A Review on Effects of Reinforcements on Mechanical and Tribological behavior of Aluminum based Metal matrix composites

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Abstract - *Aluminium-based metal matrix composites (AMMCs) are generally preferred for their low density, wide alloying range, high strength to weight ratio, intrinsic flexibility and response to heat treatment hence they are widely used in aerospace, automobile, marine industries. The various methods for manufacturing MMCs are Spray decomposition, powder metallurgy, liquid metal infiltration, mechanical alloying, squeeze casting and compo casting. By adding reinforcements to aluminium alloy matrix, the properties have improved. Hence, this paper presents a review on the effects of Al_2O_3, B_4c, Gr, Y_2O_3 and SIC reinforcements on the tribological and mechanical behavior of a AMMCs fabricated by various methods such as powder metallurgy, stir casting etc.*

Key Words: MMCs, Al_2O_3, Reinforcement, Wear, Mechanical properties, Microstructure

1. INTRODUCTION

Aluminum-based alloys used in a variety of industries such as aerospace, automotive, and defense due to good corrosion resistance, low density and high electrical conductivity. Al matrix composites can be used for manufacturing the automobile products such as engine piston, brake disc/drum and cylinder liner. Addition of hard ceramic particles to soft aluminum alloys increases the strength and wear resistance. Uniform distribution of reinforcement is essential to achieve high strength, otherwise, clustering of reinforcement can lead to lower strength, ductility and toughness of the composites. The addition of ceramic reinforcements such as SiC, TiC, Al_2O_3, B_4C and ZrO_2 to a metal matrix improves the hardness [1].

The advantages of AMCs compared to unreinforced materials are as follows:

- Greater strength
- Improved stiffness
- High strength to weight ratio
- Improved high temperature properties
- Controlled thermal expansion coefficient
- High wear resistance
- Good corrosion resistance
- Control of mass (especially in reciprocating applications)
- Improved damping capabilities.

The various methods for manufacturing MMCs are Spray decomposition, powder metallurgy, liquid metal infiltration, mechanical alloying, squeeze casting and compo casting.

Powder metallurgy is the most common method for production of MMCs because it has the capability to produce near net shapes with minimal material loss associated with production. Uniform distribution of reinforcement is possible in powder metallurgy hence powder metallurgy technique has better control on microstructure compared to casting [12].

Stir casting is low cost processing method for producing AMC matrix. In stir casting better matrix particle bonding occurs because of stirring action of particles in to the metals. The recent research studies revealed that the homogenous mixing and good wetting can be obtained by selecting suitable processing parameters like stirring time, stirring speed, preheating temperature of the mould, temperature of molten metal, and uniform feed rate of particles.

2. MECHANICAL AND TRIBOLOGICAL PROPERTIES

Hai Su et al. [2] fabricated nano-Al_2O_3/2024 composites by solid–liquid mixed casting combined with ultrasonic treatment. Compared with the matrix, the yield strength and ultimate tensile strength of 1 wt.% nano-Al_2O_3/2024 composite were increased by 81% and 37%, respectively.

Mohsen Hossein-Zadeh et al. [3] investigated the feasibility of adding nano-crystalline Al_2O_3 particles into aluminum

matrix. Al_2O_3 powder was milled for 20h using high-energy ball mill and 1 wt.% of alumina (Al_2O_3) powder was added into molten Al. Then microstructure, wear and mechanical properties and also powder characterizations of this composite were studied.
Microstructure of this composite is finer compared to pure aluminium due to the presence of fine Al_2O_3 particles as heterogeneous nucleation. Due to existence of hard particles and crystalline size reduction in matrix, mechanical properties (hardness and yield strain) of Al–Al_2O_3 composite were better compared to that of the sample without Al_2O_3. Addition of small amounts of synthesized Al_2O_3 nano-crystalline powders to Al matrix would decrease the wear extent from 0.0199 g to 0.0015 g in the wear distance of 1200 m.

Hafeez Ahamed et al. [4] studied the structural evolution associated with grain refinement and superior mechanical properties by the addition of nano-size Y_2O_3 and Al_2O_3 particulates into monolithic A16063 alloy matrix. Mechanical alloying (MA) and Mechanical milling (MM) was employed to obtain nano structured Al6063 matrix with uniform distribution of ceramic reinforcement particulates. The addition of hybrid or singular (nano-Al_2O_3 or/and nano-Y_2O_3) reinforcements in monolithic Al6063 alloy simultaneously increases 0.2% YS, micro hardness and UTS. Almost closer hardness values of the nano-composites were obtained either in hybrid form or singular form reinforcements without any detectable reaction of inter-phases between reinforcements and matrix. As compared to monolithic Al6063 alloy, hybrid reinforcement retained the potential superiority in terms of overall combination of tensile property.

Gaurav Bajpai et al. [5] fabricated Al-Nano Al_2O_3 composites with various weight % of nano Al_2O_3 using powder metallurgy process through cold Isostatic compaction chamber. Cold Isostatic compaction process results in better and high uniform properties as compared to die compaction process because of uniform application of pressure from all directions and absence of die wall friction. The tensile strength, compressive strength and hardness of Al-Nano alumina composites first increases up to 2 wt. % nano Al_2O_3 and then decrease at 3 wt. % of nano Al_2O_3. This is because of clustering (agglomeration) of nano alumina particles at higher weight percent. The amount of effective nano particles available reduced by clustering of nano particles and hence the hardness and strength decreases. Scanning electron micrographs of powder metal Al-Nano Al_2O_3 composites shows that the Argon atmosphere sintering results in proper bonding between aluminium and Nano Al_2O_3 particles. The micrographs also show uniform distribution of Nano Al_2O_3 particulates and some amount of porosity in aluminium matrix up to 2 wt. % Nano Al_2O_3.

A.A. Mazen et al [6] studied the Mechanical behavior of Al-Al_2O_3 MMCs prepared by PM Techniques. Under tensile and compressive loads, a strength improvement of 64 to 100% was obtained as compared to the matrix material strength. The percentage elongation to fracture ranged from 20 to 30% indicates good ductility as compared to the ductility of MMC manufactured by other techniques.

M. Kok [7] fabricated 2024 aluminium alloy metal matrix composites (MMCs) reinforced with three different sizes (16, 32 and 66μm) and weight fractions of Al_2O_3 particles up to 30 wt.% by a vortex method and subsequent applied pressure. He investigated the effects of Al_2O_3 particle and size of particle on the mechanical properties of the composites such as tensile strength and hardness.
He has given conclusion from his experiment that the density of the composites increased with increasing weight percentage and particles size, whereas the porosity of the composites increased with decreasing size of particle and increasing weight percentage of particles. The bonding force between Al alloy/Al_2O_3 particles were improved by the applied pressure after the casting hence the porosity was also decreased because of this pressure. He also concluded that the hardness and tensile strength of MMCs increased but the elongation of them decreased, with increasing weight percentage of the particles and decreasing size.

R.Ganesh et al. [8] investigated the effect of sintering temperature on physical, mechanical and wear properties of Al 2219 alloy matrix reinforced with SiC particulate (average particle size 23 μm) for three different weight fractions (10%, 15% and 20%) produced by powder metallurgy (PM) technique. They performed wear test under the loads of 10 N, 20N and 30N and three sliding distances of 1960 m, 2448 m and 2934 m at the room temperature. Here, the sintering was carried out at 500°C, 550°C and 600°C for four hours and normal water was used for quenching medium. From this study, they inferred that higher weight fraction of the reinforcement (20%) and higher sintering temperature (600°C) yields composite with highest hardness, highest breaking load, least percentage reduction in length and least porosity. Wear decreases with increase in weight fraction of SiC at all disc speeds, loads and also with sintering temperature.

R. Arrabal et al. [9] investigated particle concentration effects on phase composition and wear behaviour. In this study, Plasma electrolytic oxidation (PEO) coatings with integrated α-Al_2O_3 particles were formed on 6082-T6 alloy. α-Al_2O_3 particles are integrated into the outer layer of the coatings either by electrophoresis, deposition or mechanical entrapment by the ejected material from the discharge channels. Due to this, the outer layer shows increased hardness and lower porosity. Friction coefficients of untreated 6082-T6 aluminium alloy and hard chrome coating could not vary significantly as the normal load increased from 2 N to 10 N. Friction coefficients of PEO coatings were similar to those of hard chrome coatings, even though they slightly increased with the applied load. Plasma electrolytic oxidation coatings produced in the electrolyte having 10 g L^{-1} α-Al_2O_3 particles showed the lowest wear damage and suggesting that they could be a good alternative to hard chrome coatings.

T. S. Senthilkumar et al. [10] carried investigation on the mechanical properties of Al6082 based hybrid metal matrix composite. From this study, he concluded that the hardness of aluminium alloy 6082-O is increased by addition of reinforcement materials such as boron glass powder and silicon carbide . The Vickers hardness for AA 6082-O is 35HV. The hardness is increased from 41 HV to 98 HV after addition of reinforcements.

Mehdi Rahimianet et al. [11] investigated the effect of Al_2O_3 particle size, sintering time and sintering temperature on the properties of Al–Al_2O_3 MMCs made by powder metallurgy. In this study, The average particle size of alumina were taken as 3, 12 and 48 μm and 10 wt.% of Al_2O_3 is mixed with aluminium. The sintering temperature were taken as 500, 550 and 600 ◦C and sintering time was in the range of 30-90 min.
From this study they observed that the relative density of Al–Al_2O_3 composite was higher in samples containing fine particle sizes. The highest relative density of 99.95% was observed in specimens sintered at 600 ◦C. The grain size of samples having fine Al_2O_3 particles is smaller and increasing the sintering time to 90 min leads to grain coarsening and the highest hardness was 76 HB in specimens having average particle size of 3 μm sintered at 600 ◦C for 45 min. Further increase in sintering time from 45 to 90 min results in a reduction of hardness to 59 HB.

The compaction, sintering, microhardness and microstructural behavior of nanocomposite powders were investigated by Hafeez Ahamed et al. [12] using pre-mixed (elemental) Al6063, Al6063/1.5Al_2O_3, Al6063/1.5Y_2O_3 and Al6063/0.75Al_2O_3/0.75Y_2O_3 powders. Sintering time and Sintering temperature on the relative density and micro hardness of the combined nanocomposite powders were examined. Here the sintering temperature used are 773, 823 and 873K. The nanocomposite with combined Al_2O_3 and Y_2O_3 reinforcement particulates was found to be most effective in increasing microhardness and sinterability. The sinterability of the Y_2O_3 particulates reinforced nanocomposites were found to be more stable under varying sintering time.

Pardeep Sharma et al. [13] noticed the effects of graphite particles on Al6082 metal matrix composite has been observed. Here the metal matrix composite manufactured by conventional stir casting process. The graphite content was varied from 0% to 12% in a step of 3%. The microstructure of all composites reveals that there are large impurities with a non-uniform distribution of Gr particles along with agglomeration of Gr particles at some locations. The Gr particles have low density compared to that of Al6082. Due to this, the Gr particles float in the aluminium melt resulting in non-uniform distribution. As weight percentage of Gr (0–12%) increases, the hardness of composites decreased by 11.1% . The reason for decrease in hardness is also due to increased brittle nature of Gr reinforcement particles which causes the composites to deform plastically more easily with increased content of Gr.

A.Baradeswaran et al. [14] studied the Optimization of Wear Behaviour of Al-Al_2O_3 Composites Using Taguchi Technique. The composites were prepared by conventional liquid casting method with varying the Al_2O_3 content. The wear test was conducted with pin-on-disc apparatus by considering 10, 20, 30, and 40N load and sliding distance of 1200 m with regular interval of 200m at 0.6m/s sliding speed. From this study, they observed that with an addition of Al_2O_3 particle into Al, the wear resistance of the composites increased. The wear rate is significantly less for the composites compared to pure matrix material. The wear rate at 6 wt.% Al_2O_3 is only 1/10th of the wear rate for the pure matrix material. The MML formed on the worn surface of the composite is the key role player in controlling the wear properties of the composites. The graphical and analytical results of taguchi shows the optimum combination of applied load as 10N and sliding distance of 400m for minimum wear mass loss at 6 wt. % of Al_2O_3 as compared to other composites and base alloy.

Gheorghe IACOB et al. [15] studied the wear rate and micro-hardness of the Al/Al_2O_3/gr hybrid composites. It was observed that the micro-hardness improve when increasing the milling time and the reinforcement content due to presence of hard Al_2O_3 particles. Was also observed a low wear rate exhibited by the Al/ Al2O3/Gr hybrid composites due to presence of Al2O3 and Gr which they acted as load bearing elements and solid lubricant respectively.

Abdulwahab Ibrahim et al. [16] investigated the sinterability of Alumix 321 alloy which is equivalent to AA6061alloy. The alloy powder was compacted in the pressure range of 100-500 MPa and sintered at 610 - 640 °C. From this research they concluded that the sintered density of the samples compacted at 200 MPa and sintered at the lower temperature (610 °C) recorded to be 2.452 ± 0.005 g/cm^3. At sintering temperatures 620, 630 and 640 °C, the gain in sintered density was 1.7% , 4.7% and 7.9% respectively. Alumix 321 achieved an apparent hardness of 92 HRE in the T6 temper, by compacting at the optimal pressure (400 MPa) and sintering at the sintering temperature (630 °C).

Chuandong Wu et al. [17] studied the effect of plasma activated sintering parameters on mechanical and microstructural behaviour of Al-7075/B_4C composites. Al7075 alloy matrix was mixed with 7.5 wt.% of B_4C reinforcement. 450 ºC, 480 ºC, 510 ºC, 530 ºC and 540 ºC were taken as sintering temperature. From this study they revealed that the highest vicker hardness of 181.6 HV and high bending strength of 1100.3 MPa were obtained when composite sintered at 530 ºC for 3 min. further increase in sintering temperature and holding time leads to decrease in bending strength due to formation of MgO.

D. Jeyasimman et al. [18] investigated the effect of γ-Al_2O_3 nanoparticles on microstructural and mechanical behaviour of Al 6061 alloy. In this study, 0.5, 1.0, 1.5, 2.0 wt.% of γ-Al_2O_3 nanoparticles were mixed with Al6061 alloy and cylindrical specimens of 10 mm in dia. and ~10 mm in height were prepared at 500MPa compaction pressure. Cylindrical compacts were sintered at 450 ºC, 525 ºC and 600 ºC. From this investigation, authors reveals that the hardness value increases with weight percentage of γ-Al_2O_3 and sintering temperature. Authors also concluded based on study that sinterability was decreased with an increasing wt.% of γ -Al_2O_3.

S. Pournaderi et al. [19] fabricated Al6061/Al_2O3 composites by in-situ powder metallurgy (IPM). The composites contained 15–40 vol.% alumina particles of 37–276 μm particle size. Authors investigated the effect of alumina content and particle size on the size distribution, morphology and microstructure of the aluminum particles produced. From this research they concluded that finer aluminum powder particles were produced by increasing the alumina content and by decreasing both the alumina particle size (within the range of 37–150 μm) and stirring temperature (from 780 to 710 °C). The powder particles produced by IPM method are dense (pore-free) compared to the gas atomized ones.

T.Hariprasad et al. [20] studied the wear behavior of Al_2O_3 and B_4C reinforced with Al 5083 alloy matrix. Here, the hybrid aluminium metal matrix composite was synthesized by stir casting method. The hybrid composites containing 5 wt.% of Al_2O_3 and different weight percentage (3%, 5% and 7%) of B_4C reinforcements were taken to study wear behavior. 10N and 20N load were considered. From this study, author inferred that the wear rate of Al_2O_3 -B_4C 8% was approximately 10% lower compared to Al_2O_3 -B_4C 10% and Al_2O_3 -B_4C 12%.

3. CONCLUSIONS

- Reinforcements added to Aluminum alloy will improve mechanical and wear properties.
- Taguchi technique shows optimum combinations of parameters for minimum wear loss.
- Sintering temperatures can improve mechanical properties.
- Aluminum matrix composites have better properties than unreinforced materials.

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