Mechanical and Tribological Characteristics of Particulates Embedded Aluminium Based Composites - A Review

R. Arunbharathi, R.Rathish, R. Shri Vignesh, P. Sathya Seelan and R. Vishnu Prasanth

Department of Mechanical Engineering

Sri Krishna College of Engineering and Technology, Coimbatore, Tamilnadu, India

Abstract - **Composites are widely used in many industries due to its enhanced mechanical and tribological properties. It is found that hybrid composites showed superior behavior relative to mono reinforced composites. Mechanical characteristics like hardness, strength found to increase with increase in wt% of reinforcement in the matrix. Whereas, wear resistance of the composites increased proportionately with wt% of reinforcement and decreased with increase in load applied.**

Keywords: Mechanical properties, hardness, wear, strength

I. INTRODUCTION

Engineering industries continuously demand for novel materials to make their products. The materials should have wide range of properties such as low density, high modulus, good strength and large resistance to corrosion and wear. These properties are difficult to attain using monolithic metals and its alloy. Composites are the appropriate materials to satisfy the industrial demands and they are made up of two or more constituents i.e. matrix phase and reinforcements. These two materials have distinct physical and chemical properties and when they are combined together, the resulting composite material yields different and superior properties.

Among several composites metal matrix composites are widely used in many applications. Metal matrix composites contains metal as the matrix or continuous phase. The commonly used materials for the fabrication of metal matrix composites are Al, Ti, Mg and their alloys. Aluminium alloy is preferred as matrix phase among numerous materials due to its low weight, good forming ability, high resistance to corrosion and low cost. The main functions of matrix phase in composites are to hold and protect the reinforcements, transfer and distribute the loads to reinforcing phases and also it provide required shape to the cast composite. Besides, MMCs are significantly used in automotive, defense and aerospace industries due to its high strength, good stability at high temperature and excellent resistance to wear (1, 2). The factors that influence the properties of composites are volume fraction of reinforcement in the matrix, size and shape of reinforcing agent and the interface bonding between reinforcement and matrix. Besides, technological characteristics of composites can be tailor made based on the requirement of various industrial applications by selecting suitable matrix and reinforcement material along with composite fabrication route (3, 4).

Various casting routes, namely, stir casting, powder metallurgy, squeeze casting and compo casting have been employed to fabricate discontinuous or particulates reinforced aluminium alloy composites. Among several standard material fabrication techniques, liquid metallurgy stir cast process is substantially utilized in many engineering industries because of its flexibility, economical and least post processing operations. Besides, larger mass and near net shape components can also be synthesized through stir cast technique with enhanced properties and minimal porosity. In addition, positive dispersion of reinforced constituents along with excellent interfacial adhesion with the matrix is achieved due to high speed stirring action involved during stir casting process(5).

Abdizadeh *et al.* (6) made an attempt to compare the physical and mechanical properties of A356 alloy composites reinforced with (1.5-5) Vol% of magnesia produced through liquid metallurgy stir cast and powder sintering process. It was found that the important characteristics of composites namely density, compressive strength and hardness showed better results in the case of cast samples compared to sintered composites. Also, authors reported that experimental density of stir cast magnesia-A356 composites was found closer to theoretical densities and this reflects less level of porosity in stir cast samples than sintered samples. Besides, they also suggested stir cast route as appropriate technique for the synthesis of aluminium matrix composites. Moreover, in both the fabrication process, addition of magnesia to A356 matrix alloy had shown improved outcome for hardness and compressive strength when compared to non-reinforced A356 alloy. The influence of wt% of reinforcement in mechanical and tribological characteristics of composites are discussed in the following sections.

II. EFFECT OF WT% OF PARTICULATES ON MECHANICAL CHARACTERISTICS OF COMPOSITES:

Anilkumar *et al.* (7) made an investigation to explore the influence of different ranges of flyash particles size (i.e. 4-25 µm, 45-50 µm and 75-100 µm) on mechanical behaviour of stir cast AA6061 composites. In addition, for each range, three varying composition of composites (10, 15, 20)wt% were produced and mechanical characteristics namely hardness, ductility, tensile and compressive strength were evaluated. The microstructure of AA6061-flyash composites exhibited positive dispersion of reinforced phases in AA6061 matrix and no interface voids were found from the micrographs. Also, it was observed that hardness and compressive strength of composites increased proportionally with rise in concentration of flyash in the matrix phase, whereas, ductility (elongation percentage) of composites decreased. The tensile strength of composites increased upto 15wt% of flyash and beyond that it started to decrease. Moreover, the considered mechanical characteristics of composites decreased with increase in flyash particulate size.

Ramnath *et al.* (8) examined mechanical characteristics of Al_2O_3 and B_4C reinforced LM25 aluminium alloy hybrid composites along with non-reinforced cast sample. Vortex method was used to produce two different composition of composites (i.e. LM25-3B_4C-2Al_2O_3 and LM25-2B_4C-3Al_2O_3) by incorporating preheated (400˚C) ceramic particulates into highly stirred molten alloy at 600 rpm. Authors examined the contribution of reinforced phases in composite samples through evaluation of macro-hardness, impact energy, tensile and flexural strength. From the results, it was found that LM25-2B_4C-3Al_2O_3 had shown significant improvement in flexural and tensile strength compared to other castings. Whereas, LM25-3B_4C-2Al_2O_3 had larger value for absorbed impact energy and hardness relative to other cast samples. Moreover, SEM micrographs of impact and tensile fracture surface revealed ductile and brittle failure mechanism in hybrid composites.

Moses *et al.* (9) studied the impact of different levels of stir cast parameters, namely, stirring time, casting temperature, stirrer blade angle and speed on tensile strength of aluminium 6061 alloy-15TiC. The obtained tensile results of the castings based on CCD design was compared with microstructural study and the authors reported that the low level and high level of the considered process variables is not suitable to produce castings with considerable strength. Low level of stirring time (10 mins), casting temperature (630˚C), stirrer blade angle (0˚) and speed (100 rpm) resulted in poor spread and more clusters of reinforced TiC in AA6061 matrix. Besides, higher levels of stirrer speed (500 rpm), casting temperature (1030˚C), blade angle (60˚) and stirring time (25 mins) resulted in heterogeneous dispersion of TiC and high degree of porosity or voids in the matrix phase. Moreover, the desired strength of AA6061-15TiC was obtained at the optimum condition such as, stirring time of 10 mins, cast temperature of 830˚C, blade angle of 30 ˚ and stirrer speed of 300 rpm. This condition yielded even dispersion of TiC particles along with cluster and void free castings.

Mathan *et al.* (10) synthesized aluminium 2618 alloy hybrid composites embedded with (2-8) wt% of ZrB2, Si_3N_4 and AlN particulates by means of in-situ stir cast route. Authors, carried out micro-hardness, microstructure, tensile and compressive test on the produced cast samples to analyse the effect of different concentration of reinforced phases in AA2618 matrix. The results revealed that tensile strength, hardness and compressive strength of AA2618 composites increased proportionally with amount of reinforced particulates in the continuous medium. Whereas, matrix grain size reduced with increase in wt% of reinforcements in the order of 2wt%. The authors also performed non-lubricated wear teat on cast samples using RSM approach and based on ANOVA technique the significant parameters on wear loss were found as load applied (79%), quantity of reinforcements (14%) and sliding speed (6%).

Muthusamy and Pandi (11) explored the corrosion and mechanical behaviour of TiC and B_4C reinforced AA2024 hybrid composites synthesized through dual-stage vortex technique. The strengthening phases (TiC and B_4C) of average size 150 µm were varied from 5-20 wt% in steps of 5 wt%. Several properties, namely Izod impact energy, tensile strength, corrosion resistance, ductility and hardness were evaluated for the produced castings and the results clearly showed that the amount of reinforcing constituents in matrix alloy resulted in linear relationship with hardness, corrosion resistance and strength. Whereas, it displayed inverse effect for absorbed impact energy and ductility of AA2024 based composites. This occurrence was due to composite transition from ductile to brittle nature, while increasing amount of enhancers in the matrix alloy.

Vinod *et al.* (12 synthesized A356 alloy based hybrid composites by embedding (0-12.5)wt% of preheated (250˚C) flyash (FA) and rice husk ash (RHA) through stir cast process. The size of FA and RHA reinforcements considered were 15 µm and 23 µm respectively and they were incorporated in steps of 2.5 wt% with A356 matrix alloy. The properties namely strength, porosity, density and hardness were determined for the castings produced and found that strength and hardness was maximum for A356-10FA-10RHA composite with least level of porosity (1.87%) compared to other hybrid composites. Besides, authors stated from the obtained results that porosity percentage in composites resulted in decreasing trend with increasing amount of strengthening phases upto 10wt%. Moreover, higher degree of pores was resulted in A356-12.5FA-12.5RHA composite and it was due to destructive effect of less bonding and agglomeration.

III. EFFECT OF PARTICULATE REINFORCEMENT IN WEAR BEHAVIOUR OF ALUMINIUM BASED COMPOSITES.

Kumar *et al.* (13) applied in-situ route to synthesize AA6061 composites with varying wt% of ZrB_2 particulates (0, 2.5, 5, 7.5 and 10). X-ray diffraction analysis was utilized to identify the existence of ZrB_2 in AA6061 matrix and the results revealed only the presence of enhancement phase (ZrB_2) in the matrix without any undesired compounds. From this obtained results, authors stated that the absence of any intermetallic constituents other than reinforcement confirms better bonding between strengthening phases and matrix. Wear characteristics of the composites were studied at 1.5 m/s sliding velocity, constant sliding distance of 1200 m and 15 N load. The outcomes of wear test exhibited decreasing pattern in wear loss of composites with addition of ZrB_2 in AA6061 matrix.

Prasat and Subramanian (14) fabricated AlSi10Mg alloy based hybrid composites by varying (0, 3, 6 and 9) wt% of flyash with constant 3 wt% of graphite particles using stir cast method. The tribological characteristics of produced composites were examined through pin on disc equipment in dry sliding condition. Wear tests were performed using different loads varying from 10 N to 50 N with constant sliding distance of 2400 m at 2 m/s of sliding speed. The results revealed that rate of wear and friction coefficient of all tested samples had a direct proportional relationship with load applied over the samples. In contrast, addition of wt% of fly ash particles in aluminium-graphite composites decreased the rate of wear and coefficient of friction of samples. In addition, SEM worn surface micrographs revealed transition of wear mechanism from severe to mild abrasive wear while increasing wt% of flyash particles in pin samples. Gradual rise in load applied changed the wear mechanism from delamination to adhesion wear in the case of aluminium alloy and wear shifted from mild abrasive to dominant delamination for hybrid composites.

Umanath *et al.* (15) explored the influence of concentration of SiC and Al_20_3, rotational speed, load applied and rotating disk hardness on wear (µm) of AA6061-SiC-Al_2O_3 hybrid composites. Weight fraction of reinforcing constituents were varied from 5-15% and the composites were produced through stir cast technique using stirrer speed of 600 rpm with average particles size (25 µm). Regression equation for wear was developed as a function of four variables considered in this study and they examined parametric influence over wear through response surface graphs. It was observed that higher degree of wear in composites occur at high level of load and rotational speed of counter disk. In contrast, lower level of wear was noticed at increased counter disk hardness and 15% of reinforcing phases in AA6061 matrix. In addition, authors stated from the preliminary trials that the composite exceeding 15% of reinforcement in the matrix resulted in minor abrasion in the steel counterface.

Vijayakumar and Karunamoorthy (16) examined the contribution of wear test parameters on wear rate of heat treated LM25-$ZrSiO_4$ stir cast composites. The particles of different size (63-149 µm) and concentration (5-25) Vol% along with wear controllable variables namely, load, sliding speed and time were considered as inputs for wear analysis. ANOVA tool was employed for the experimental data and the results showed that all the considered variables were found to have considerable impact on wear rate of LM25-$ZrSiO_4$ composite samples. In addition, authors have developed second order mathematical model for wear rate in relationship with load, particles size, concentration of $ZrSiO_4$, sliding speed and time and subsequently they studied their effects on rate of wear loss through response surface graph. The results revealed that rate of wear in composites was directly proportional to the sliding time and load applied. Besides, particles size, sliding speed and concentration of $ZrSiO_4$ had inverse effect on wear rate of LM25-$ZrSiO_4$ composites.

Viswanatha *et al.* (17) investigated microstructure, hardness and wear properties of A356 matrix composites containing 3, 6 and 9 wt% of SiC along with fixed 3 wt% of graphite particles. Silicon carbide of average size 25 µm and graphite particles of 44 µm size were used during stir cast composites fabrication process. Vickers hardness test results showed that there was a gradual rise in hardness of the composites as and when wt% of SiC increased in A356-3Gr composite. The hardness value of A356-9SiC-3Gr composite enhanced up to 9% when compared to A356 alloy. Wear test results showed that the rate of wear in all the samples increased with increase in applied load, sliding distance and velocity. Moreover, A356-3Gr-9SiC composite showed significant resistance to material loss when compared to other composites and it was due to the formation of stable hardened layer at the interface.

Suresh *et al.* (18) have synthesized LM25 aluminium alloy based hybrid composites by embedding 4 wt% of graphite (C) and 3 wt% of boron carbide (B_4C) using liquid metallurgy route vortex technique. The authors analysed the wear characteristics of LM25-4C-3B_4C composite by varying the load applied (20-60 N), sliding speed (2-6 m/s) and distance (1000-3000 m) as per L9 taguchi design. It was found that the volume loss and friction coefficient of composite is directly proportional to the applied load. Whereas, sliding distance and speed contributed to negative effect on friction coefficient and material loss in composite. Moreover, meagre abrasion on worn surface was observed for low load conditions. In contrary, heavy distortions with sub-surface cracks were revealed for 60 N load.

IV. CONCLUSION

- Aluminium based composites are considerably used in several engineering applications owing to their high specific strength, excellent wear properties, corrosion resistance, good thermal conductivity and low cost.
- Stir cast route is economical, appropriate and effective process to synthesize aluminium based composites which offers uniform spread of reinforced constituents and good adhesion with the matrix.
- The inclusion of reinforcement provides positive effect to mechanical characteristics and wear resistance of cast samples. This improvement is because of matrix grain refinement, effective load transfer from matrix to enhancement phase, hindrance to dislocation movement and minimal porosity.
- Composites holding two or more reinforcing particulates in the matrix (hybrid composites) offers superior mechanical and tribological properties than single enhancement phase embedded composites.

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