

# Effect of Reinforcement's Material on Tribological and Mechanical Behaviour of Aluminium Composites: a Potential Review

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**ABSTRACT:** Aluminium alloys are widely used in composite for various applications, due to their low density, good mechanical properties, better corrosion resistance and wear, low cost, low thermal coefficient of expansion as compared to conventional metals and alloys, and are 100% recyclable and abundantly available on earth. But some applications entail high hardness and tensile strength, high modulus of elasticity than the conventional aluminium alloy with good tribological properties. Keeping in view the enhancement of mechanical as well as tribological properties with reduction in weight, the aluminium alloy is reinforced with a second phase which is hard and brittle, and the newly formed material has better mechanical and tribological properties. This paper provides the detailed review of various manufacturing processes and discusses the influence of reinforcement material on the tribological and mechanical properties of Aluminium Hybrid Metal Matrix Composites. From the extensive survey it was observed that AHMMCs exhibit the excellent mechanical and tribological properties and relatively low production cost make them a very attractive candidate for a variety of applications both from scientific and technological viewpoints.

**KEYWORDS:** Composites material, Hybrid composites, AHMMCs, Fabrication methods, Tribological properties, Mechanical properties

## I. INTRODUCTION

Due to the wide choice of materials, today's engineers are posed with a big challenge for the right selection of a material and the right selection of a manufacturing process for an application. The common metals are iron, aluminium, copper, magnesium, zinc, lead, nickel, and titanium etc., and there are more than 50,000 materials available to engineers for the design and manufacturing of products for various applications. These materials range from ordinary materials (e.g., copper, cast iron, brass), which have been available for several hundred years, to the more recently developed, advanced materials, e.g., composites, ceramics, and high-performance steels [1].

In the past few years, the global need for cost effective, high performance and good quality materials has caused a shift in research from monolithic to composite materials. In many developed countries and in several developing countries there exists continued interest in composites materials since 1950s when the work on Metal Matrix Composite (MMCs) began [2, 20]. Composite materials have become common engineering materials and are designed and manufactured for various applications including automotive components, sporting goods, aerospace parts, consumer goods, and in the marine and oil industries. Composite material is a material composed of two or more distinct phases (matrix phase and reinforcement phase) and having bulk properties significantly different from those of any of the constituents.

The simple term 'composites' gives little indication of the vast range of individual combinations that are included in this class of materials and Figure 1 shows a clearer idea of the scope for ingenuity which is available to the materials scientist and his customer and the design engineer [3].

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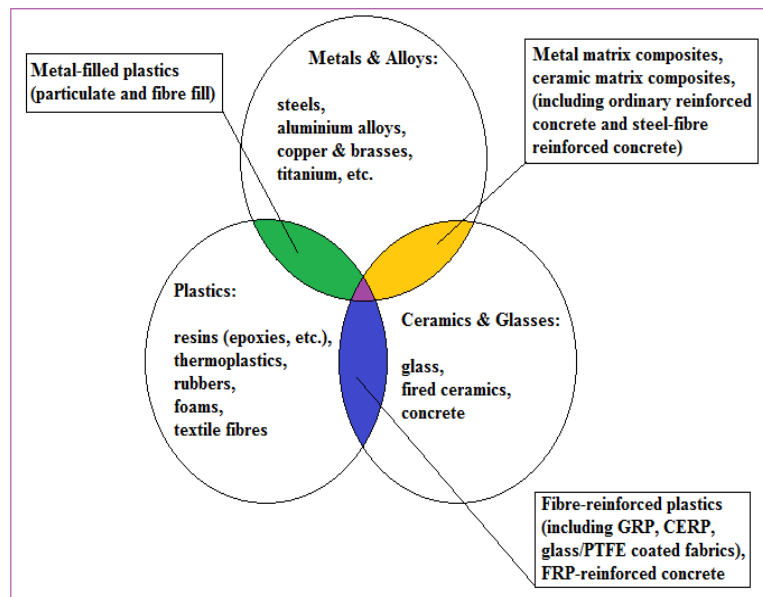


Fig. 1 Relationships between classes of engineering materials, showing the evolution of composites [3]

These days MMCs are replacing conventional materials in many applications because of their superior properties such as high strength to weight ratio, hardness, stiffness and wear and corrosion resistances over conventional materials [4]. MMCs are a diverse class of materials that consist of a metallic alloy matrix (aluminium, magnesium, copper, and titanium) typically reinforced with a ceramic phase in the form of particles, flake, platelets, whiskers, short fibres, and continuously aligned fibres. The most common commercial MMCs are based on aluminium, magnesium, and titanium alloys reinforced with either silicon carbide (SiC), aluminium oxide or alumina ( $Al_2O_3$ ) and other ceramic reinforcements [5]. Numerous combinations of matrices and reinforcements have been tried since work on MMCs began in the late 1950s. However, MMCs technology is still in the development stage, and several important combinations are still emerging [6]. The grades of MMCs have been found to have fairly limited use and enhance the further properties of MMCs more than two materials were added in the matrix such that to give birth to Hybrid Metal Matrix Composites (HMMCs) [7]. Hybrid metal matrix composites are second-generation composites where more than one type, shape, and sizes of reinforcements are used to obtain better properties [8]. Hybrid composites possess better properties compared with single reinforced composites as they combine the advantages of their constituent reinforcements [9].

Aluminium is the most abundant metal in the Earth's crust, and the third most abundant element, after oxygen and silicon. Some of its properties like high strength to weight ratio, prominent mechanical and wear properties and easy availability make it more interesting material compared to other non-ferrous metals. Aluminium is the most popular matrix in vogue and is quite attractive owing to its low density, low cost and ability to be strengthened by precipitation. From a material point of view, compared to other composites, the advantages of Aluminium Metal Matrix Composites (AMMCs) lie in their retention of strength and stiffness at elevated temperatures along with good abrasion resistance. Aluminium alloys, such as the 1000, 2000, 5000, 6000 and 7000 alloy series, are the most commonly utilised materials in composite fabrication. Aluminium composites are widely employed in the aerospace, automotive and marine industry [10]. In the present research paper discussed the effect on tribological behaviour and mechanical properties of the aluminium hybrid metal matrix composites in the presence or with addition (wt. % and vol. %) of reinforcement materials and with suitable production technologies related to HMMC.

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## II. LITERATURE SURVEY

### 2.1 Techniques for fabrication of Hybrid metal matrix composites

There are basically two processing methods which are used for fabrication of more than one reinforced AMMCs, which are called AHMMCs as follows [11, 12]:

- Liquid phase processing techniques
- Solid-phase fabrication methods

#### 2.1.1 Liquid phase processing techniques

In liquid phase processes, the ceramic particulates are incorporated into a molten metallic matrix using various proprietary techniques, followed by mixing and casting of the resulting MMC. The molten metal in liquid state is casted into various mold of desired shapes by conventional casting. The main processes under this category are as follows:

##### Stir Casting

In stir casting, a dispersed phase (ceramic particles, short fibres) is mixed with a molten metal matrix by means of mechanical stirring. In a recent development in stir casting is a two-step mixing process. The process of stir casting came into existence in 1968 through S. Ray, when he stirred the molten aluminum alloy by incorporating alumina ceramic powder particles into the aluminum melt, and in this process, the discontinuous reinforcement phases are incorporated into matrix when the matrix is in molten form by a mechanical stirrer.

##### Squeeze casting

In this process, the molten metal with adequate superheat is poured in a die with closed ends, and it is solidified to get desired shape. Consequently, this process is the combination of gravity die casting and closed die forging. The concept of squeeze casting was originally introduced in 1819 via a British Patent and further envisioned by a Russian, Chernov in a report. However, it was not until 1931 that the first squeeze casting experiment was scientifically carried out in Germany on Al-Si alloy. During the late 1930s, the detailed investigation of squeeze casting of brass and bronze cylinders was initiated in Russia. Following extensive work on various ferrous and non-ferrous metals and alloys, the process variables dictating the technique were established, and by the mid 1960s.

##### Spray Deposition

Spray deposition method is an attractive method for fabricating the composite materials. In this process, atomized droplets of molten material with a very high velocity are impressed on a preheated substrate, the reinforcing particles are also co-impacted with the molten metal spray allowing reinforcement particles engulfment in the molten or partially molten metal droplets to form a composite.

##### Infiltration technique

In infiltration technique, liquid metal is injected into an assembly of short fibres is called the preform. Commonly, the preform is designed to have a specific shape to form an integral part of a finished product. Preform is commonly fabricated by sedimentation of short fibres from liquid suspension. The process can also be adapted for production of particulate MMCs.

##### Compo casting

Compo casting is the process in which when the melt is solidifying, it is dynamically disconcerted and reinforcement particles are added to this solidifying melt. The primary solid particles which are formed in the semisolid melt causes the entrapment of reinforcement particles which reduces their segregation and agglomeration due to gravity which resulted into better wettability of reinforcement particles with the matrix.

##### Ultrasonic assisted casting

Ultrasonic stirring has been extensively used in the purifying, degassing, and refinement of metallic melt. Ultrasonic fields in a liquid gives rise to nonlinear effects such as cavitations and acoustic streaming. Acoustic streaming is a turbulence which occurs near obstacles as a result of energy loss in sound waves. Cavitations, or the formation of small cavities in the liquid, occur as a result of the tensile stress produced by an acoustic wave in the rarefaction phase. These cavities collapse under the action of compressing stresses during the compression half-period, producing high intensity shock waves in the fluid.

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## 2.1.2 Solid-phase fabrication methods

Solid state fabrication of metal matrix composites is the process, in which MMC are formed as a result of bonding of matrix metal and dispersed phase due to mutual diffusion occurring between them in solid state at elevated temperature and under pressure. The main processes under this category are as follows:

### Powder Metallurgy

Powder metallurgy is the process of blending fine powdered materials, pressing them into a desired shape (compacted), and then heating the compressed material in a controlled atmosphere to bond the material (sintering). Powder metallurgy can produce exactly net shaped components of complex shape with high accuracy.

### Diffusion Bonding

It is a common solid-state processing technique for joining similar or dissimilar metals. Inter diffusion of atoms between clean metallic surfaces, in contact at an elevated temperature, leads to bonding. The principal advantages of this technique are the ability to process a wide variety of metal matrices and control of fiber orientation and volume fraction [35].

### Frictions stir processing

FSP is a solid state processing technique to obtain a fine-grained microstructure. This is carried out using the same approach as friction stir welding (FSW), in which a non-consumable rotating tool with a specially designed pin and shoulder is plunged into the interface between two plates to be joined and traversed along the line of the joint. Localized heating is produced by the friction between the rotating tool and the work piece to raise the local temperature of the material to the range where it can be plastically deformed easily. It is effective and efficient technique which can be used to refine microstructure and to fabricate MMCs.

### Ball milling

In this process, a homogeneous material is obtained by blending the powder in a vial with balls made up of hardened steel or zirconia (so called ball milling in which high energy collision of balls and vial leads to the repeated cold welding and fracturing of powder and finally preparation of alloyed powder).

Out of these two methods liquid phase process is more effective and efficient than solid state because solid state process is time consuming and costly [13] and in the liquid state process, stir casting process is very simple and most cost effective method.

## 2.1.3 Importance of stir casting method and effect on mechanical properties

Stir casting method is the most commonly accepted commercially as a low cost method for production of MMCs. Its usages lie in its simplicity, flexibility, and applicability to large volume production. The stir casting process is most economical among all the available methods for fabrication of MMCs, and also very large sized components to be fabricated [14]. The present time, stir casting is the greatest viable and prevalent method for the fabrication of the particulate-reinforced MMCs and comparison with other process shown in the Table 1.

Table1 Comparative analysis of different technique used for fabrication of MMCs [15]

Method	Range of shape and size	Range of volume fraction	Damage to reinforcement	Cost
Stir casting	Wide range of shapes, Larger size: up to 500 kg	Up to 0.3	No damage	Least expensive
Squeeze casting	Limited by preform shape, up to 2cm height	Up to 0.45	Severe damage	Moderately expensive
Powder metallurgy	Wide range; restricted size	-	Reinforcement fracture	Expensive
Spray casting	Limited shape, large shape	0.3-0.7	-	Expensive

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Vol. 7, Issue 1, January 2018

With the stir casting method to be achieved that no adverse chemical reaction between the reinforcements material and matrix alloy, no or very low porosity content in the cast AHMMCs, wettability between the two main phase, and a uniform distribution of the reinforcement material. Wettability and reactivity determine the quality of the bonding between the constituents and thereby greatly affect the final properties of the composite material [16], and also fabricated composites exhibited many features and irregular contours may be made using stir casting method. The stir casting parameters which influence the microstructure and mechanical properties of MMCs are shown in Figure 2. Radhika et al. [17] also fabricated aluminium based composites reinforced with  $Al_2O_3$  and Graphite particles by stir casting method and found that reinforcement particles were distributed uniformly. The hardness and tensile strength also observed that with increase in weight percent of reinforcement particles in the composite, the hardness and tensile strength were increased.

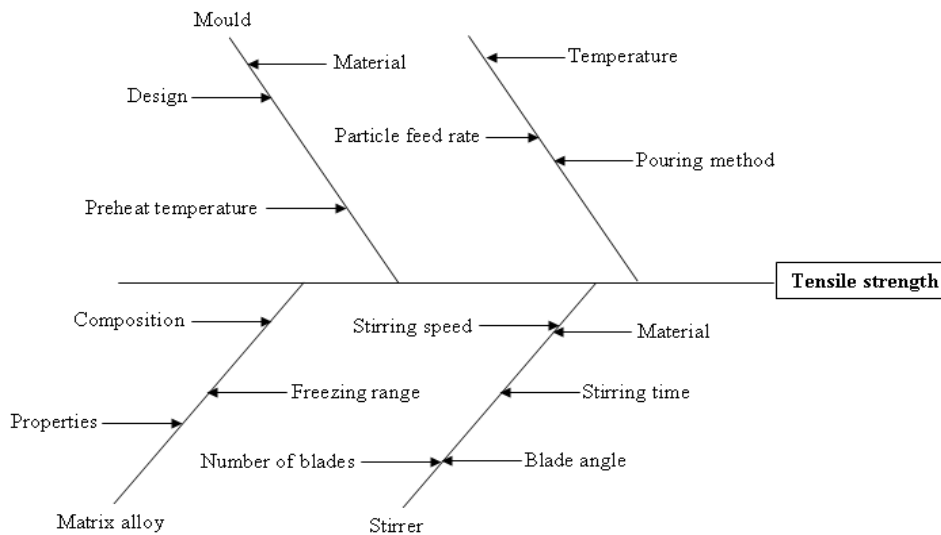


Fig. 2 Stir casting parameters influencing tensile strength of MMCs

## 2.2 Tribological behaviour of Aluminium Hybrid Metal Matrix Composite

Study of Tribological behaviour (Wear, Coefficient of friction and Friction force) of the material very important for various engineering applications, like aerospace, automotive, marine etc... Tribology is inherently a problem in the study of interfaces between solid surfaces in relative motion and the primary interest are the mechanical properties of such interfaces including friction, adhesion, and wear [18]. Wear is generally regarded as the unwanted removal of material as a result of rubbing surfaces. In 1958, Burwell [19] stated that since no quantitative relation can be arrived upon, (E.g., Coulomb's law of friction, Newton's law of viscous flow or Hook's law for elastic bodies), there is no wear coefficient.

Tribological behaviour of aluminium composite with effecting various factors, like percentage of reinforcement material, dry sliding condition, lubrication sliding condition, sliding velocity, sliding distance, applied normal load and temperature reviewed shown in Table 2.

Riahi and Alpas [20] have found that SiCp-graphite reinforced composites displayed a transition from mild wear to severe wear at loads and sliding speed combinations which were higher than those of the unreinforced A356 aluminium alloy and graphite free A356 Al-20% SiCp composites. The uniform graphite microcrystalline layer on top of the worn surface helps to decrease the friction coefficient and alleviate the plastic deformation in the subsurface region avoiding severe adhesion wear. S. Basavarajappa et al. [21] stated that wear rate of Al-15SiCp-3graphite at weight percent hybrid composite, Al-15SiCp at weight percent composite and matrix alloy (Al 2219 alloy) at various sliding speed shown in Figure 3, it was observed that the wear rate was constant at the sliding speed increased up to 4.6 m/s in the

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Vol. 7, Issue 1, January 2018

composite and matrix alloy, but further increased sliding speed showed that wear rate was increased in the alloy and Al-15SiCp at weight percent composite in comparison with Al-15SiCp-3graphite at weight percent hybrid composite.

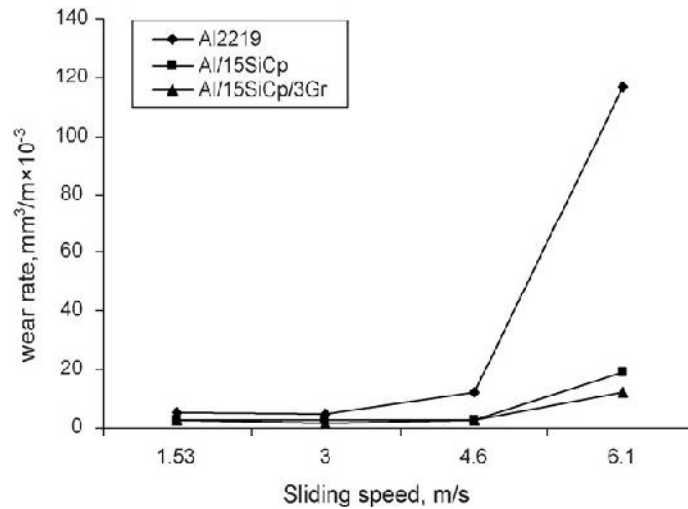


Fig. 3 Variation of wear rate with the sliding speed for the three different materials subject to the dry sliding wear [21]

S.A. Alidokht et al. [22] also observed low wear rate in the SiC and MoS<sub>2</sub> reinforced hybrid composite than A356 alloy and Al-SiC composite at different applied loads shown in Figure 4, due to the SiC acted as load bearing material and MoS<sub>2</sub> acted as solid lubricant.

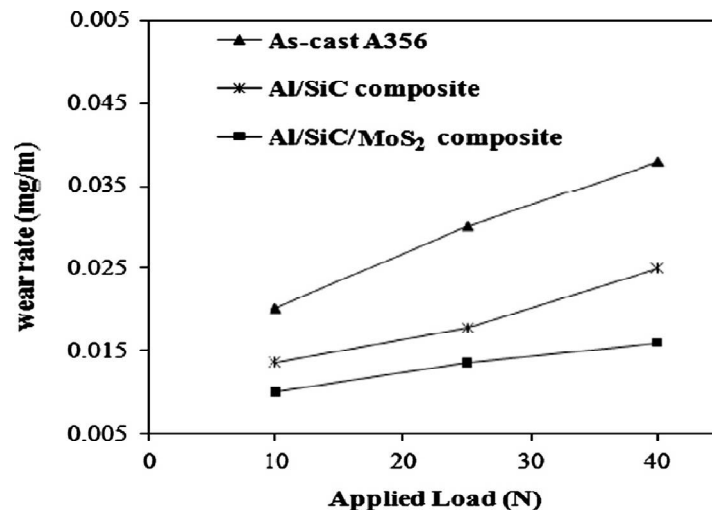


Fig. 4 Steady state wear rate as a function of applied load for as-cast A356, Al/SiC and Al/SiC/MoS<sub>2</sub> hybrid composites [22]

From the extensive survey it was observed that enhancement tribological behaviour in the form of superior wear resistance and low coefficient of friction of the material in the hybrid composite which is reinforced with more than one reinforcement material when compared with unreinforced alloy and single reinforced composite in most research work.



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Vol. 7, Issue 1, January 2018

Wear rate was observed at various applied load, sliding velocity, sliding distance and percentage of reinforcement. In the hybrid composite the wear rate was observed low due to with addition of reinforcements such as SiC, B<sub>4</sub>C, Gr, MoS<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> etc., acted as load bearing element and, solid lubricant and formed lubricating layer between surfaces. The wear rate was increased with increase in applied load in all the material, but in the hybrid composite observed that the wear rate was low when compared with unreinforced alloy and single reinforced composite material.

### 2.3 Mechanical properties of Aluminium Hybrid Metal Matrix Composite

Mechanical properties like tensile strength, compressive strength, ductility, hardness, toughness, density and porosity etc., are playing important role in the various industrial application along with tribological properties. Particulate reinforced light metals have shown great promise because of their outstanding mechanical and physical properties. A major goal in manufacturing and utilizing MMCs is to achieve the highest possible strength to weight and weight to stiffness ratios in a low cost light material. Particulate reinforced aluminium matrix composites are widely used in its application in the automotive industries because of their low cost and isotropy in property values [23]. However, as the mechanical properties of the composite material are strongly dependant on the microstructural parameters of the system matrix-reinforcement, a judicious selection of a certain number of variables has to be achieved to optimize the properties of the composite. In particular, the shape, size, volume fraction and the orientation of the reinforcing particles, as well as the matrix composition or its thermal heat treatment have to be carefully chosen [24]. The homogeneous distribution of the reinforcement in the matrix is essential to form a composite with uniform mechanical properties.

Mechanical properties of AHMMCs affected by soft and hard reinforcement's material reviewed as shown in Table 2. It was observed that hardness; tensile strength and compressive strength of composite material increased with hard and decreased with softer reinforced material, but in AHMMCs observed that enhancement mechanical properties due to addition of more than one reinforced material with various volume percentage and particle size.

O. Carvalho et al. [25] have investigated that hardness of hybrid composite of the matrix alloy (AlSi ally), Al-CNT and Al-SiC composites and Al-CNT-SiC hybrid composite. The hardness was increased with addition of CNT and SiC reinforcement material and highest value observed in the hybrid composite when compared with matrix alloy and single reinforcement material as shown in Figure 5.

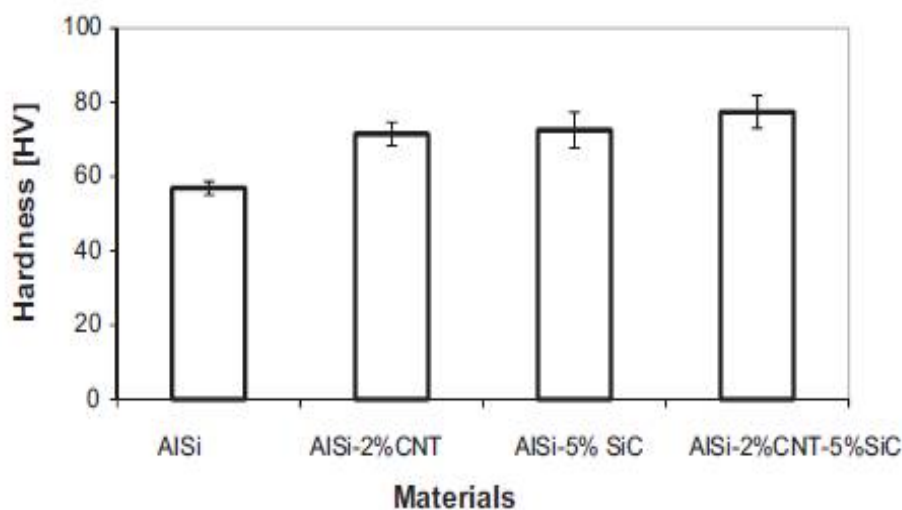


Figure.5. Hardness of the unreinforced AlSi alloy and all AlSi composites. [25]

Alidokht et al. [26] also observed that hardness of matrix alloy (A356 alloy) and composite materials with addition of SiC and MoS<sub>2</sub>. The hardness was increased with increase with addition of SiC<sub>p</sub> and MoS<sub>2</sub> content and the highest value

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Vol. 7, Issue 1, January 2018

was observed in the Al-SiC composite when compared with matrix alloy and Al-SiC-MoS<sub>2</sub> hybrid composite as shown in Figure 6.

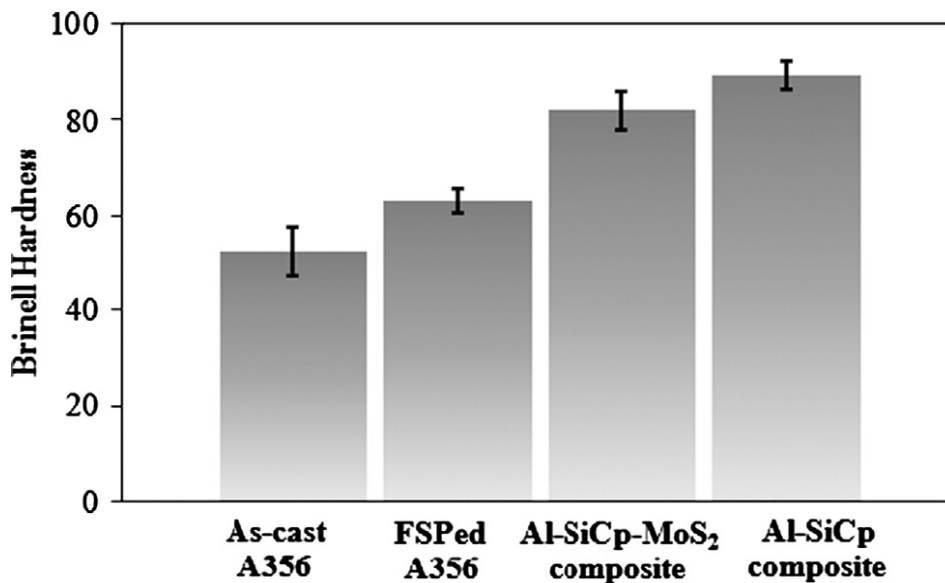


Fig.6 Variation of Brinell hardness in as-cast, FSPed A356 and composite samples [26]

Table 2 Mechanical and tribological behavior of aluminium hybrid metal matrix composites

Name of the author and year	Material			Mode of preparation	Behaviour of Hybrid Composite		Remark
	Matrix	Reinforcement			Mechanical	Tribological	
		a	b				
Suresha et al. 2010 [27]	Al-Si7Mg alloy	Graphite	SiC	Stir casting	---	Wear resistances increased in composites with increase in graphite and SiC particles.	Al-SiC-Gr hybrid composites are better substitutes to Al-Gr and Al-SiC composites owing to improved wear resistance.
Dharmalingam et al. 2011[28]	Al-Si10Mg alloy	Al <sub>2</sub> O <sub>3</sub>	MoS <sub>2</sub>	Stir casting	---	Wear resistance increased with increased weight percentage of MoS <sub>2</sub> particles.	Wear rate decreased the composite with addition MoS <sub>2</sub> particles than Al <sub>2</sub> O <sub>3</sub> and with base alloy.



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Vol. 7, Issue 1, January 2018

Rajmohan et al. 2013 [29]	A356 alloy	SiC	Mica	Stir-casting	Al/10SiC-3mica composites show the maximum strength and hardness.	Wear resistance increased with increased mass fraction of mica.	Maximum strength and hardness, and wear rate decreased in HMMC's over than MMC's.
Alidokht et al. 2013 [30]	A356 alloy	SiC	MoS <sub>2</sub>	Friction stir processing	Hardness increased when incorporated SiC and decreased with MoS <sub>2</sub> particles.	Wear resistance increased in hybrid composite.	Deformation of subsurface in the hybrid composite lower than A356/SiCp composite due to the addition of MoS <sub>2</sub> .
Alaneme et al. 2014 [31]	Al-Mg-Si alloy	SiC	RHA	Double stir casting process	----	Wear resistance increased with increase in reinforcements.	Al-Mg-Si alloy with 7.5 wt% RHA-SiC reinforcements had better wear resistance compare to all compositions.
Mitesh Kumar et al. 2014 [32]	Al 6063 alloy	MoS <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Stir casting	Density increased with increase in MoS <sub>2</sub> and Al <sub>2</sub> O <sub>3</sub> particles. It was also observed that hardness increased, conversely ultimate tensile strength decreased with increase in MoS <sub>2</sub> weight percentage.	----	The Ultimate Tensile Strength decreased due to the additions of 3% to 9% of MoS <sub>2</sub> and Al <sub>2</sub> O <sub>3</sub>
Prasad et al. 2015 [33]	A356.2 alloy	SiC	RHA	Vortex method	Hardness of A356.2/RHA composites increased with the increase in weight percentage of RHA content.	Hybrid composites had appreciable wear resistance than that of pure aluminium matrix and it increased with increase in the content of reinforcement.	The wear rate decreased with the increasing weight percentage of the RHA and SiC particles.

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Vol. 7, Issue 1, January 2018

## III. SUMMARY AND CONCLUDING REMARKS

This paper discussed the different combination of reinforcements used in the synthesis of aluminium hybrid metal matrix composite and how it influences its performance. The double synthetic ceramics reinforced AHMMC despite showed good mechanical and tribological properties over the unreinforced alloys and single reinforced composite. From extensive survey, observed the tribological and mechanical behaviour of aluminium hybrid metal matrix. Hybrid composite properties influenced by reinforced materials and also tribological properties affected by sliding velocity, sliding distance & applied load of composite. It was observed reinforced materials were mixed in the composite with various methods and, different size, type and various percentages.

The following points were observed regarding hybrid composite.

1. It has been observed that among all the fabrication techniques considered, stir casting stands out as the most economical method. Most of the researchers used stir casting as the fabrication method, as it is least expensive of all the manufacturing methods available to fabricate AHMMCs and is very simple and can be used for mass production also.
2. AHMMCs are one of the recent advanced materials having the properties of light weight, good wear resistance, high specific strength and low thermal expansion.
3. Aluminum hybrid metal matrix composite is successfully fabricated by stir casting techniques. The mechanical properties like tensile strength, yield strength, hardness were increased as compare to simple composite & matrix while the percentage of reinforcement increased, while the other end elongation gets reduced in composite as percentage reinforcement gets increased. And observed better tribological properties in hybrid composite at higher applied load, sliding velocity and sliding distance than unreinforced and single reinforced material.
4. With hard particles like SiC, B<sub>4</sub>C, TiC, C etc observed enhanced mechanical properties, but elongation was decreased and wear rate increased. With addition of solid lubricant material like Gr, MoS<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> etc along with hard materials in composite, observed wear resistance increased & low coefficient of friction and elongation also enhanced.

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