Tribological Behaviour of Aluminum Metal Matrix Composites – A Review

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Abstract. An examination of Aluminum Metal Matrix Composites (AMMCs) dry sliding wear activities reinforced with reinforcements along with carbides, oxides, and nitrides. However, from the analysis, the method adopted for the composite processing plays a crucial role in achieving a uniform homogeneous composition. Preparation of base metal and reinforcement powders plays a vital role in the process of powder metallurgy, improving wettability between reinforcement particles and molten base metal in liquid metallurgy is a difficult task. AMMCs wear activity is based on different test parameters. As mechanical and tribochemical are the process involved in substance removal during dry sliding wear is subdivided into groups. The loss of reinforcement from the AMMCs through sliding wear decreases the wear rate due to abrasion by three parts. The use of solid lubricant decreases wear severity through the formation of a tribolayer between the rubbing surface. Optimizing the wear intensity is through the use of suitable replacements with optimal lubricants

Keywords: Aluminium Metal Matrix Composites (AMMCs); Dry sliding wear; solid lubricant particles; scanning electron microscopy

1. Introduction:

Metal matrix composites (MMCs) are interfusion of two or more materials, which expose properties that are hard to obtain from a single material with high strength and stiffness with less density[1]. Hybrid matrix composite is the preferred form of metal matrix composites used for lightweight high strength application in aerospace and automobile field[2]. The present engineering applications need materials that are less expensive, stronger and lighter so the aluminium is the perfect example in the development of materials. In aluminium, matrix composites the attributes like high stiffness, low density and strength and superior wear resistance [3]. It has been proclaimed that the tribological properties of Al alloys can be enriched by adding ceramic reinforcements. AMMC reinforced with silicon carbide (3.18gm/cm^3) particles are used to increases the hardness of the composite. Since we are producing a hybrid metal matrix composite there must be another reinforcement material added to the composites, so in this study we introduce quarry dust as the secondary reinforcement material for the enhanced properties. It had been found that the use of AMMCs in engine application can reduce the overall weight, fuel consumption and pollution in
automobile field [4,5]. Aluminium alloys have an effective application in various mechanical components because of the extraordinary combination of properties like good thermal conductivity, high corrosion resistance and the strength to weight ratio also being high. Followed by the composite and reinforcement material selection, the casting techniques should be selected wisely[6]. From different casting practices, we prefer stir casting technique for its clarity, resilience and applicability to large quantity production with cost leverage. The stir casting process has opted for the production of AMMCs which will reduce the cost of the composites and it is economical so this technique is used massively. Finally, the casted Al composites are directed to the Scanning Electron Microscope (SEM) analysis for the study of the grain and microstructure. On the other hand cast aluminium is subjected to wear testing. Here the pin-on-disc is preferred for the wear testing when investigating the crack of a coating at the boundary of a wear track. The result of this test gives the tribological behaviour of the hybrid AMC’s[7].

2. Material Selection

Alloy is extensively used in aerospace and marine industries for their high corrosion resistance and for their superior welding features. In this process, we use Al alloy as a base metal in the metal matrix composites.

2.1. Matrix Material

Aluminium is widely used as matrix material in MMCs.

2.1.1. Al 6061

Al 6061 is precipitation-hardened aluminium alloy, containing magnesium and silicon as its major alloying element widely called as “Alloy 61s”. The composition of Al6061 is given in Table 1. It is developed in 1935. It has good mechanical properties. It is the most common alloy of aluminium and general-purpose use. In this study, we prefer Al7075 than Al 6061. The primary difference between 6061 and 7075 is exhibits immense strength to weight ratio. Al 7075 provides the greatest strength available in aluminium bar. Al 7075 contains more zinc than Al 6061 alloy[8].

| S.No | Composition | Alloying element |
|------|-------------|-----------------|
| 1.   | 0.65%       | Silicon         |
| 2.   | 1.0 – 1.5 % | Magnesium       |
| 3.   | 0.19 – 1.2 %| Copper          |
| 4.   | 0.64%       | Iron            |
| 5.   | 0.5%        | Manganese, chromium, lead |

Table 2. Composition of Al7075

| S.No | Composition | Alloying element |
|------|-------------|-----------------|
| 1.   | 5.1 – 6.1%  | Zinc            |
| 2.   | 2.1 – 2.9%  | Magnesium       |
| 3.   | 1.2 – 2%    | Copper          |
| 4.   | 0.5%        | Silicon, Iron, Manganese |
2.2. Reinforcement

Reinforcements are the hard particles added in MMCs to improve the properties of base matrix material.

2.2.1. Boron Carbide (B\textsubscript{4}C)

Boron Carbide is blackish powder-like material which is odourless in nature. Also known as “Tetrabor”, it is one of the hardest materials similar to Diamond. It exhibits better toughness compared to other materials and also stable under radioactive conditions. In this powder, reinforcement chemical reaction ensues at 800°C to 1400\[\text{[11]}\]. Al alloys, when reinforced with boron carbide, results in higher strength with lower ductility materials when compared with other reinforcements. There are various techniques of reinforcement with Al alloy composites such as Hot iso-static pressing (HIP) followed by High-strain rate forging (HSRF), HIP followed by dual-step quasi-isostatic forging (QIF) and quad-step QIF resulting similar mechanical properties. Among these methods, the first two are used widely due to their improved characteristics\[12\].

2.2.2. Aluminium Oxide (Al\textsubscript{2}O\textsubscript{3})

Aluminium Oxide, also commonly known as “Alumina”, is a white odourless crystalline powder. It is amphoteric in nature, which occurs commonly in corundum form. It is used as an abrasive material and as refractory material due to its good hardness and high melting point respectively. Increase in a volume fraction of aluminium oxide as reinforced phase results in lowered fracture toughness of the metal matrix composites\[11\]. The durability, hardness, wear and tensile fortitude of the aluminium composites are found to be increased with smaller grain size when the typical stir casting process. By vortex method, the wettability and the binding between Al\textsubscript{2}O\textsubscript{3} particles are improved by applying pressure. It also increases the wear resistance of the MMC\[13\].

2.2.3. Silicon Carbide (SiC)

Silicon Carbide (SiC) is a prominent abrasive and contemporary engraver due to endurance and low cost. It is acknowledged as carborundum incorporated with silicon and carbon. Silicon carbide particle grains can be constrained together by sintering to contour very hard ceramics that are universally used in applications like car brakes. Large sole crystals of silicon carbide could be developed by Lely Method and they can be downsized into gems recognized as synthetic moissanite. The reinforcement of Silicon Carbide into AMCs had proved that increase in tensile strength and the hardness. \[11,14\]. The microstructure of SiC is shown in Figure 1. The major conclusion derived from the former entirety carried out tells us:

- Silicon carbide reinforced with Al-MMCs possess higher wear protection compared to (Al\textsubscript{2}O\textsubscript{3})
- SiC reinforced Al-MMCs are convenient material for brake drum as they have more advanced wear hindrance properties but cannot be used in the brake linings.
- The wear resistance of SiC reinforced Al MMCs is superior to boron carbide reinforced MMCs.
Figure 1. Microstructures of pure Al (a) and Al/5SiC (b), Al/10SiC (c) and Al/20SiC (d) composites (Some porosities are marked with arrows) [13]

2.2.4. Quarry Dust (Waste material used as secondary reinforcement)

Quarry Dust which is an outcome from pulverised rock/stone as a waste by-product. The EDAX result is shown in Figure 2. It is proposed in research as an alternate for SiC and with the objective, to ample, the gaps spotted in wastes that are already in use as reinforcement in AMMCs. The studies had proved that the addition of quarry dust in AMCs will increase macro hardness and tensile properties of the composite. When dry sliding wear performance of AMC is investigated with the help of a pin-on-disc wear testing setup, it is found that inclusion of quarry dust particles as reinforcements elevates the wear resistance of the composites[15]

Figure 2. EDAX report of quarry dust [15]

3. Fabrication Technique

The most important thing with Al composite is the uniform distribution of reinforcement particles within the matrix alloy hence ball milling is the pre-process carried out. Two generic techniques of fabrication can be used for the composite production (i.e.) powder metallurgy and molten metal method. These both processes have their own dominance and deprivation.

3.1. c

A ball mill is one kind of grinding used to grind and mixing of the materials in ceramics and the mineral dressing processes. It works on the principle of attrition, as grain size decrement is done by the impact as the balls drop from near the top of the cylindrical shell. If we have to reduce the size of...
the particles in a (SiC) we can do ball milling and thus we can reduce the micro size of reinforcement materials like SiC, Al₂O₃ etc [16]. A sample of ball milled microstructure is shown in Figure 3.

3.2. Powder Metallurgy

Powder Metallurgy (PM) greatly reduce the need to use metal removal processes. It is used to make unique materials, impossible to get from melting in other ways. In this metallurgy, Al alloy powder is blended with reinforcement particles to obtain a homogenous mixture. The appropriate size ratio of alloy and reinforcement particles will help to obtain uniform distribution in the composites[18]. The procedure of developing an aluminium composite in Figure 4.

![Figure 3. Influence of the mechanical milling time on the morphology of M10Sn nanocomposite powders: (a) 1 h, (b) 3 h (c) 5 h (d) 15 h (e) 20 h and (f) 25 h [17].](image)

![Figure 4. Developing of AMMCs by PM Technique](image)
Powder Metallurgy has a number of benefits, one of that is any type of alloy and reinforcement can be done for the fabrication of the composite, but it also has many defects, that is long mixing time is required for the uniform distribution of the particles[19].

3.3. Liquid Metallurgy

This method is also known as molten metal vortex method. It is a highly attractive method because it is very cheap and highly productive. The procedure of developing an aluminium composite in Figure 5.

![Figure 5. Developing of AMMCs by Liquid Metallurgy Technique](image)

3.3.1. Stir Casting Technique

Stir casting is a liquid state technique for the production of composite materials, in this technique dispersed phase of reinforcement is blended with a molten matrix metal by mechanical stirring. It is a simple and cost-effective method for composite material fabrication. Aluminium metal matrix composites are fabricated by stir casting method parameters, which will affect final microstructure and properties of the composites. AMMCs was developed by using two different techniques, conventional stir casting and ultrasonic stir casting, conventional stir casting is preferred for low cost production [7,19].

In the conventional stir casting, the reinforcement SiC powder should be carefully encapsulated in an aluminium foil packer for insertion in molten aluminium in ordered to fabricate composites with SiC as 3% weight. The SiC powder should be pre-heated at 350 °C for 4 hours before the casting process for the removal of moisture and impurities. The aluminium should be heated up to the temperature of 850 °C within a furnace and stirring periods should be above 6 minutes, the factors of matrix interface, ceramic incorporation were evaluated by Scanning Electron Microscope (SEM) and it had been concluded that shorter stirring is required for the ceramic incorporation to achieve the maximum metal bonding at the interface [20]. The higher stirring temperature can give improved ceramic embodiment. A microstructure sample is shown in Figure 6.
Figure 6. SEM image of the specimen after stir casting [21]

4. Tribological Properties

Tribology is often defined as a study handling application and subjects of friction, wear and lubricating applications, and all together of the most aspects of tribological work on wear. Wear are often defined because the phase-out of materials on solid surfaces. The form, size and style of the reinforcement are key factors for the Al-based MMCs’ wear characteristics [22].

4.1. Al2219 / Gr / B4C

It has been demonstrated that the abrasion behavior of hybrid Al2219/Gr/B4C AMMC had been fortified by utilizing reinforcement, Al 2219 with 8% of B4C and cross breed composite (8% B4C + Al 2219 + 3%Gr). because of the presence of earthenware support particles, the hybrid composite had indicated more noteworthy wear spot opposition which is appeared in Figure 7. during this hybrid composite, the reinforcement particles had been haphazardly and finely scattered in the matrix alloy. During this examination, it had been discovered that tensile strength and yield pressure were diminished by the expansion of auxiliary support, yet it had been demonstrated that in absence of Boron carbide reinforcement (B4C), wear pace of the Al combination is more, by expansion of this support diminishes wear, Figure 8 shows a down surge in the wear rate by this composite. [12].

Figure 7. SEM Analysis for different composition (a) Micrograph at the wear surface of alloy[12][12][11] (b) Al + 8% B4C  (c) Al + 8% B4C +3%Gr [12]
4.2. Aluminium reinforced with the Silicon Carbide particles (SiC)

The wear conduct of the aluminum fortified with the Silicon Carbide has been examined. It has been indicated that the reinforcement weight percentage was the most significant factor in the composite wear rate, sliding velocity and burden were second and third factors. Right now, wear conduct and friction attributes of aluminum combinations and Al MMCs containing (SiC) aluminum composites have been concentrated in their work., it has been demonstrated that wear pace of the aluminum lattice in Figure 9 [23].

4.3. Aluminium- Silicon alloys with graphite particulates

As per the review, the engine chambers produced using Al alloy/graphite composite will show a drop in the pace of wear, higher corrosion obstruction and lower coefficient of rubbing and in correlation with aluminium matrix composites with earthen ceramic particles and the looks into has indicated that graphite will advance tribological properties by delivering a graphite rich lubrication between the territory of sliding. From the study, it had been discovered that co-efficient of friction will drop with increment of graphite particles content, because of that a thick graphite lubrication film on the sliding surface. Tribological qualities had been going down when the substance of graphite in the composite is high because of the holes in bunched graphite particulates is appeared in Figure 10 &11 [24].
Figure 10. Optical micrographs of fabricated composites (a) Al2024/5%SiC/5%Gr and (b) Al2024/5%SiC/10%Gr composites.[24]

Figure 11. SEM morphologies of the worn surface of Al/5%SiC/10%Gr composite at an applied load of 20 N at (a) low magnification and (b) high magnification.[24]

4.4. Aluminium- Silicon alloys with graphite particulates

Quarry dust is an extremity from the devastating of rock/stone. The XRD of Quarry dust is shown in Figure 11. It is having a density (1.7 – 1.9 g/cm3) which is not as much as that of aluminum (2.7 g/cm3) and SiC from the examination [3,4], it had been demonstrated that specific wear rate is seen to be raised somewhat with an expansion in the appropriation of quarry dust in the MMC in Figure 12 [6,25]. The incorporation of quarry dust downturn the wear opposition rate underneath 7% which show us that the as fortification in Al base compound won't speedy the wear properties of the composite. The overview has demonstrated that the fuse of the quarry dust in Al-Mg-SiC combination will bring about a minor decrease on the thickness of composite, the diminishing in the wear and hardness of 5% were seen with an upsurge in quarry dust in Figure 13 and 14 [25].
Figure 12. X-ray Diffraction pattern of quarry dust[25].

Figure 13. Wear index for the Silicon Carbide and Quarry Dust reinforced Al-Mg-Si Composites [25]

Figure 14. Optical micrographs of Hybrid Al/SiC/Quarry Dust (1:1) reinforced[25]

5. Conclusion

This analysis indicates the theories, the experimental results obtained and the observations of numerous investigators over the years in the study of particle reinforced Al-MMCs. This paper also sets out the manufacturing techniques for the composites and tribological properties of SiC reinforced Al-MMCs. SiC reinforced Al-MMCs exhibit stronger tribological properties over unreinforced base alloys. The widely used technique for the production of Al-MMCs is stir casting, as it is the cheapest process. Ultrasonic casting and spark plasma sintering are more complex methods that can be used for high delicacy units. From the analysis of the abrasion tolerance and wear index composites. It is assumed that the abrasion resistance and wear index of the composites are also increased if the reinforcement fillings are indicated in the matrix material. The analysis of the tribological properties was carried out with regard to the wear ratio and the outcome of the wear test process.
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