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Review Paper

Effect of different reinforcement on mechanical properties of aluminium metal matrix composites

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Abstract

There is a significant role of reinforcing materials in determining the overall performance of the composites. Metal matrix composites (MMCs) shows very attractive physical (density, thermal expansion etc.) and mechanical (tensile, compressive and yield strength, toughness, hardnessetc.) properties for aerospace, automotive and numerous other applications where they can successfully replace other materials like cast iron and steel. Aluminium matrix composites (AMCs) are potential candidate materials for numerous applications because they have combination of above properties; enhancement in such properties is obtained by suitable tailoring reinforcements in base metal. In the casting process the reinforcement particles like metal borides (TiB_2), metal oxides (Al_2O_3), metal carbides (SiC, TiC, etc.) and metal nitrides (Si_3N_4, AlN) are reinforced in the melt of aluminium matrix. The widely used reinforcing materials to fabricate AMCs are silicon carbide (SiC) and aluminium oxide (Al_2O_3) in the form of particles or whiskers. Mechanical properties are controlled by initial processing method, reinforcement size, weight faction etc. The ceramic particles reinforced AMCs are termed as new generation material and these can be tailored and engineered to achieve enhanced properties. In present review an attempt has been made to describe the effect of tailoring different reinforcements in aluminium alloy on aspects relating to mechanical properties. The successful commercial production of AMCs is finally depending on their cost effectiveness for different applications.

Keywords: Metal matrix composites (MMCs), Aluminum matrix composite (AMCs), Silicon carbide particle(SiCp), Reinforcements, Stir casting, mechanical properties, Dry sliding wear, Tribo-layer, wear resistance, friction coefficient.

Introduction

The immense use of MMCs are in aerospace and automobile industries due to enhanced properties such as modulus of elastic, hardness value, tensile strength at normal room temperature as well as at elevated temperatures, wear resistance combined with remarkable weight savings over unreinforced alloys[1-2]. MMCs are metallic alloys reinforced with mostly ceramic particles. The frequent metallic alloys utilized are alloys of light metals like aluminium(Al) and magnesium(Mg), other are zinc (Zn), copper (Cu) and stainless steel have been used[3,4]. Aluminium remains the most utilized metallic alloy as matrix material for the MMCs development and, the reasons for this have been reported[5,6]. The use of hard ceramic particles in the aluminium alloy makes it possible to obtain a material with enhanced mechanical properties than that of matrix alloy[7].Various kinds of ceramic materials, e.g. SiC, Al_2O_3, MgO and B_4C are extensively used to reinforce aluminum matrix alloys. Superior properties like wear resistance, refractoriness, high compressive strength and hardness etc. make themsuitable candidate reinforcement in MMCs[8-9]. Silicon carbide (SiC), alumina (Al_2O_3), graphite (Gr), boron carbide (B_4C), tungsten carbide (WC), and silica (SiO_2) are some of the ceramic particulate, but Al_2O_3 and SiC are mostly utilized compared to other synthetic reinforcing particulates[10]. Improvement in abrasion resistance of composites is obtained by the reinforcement of hard ceramic particles[11]. SiC reinforced AMCs have found widespread use in engineering industries due to their high strength and high specific modulus[12]. Among the group of hard ceramic particles available, SiC have been found to have excellent compatibility with aluminium matrices[13,14]. The reinforcement size, their type and the nature of bonding are the important factors which control the structure and the properties of composites[15,16]. Mechanical and tribological properties of the AMCs can be improved by decrease in size of the reinforcement particles from micro tonano scale[17]. Among the variants of reinforcements, particle reinforcements having low aspect ratio (ratio of length to diameter) are of much significant in imparting the hardness of the material in which they are dispersed. Particle reinforced composites exhibits higher hardness over other reinforcement like fibre or whiskers[18]. Limited research has been conducted on B4C reinforced AMCs due to the higher cost of B4C[19].

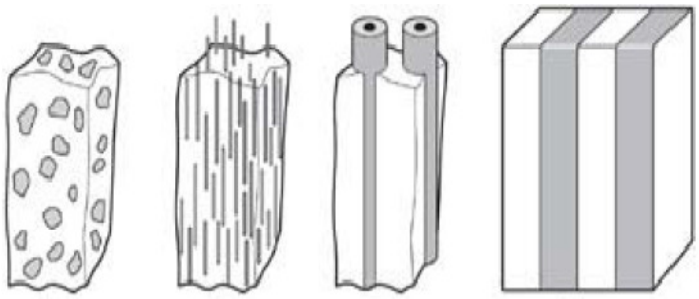
Composite Material

Two or more ingredients are combined on microscopic level to synthesize an effective alternative material to achieve characteristics that are not depicted by any of its components in

isolation are termed as composite material and its individual constituents retain their characteristic unlike alloys[20]. As a result, various combinations of effective properties, usually not obtainable by matrix, can be obtained by composite by tailoring the matrix and reinforcement (dispersoid). The reinforcement/ second phase may be either harder or softer compared to the matrix alloy and affect the properties of the composites consequently. For e.g. softer reinforcement like graphite, talc, mica shell etc. impart solid lubricating properties, resulting in improved wear resistance[21,22].

Matrix and Reinforcement

In composite the discrete constituent is called the reinforcement and the continuous phase is called the matrix. The matrix holds the reinforcement to obtain the desired shape while the reinforcement improves the mechanical properties of the metallic matrix. When combined properly, the new material exhibits better strength than each individual material. Pure Al (AA 1XXX), AlCu (AA2XXX), AlMg (AA5XXX), AlMgSi (AA6XXX), AlZn (AA7XXX), and AlLi (AA 8XXX) are the common matrix materials used in accordance with aluminium association system[23]. Appropriate reinforcement has to be selected to suit a given metallic matrix material. Normally the prime role of the reinforcement material within the matrix alloy is to hold the load and also to increases the mechanical properties like strength, stiffness, and temperature resistance capacity of the neat resin system, but lowers the density fracture toughness and ductility of the MMCs. The correct selection of type, shape or geometry of reinforcement is important in order to obtain the best combination of properties at substantially low cost. Shape (fibre, whiskers orparticle), Size (length and diameter), Surface morphology (rough or smooth), Structural defects (voids etc.), Inherent properties (density, strength etc.) and Chemical compatibility with the matrix; these are the important aspect while selecting the reinforcement materials[24,25].



(a) (b) (c) (d)

Particle short fiber continuous fiber laminated, Reinforcement ReinforcementReinforcement Reinforcement

Figure-1: Types of Metal Matrix Composites[26]

Classification of reinforcement

Two broad categories for classification of Reinforcements are: i. Continuous reinforcements: Filamentary materials (in the form of wire) which can be either, single crystalline, polycrystalline, or amorphous whose lengths are greater than 100 µm. Due to their unidirectional nature, its properties areanisotropic[27]. Ii. Discontinuous reinforcements: Short fibers, particles, and whiskers are fall under discontinuous reinforcements. The reinforcement of particles has gained great interest as they enable obtaining an improvement of mechanical properties while maintaining an isotropic behaviour, with relatively simple production routes[28,29]. Whiskers (Elongated single crystals) have a high degree of structural and chemical perfection. Short/discontinuous fibers have lower aspect ratio (ratio of length to diameter) compared to Continuous fibers. Ease in fabrication, Isotropic nature, high temperature Sustainability, Increased modulus, strength, thermal stability, wear resistance and cost-effectiveness are the advantages of Discontinuous fibers and particles when used as reinforcements.

Silicon Carbide (SiC) reinforced AMCs

Sourav Kayal et al.[30] observed the solidification behavior of stir cast Al alloy MMCs. Authors fabricated Aluminium alloy LM6/SiC composite. Experiments were carried out over a range of particle weight percentages of 2.5%, 5% 7.5%, 10%, 12.5%, 15%. Uniform distribution of SiC particles over matrix, revealed by SEM images. Experimental results revealed that reduction in cooling rate was due to the increased SiC content. Hardness increases with increase in fraction of SiC particles.

Amirkhanlou and Niroumand[31] evaluated the hardness and impact energy of the A356/SiC composite and observed that the impact energy and hardness of the composite was superior compared to the pure alloy. Doel and Bowen[32] observed the improvement in tensile property and reduction in ductility of theAl7075 reinforced with 5µm and 13µm SiC particles than that of unreinforced alloy. Gurcan and Baker[33] have concluded that increasing the percentage of SiC particulates resulted in improved wear resistance and hardness of the material thereby reducing the wear.

G.B. Veeresh Kumar et al.[34] studied the Al6061/SiC composite prepared by stir casting route which contain the filler up to 6 wt%. The microstructural studies revealed the uniform distribution of the particulates over matrix system. Author concluded that Al6061/6 wt% SiC exhibits better mechanical and wear performance compared with Al6061, Al6061/2 wt% SiC and Al6061/4 wt% SiC composites. It was found that the density of composites have improved than the base metal whereas hardness and ultimate tensile strength properties of the Al6061/6 wt% SiC composites were found to be superior to base matrix and other composites studied. Further, the SiC reinforcement contributed significantly in improving the wear resistance of Al6061/SiC composites.

Miyajima and Iwai[18] Reported that for the same amount of volume fraction, the density of Al2024/SiC particle reinforcement composites is greater than that of Al2024/SiC whisker reinforced composites, and the increase in density of

composite are due to the higher density possessed by ceramic particles. Amer Ozbenet al. [35] investigated the mechanical and machinability properties of SiC particle reinforced Al-MMCs. With increase in reinforcement content; tensile strength, hardness and density of Al MMCs material increased but impact toughness decreased.

Ramachandra and Radhakrishna[36] Fabricated MMC which contain 12% SiC by using vortex method and observed thatdue to increase in SiC content the hardness of MMC increased and near the region of SiC particle the increase in micro hardness was found. The abrasive wear resistance of MMC has increased with increase in SiC content, but wear has increased with increase in sliding velocity and normal load.

Aluminium Oxide (Al_2O_3) reinforced AMCs

Aluminium oxide, referred as alumina, imparts strong ionic inter atomic bonding results inrise of its desirable characteristics and can exist in many crystalline phases. Its high hardness, excellent dielectric, thermal properties, and refractoriness make it the material of choice for a wide range of applications.

Sajjadi et al.[37] studied the mechanical properties of the stir cast Al (A356)/ Al_2O_3particle reinforcement composite andreported that the compressive strength and hardness of the composite increased with increasing the weight percentage of Al_2O_3 and also by decreasing the particle size. Compressive strength of composites is more when particle size reduces from micro to nano scale.

Haisu et.al[38] fabricated Al2024/Al_2O_3composite using nano sized ceramic particle reinforcement by solid-liquid mixed casting followed by ultrasonic treatment. Initially matrix was superheated at 750^{oc} and held for 15 min., then powdered matrix/Alumina particles were added to the melt and stirred, finally ultrasonic probe was dipped in the melt for 5 min. Solid-Liquid casting method decreases the agglomeration of alumina nano particles whereas ultrasonic treatment improved the distribution of Al_2O_3nano sized particles and refined the grain structure. Also the ultimate tensile and yield strength of the nano composite are found to be increased.

Kamat et al.[39] evaluated the mechanical properties of Al2024/Al_2O_3 composite and noted that yield and ultimate tensile property of the composite increased, as the volume fraction of Al2O3 particles increases.Park et al.[40] investigated the effect of Al_2O_3 in Aluminium by varying the volume fractions of second phase from 5 to 30% and concluded that with increase in volume fraction of Al_2O_3,there was a decrease in the fracture toughness of the AMCs was observed.

Nitride reinforcement AMCs

Silicon nitride (Si_3N_4) constitutes hard ceramic particles with improved mechanical properties and good wear resistance, and also can be used as a reinforcement material in the manufacturing of AMCs[41].

Pradeep Sharma et al.[42] fabricated Al6082/Si_3N_4 composites usingstir casting routeby varying the wt. % (viz. 0, 3, 6, 9 and 12%) of reinforcement particles and from different experiments author observed that; with respect to the addition of different weight percentage of Si_3N_4 particles (i.e. from 0% to 12%) density and porosity of the prepared composites wereincreased from 2.69 to 2.75 g/cm^3 and from 0.37 to 1.43 respectively and Hardness of the composites was increased from 49.5 VHN to 93.5 VHN and 31.6 BHN to 58 BHN. tensile strength of cast Al6082 improved from 161.5 MPa to 201 MPa with a reduction in ductility from 8.7 to 4.3.

Arik H.[43] observed that AMCs reinforced with Si_3N_4 particles manufactured by powder metallurgy technique showed improved hardness in comparison with conventional aluminium matrix and hardness increased by increasing the volume fraction of Si_3N_4 particles. Song et al.[44] concluded that Al/Si_3N_4 AMCs manufactured by pressure infiltration method exhibits enhanced mechanical properties than that of Al alloy. Ramesh et al.[45] concluded that the increased content of silicon nitride particulates in Al6061 matrix alloy has resulted in higher tensile strength and hardness value of the composites.

Kumar and Murugan[46] investigated the mechanical properties of Al (6061) matrix Composite reinforced with Al-N particles prepared by stir cast and concluded that composite material gives the higher ultimate tensile and yield strength than pure alloy. The author also revealed that both micro and macro hardness increases in composite as Al-N percentage increases into the alloy matrix.

Boron carbide (B_4C) reinforced AMCs

Due to excellent chemical and thermal stability of B4C make it attractive reinforcement material; most importantly, B_4C has lower density (2.52 g/cm^3) and higher hardness relative to Al_2O_3 and SiC[47]. Kennedy and Brampton[48] found that it is difficult to produce Al–B_4C composites by mixing B_4C particles into the liquid phase below 1100^{oc} due to the poor wetting between matrix and reinforcement therefore concluded that enhancement of wetting between ceramics and second phase improved by heat treatment of Al melt.

Mohanty et al.[49] found that, in comparison with other reinforcement particles, B_4C imparts superior reinforcement properties like better chemical stability, high strength and hardness with low density. Baradeswaran and Perumal[50] studied the mechanical behaviour of Al7075/B_4C composite.

The author has revealed that the ultimate tensile strength (Figure-1), the compressive strength (Figure-2) and the hardness (Figure-3) of composite increased linearly with increase in volume percentage of B_4C.

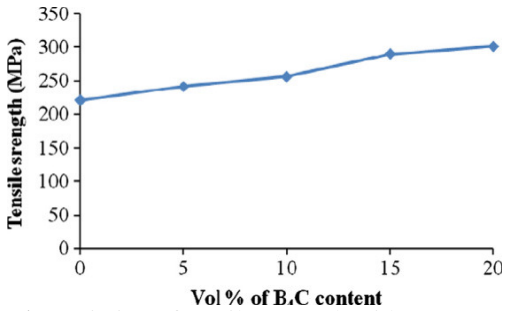


Figure-1: Variation of tensile strength with B4C content[50].

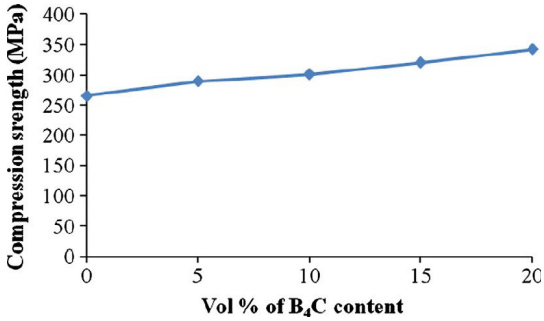


Figure-2: Variation of compressive strength with B4C content[50]

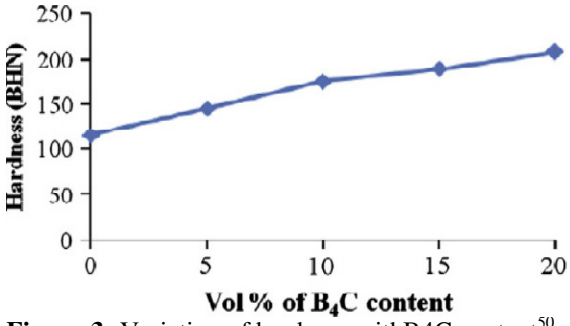


Figure-3: Variation of hardness withB4C content[50].

Zircon reinforced AMCs

Zircon having high hardness and elastic modulus along with excellent thermal stability was studied for AMCs where contacting parts operate in relative motions[51]. Kaur and Pandey[52] Investigated the mechanical properties of Al based MMCs LM13, reinforced with Zircon sand, optical microscope revealed good zircon particle/matrix bonding with almost no porosity along the particles and concluded that, increase in addition of zircon sand particles in LM13 alloy the micro-hardness of zircon sand reinforced composite shows higher hardness compared to cast alloy.

Okafor and Aigbodion[53] studied the microstructure and properties of Al-4.5Cu/$ZrSiO_4$ particulate composite synthesized via squeezed casting technique and concluded that as the wt. % of $ZrSiO_4$ increases in the matrix from 5 to 25, strength and hardnessare increased whereas reduction in toughness, density and impact energy by 43.16 %was observed, the yield and ultimate tensile strength increased by 156.52% and 155.81% up to a maximum of 15% $ZrSiO_4$ addition respectively. Also, little increase in the apparent porosity of the composite with percentage increase in ZrSiO4 addition was observed. Author also concluded that in order to maintain the necessary properties in Al- 4.5Cu/$ZrSiO_4$composite particulate should not exceed 15%.

Scudino et al.[54] investigated the mechanical properties of Al-based MMCs reinforced with Zircon-based glassy particles fabricated by powder metallurgy route. Experimental results revealed that the compressive strength of pure Al increases by 30% with 40% volume of glass reinforcement. When the volume fraction of the glassy phase increasing to 60%, the compressive strength further increased by about 25%.

Graphite reinforced AMCs

AMCs containing graphite particles have the potential for light weight tribocomponents. Graphite as a solid lubricant material improves seizure resistance of composites, increased graphite content results in decreased fracture toughness of the composites[55]. Mohan et al.[56] conducted the dry sliding wear test of Al/Gr particle composite and found that the reduction in wear are due to the graphite smears at the sliding interface, but graphite addition beyond 1.5% reduces the mechanical properties of the composite.

Gibson et al.[57] reported for composites with a higher (greater than 8 wt. %) graphite content, results in loss of tensile strength and ductility and suggested that the proper control over matrix microstructure is the solution of problem. Seah et al.[58] reported a drastic increase in the wear resistance of cast ZA-27(zinc aluminum alloy)/Gr composites with increase in graphite content up to 1%. Further addition of graphite results only in marginal improvement in the wear resistance. The graphite also lowers the hardness of the material.

MgO reinforced AMCs

Hossein Abdizadeh et.al[59] fabricated nano Mgo reinforced Al composites by stir casting and powder metallurgy routes and investigated their mechanical properties. Mgonano particles of 1.5, 2.5 and 5 vol% were taken. Processing temperature of 800, 850 and 950^0 C for stir casting and 575, 600 and 625^0 C for powder metallurgy was considered. Al-Mgonanocomposite showed improved hardness for 5 volume percent ofMgo. Also better mechanical properties were observed at 625 and 850^0 C for powder metallurgy and stir casting respectively. In stir casting better homogeneous distribution and mechanical properties were observed as compared to powder metallurgy method.

Andrews et al.[60] found that the addition of magnesium up to 1% wereuseful for improvement in wear resistance of composite. However, large amounts of magnesium degrade the mechanical properties by forming acicular-shaped compounds. Yara et al.[8]

produced Al (A356.1) matrix composite reinforced with nano particle of MgO. The authors reported that the compressive strength and hardness of the composite was higher compared to the matrix alloy.

Fly ash reinforced AMCs

The utilization of fly ash (FA) instead of dumping it as a waste material can be both on economic and environmental grounds[61]. Gikonoo et al.[62] found that using FAas a reinforcing material in cast alloy A535reduces tensile strength and hardness of composites due to segregation and particle clustering of the FA in the aluminium matrix. Also the decreased ductility with increase in weight fraction of FA was observed with uniform distribution of the FA in the metal alloy. Reduction in strength and hardness of the resulting composites were observed as the size of FA particle increased.

Ramachandra and Radhakrishna[63] reported for the wear and friction characteristics of Al (12% SiC) matrix composite reinforced with fly ash particles and concluded that, when weight percent of fly ash was increased, improved wear resistance of composite was observed, while it decreased with increase in normal load and sliding velocity. Mahendra Boopathi et al.[64] fabricated Al-SiC and Al-fly ash composites by two-step stir casting process andwith reference to results obtained authors concluded that, instead of Al-SiC and Al-fly ash composites, Al-SiC-fly ash composites give greater weight reduction and Increase in area fraction of reinforcement in matrix result in improved tensile strength, yield strength and hardness.

Conclusion

This paper presents the different reinforcement used for synthesis of AMCs and how it influences its performance. The state of art indicates improvement in properties of Al based MMC with different reinforcement. The literature also shows that hard ceramic reinforcement addition favours the increase in density of the composite. The mechanical as well as tribological properties were enhanced of AMCs with reinforcement compared to without reinforcement. Addition of ceramic particles like SiC, Al2O3etc. increases the hardness and tensile properties whereas ductility decreases in AMCs. The reduction in tensile strength, ductility as well as toughness and decrease in coefficient of friction were observed with addition of graphite but, by the addition of fly ash, the improvement in mechanical properties was observed. Reduced sizes of the reinforcement particle were also an effective parameter for improving the strength. In Al MMCs the process parameters also shows improved properties.

Future Scope: The optimum materials of the present era are composites and its practical applications are introduced as the year's progress. Greater potential of resulting composites that combine diverse properties can be enhanced with the addition of hybrid reinforcement instead of single reinforcement. Better mechanical and other properties in composite material can be fulfilled by increasing the number of reinforcements by incorporating two or more reinforcements and Compare the results obtained by hybrid composites with the single reinforced grades in order to find how much improvement in properties are obtained when more than one reinforcement is used, also Comparison with the unreinforced alloy should be established. This will helpful for determining optimum processing parameters in line with production cost.

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