed layer formation in Al2168 matrix is less than glazing layer formation formed on hybrid composites Adhesive wear is observed during test.

Keywords: Hard ceramic; Boron carbide; graphite; glaze; oxide; tribo layer; worn surface.

1. Introduction

The industrial use of lightweight materials is gaining growing attention from different sectors of manufacturing. The use of aluminium alloys for metal matrix composites is growing rapidly to meet various end uses in automotive components like valve, piston, liners etc. Aluminium alloy, on the other hand, causes high tensile strength and stiffness with lower impact resistance. These composites could be used for components under tensile stress, such as connecting rod [1]. A combination of aluminium alloy and ceramic reinforcement may incorporate the positive tensile characteristics as well as the good impact properties of aluminium alloys. The automobile industry is successfully applying composites reinforced with a variety of Aluminium alloy to replace components such as outer body of car, cylinder head, turbo charger, brake calliper, connecting rod etc. [3]. Metal matrix composites show strong properties, but there is a large volatility in their properties. A vulnerability can and will be solved by introducing more sophisticated manufacturing of aluminium alloys and a composite. Its specific properties will establish a stable foundation for the development of new applications and prospects for hybrid metal matrix composite in the 21st century [2]. Across different applications, the use of hybrid metal matrix composites has opened new opportunities for both academia and industry to build a viable framework for the potential use of hybrid metal matrix composites [4]. Al-Si alloy is a proven alloy with a high wear resistance and low coefficient of thermal expansion, strong tolerance to corrosion and enhanced mechanical properties at high temperature. However, the silicone density is about 3.23g / cm, which is very high compared to Boron Carbide, in fact, Boron Carbide is the third hardest substance used to improve aluminium matrix alloy wear strength. Graphite is typically useful for use at high temperatures and has superior mechanical
properties. Graphite also has a self-lubricating ability to mitigate the wear of tribological component [8]. Therefore, an experiment to examine the results of this study is clearly explained wear behaviour of unreinforced Al2618 and reinforced with B₄C & Gr.

2. Experimentation

2.1 Solidification of composites

There are various routes to synthesize Al2618– B₄C– Gr hybrid metal matrix composites, But in stir casting approaches to its simplicity of fabric and large volume. In order to achieve a high level of mechanical properties in the production of AMCs, a good interfacial bonding between the matrix material and the reinforcement is an important aspect. Care should be taken to preserve optimal casting parameters, such as wettability of the molten metal, homogeneous mixing of the particles, density, and solidification rate. The crucible is made of graphite and the ingot is poured into the crucible by 1.25 kg of matrix material. The melt was held for 1.5 hrs at a temperature between 650 and 700ºC. Crucible is made up of graphite and 1.25kg matrix material ingot is poured into the crucible. The melt was maintained at a temperature between 650 to 700ºC for 1.5hr, because the slag accumulated on top of the molten metal had been extracted. When the ingot content entered a liquid state, magnesium (4gm) was applied to the molten metal to enable particle dispersion within the molten metal. Weighted Reinforcement 10% of boron carbide was preheated at a required temperature of 550ºC to eliminate moisture or any other gas contained in the reinforcement. A fine reinforcement particle (30-50μ) of boron carbide has been added to a molten metal which can afford more nuclei for heterogeneous grain nucleation. Stirring operation at 150 rpm for 10-15 minutes to achieve homogeneous B₄C particle distribution in Al2618. There After the secondary reinforcement, i.e. graphite (3%) has been preheated and poured into the molten metal, constant stirring takes place up to 10-15 min. Hexa-chloro-ethane degassing agent (C2Cl6) is used to reduce porosity, voids and casting defects in molten metal. Once the hot molten metal has been poured into the preheated die, the pouring temperature 650 to 700ºC, molten metal must be cooled under the freezing point before solidification begins. Due to the presence of mould surface, the degree of super cooling is reduced as a consequence number of tiny nuclei are formed in molten metal. The rate of cooling in conventional Al2618 is high compared to hybrid composite. Al2618 reinforcement particles in molten metal, the nearest neighbouring gap between nuclei is small, thus suppressing the grain size of the crystal. Compared to the Al2618 alloy grain size, the average grain size is reached in the final solidified composite. The melt is then allowed in the mould to solidify the cast specimens were taken out when it hit room temperature. G99 Cast samples that are synthesized from the stir casting process have been machined to prepare the test specimens in accordance with the ASTM standards. As for this standard, the size of the specimen should be 10 mm in diameter and 30 mm in length. To achieve the uniform flatness on the test specimen buffing was made on the specimen surface, the specimen is then washed with acetone [8].
2.2 Microstructure of composites
The prepared composite is subjected to SEM analysis, allows to see the composite microstructure and to check the distribution of strengthened particles in the matrix as shown in the Figure 3. It is clearly illustrated that B₄C and Gr distribution in Al2618 occurred uniformly. Composite grain structure is fitted with an adequate wear resistance and relies on the presence of reinforced particles which confirmed through XRD spectrum (Figure 5).

![Figure 2. Microstructure of Al2618](image)

![Figure 3. Microstructure of Al2618+B₄C+Gr](image)

![Figure 4. XRD spectrum of Al2618](image)

![Figure 5. XRD spectrum of Al2618+B₄C+Gr](image)

2.3 Dry sliding wear test at high temperature
The pin-on-test (DUCOM-and friction control TR-20-PHM 400) was used to investigate the attributes of dry sliding wear of hybrid metal matrix composites above Atmospheric temperature. En-32 steel (65HRC) is used when performing the test in compliance with ASTM G99 requirements. Disc track diameter is approximately 140 mm; thickness is 8mm. Disc wear properties have not been studied. Arrangements are rendered as illustrated in Figure 6. Test holder has been placed against the revolving disk that is perpendicular to the disc. The load in step 10N varies from 20N to 40N and Velocities range from 1.25 m/s to 3.75 m/s, the sliding distance was used in the range from 400 to 800 m and Temperature ranges between 50 to 150°C. During the period of the wear investigation, the standard test procedure was applied to the samples.

![Figure 6. Pin-on-disc apparatus](image)
The surface of both the test samples and the disc were cleaned by soft cotton drenched with acetone prior to the test. Cleaning is required to get rid of any oil and other contaminants found on the disk and sample surface. Specimens are weighed by an electronic measuring system with a precision of 0.0001 mg before and after the test, to measure the difference in weight and is used calculate the rate of wear, to measure the weight difference and use it to compute the wear rate. Using pin heating to describe the wear properties of hybrid metal matrix composite at various temperatures and the experiments were carried out in accordance with the standard orthogonal series L27(taguchi model).

3. Results and Discussions

3.1 High temperature wear analysis

The purpose of this study is to investigate the wear resistance of HMMc (Al2618 + 10% B4C + 3% Gr as referred with hypo-eutectic alloy [2]. Test temperatures were chosen over ambient temperature i.e. 50, 100 & 150 °C for the selection of that particular range was, generally aluminium alloy allows for oxidation at 50°C. Recrystallization is carried out at 100°C so that these temperatures plays an important role on properties of HMMc particularly when the composite is subject to the temperature described above.

![Wear rate vs Applied load](image)

**Figure 7.** Wear rate v/s Applied load

Prevalence of hard B4C & Gr particles in the Al matrix leads to expansion in transition load due its strengthening mechanism. Also, they minimize the distance between particles and serve as a strong barrier to dislocation.so that Dislocation movement under the contact load causes the surface to strengthen. The reinforcement particles endorse the lower contact load of 20 N. Hence the load-bearing power of the hybrid composite is increased by the incorporation of B4C and Gr particles. In addition, the increase in temperature between the pin and disk is the result of by increasing applied load (40 N), it influences to increases in wear rate. Solid ceramic B4Cp can bear a higher load predominantly because of its potential hardness. In comparison with base alloy (Al 2168), and reinforced alloy is shows maximum wear resistance (5times) at higher load 40 N as shown in Figure 7. In reinforced alloy B,C particles holds, the applied load and solid lubricant Gr forms a lubricating film, thereby minimizing plastic deformation. The wear rate of A12168+10%B4C+3%Gr is not significantly exaggerated by load increases, due to the presence of Gr and it is primarily responsible for maintaining wear resistance at all the temperature. The Gr lubricant can quickly flow and squeeze out even at a high load on the surface under contact pressure. Furthermore, this phenomenon is intensified by the distribution of Gr and forms thick tribo film is called glazed layer. This protects the surface against the counter area and reduces the wear rate of A12168+10%B4C+3%Gr as compared to Al2168. Aluminium and alloy work under heat, their properties must be changed so that such alloys are needed to investigate above the atmosphere temperature. On other hand oxidational & recrystallization temperature is plays a vital role in changing the property of the material that’s why (100°C, 150°C) these temperatures have been consider for test.
At 50°C wear resistance of the Al2168 is less compared to reinforced Al2168 because of material softening of unreinforced alloy at the same time oxide layer is begun to form and was not thick in unreinforced alloy so that wear rate is high at 50°C. At the other hand, hybrid composites have a decreased wear rate by Temperature rise(100°C) mainly due to oxide films formation, it prevents their direct metal-to-metal contact. Oxide films are removed from the surface during continuous sliding. This increases direct metal-to-metal interaction and exposes the fresh area to the atmosphere. When the temperature is, from 50°C to 100°C, during the sliding phase, Shaping and separating oxide layers contribute to reduces in wear rate in hybrid composite as compared to Al2168 alloy. Glazed layer formation in Al2168 matrix is less than glazing layer formation formed on hybrid composites. The formation is less, can be clearly observed from Figure 8 (a, b &c). With the temperature rise, the alloy Al2168 is made smoother. The material transition from metal to steel is improved, leading to an improvement in wear rate. Furthermore, the non-existence of B,C and Gr particles, thickness of tribo-film is less so that wear rate higher in Al2168 matrix as compared hybridised Al2168. It is also evident from Fig.8 (a-c) and Fig.9 (a-c).
Sintering of superior wear residues occurs at the higher temperature (100°C) with applied load. High compression pressure occurs during the wear test, solid and hard surface known as "glaze." layer is formed because of sintering. The Glaze layer offers long-term wear protection, as breakdown contributes to the formation of additional wear residue as shown in Figure 8b. The damaged Al2168 surface at (50°C) reveals plastic deformation, lesser oxide layer and Al2168 matrix delamination. The large amount of friction heat with 40N loading temperature results in Al2168 being thermally softened. It is clear from the SEM (Figure 9a.) deeper wear and ploughing grooves are visible. The design in Al Al2168 matrix at the temperature 100°C & 150°C, the deteriorated surfaces are formed on the surface with evidence of oxide and glazing layers. The lack of a glazing layer was clearly detected at a lower temperature (50°C) in Figure 9a.

4. Conclusions

1. Wear resistance is increased by the incorporation of the Boron carbide and Graphite particles in the hybrid metal matrix composites.
2. Glazed layer formation in Al2168 matrix is less than glazing layer formation formed on hybrid composites.
3. Applied load is directly proportional to wear rate
4. Sliding velocity and applied load is more predominated on the wear rate than the sliding distance.
5. SEM micrographs reveal that material removal is micro ploughing and micro pit formation at 50°C

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