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Aluminium Composites and Further Improvement in Their Tribological Properties - A Review

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Aluminium and aluminium-silicon alloys based metal- matrix composites are widely used in aerospace and automobile industries (pistons, cylinder blocks) where dry sliding wear is a predominant process of material loss. Materials which have high hardness, forms mechanical mixed layer (MML) on wearing surface and fine wear debris show high wear resistance. Aluminium metal matrix composites reinforced with hard ceramic particle such as Al_2O_3, SiC provides significantly improved mechanical properties and high wear resistance due to the addition of ceramics particles into the aluminum matrix. The ceramic particles disperse into aluminium matrix, which leads to a high bonding strength between the particles and matrix. For sliding wear, the influence of applied load, sliding speed, sliding distance, wearing surface hardness, reinforcement fracture toughness and morphology are critical parameters in relation to the wear regime encountered by the material. Wear also depends on the percentage of reinforcement, shape and size of the reinforcement, hardness of the reinforcement and the distribution of the reinforcement particle in aluminium matrix. The aim of this paper is to review the advantages of using Metal Matrix Composite over other Al/Al alloy with respect to tribological properties. The counter face wear, wear mechanisms, different parameter that influences the wear loss and the role of the reinforcement phases are also presented. It is possible to optimize the tribological properties of aluminium metal matrix composites by using the proper combination and proportion of different ceramic particle as reinforcement.

Field of Research: Materials Science

Keywords: Composites, Alumina Particles, Dry Sliding Wear Properties, and Delamination

1. Introduction

In recent years, aluminium and its alloys are becoming more and more popular in the manufacture of automobiles and its body parts owing to their best combination of excellent strength, low density, thermal stability, good toughness, admirable machinability, ease of casting, better corrosion resistance and accessibility with respect to other materials (Sajjadi and Beygi, 2011). As Aluminium alloys have supremacy in strength to weight ratio, they play a vital role in different engineering fields (Baradeswaran and Elayaperumal, 2011) and because of lightweight aluminium alloys also provide significant economic advantages (Mazahery and Shabani, 2012, 2011). However, one of the most significant drawbacks of aluminium alloys is that they demonstrate low wear resistance in tribological applications (Baradeswaran and Perumal, 2014). In order to develop tribological properties, Aluminum Matrix Composites (AMCs) are being investigated with different ceramic particles like SiC, TiC, B_4C, Al_2O_3, MgO, TiO_2, BN, rice husk ash, fly ash and TiB_2 along with graphite particulates.

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Aluminium along with self-lubricating (graphite) composites provides accelerated properties as a result of graphite's outstanding anti- seizure effect (Chu et al., 2010), low thermal expansion, better damping capability (Wei et al., 2002), and good friction and wear resistance (Riahi and Alpas 2001) and minimized the risk of temperature rising at the contact surface of wear. Jaber et al. (2014) fabricated piston alloy alumina composite by stir casting technique. He found higher tribological properties than matrix alloy. He also concluded that wear loss increases with increasing applied load, sliding speed and sliding distance but wear resistance increases with addition of alumina particles. Hassan et al. (2007) found that with the addition of SiC particles, wear properties of the Al–Mg–Cu alloys can be significantly improved and it was confirmed by wear test with a pin-on-disk wear testing machine. However, compared to unreinforced aluminium alloys, resistance to wear of the composites was excellent. It was also confirmed that wear resistance can be improved significantly with the addition of copper up to 5 wt. % in Al–4 wt. % Mg alloy, but the increment of coefficient of friction remained trivial. Aluminium fly ash composite was fabricated by means of stir casting technique and found excellent hardness property (Vivekanandan and Arunachalam, 2013). It is because of the addition of fly ash which acts as an obstacle to dislocations movement and by this means hardness of the aluminium composite is improved. It was also found that abrasive wear resistance of aluminium composites can be improved by the addition of fly ash into molten aluminum and the reasons are dispersion strengthening, solid solution strengthening and particle reinforcement. Aluminum matrix composites (AMCs) have wide range of applications in many different industries such as in automotive industries, armed forces (Pournaderi, 2012), aircraft manufacturing (Bekir, 2008, Mehdi et al., 2010) and electronic industries (Sajjadi et al., 2012; Rafezi et al., 2007). It is also used as bearing parts, cutting tools and medical rigs (Junko et al., 2008). As reported by (Mehdi et al., 2010) AMCs are an excellent choice because they provide better elastic modulus with light weight, very good tensile strength, high-quality fatigue and particularly resistance to wear.

The goal was to improve dry sliding wear and also the design parameters which have significant effects on dry sliding wear. Manufacturers always try to fabricate such automobiles and automotive parts which are energy efficient by means of near to the ground production cost. In order to meet up such demands and to make automotive parts more resistance to wear with reduced weight and energy saving, the automotive manufacturers always tried to discover alternative materials and manufacturing process [8]. As the aluminum alloys alone are unable to meet these demands, design of Aluminum Matrix Composites (AMCs) to find optimum wear resistance are necessary. In this review study, the effect of reinforcement wt. percentage, reinforcement size, applied load, sliding distance, sliding speed (S), properties of the reinforcement phase and hardness of the counter face on wear properties have been discussed with great detail.

2. Materials and Methods

2.1 Wear Mechanism of Aluminium Composite

At lower speed wear occurs by the mechanism of abrasion while delamination is the mechanism at higher speed and load in aluminium composites reinforced with ceramic particle (Basavarajappa et al., 2006). When significant deformation occur a morphologically distinct structure known as mechanical mixed layer with wear products such as matrix particles, broken fibres, even counterpart materials forms (Daoud, 2014). When load between that surface layer and undamaged material inside is exceed some critical values subsurface crack may be nucleated and due to applied stress crack propagates with wear test progression. These cracks link the wear surface and wear occurs. This mechanism is known as delamination which is the dominant wear mechanism studied by Sharma et al (2002).

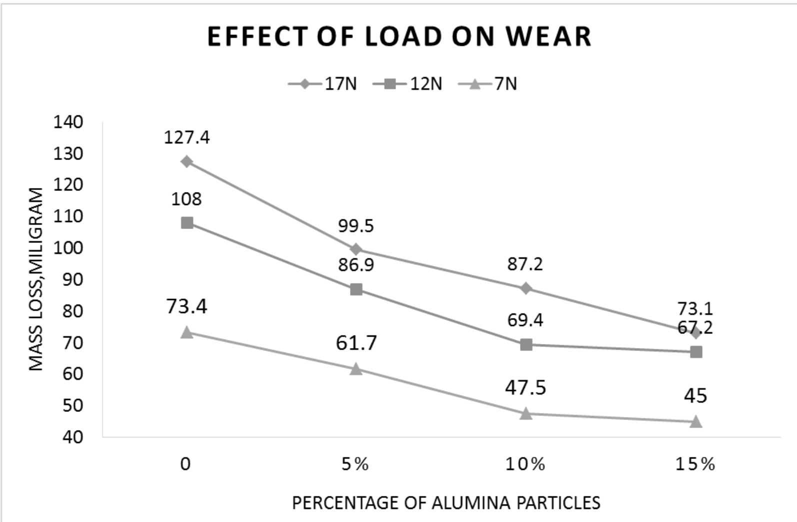
Wear damage may be caused by micro-cracks or localized plastic deformation studied by Sanchez et al. (2006). Real contact area is very small relative to the apparent contact area of two solid surfaces, limited to the points of contact of surface asperities. Localized load at these points become very high when load is applied to the surface. Reinforcement hard particles cause higher hardness, superior elastic modulus of the matrix alloy. It was stated that wear rate decreased with increasing the percentage of ceramic particles.

2.2 Parameters Influence Wear

2.2.1 Percentage of Reinforcement

Adhesive wear rate decreases with the increasing of particle weight fraction at a constant particle size and dimension in aluminium alloy. It is also reported that reinforcement volume fraction is a function of sliding wear rate. The wear rates of the counter-face material increased with increase of volume fraction of the ceramic particles. This is mainly due to the fact that the hardness and strength of composites are higher and they increased with increase in filler content studied by Das (2008). Jaber et al. (2014) studied wear properties of piston alloy alumina composite by varying alumina percentages and load at constant sliding speed 0.77ms^{-1} which is shown in figure 1

Figure 1: Mass Loss of the Master Alloy and Composite At Different Load at Constant 0.77 Ms-1 Sliding Speed (Jaber Et Al., 2014)

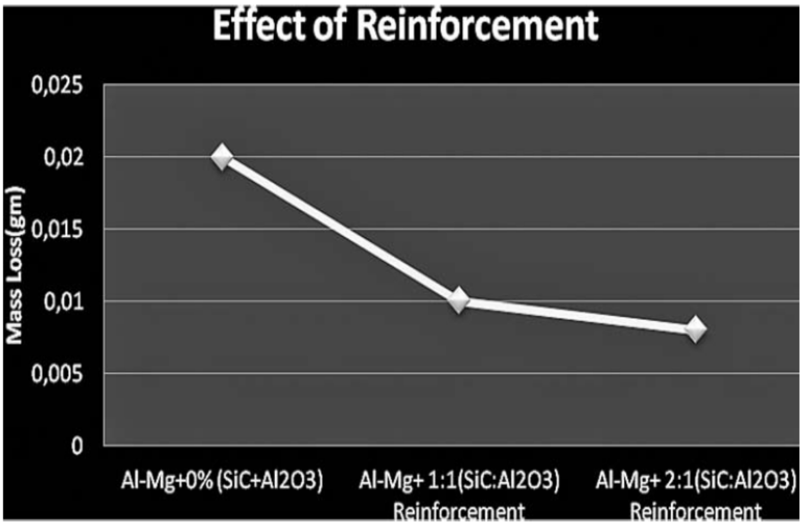


It is clearly seen from figure 1 that wear loss is decreased with increasing the percentage of reinforcement alumina particles. Hard alumina particles give resistance to penetration, grinding and ploughing by steel counterpart. Hard alumina particles also act as a main load bearing system for the multicomponent system which also improves wear resistance. According to this study it was concluded that wear rate decreases with increasing reinforcement volume fraction.

2.2.2 Types of Reinforcement

According to Senapati (2014) the variation of reinforcement particles such as SiC, TIC, Si_3N_4, Al_20_3, silica sand, MgO, mica and B_4N in alumina metal matrix also control the tribological properties. But correlation of particulate size and volume fraction with the tribological properties was not systematic and was undefined by them. Particles shape can also be effective factor for this low wear rate of SiC reported. I˙zciler Et al. [8] in their study concluded that SiC particles have more wear resistance than alumina particles when used as reinforcement in aluminium alloy. Mahedi et al. (2011) also found higher wear resistance when they prepared hybrid composite by adding SiC and alumina 2:1 in aluminium alloy.

Figure 2: Effect of Reinforcement on Wear Loss (Mahedi Et Al., 2011)



Form the figure 2 it is seen that wear resistance is much higher of the composite containing SiC and alumina ratio 2:1 than the composite containing SiC and alumina ratio 1:1. Miyajima and Iwai (2003) studied the effect of dry sliding wear of SiC whisker, Al_2O_3 fibre and SiC particles reinforced with Al2024 and ADC12 aluminium alloys, in the initial wear regime, the fibres were larger in diameter and length than the whiskers, so that the fibres were more effective in decreasing the initial severe wear as compared with whiskers. The particle reinforcement effectively prevented the plastic flow and the adhesion of matrix material since the particle shape was of great advantage on carrying contact load compared to whisker and fibre reinforcements.

2.2.3 Applied Load

Adhesive wear mechanism of ceramic particles reinforced aluminum matrix composites increased hundred time when applied normal load exceeded a critical level. Abrasion is the principle wear mechanism for the composites at lower loads. At higher loads, the wear mechanism changes to delamination (Basavarajappa, 2006). Jaber et al. (2014) also studied wear properties of piston alloy alumina composite by varying load at constant sliding speed. It is seen from figure1 that wear loss increases with increasing the amount of load. The penetration ability of the fractured particles increases with increasing the load will increase the removal of the material on the specimen surface. The fractured small alumina particles between the specimen surface and the counterpart surface form a three-body abrasion system and remove the material from the specimen surface. Two wear regimes were observed by Sarkar (1975) in study of dry sliding wear of two Al-Si alloys against steel counterface. First wear regime was observed as a mixed mood of elastic-plastic contact where Archard's law was obeyed. The second regime was characterized by gross plastic flow activated at a critical applied load where wear rate was not proportional to the load. According to Alpas and Zhang (1994) MMC reinforced with particles shows three different wear regimes at three different loading conditions. Wear resistance of MMC is order of magnitude better than Al alloy in regime 1. Wear resistance is similar to regime 2. Severe wear (regime 3) was obtained at high load.

2.2.4 Particle Size

According to Chung and Hwang (1994) at a constant volume fraction of SiO_2 in aluminium matrix coarser reinforcement SiO_2 particles show more wire resistant than fine particles. Coarser particles are more resistance for subsurface cracking. Below 13 µm of ceramic particles adhesive wear mechanism and micro ploughing are predominant and higher wear rate was observed for large particle size.

2.2.5 Interface Bond Strength

It was reported by Heguo (2008) that high bond strength of several micrometre reinforcement particles with matrix have better ability to support load effectively and prevent initiation and propagation at the subsurface wear region. Interfacial strength between particles and matrix influence wear rate. Poor particle-matrix interfacial bonding is predominant factor for increasing the wear rate. Strong interfacial bonding transfers the load from matrix to hard particle, resulting in less wear loss. Surface hardness also influence wear rate. Sanchez et al. (2006) concluded high rough surfaces increase wear rate. Due to poor interfacial bonding, wear surface offer site for crack nucleation and tends to particle from the wear surface tending to higher wear loss.

2.2.6 Temperature

At a certain critical temperature the material exhibits mild to severe wear transition. At elevated temperature addition of hard particles improve the resistance to seizure. Wear rate was increased with increasing heat in between wear surface studied by Daoud and Rohatgi (2004). Small grain boundaries attribute grain boundary strengthening of Al leading to strain hardening and decrease wear rate observed by Prasada et al. (2008).

2.2.7 Contact Surface Area

According to Yang (2007) contact area of composite and counterpart is a factor for wear coefficient and wear volume. Higher contact surface possess higher wear coefficient and wear volume.

2.2.8 Temperature

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2.2.9 Counter face Surface Hardness

Counter face high surface hardness decrease wear rate reported by Kumar Balasubramanian (2008). Lower hardness reduces the wear resistance due to the mutual abrasion between the counter material and the wear surface of the specimen.

3. Result and Discussion

3.1 Optimum Tribological properties of Aluminium Composite

The addition of Alumina with aluminium alloy improves both wear resistance and mechanical properties. Baradeswaran et al. (2013) concluded that 6wt. % Al_2O_3 in the AMCs is optimum to get best wear resistance and mechanical properties. Singla et al. (2009) [13] studied wear properties of Aluminium SiC composite. He concluded that average coefficient of friction decreases linearly with the increase of normal load and percentage of silicon carbide particles and wear rate decreases linearly with the increase of percentage of silicon carbide particles. At 20% wt. percentage of 320 grit size sic particles in aluminium composites provide minimum wear. Prasad et al. [4] have used different casting techniques to investigate the wear rate and hardness. He found that the sample produced by gravity casting has lower wear resistance and low hardness.

Sudarshan et al. (2005) reported that dry sliding wear resistance of A356 composite reinforced with fly ash particles is almost similar to that of Aluminium alloy reinforced with SiC and Al_2O_3 particles. Composites show better wear resistance up to 80 N. Wear and friction properties of composites also depend on particle size and volume fraction particles. A356 composites reinforced with fly ash particles of wide size range (0.5-400 µm) provide less wear properties than small size range (53-106 µm) for same volume fraction at high load. Wear behaviuor also depends on the sliding speed. Interaction of velocity and distance was clearly observed in Gr-SiC composite (Basavarajappa, 2006). According to Kumar et al. (2013) dry sliding wear rate mostly depends on applied load followed by sliding speed. Hayrettin Ahlatci (2003) et al produced an aluminium matrix hybrid composite and observed abrasive wear behaviours. On the basis of this experiment it was observed that Mg content of the matrix increases the wear resistance and high test temperature (especially above 200ºC) decreases the abrasive resistance.

Tuti et al. (2003) studied on as-cast and heat treated Al-Si eutectic alloy and observed the wear behaviuors of both alloys. Heat treated Al-Si alloy exhibits better wear resistance than as cast alloy because different heat treatment cycles provide some inherent characteristics of the alloy. Abrasive wear behiviours of alumina and zircon sand reinforced aluminium matrix composite were investigated by Das et al

(2007). According to the authors with the decreasing of the reinforcement particle size wear resistance increases for both composite. They also observed composites reinforced with zircon sand provide better wear resistance than alumina. Combination of SiC and Graphite particles reinforced hybrid aluminium matrix composites were studied by Suresha et al. (2012). They observed the dry sliding behaviour of the composite. They concluded that sliding speed is less important factor than load on friction coefficient of the composite. With increase in load and sliding speed coefficient of friction increased. Composite exhibits less friction coefficient than pure alloy.

A recent study shows that aluminium matrix composite with multiple-particle size SiC exhibit better wear resistance than single or double particle size SiC reinforcement as a result of suitable protective effect of base metal and the finer particles by the coarser particles (Adebisi et al., 2010).

4. Conclusion

From the brief discussion it is summarized that hard ceramic particle addition with aluminium alloy improves wear resistance. But superior addition of ceramic particles with aluminium alloy is still being a research gap. This aims to assess the different ceramic particles in aluminium alloy composite and find out the superior wear resistance. Finally there is a vast potential and opportunities for the researchers to improve wear properties of aluminium composites by varying parameter associated with wear such as reinforcement particle size, adding different reinforcement combined (hybrid composite) and changing ratio of them, changing fabrication technique and parameters associated with that.

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