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A Review on Composite Aluminum Materials and its Application

P. Hari Prasanth[1], B. Balaji[2], M. Gopinath[3], C. Bhagyanathan[4]
[1,2,3]*Student, Department of Mechanical Engineering, Sri Ramakrishna Engineering College, Coimbatore, India*
[4]*Assistant Professor, Dept. of Mechanical Engg., Sri Ramakrishna Engineering College, Coimbatore, India*

***Abstract*: With the advancement of the technological era the usage of composite aluminium materials is increasing day by day in the entire manufacturing sectors due to their unique properties such as high strength to weight ratio, good mechanical properties and better durability. In the present paper an attempt is done to study the property enhancement of aluminium matrix composite (AMC) with different organic and inorganic compounds. This paper presents the insight of the effect of addition on different reinforcements in aluminium alloy highlighting their merits and demerits. The tribological behavior of aluminium based composite has been covered. Main applications of different AMCs are also highlighted in this work. The characterization of the metal matrix is done using microstructures.**

***Keywords*: Aluminium composites, Aluminium matrix composite (AMC), Metal matrix, Reinforcement**

1. Introduction

In the present competitive market, there is a huge demand for the superior materials which is having different properties in single material. The demand properties required is such as high core toughness, high surface hardness, high corrosion resistance, better weld ability and machinability. The best material to answer the above problem that is material having different property combination is composite material. MMC (Metal matrix composites) are the metals reinforced with other metal, ceramic or organic compounds. Aluminium and its alloys have drawn most attention as base metal in metal matrix composites. They are done by dispersing the reinforcements in the metal matrix. Reinforcements are typically done to improve the properties of the base metal like strength, stiffness, conductivity, etc. [1]. The reinforcements should be steady in the given working temperature and non-reactive too. The most commonly used reinforcements include Silicon Carbide (SiC) and Aluminium Oxide (Al2O3). SiC reinforcement increases the tensile strength, hardness, density and wear resistance of Al and its alloys [2]. Aluminium MMCs are widely used in aircraft, aerospace, automobiles and various other fields [3]. Increasing the volume fractions of Nano-reinforcements can be a more effective way to enhance the mechanical strength than increasing the sizes [4]. The particle distribution plays a very important role in the properties of the Al MMC and is improved by intensive shearing. Al2O3 reinforcement possess good compressive strength and wear resistance. Boron Carbide is one of hardest known elements. It has high elastic modulus and fracture toughness. The addition of Boron Carbide (B4C) in Al matrix increases the hardness, but does not improve the wear resistance significantly [5]. Fibers are the important class of reinforcements, as they content the desired conditions and transfer strength to the matrix constituent influencing and enhancing their properties as desired. Zircon is usually used as a hybrid reinforcement. It increases the wear resistance significantly [6]. In the last decade, the use of fly ash reinforcements has been increased due to their low cost and handiness as waste by-product in thermal power plants. It increases the electromagnetic shielding effect of the MMC. Based on the stated potential benefits of MMC this paper examines the various factors like

- Effect of various reinforcement
- Mechanical behavior like strength, wear, fatigue behavior, etc.
- Processing methodology and its effects.
- Application of the specialty AMC were discussed.

The survey is conducted in the following areas:

- Synthesis methods
- Reinforcement techniques
- Characterization Techniques

2. Survey on synthesis methods

Liquid State Fabrication of Metal Matrix Composites include
1. Stir casting
2. Compo casting
3. Squeeze casting
4. Spray Deposition

Rama rao et al [7] examined that aluminium alloy-boron carbide composites were fabricated by liquid metallurgy techniques with different particulate weight fraction (2.5, 5 and 7.5%). Phase identification was carried out on boron carbide by x-ray diffraction studies microstructure analysis was done with SEM a composite were characterized by hardness and compression tests. The results show increase the amount of the boron carbide. The density of the composites decreased while the hardness is increased. However, the compressive strength of the composites was increased with increase in the weight percentage of the boron carbide in the composites.

Ravichandran et al [8]. Synthesized and studied the forming behavior of aluminium-based hybrid powder metallurgic composites. Aluminium-based metal matrix composites were synthesized from Al-TiO2-Gr powder mixtures by the powder metallurgy technique and their forming characteristics were studied during cold upsetting. Sedat Ozdenet al. [9] investigated the impact behavior of Al and SiC particle reinforced with AMC under different temperature conditions. The impact behavior of composites was affected by clustering of particles, particle cracking and feeble matrix reinforcement bonding. The effects of the test temperature on the impact behavior of all materials were not very significant.

A. Survey on reinforcement techniques: Silicon carbide reinforced AMC

Tamer Ozbenet al. [10] investigated the mechanical and machinability properties of SiC particle reinforced Al-MMC. With the increase of reinforcement ratio, tensile strength, hardness and density of Al MMC material increased, but impact toughness decreased. Sedat Ozdenet al. [11] investigated the impact behaviour of Al and SiC particle reinforced with AMC under different temperature conditions. The impact behaviour of composites is affected by clustering of particles, particle cracking and weak matrix-reinforcement bonding. The effects of the test temperature on the impact behaviour of all materials were not very important. Balasivanandha Prabhuet et al. [12] analysed the effect of stirring speed and stirring time on distribution of particles in SiC AMC. The study was about high silicon content aluminium alloy silicon carbide matrix composite material, with 10% SiC synthesized using different stirring speeds and stirring times. The analysis exposed that at lower stirring speed and time, the particle clustering was more at some places, by increasing them the distribution resulted better and also it had its effect on hardness of the composite. Uniform hardness values were achieved at 600 rpm by 10 min stirring. Tzamtzis et al. [13] suggested processing Al/SiC particulate MMCs under intensive shearing by novel Rheo-process. The current processing methods such as conventional stir casting technique frequently produce agglomerated particles in the ductile matrix and as a result these composites exhibit extremely low ductility. Whereas the Rheo-process significantly improved the dispersal of the reinforcement in the matrix by allowing the application of sufficient shear stress (s) on particulate clusters embedded in liquid metal to overcome the average cohesive force or tensile strength of the cluster.

B. Aluminium oxide reinforced AMC

Park et al. [14] investigated the effect of Al2O3 in Aluminium for volume fractions varying from 5-30% and found that the increase in volume fraction of Al2O3 decreased the fracture toughness of the MMC. This is due to decrease in the inter-particle spacing between nucleated micro voids. Park et al. [15] investigated the high cycle fatigue behavior of 6061 Al-Mg-Si alloy reinforced Al2O3 microspheres with the varying volume fraction ranging between 5% and 30%. They found that the fatigue strength of powder metallurgy processed composite was higher than that of the unreinforced alloy and liquid metallurgy processed composite. Kok [16] fabricated the Al2O3 particle reinforced 2024 Al alloy composites by vortex method and studied their mechanical properties and found the optimum conditions of the production process with a pouring temperature of 700 N C, preheated mould temperature of 550 N C, stirring speed of 900 rev/min, particle addition rate of 5 g/ min, stirring time of min and with a applied pressure of 6 MPa. The wettability and the bonding between Al2O3 particles were improved by applied pressure but porosity will be decreased by this pressure.

C. Boron carbide reinforced AMC

Bo Yao et al. [17] investigated the trimodal aluminium metal matrix composites and the factors affecting its strength. The test result shows that the attributes like Nano-scale dispersoids of Al2O3, crystalline and amorphous AlN and Al4C3, high dislocation densities in both NC-Al and CG-Al domains, interfaces between different constituents, and nitrogen concentration and distribution leads to increase in strength. Vogt et al. [18] studied the cryomilled aluminium alloy and boron carbide Nano-composite plates made in three methods, (1) hot isostatic pressing (HIP) followed by high strain rate forging (HSRF), (2) HIP followed by the two-step quasi-isostatic forging (QIF), and (3) three-step QIF. The test results showed that HIP/HSRF plate exhibited higher strength with less ductility than the QIF plates, which had similar mechanical properties. The increased strength and reduced ductility of HIP/ HSRF plate is attributed to the inhibition of dynamic recrystallization during the high strain rate forging procedure.

D. Fiber reinforced AMC

Sayman et al. [19] studied the elasto plastic stress analysis of aluminium and stainless steel fiber and found that under 30 MPa pressure and at a temperature of 600 N C, good bonding between the matrix and fiber was observed, moreover increase in the load carrying capacity of the laminated plate was also visualised. Cesim Atas and Onur Sayman [20] reported that for steel fiber reinforced Al MMC plates, yielding begin at the edge of the laminated plates. They found that yielding does not occur at the corner of the plate. Ding et al. [21] investigated the behaviour of the unreinforced 6061 aluminium alloy and short fiber reinforced 6061 Al alloy MMC. They found that the addition of high-strength Al2O3 fibers in the 6061 aluminium alloy matrix will not only strengthen the microstructure of the 6061-aluminium alloy, but also channel deformation at the tip of a crack into matrix regions between the fibers and therefore constrain the plastic deformation in the matrix which leads in reduction of fatigue ductility. Gudena and Hall [22] studied the high strain rate compressive deformation behavior of a continuous Al2O3 fiber reinforced Al MMC tested in the longitudinal and transverse direction and found that in transverse direction, the composite exhibit strain rate similar to that of monolithic alloy.

E. Zircon reinforced AMC

Das et al. [6] comparatively studied the abrasive wear of Al-Cu alloy with alumina and Zircon sand particles and found that wear resistance of the alloy increases significantly after the addition of alumina and zircon particles. However, zircon reinforced composites showed better wear resistance than that of alumina reinforced composite due to its superior particle matrix bonding. Scudino et al. [23] investigated the mechanical properties of Al-based metal matrix composites reinforced with Zircon-based glassy particles produced by powder metallurgy. The test results showed that the compressive strength of the pure Al increases by 30% with 40% volume of glass reinforcement. While the volume fraction of the glassy phase increasing to 60%, compressive strength further increases by about 25%.

F. Fly ash reinforced AMC

Fly ash particles are potential discontinuous dispersoids used in the metal matrix composites due to their low cost and low-density reinforcement which are available in large quantities as a waste by product in thermal power plants. The major constituents of fly ash are SiO_2, Al_2O_3, Fe_2O_3, and CaO. Ramachandra and Radhakrishna [24] experimentally found that the wear resistance of Al MMC increases with the increase in fly ash content, but decreases with increase in normal load and sliding velocity, and also observed that corrosion resistance decreases with the increase in fly ash content.

G. Survey on characterization techniques

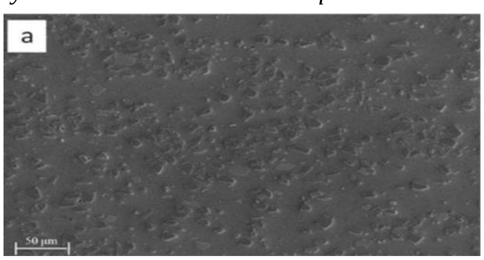

Fig. 1. Microstructure of the as-extruded HAMCs: SEM image

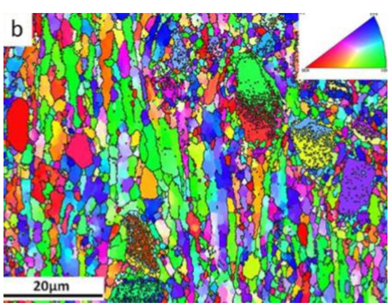

Fig. 2. Microstructure of the as-extruded HAMCs: EBSD map

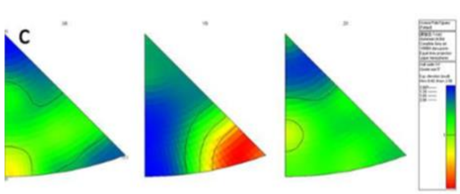

Fig. 3. Microstructure of the as-extruded HAMCs: inverse pole figure.

The Fig. 1 shows the initial microstructures of the as-extruded hybrid composites. It is apparent that SiC particles are uniformly distributed throughout the Al matrix, and no agglomerations of TiB_2 particles are found (Fig. 1a). Fig. 1b is the EBSD image which shows the grain boundaries of the as-extruded composites. It can be seen that fine grains with an average size of 3µm were formed, and additionally some grains were elongated after extrusion. The presence of hard particles, to some extent, favors the production of fine-grained structures. The fraction of high angle grain boundaries (HAGBs) was >70% with an average disorientation angle of 30°. The change of the micro-texture after extrusion was demonstrated by inverse pole figures (Fig. 1c). Weak textures were observed with only a 2.08 intensity above random, which can be attributed to the combination of recrystallization and shear mode of the plastic deformation [25].

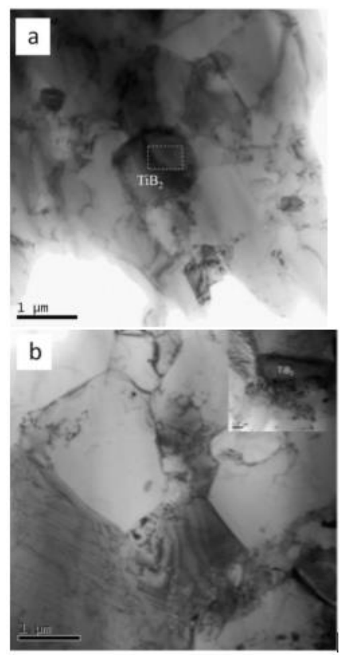

Fig. 4. (a), (b) microstructure of TiB_2 composite

H. Microstructural characterization

It is well known that there is a mismatch between the hard-reinforcing particles and the Al matrix, which leads to the enforced strain gradient in the matrix near particles during deformation. The strain gradient always creates a region of high dislocation density [26]. Fig.2 shows the TEM images of the HAMCs under different deformation conditions. It is apparent that the high-density dislocations tangled around hard particles shown in Fig. 5a and the inserted figure in Fig. 2b. It is also important to note that some fine grains with smooth boundaries have a low dislocation density. This may be related to DRV and/or DRX during deformation. With the increase of deformation temperature and the decrease of strain rate (lower Z values), the rearrangement and annihilation of dislocations take place with ease, generally leading to the formation of subgrains. At the same time, the density of dislocation decreases and the subgrain boundary becomes more and more. The EDS results for the dashed rectangles in Fig. 5 (a, b and c,d) corresponding to TiB2 and SiC, respectively.

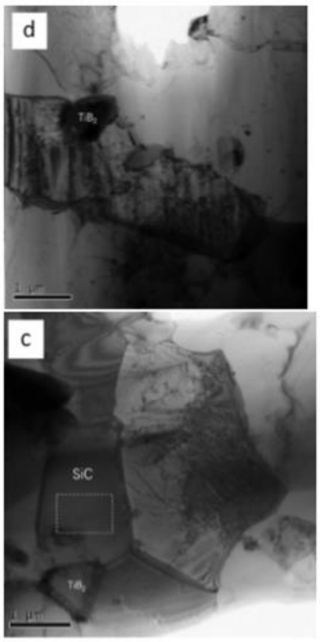

Fig. 5. (c), (d) microstructure of SiC composite

Results and discussion

Several confronts must be surmounted in order to strengthen the engineering usage of AMCs such as processing methodology, influence of reinforcement, effect of reinforcement on the mechanical properties and its corresponding applications. The conclusions derived is summarized below:

- SiC reinforced Al MMCs are suitable materials for brake drums as they have high wear resistance but cannot be used in brake linings as it will damage the brake drum.
- It has been found that the increase in volume fraction of Al2O3 decreases the fracture toughness of Al MMC.
- The wear resistance of SiC reinforced Al MMC is higher than the B4C reinforced MMC
- The wear resistance and compressive strength of the Al MMCs increase with the addition of Zircon sand reinforcement.
- The addition of fly ash reinforcement in Al increases the wear resistance but decreases the corrosion resistance.
- Uniform dispersion of reinforcements with some regional clusters was observed in SiCp reinforced Al 7075 alloy matrix composites developed through liquid metallurgy stir casting process. The clustered regions increased with increase of reinforcement content or with reduction of particle size.
- The main softening mechanism of the hybrid composites is DRV, accompanied by partial DRX. In particular, the addition of TiB2 nanoparticles promotes the dislocation pile-up and simulates DRX nucleation. At the same time, the DRXed grains are small and DRX is incomplete due to the pinning effect of the finer particles.

3. Conclusion

The above research article indicates that there are numerous methods available for synthesis of aluminium matrix composites, in the survey available the best method for the synthesis of aluminium matrix composites is stir casting in which the grain distributions are uniform. The right combination of metal matrix and reinforcement combined with the synthesis technique facilitates the tailoring of composites possessing a number of desirable properties in a single composite material. After synthesizing the composite, it is subjected to the various characterization techniques such as electron back scattered diffraction (EBSD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), tensile test, compressive test, fatigue test and wear test. In future the composite plays a major role in every domain heralded by further research and development of composites.

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