

# A Review on Properties of Aluminium Based Metal Matrix Composites via Stir Casting

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**ABSTRACT:** Aluminium metal matrix composites are significantly important in the various demanding fields of medicine and engineering like aerospace, defense, automobiles, dental and consumer goods. The industrial need of good materials with light weight, excellent properties and low cost demanded the scientists to research on composite materials. Among the MMCs, aluminium matrix composites (AMMCs) sought over other conventional materials because of their high strength to weight ratio, high wear resistance and low economic. These AMMCs offer a large variety of mechanical properties depending on the chemical composition of the Al-matrix. The reinforcement in AMMCs could be in the form of continuous/discontinuous fibers, whisker and particulate as second phase depending on their applications and property requirements. Addition of various reinforcements such as fly ash, TiC, SiC, Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, B<sub>4</sub>C etc., to aluminum matrix will enhance the mechanical and tribological properties. This paper attempts to review the different combinations of the usage of reinforced materials as a reinforcing agent in different Aluminium matrix alloys in the processing of aluminium metal matrix composites along with its properties.

**Key words:** AMMC, reinforcement, stir casting, Mechanical and Wear properties.

## INTRODUCTION

Over the past few decades, researchers have emphasized on production of light and strong materials. This caused the scientists to shift their research from monolithic to composite materials. A composite material is a combination of two or more chemically distinct materials to form a stronger material. The term "composite" broadly refers to a material system which is composed of a discrete constituent (the reinforcement) distributed in a continuous phase (the matrix), and which derives its distinguishing characteristics from the properties of its constituents, from the geometry and architecture of the constituents, and from the properties of the boundaries (interfaces) between different constituents. Composite materials are usually classified on the basis of the physical or chemical nature of the matrix phase, e.g., polymer matrix, metal-matrix and ceramic composites [1-2]. MMC (Metal matrix composites) are metals reinforced with other metal, ceramic or organic compounds. They are made by dispersing the reinforcements in the metal matrix. Reinforcements are usually done to improve the properties of the base metal like strength, stiffness, conductivity, wear and corrosive resistance etc... Aluminum, Silicon, Copper, Titanium, Magnesium, and Nickel metals are widely used for preparation of metal matrix in composites materials [3]. In Metal Matrix Composites (MMCs), aluminum and its alloys have attracted most attention as base metal in metal matrix composites because of its low density, low weight, high strength, superior malleability, easy machining, excellent corrosion resistance and good thermal and electrical conductivity, etc. In AMMCs one of the constituent is aluminium, which forms percolating network and is termed as matrix phase. Aluminium alloys, such as the 2000, 5000, 6000 and 7000 alloy series are the most commonly utilised materials in composite fabrication the other constituent is embedded in this aluminium and serves as reinforcement. Mono filaments, whiskers, fibres or particulate types are widely used as reinforcement phases. In recent years, Al based composite materials have gained significance in aerospace, automotive and structural applications due to their enhanced mechanical properties and good stability at high temperature [4].

The various reinforcements used are Silicon Carbide (5), Aluminium Oxide (6), Titanium carbide (7), Boron Carbide (8), etc. SiC reinforcement increases the tensile strength, hardness, density and wear resistance of Al and its alloys.  $Al_2O_3$  reinforcement has good compressive strength and wear resistance.  $B_4C$  is one of hardest known elements because of its high elastic modulus and fracture toughness, its presence in Al matrix increases the hardness but does not improve the wear resistance significantly whereas the Zircon used as hybrid reinforcement increases the wear resistance. Fibers are the type of reinforcements which increase the properties of matrix by transferring the strength to the matrix constituent. In the present day, fly ash reinforcements are using widely due to their low cost and its property to increase the desired properties for composite material.

The interfacial reaction between the materials is also important because if the load carrying transferred to the interface, it will affect the mechanical properties of the composite material. So, the properties of the material also depend on the other characteristics like micro structure, shape, processing time of technique and the way of reinforcement etc. The way of reinforcement also changes the physical properties like wear resistance, hardness, thermal conductivity. The reinforcement can be either continuous or discontinuous. The MMC's prepared by discontinuous process are isotropic and by continuous process are anisotropic structure. The anisotropic structure occurs because the fibers such as carbon fibers and monofilament wires embedded in to the matrix in particular direction.

For processing of AMMCs at industrial scale, the processing operations classified in to two main groups. Liquid state processes and solid state processes. Stir casting, compo casting and squeeze casting spray casting and in situ (reactive) processing; ultrasonic assisted casting comes under the liquid state process. Powder blending followed by consolidation (PM processing), high energy ball milling, friction Stir Process, diffusion bonding and vapours deposition technique comes under Solid state process.

For discontinuous metal matrix composites various techniques are available. Among them stir casting method is generally preferred. Its advantages lie in its simplicity, flexibility and applicability to large quantity of production. It is also attractive because of minimized final cost of the product. It also allows very large sized components to be fabricated. In the stir casting method, there are several factors that need considerable attention, including the difficulty of achieving a uniform distribution of the reinforcement [9].

## **STIR CASTING**

In the stir casting process as shown in fig.1, the particulate reinforcements are distributed by mechanical stirring in the molten matrix. S. Ray [10] introduced alumina particles into aluminium melt by stirring molten aluminium alloys containing the ceramic powders. This is the initiative of stir casting of the metal matrix and it took place in 1969. Mechanical stirring is the key element of this process. Composites with up to 30% volume fractions can be suitably manufactured using this method. Sometimes the cast composites are further extruded to reduce porosity, refine the microstructure, and homogenize the distribution of the reinforcement. Segregation of reinforcing particles which is caused by the surfacing or settling of the reinforcement particles during the melting and casting processes is one of the major concerns associated with the stir casting process. The distribution of the particles in the final solid depends on strength of mixing, wetting condition of the particles with the melt, rate of solidification and relative density. Geometry of the mechanical stirrer, position of stirrer in the melt, melt temperature, and the properties of the particles added determines the distribution of particles in molten matrix.

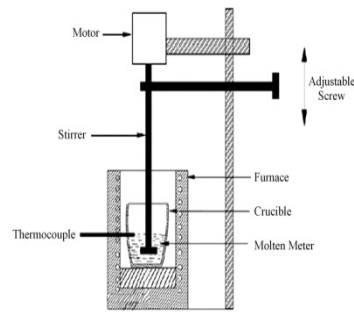


Fig.1.Stir casting process

The recent development in the stir casting process is the double stir casting process or two step process. In this process, initially the metal matrix composite is heated to above its liquidous temperature and then cooled then cooled down to a temperature between the liquidous and solidus points to a semi-solid state .the reinforcement material which is preheated is then added and mixed to the semi-solid state matrix material. Again the slurry is heated to a fully liquid state and mixed thoroughly. The microstructure of the composite made by double stir casting is more uniform than conventional stirring. The potency of this two-step mixing method is mainly due to its ability to break the gas layer around the particle surface which otherwise impedes wetting between the particles and molten metal. Thus the mixing of the particles in the semi-solid state helps to break the gas layer because of the abrasive action due to the high melt viscosity. Su et al. [11] designed a new three step stir casting method for fabrication of nano particle reinforced composite. First the reinforcement and Al particles are mixed using ball mills to break the initial clustering of nano particles. The composite powder is then incorporated into the melt with along with mechanical stirring. After adequate stirring the composite slurry is sonicated using an ultrasonic probe or transducer in order to improve the distribution of reinforced particles. Kumar et al. [12] used a 3-phase induction motor for electromagnetically stirring the aluminium melt and showed improvement in particle matrix interface bonding with a small grain size structure.

In the mass production stir casting is more economical when compared with other fabrication techniques. So industrially stir casting process is the most preferable one during the mass production.

## MECHANICAL PROPERTIES

Rama Rao et.al. [13] studied the fabrication and mechanical properties of aluminium-boron carbide composites. The aluminum alloy-boron carbide composites were fabricated by liquid metallurgy techniques with different particulate weight fractions (2.5, 5 and 7.5%).The authors observed that Uniform distribution of the boron carbide particles in the matrix phase, hardness of the composites increased and density was decreased with increasing the amount of the boron carbide in the matrix phase.

S.Balasivanandha Prabu et.al. [14] investigated on Influence of stirring speed and stirring time on distribution of particles in cast metal matrix composite. The AMMC (A384 as matrix alloy and SiC as reinforced material) was stirred continuously for the different combination of processing conditions by varying the stirring speed(500/600/700 rpm) and stirring time (5/10/15 min).The author observed that in some places without SiC inclusion in matrix at lower speed and lower stir time, while increasing the stirring speed and time better homogeneous distribution of SiC in the Al matrix. The author also revealed that stirring speed and stirring time effect on the hardness of the composite and obtained better hardness of the composite at higher stirring speed and stirring time.

V.Ramakoteswara Rao et.al. [7] produced AA7075/TiC metal matrix composite with stir casting process. They observed that hardness shows increasing trend with increasing weight percentage of TiC particulates in both cast and heat treated condition (fig.2). The author also revealed that the ultimate tensile strength of the composite increased linearly with increase in weight percentage of TiC.Manoj Singla et.al. [15] studied that with increase in composition of SiC, an increase in hardness, impact strength and normalized displacement. Mahendraboopathi.M et.al. [16] studied evaluation of mechanical properties of aluminum alloy 2024 reinforced with silicon carbide and fly ash hybrid metal matrix composites. Al-SiC, Al-fly ash, Al-SiC-fly ash composites were successfully prepared by two-step stir casting process. The author observed that optical micrographs both the SiC

and fly ash particles were distributed uniformly in aluminium matrix. They reported that tensile strength, yield strength and hardness of the hybrid composite increased with Increase in area fraction of reinforcement in matrix. They also concluded that the addition of SiC and fly ash with higher percentage the rate of elongation of the hybrid MMCs is decreased significantly.

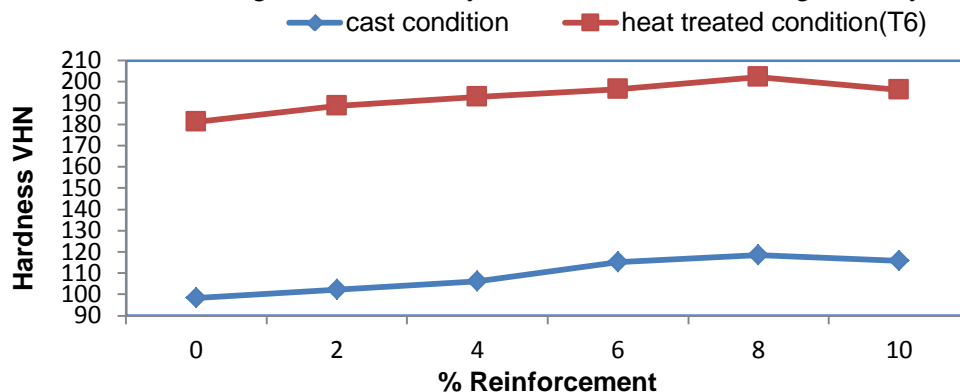


Fig.2. Hardness behavior of Al 7075 alloy and Al7075/TiC Composites

Anilkumar et.al. [17] produced three sets of Al (Al6061) metal matrix composites reinforced with fly ash of particle sizes 75-100, 45-50 and 4-25  $\mu\text{m}$  with the weight fractions of 10, 15 and 20%. The author observed that tensile Strength, compression Strength and hardness increased with the increase in the weight fraction of reinforced fly ash and decreased with increase in particle size of the fly ash and ductility of the composite decreased with increase in the weight fraction of reinforced fly ash and decreased with increase in particle size of the fly ash. Dora Siva prasad et.al. [18] investigated on mechanical properties of aluminum hybrid composites. They produced aluminum hybrid composites reinforced with different volume percentages of (2, 4, 6, and 8wt%) Rice hush ash (RHA) and SiC particulates in equal proportions by double stir casting process. They found that up to 8% rice hush ash and SiC particles could be easily fabricated. The authors observed that density of hybrid composites decreases, whereas the porosity and hardness increases with the increase in percentage of the reinforcement and yield strength and ultimate tensile strength increase with the increase in RHA and SiC content. N. Fatchurrohman et.al. [19] studied the solidification characteristic of titanium carbide particulate reinforced aluminium alloy matrix composites. They used aluminium-11.8% silicon alloy (LM6) specimen as matrix material and reinforced with weight fractions of 5 and 15% of titanium carbide particulate (TiCp) by gravity casting. They have shown that by adding TiCp as reinforcement to LM6, the solidification time faster and it gives finer grain size and better mechanical property. The author also observed that hardness number is increased as more TiCp particulate are added to the matrix material. S Sulaiman et.al. [20] have reported that the split tensile strength and Young's modulus values decreased gradually as the silicon dioxide content in the composite increased from 5% to 30% by volume fraction due to the dominating nature of the compressive strength of the quartz particulate reinforced in the LM6 alloy matrix. Anand Kumar et.al. [21] studied the fabrication and characterizations of mechanical Properties of Al-4.5%Cu/10TiC Composite by In-Situ Method. In this composite, TiC was used as reinforcement which was formed by adding Ti in elemental form and activated charcoal powder in the melt. It was found that yield, ultimate tensile strength and hardness was increased by 12.64%, 19.72%, and 35.79% respectively in the composite material. The yield strength and ultimate strength varies from 76 to 87 Mpa, 118 to 147 Mpa respectively after 10% TiC reinforcement in Al-4.5%Cu.

### WEAR PROPERTIES:

Aluminium alloys have been widely used as a matrix material and reinforced with various materials like SiC, Al<sub>2</sub>O<sub>3</sub>, TiC, alumina and Tib<sub>2</sub> etc., in the form of particles or fibers for the fabrication of metal matrix composites. Along with this the addition of the metals like Cu, Zn and Nickel will further improve the properties because they have developed strong bonding between matrix material and reinforced material. These AMMCs are operated under severe friction conditions because of their

good tribological properties. Various factors will influence the tribological properties of AMMCs, such as normal load, sliding distance, interfacial bond strength, environment conditions, surface finish, shape and size of the reinforced particles and weight percentage of the reinforcement etc.

V.Ramakoteswara Rao et.al. [22] studied dry Sliding wear behavior of Al7075 reinforced with Titanium Carbide (TiC) particulate composites. The wear tests were conducted at dry condition with condition normal load 20 N, sliding speed 1.57, 2.09 and 2.61 m/s and sliding distance 1, 2 and 3 Km on pin-on-disk machine model TR-20, supplied by M/S DUCOM, Bangalore (India). The wear resistance, coefficient of friction and specific wear rate of the composites were reduced with increase in weight percentage of TiC at above parameters. The results has revealed that the sliding distance is directly proportional to wear loss and specific wear rate and inversely proportional to coefficient of friction, however sliding velocity is inversely proportional to wear loss, specific wear rate and coefficient of friction.

J.Clarke et.al [23] investigated on Wear characteristics of as-cast binary aluminium-silicon alloys. The authors concluded that wear and load-carrying capability is optimum at near-eutectic alloy where the Si content is maximum at that stage and beneficial effect of silicon is to decrease the propensity to seizure. Reddy et.al. [24] investigated the wear and seizure behaviour of Al-Si alloys with addition of Si content up to 23% by using a pin on disc machine with a load range of 15-200N. The results revealed that seizure occurred at a particular temperature which is named as critical seizure temperature.

N. Radhika et.al. [25] Investigated on Tribologicalbehaviour of aluminium alloy (Al-Si10Mg) reinforced with alumina (9%) and graphite (3%) fabricated by stir casting process and conducted dry sliding wear test on pin- on-disc machine. They used Taguchi's technique with  $L_{27}$  Orthogonal array to find the influence of parameters on wear rate and coefficient of friction. The author has observed that the highest influencing factor on wear rate was Sliding distance (46.8%) followed by applied load (31.5%) and sliding speed (14.1%) and for coefficient of friction the contribution of sliding distance is 50%, applied load is 35.7% and sliding speed is 7.3%. They also observed that the significant effect on wear resistance is due to graphite as a primary reinforcement and alumina as a secondary reinforcement.

H.B.Bhaskar et.al. [26] investigated on the Tribological properties of Al 2024 alloy-beryl particulate MMC fabricated by liquid metallurgy route by varying the weight percentage of reinforcement from 0 to 10 wt.% in steps of 2 wt.%. They revealed that although the wear rate and coefficient of friction increases with increase in sliding distance and applied load (fig. 3) in the case of composites as well as the unreinforced material, it decreases when the percentage of reinforcement is increased. The authors also concluded that at low sliding speeds the wear rate and coefficient of friction has decreased, however it slightly increase with increase in sliding speed.

C.S.Ramesh et.al. [27] fabricated Al6061 matrix composite reinforced with nickel coated silicon nitride particles by liquid metallurgy route and investigated the micro structure and tribological properties .By using pin on disk machine, wear tests and dry sliding friction were carried out over a load range of 20-100N and sliding velocities 0.31-1.57m/. They noticed that the coefficient of friction has decreased with increase in load up to 80 N and increases with increasing sliding velocity. However the wear rate has increased with increasing load and sliding velocity.

Das et.al. [28] investigated on the abrasive wear behavior of aluminum alloy based composite reinforced with alumina and zircon sand. The authors observed that with decrease in particle size of the reinforcement the wear resistance for both the composites increases. The author found that the bonding between aluminum and zircon particles is good compared with alumina particles, which produces better wear resistance of zircon sand reinforced composite than alumina particles reinforced composite. The below (Fig. 4) shows that wear rate is constant with increase in sliding distance.

Suresha et.al. [29] investigated statically the dry sliding friction behavior of the hybrid aluminum matrix composite reinforced with SiC and graphite particles. The investigation shows that load is prominent factor in affecting the friction coefficient of the hybrid composite followed by sliding speed and with increase in load and sliding distance the coefficient friction also increases. Further, when compared with pure alloy the average coefficient of friction is low.



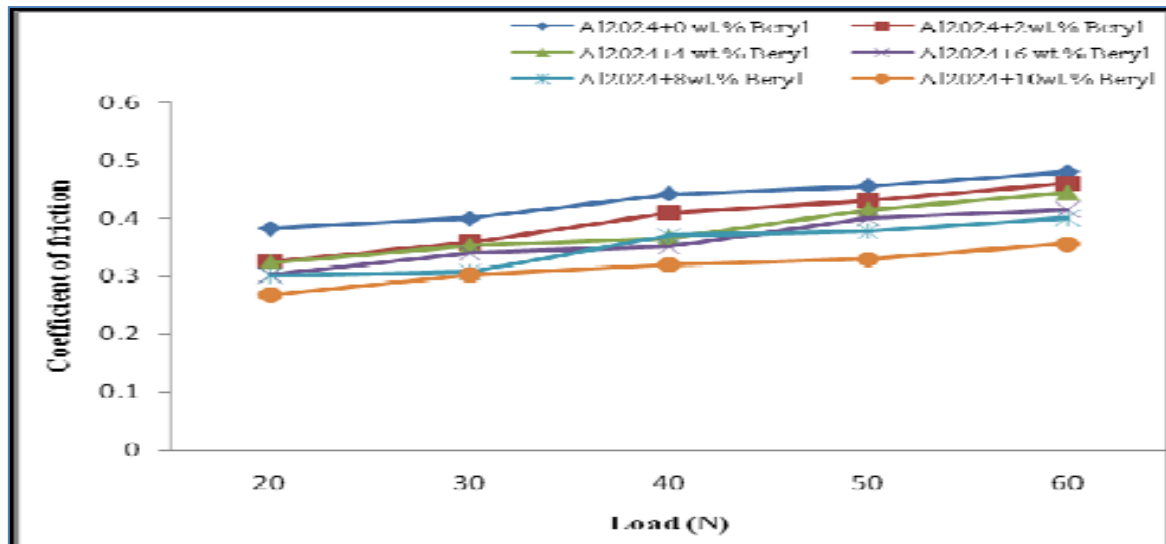


Fig. 3. Variation of Coefficient of Friction at Different Loads.

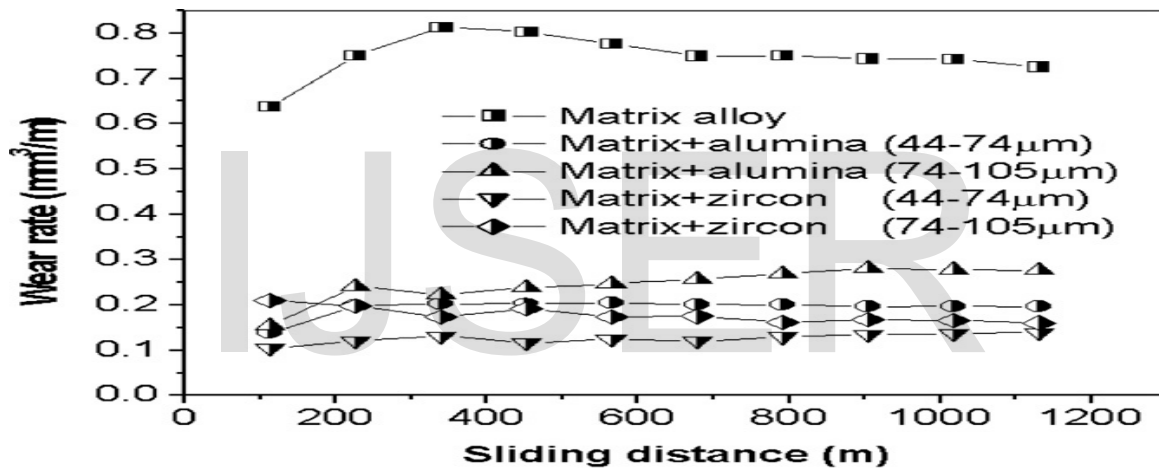


Fig. 4. The wear behavior aluminium matrix alloy with sliding distance.

## CONCLUSIONS

The above review for the aluminum based metal matrix composite leads to the following conclusions:

1. Stir casting process is well suited and economical for the preparation of AMMC's with desired properties.
2. By increasing the wt % and decreasing the particle size of reinforced material in the aluminium composites the hardness, tensile strength and yield strength increases.
3. From the above investigations, we observed that the wear rate mostly depends on applied load, sliding distance and sliding speed and the most influence parameter is sliding distance.
4. The tribological properties of the aluminium composites are increased by reinforcing with various materials, when compared to monolithic alloy up to some extent as per the above investigations.

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