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A Review on Effects of Reinforcements on Mechanical and Tribological Properties of Metal Matrix Composites

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ABSTRACT: The unique characteristics of composites and distinct advantages over monolithic metals has made composite materials popular in many engineering applications such as automotive (piston, cylinder liners, bearings), aerospace and structural components resulting in low material wastage and high savings. MMC's, in particular aluminium matrix composite have gained more popularity due to low cost, low density, high strength to weight ratio, high thermal conductivity and high wear resistance. This paper presents a review on the effects of reinforcements on the mechanical and tribological properties of a composite fabricated by various methods such as powder metallurgy, stir casting, mechanical alloying, FSP, etc containing single or multiple reinforcements. Reinforcements are added to get desired mechanical and tribological properties. The effects of different reinforcements on mechanical and tribological properties are studied in this paper.

KEYWORDS: AMCs, Reinforcement, Matrix, Wear, Mechanical properties.

I. INTRODUCTION

A composite is a structural material which contains two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called the matrix phase and the other one is called reinforcing phase. Reinforcing phase is embedded in the matrix phase [1]. The reinforcing materials may be in the form of particles, fibers or flakes and the matrix phase materials are usually continuous. Composites are classified into three main categories depending on the chemical nature of matrix phase- Polymer matrix composites, Metal matrix composite and Ceramic matrix composites [4]. One of the difficult tasks for researchers today is to select material which has low weight and high strength. Aluminium is one such material. It is light weight, strong, ductile, highly corrosion resistant, and excellent conductor of heat and electricity. Also it is recyclable, odourless, long lasting and has good reflective properties. Aluminium alloys are alloys in which aluminium is predominant metal. The primary alloying elements include copper, magnesium, silicon, zinc and manganese. Selection of right alloy for given application requires considerations like tensile strength, density, ductility, formability, workability corrosion resistance etc. [2].

Typical mechanical properties of aluminium are specific gravity =2.6, Young's modulus= 68.95 GPa, Ultimate tensile strength= 234.40 MPa and Co-efficient of thermal expansion = 23 μ m/m/ $^{\circ}$ C [1]. Aluminium because of its low weight is preferred, but all the required strength cannot be provided by aluminium alone. Therefore various reinforcement particles such as SiC, B₄C, Al₂O₃, Si₃N₄ are added to enhance the strength to weight ratio and tribological properties [3].

AMMC's exhibit higher strength, hardness, temperature resistance, abrasion and wear resistance etc because of which AMMC's are extensively used in space, military, automobiles, aerospace, sports, marine, transportation etc. Composites are gifted with good tribological properties due to presence of hard reinforcements. AMMC's became

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popular due to the improved tribological properties which replaced their monolithic counter parts mainly in automotive and aerospace sector [5].

II. DIFFERENT FABRICATION METHODS OF COMPOSITES

Composites are manufactured using different techniques such as powder metallurgy, stir casting, mechanical alloying, compocasting, spray decomposition, liquid metal infiltration. Among this powder metallurgy (P/M) is one of the highly developed methods for fabricating composites. One of the biggest benefits of P/M is its ability to shape powders directly into its final component form (net shaping) or a component near to its final form (near net shaping). P/M has succeeded in replacing other traditional methods of metal forming operations because of low energy consumption, high quality, maximum material utilization, low capital cost and its ability to fabricate complex parts economically. As a result P/M has found applications in aerospace, automotive and other manufacturing industries. Distinct properties and microstructure can be produced using P/M technique, which cannot be produced by other metal working techniques. The mechanical properties here are mainly dependent on the final density of sintered P/M alloys. It was identified that main factors responsible for the reduction of mechanical properties of P/M alloys are presence of voids or porosity in compacted preforms and sintered products [7 - 8].

Stir casting is another commonly used commercial method of producing aluminium based composites. In this process the reinforcement particles such as metal carbides (SiC, B₄C, TiC), metal oxides (Al₂O₃) and metal borides (TiB₄) under atmospheric pressure reinforced in the melt of aluminium matrix with the help of mechanical stirrer. With stir casting process composites with upto 30% volume fraction of reinforcement can be produced. Stir casting process is capable of mass production, low cost, and wide range of material and processing conditions. Because of above mentioned advantages stir casting has been used more frequently [10].

III. MECHANICAL PROPERTIES

Komai et al. (1992) fabricated Al7075/SiC_w composite and was further heat treated to T6 condition. Experimental investigations were carried out on tensile, fatigue fracture behavior and influence of water environments on fabricated component. The authors reported that there was enhancement of mechanical properties of the formed composite when compared to that of unreinforced 7075-T6 alloy, apart from elongation at failure [11]. Bhaduri et al. (1996) produced SiC particulate reinforced aluminium alloy (7010) matrix composites by mechanical alloying. Authors revealed that addition of SiC particulates has detrimental effects on mechanical strength of a composite at room temperature and beneficial effects at temperature above 200°C. It was found that by addition of 20 wt% SiC to aluminium alloy there was approximately 64% increase in yield strength at high temperature of 350°C. It was summarized that effect of addition of SiC on mechanical strength can be advantageous only at elevated temperatures [12]. Suresh et al. (2003) produced the composite by using ASM 356 Al-Si-Mg alloy as matrix and Beryllium-aluminium-silicate (Be₃Al₂(SiO₃)₆) as reinforcement material by squeeze casting and compared tensile properties with gravity cast beryllium-aluminium composites. He reported that squeeze cast composites show a peak strength of 216 MPa, which resulted in an increase of 11.6% in tensile strength [13].

Daoud et al. (2004) investigated the effect of Al₂O₃ particles on 7075 Al alloy. Different squeeze pressures were applied on a stir cast composite and it was observed that interfacial strength between the matrix and Al₂O₃ particles and hardness increased linearly with increase in volume fraction of particles and applied squeeze pressure and also finer structure of the composites was obtained with improved wear resistance [14]. Kalkanli et al (2008) synthesized the squeeze cast AA7075/SiC_p and comparison was made between as-cast and heat treated aluminium composite under T6 heat treatment condition. It was reported that with 10% SiC_p aluminium matrix composites there was increase in flexural strength and hardness in both the cases [15].

Mazahery et al. (2011) studied the mechanical properties of stir cast Al(A356)/Al₂O₃ nano-particles composites and revealed that yield stress and ultimate tensile strength increased with increasing the volume percentage of Al₂O₃ particles and ductility of Al matrix was retained [16]. Alaneme et al. (2012) investigated the tensile behavior and fracture behavior of Al6063/SiC_p produced using borax additive and two step stir casting method for different volume % of SiC. It was reported that there was increase of strength and fracture toughness of formed composite due to higher volume % of SiC and aging treatment respectively [17]. Baradeswaran et al. (2013) studied the mechanical properties

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of Al 7075/Al₂O₃/graphite hybrid composites fabricated by liquid metallurgy route. The author has revealed that the hardness, ultimate tensile strength and ultimate compressive strength of the composite increased linearly with increase in weight percentage of Al₂O₃. He also revealed that addition of graphite to Al alloy leads to decrease in hardness, flexural strength, compression strength and tensile strength. Graphite tends to increase wear resistance properties [18].

Dora silva Prasad et al. (2014) carried investigations on mechanical properties of double stir cast aluminium hybrid composites, where aluminium composites were reinforced with different volume fractions of rice husk ash (RHA) and SiC particulates in equal proportions. He reported that with increase in percentage of reinforcement, the density of hybrid composite was decreased but hardness and porosity increased. Increase in RHA and SiC contents helped to increase yield strength and tensile strength [20]. Krishna Prasad et al. (2014) studied the mechanical properties of Al/Beryl composites by adding small amount of copper. Results revealed that there was significant improvement in yield strength, hardness, ultimate tensile strength, strength co-efficient and strong interfacial bonding between beryl particle and Al matrix [21]. Vignesh et al. (2014) performed corrosion study on Al7075 monolithic alloy and Al7075/Al₂O_{3p} composite in sea water and industrial environment for different samples. He reported that Al7075 was more corrosion resistant when compared to prepared composite and Al7075/Al₂O₃ corroded less in industrial environment than in sea water environment [22]. Balaji et al. (2015) manufactured Al7075/SiC_p by stir casting technique and reported that there was increase in strength and hardness by 10% when compared to Al6061. He also observed that density of the composite was greater than the base matrix [23]. Amal et al. (2015) studied the properties of Al/TiO₂ Nano-composites developed by powder metallurgy technique. Authors reported that that addition of nano TiO₂ particles resulted in significant improvement in mechanical properties such as hardness, ultimate strength and yield strength but the ductility of aluminium was reduced [6]. Muhammad Rashad et al. (2015) prepared a hybrid composite where micron sized titanium and aluminium reinforced with pure magnesium by semi-powder metallurgy. Authors reported that the synthesized composite (Mg-10 Ti and Mg-10 Ti-1Al) showed improved hardness, tensile strength, elastic modulus, 0.2% yield strength, Ultimate strength and failure strain [25].

IV. TRIBOLOGICAL PROPERTIES

Garcia et al. (1995) compared abrasive wear resistance of compocast A357/SiC, A339/SiC, AA6061/SiC and AA6061/Al₂O₃ composites in as cast condition with grey conventional cast iron. Authors revealed that with increase in volume fraction and particle size of reinforcement there was reduction in specific wear rate. It was also observed that aluminium alloy composite reinforced with Al₂O₃ particulates are less effective against abrasive wear than those reinforced with SiC particulates [26]. Iwai et al. (2000) studied dry sliding wear behavior of Al/Al₂O₃ composites developed by high pressure and low speed die casting technique. It was reported that there was improvement in dry sliding wear resistance upon addition of Al₂O₃ fibers with Al alloy [27]. Sharma et al. (2001) investigated the tribological behavior of liquid metallurgical processed Al6061- garnet particulate composites using pin on disk wear testing machine, where wear rate and friction were examined as a function of sliding distance, sliding velocity and applied load. Authors observed that with increasing wt% of garnet, the wear resistance increases and also there was reduction in average coefficient of friction of Al6061 composite when compared to matrix alloy [28].

Ramesh et al. (2005) prepared Al6061-TiO₂ composite by liquid metallurgy route where TiO₂ wt% was varied from 2 to 10 wt%, load was varied from 10 to 40N and sliding distance from 90 to 540 m. He reported that under identical test conditions, the increase in contents of TiO₂ resulted in lower wear coefficient and higher hardness. Also at higher loads and larger sliding distances the wear coefficient of Al6061- TiO₂ composite was decreased [29]. Amro et al. (2008) studied the wear and friction characteristics of Al-Al₂O₃ composites using pin on disk tribometer for various sliding speeds. He reported that wear rate increases with increasing load and higher concentration of Al₂O₃, whereas with higher sliding speed and relatively lower concentration wear rate decreases [30]. Akhlaghi et al. (2009) investigated the influence of presence of graphite on dry sliding and oil impregnated sliding wear behavior of 2024 Al alloy/ 5 – 20 wt % flake graphite particulate composite produced by in situ powder metallurgy method. Authors revealed that, Al/Gr composite consisting 5 wt % graphite showed superior wear properties over base alloys but higher graphite addition led to detrimental effects on wear properties. At lower levels 5 wt% of graphite addition, wear resistance was improved for both dry sliding and oil impregnated sliding [31].

Suresha et al. (2012) investigated the friction characteristics of a stir cast Al-SiC-Gr hybrid composites with the combined reinforcement levels up to 10% of Sic and Gr particulates by using pin on disk testing equipment. Authors

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observed that friction coefficient was affected by sliding speed and load and not by the % reinforcement and the sliding distance [32]. Qutub et al. (2013) investigated friction and wear nature of Al6061 alloy reinforced with carbon nanotubes. He reported that friction and wear of Al-CNT mainly dependent on applied load and CNT's have a negative impact on the wear resistance if the applied load crosses critical load [33]. Suresh et al. (2013) studied wear behavior of stir cast Al6061/TiB₂ composite and reported inclusion of TiB₂ in the aluminium improves wear resistance of aluminium composites [19]. Thangarasu et al. (2014) fabricated AA6082-TiC composite by friction stir processing to study wear characterization. It was reported that with increase in volume fraction of TiC particles wear rate was reduced [34].

Siddhartha et al. (2014) fabricated Al/B₄C metal matrix composite by stir casting and carried investigations on its tribological behavior. The authors revealed that wear rate and coefficient of friction was directly proportional to applied load and inversely proportional to sliding speed and distance [35]. Ramachandra et al. (2015) studied the wear behavior ZrO₂ nano particles reinforced with Al nano composites, he revealed that addition of n-ZrO₂ particles resulted in increase of wear resistance and hardness of fabricated composite [36]. Amal et al. (2015) produced pure aluminium nano composite with nano TiO₂ particles as reinforcement. Results revealed that wear resistance of aluminium matrix was lower than that of composite and wear rate was reduced with addition of n-TiO₂ particles [6].

V. CONCLUSIONS

- Composites can be effectively manufactured by use of appropriate fabrication technique depending on choice of reinforcement and matrix material.
- Composite materials have better properties than monolithic metals and their alloys.
- Reinforcements added to matrix materials will help to improve mechanical and wear properties.
- Incorporation of SiC, B₄C, alumina particles in aluminium improves tensile strength, hardness and yield strength, but reduces ductility.
- Incorporation of graphite in aluminium increases its tensile strength and elastic modulus, but hardness is reduced. Also friction coefficient is reduced in case of tribological behavior.
- Hybrid reinforcements have given better mechanical properties than composites in most of the cases.

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