

# A Review on Mechanical and Thermal Properties of Aluminum Metal Matrix Composites

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**Abstract.** The Aluminum Metal Matrix Composites (AMMCs) have been becoming suitable materials for many devices in the application of various fields like heavy equipment's industry, automobile, aeronautics and etc. because of its excellent physical and structural characteristics. The research on AMMC dealt the effect of reinforcement such as fly-ash, SiC, Al<sub>2</sub>O<sub>3</sub>, Graphite, B<sub>4</sub>C, Cubic Boron Nitride (CBN) on aluminium in different percentages. Every reinforcement has its own characteristics that enhance the base aluminium characteristics when added. By adding these types of reinforcement to metal base led to enhance the properties like wear resistance, stiffness, creep, tensile strength, fatigue, toughness, thermal conductivity, hardness in comparison with traditional approach on materials engineering. This review paper was aimed to give the detailed information about the impact of various reinforcements incorporated in matrix by illustrating its benefits and drawbacks. This extensive survey on AMMC could be useful to develop farther.

## 1 Introduction

Metal Matrix Composites (MMCs) are the composites of a material with a minimum of two components, one should essentially be a metal, another one could be a different metal like compound or ceramics. They are formed by distributing the reinforcement materials within the matrix. By the introduction of reinforcements like B<sub>4</sub>C, SiC, Al<sub>2</sub>O<sub>3</sub> to matrix alloy, much useful properties of alloy matrix like hardness, thermal conductivity, strength, wear-rate and so on would be enhanced. Composite's properties rely upon the properties of particle's phases, its relative quantity, distributed phase geometry in addition to the shape, size and alignment with matrix [1].

In our daily life, AMMCs have found many applications. AMMCs are composites that only use aluminium as the matrix and incorporate a few reinforced components into the matrix. There are a few benefits such as low Coefficient of Thermal Expansion (CTE), improved stiffness, greater hardness and strength, light weight, high specific modulus, enhanced damping capabilities, enhanced wear-resistance and greater Thermal Conductivity (TC) when the reinforced is used in matrix. The matrix may include reinforcing elements in a manner of continuous fibers, particulates

or monofilaments. They have been used in the fields of industrial goods, automotive and aeronautics applications [1]. The reinforcement particulates must be robust, flexible and anti-reactive in the specified operating temperature. SiC, Al<sub>2</sub>O<sub>3</sub>, graphite, Cubic Boron Nitride (CBN) are commonly used as reinforcements.

In order to gain the optimum properties, selection of good reinforcement and the matrix materials are not only sufficient, processing method also plays a significant role. There are different techniques available to produce AMMCs like powder metallurgy, squeeze casting, stir casting, chemical vapour deposition, pressure infiltration etc. Among these manufacturing techniques stir casting is the prevalent technique which has been used by many investigators since the process is cost-effective, and this process have greater hardness and refined microstructure-grains than other techniques. Skibo et.al [2] noted that the cost for preparing AMMCs is approximately one-third to half that of other techniques and that price of high- volume manufacturing will be reduced to one- tenth.

## 2 Mechanical Properties

The mechanical properties of MMCs are necessary to

describe the composite material's behavior. Few mechanical properties like tensile strength, stiffness, hardness, wear resistance, toughness were few of the significant mechanical properties assessed. These mechanical properties play a key role to characterize the behavior of composites. By adding greater strength, greater-modulus refractory particulates to a highly ductile matrix material give a new product which would have mechanical properties in between reinforcement and metal matrix. Metals had beneficial properties like ductile, greater temperature resistance, immense strength but typically can have poor stiffness, while ceramic materials have greater stiffness and strength, although brittle. By combining both will get a new product which has stiff, immense strength and greater temperature resistance.

AMMCs have different positive impact on mechanical properties, those properties are important in several current applications. Experiments on the mechanical properties try to create the research on composite materials in exhaustive. The different mechanical properties that are regarded as follows in this review.

## 2.1 Hardness

Hardness is the material's ability to resist scratching (abrasion) or the ability of a material to resist indentation. It is also defined as the material's capacity to cut different metal. It encompasses other different properties like machinability, deformation, scratching, wear-resistance and so on. Preparation of composite materials processes that enhance a material's hardness and its tensile strength but at the same moment reduces the material's toughness as it gets further brittle.

Shanmuga Sundaram et.al [3] studied of the impact of particulate types and extrusion on Al<sub>2014</sub>/Si<sub>3</sub>N<sub>4</sub>, Al<sub>2014</sub>/SiC and Al<sub>2014</sub> matrix material. From hardness test, there is an enhancement of 23% and 42% was noticed in Al-SiC composite material in as-cast and extruded situations compared to matrix material. The general reason for enhancement of hardness of a matrix material was owing to the introducing hard ceramic particulates to the highly ductile and smooth metal matrix. Likewise, there is an enhancement of 35% and 31% was witnessed in Al/Si<sub>3</sub>N<sub>4</sub> compared to matrix material. This was owed to the existence of strong ceramic particulates that prevent the matrix dislocation motion that causes a matrix to harden. Sunil Kumar Reddy et.al [4] noted that the peak hardness 72 HR was achieved in Al<sub>7475</sub>/SiC/Gr composite material with 10 wt % SiC and 9 wt% Gr.

Song et.al [5] found hardness values were enhanced with rise in ageing temperature and peak hardness value acquired at temperature 150°C to 200°C and also noted

that the Al<sub>2014</sub> composites are very hard in compared to 6061Al. By rising the ageing temperature to 250°C, there was considerable loss in hardness values for all composites were also noted. Vanarotti et.al [6] observed with increment of wt.% of SiC in Al 356, the BHN was increased. Fang et.al [7] noted that contaminations and greater porosity problems due to few reaction and Al composites had poor vickers hardness too. Biswas and Jairam [8] revealed that porosity has been the key factor effecting SiC and Al<sub>2</sub>O<sub>3</sub> reinforced Al composite's hardness. Bansal and Saini [9] found Al 359 MMC's hardness reinforced with SiC was so much greater than the Al 359-graphite's hardness. Reinforcements like Gr/SiC bonding enable the material to resist greater loads.

Mali et.al [10] explored few properties on Al 356 alloy with alumina and fly-ash as reinforcement with different percentages. It had been noted that composite's hardness rose to 94 BHN till 12% and subsequently reduced owing to porosity. Rao et.al [11] examined vickers hardness of Al/Zn/Mg (Al7009) and SiC reinforced Al/Zn/Mg (Al7009) were enhanced with the heat treatment and as well with the increment of SiC percentage in the alloy matrix. Kumar et.al [16] noticed 10.48% rise in hardness with an increment of 5- 15% SiC reinforcement in Al 7075 alloy. Purohit and Deshamanya

[12] found Al<sub>7075</sub>/Al<sub>2</sub>O<sub>3</sub> composite's hardness was reduced as reinforcement size increased owing to a greater size of grains resulting in a less dense dispersion of Al<sub>2</sub>O<sub>3</sub> particles in Al matrix. Indeed, the hardness was enhanced significantly after approximately 8% of the reinforcement added and a peak hardness value 140 BHN for a composite material comprising 15% Al<sub>2</sub>O<sub>3</sub> was noted. As reinforcement quantity rises, the reinforcement-matrix ratio becomes richer, resulting in enhanced composites hardness.

It is understood from the above discourse that Silicon Carbide (SiC) and Al<sub>2</sub>O<sub>3</sub> play a significant role on enhancing the composite's hardness. Introducing different reinforcements shows rise in hardness, but it is restricted to some range and after that it tends to reduce the hardness. If we rise wt.% of SiC beyond 25% then it results in reduction of hardness values because the greater wt.% of SiC particulates began to settle in melt of aluminium.

## 2.2 Tensile Strength

Tensile strength is a material's capacity to bear the tensile load (stretching) without material breaking under tension. D. Sujan et.al [13] discovered that, AMMCs with Al<sub>2</sub>O<sub>3</sub> as a reinforcement had a greater density values compared to AMMCs with SiC as a

reinforcement, since Al<sub>2</sub>O<sub>3</sub> density value was greater than the SiC density. It was also discovered that tensile strength and hardness of Al/SiC greater in comparison with Al/Al<sub>2</sub>O<sub>3</sub> composites. The reinforcing particulates serves as a strengthening substance that enables close the pores in matrix alloy, establishing a greater contact between matrix particulates. Rahman and Rashed et.al [14] reported peak tensile strength value obtained at 20 wt.% of SiC incorporated within matrix alloy. The general reason for rise in tensile strength is owing to the shifting of tensile load to the heavily attached SiC reinforcement which mostly increases the density of dislocation and therefore results in refining impact of grain. The results indicated from tensile test on Al6061 which was reinforced with graphite had greater tensile strength compared to SiC reinforced Al 6061. This was all because of graphite filler's greater strength. Strangely, the tensile strength stayed same at 12wt.% owing to inadequate graphite wetting.

Shanmuga Sundaram et.al [3] had found that the yield strength of 11% and 33% was enhanced within the composites of Al/Si<sub>3</sub>N<sub>4</sub> and Al/SiC compared to base matrix metal. The general reason for enhancement of composite's strength is owing to increasing density of dislocation that was due to incorporation of ceramic particulates such as Si<sub>3</sub>N<sub>4</sub> and SiC. Kumar et.al [15] observed from Al 6061 reinforced with three variations of fly- ash 10%, 15%, 20 wt.% and the maximum tensile strength was found at 20% wt. of fly-ash, because fly ash has a greater strength. But the tensile strength property was diminished when the reinforcement added beyond 15 wt.%. The principal reason for diminishing the tensile strength is owing to the poor wettability. It was also noted that the UTS enhanced to 192 MPa. Kanagaraj et.al [16] evident that UTS was enhanced with incorporation 17 wt.% alumina but there was no obvious change with the graphite reinforcement. This may owe to the thermal mismatch that tries to be the primary driving force to raise matrix's dislocation density. Vinitha et al. [17] observed from their research that Al 7075/SiC/fly ash MMCs has higher strength than Al7075/redmud/SiC composites. Muruganandan et.al [18] mentioned that there was 32% enhancement of tensile strength in Al 7075/TiC/fly ash MMCs in compared to matrix alloy. This was owing to fly-ash hardened the matrix material. Onel et al. [19] study revealed that the values of tensile and yield strength were enhanced until SiC of 17 vol.% in as-cast situations and after that the values were decreased. These values enhanced for extruded specimens by 40% and consistently enhanced with increase of vol.% of reinforcement. Yilmaz et al. [20] noticed the tensile strength difference between T6 heat treated and as-cast silicon carbide reinforced Al7075 and mentioned that 10 wt.% SiC heat-treated composite had greater tensile

strength in comparison with as-cast reinforced Al 7075.

From above discussion, both graphite and SiC were prolific reinforcements in the field of tensile strength. Another reinforcement alumina demonstrates nice outcomes as well, but there was not much talk about it. The incorporation of different reinforcements like fly-ash and red-mud also helped to raise tensile strength values up to certain limit but beyond the limit it rapidly diminished.

### 2.3 Ductility

Ductility is the measure of the capacity of material to deform plastically, when put under tensile load that surpasses its yield strength without splintering. The material with high ductility shows, more suitable for deformation and does not shatter. Whereas less ductile substances are brittle and breaks before it deforms under a tensile load. Ductility relies mainly on the structure of crystalline substances, chemical composition of substances and temperature at which ductility is evaluated.

Onel et al. [19] reported that with the raise in SiC vol.%, diminished ductility of as-cast MMC's and also noticed that there was enhancement of ductility by the implementation of extrusion. Srivastan et.al [21] observed % elongation, decrease in % area, with various % of reinforcement. Study of fractography disclosed that existence of brittle and tough SiC within the ductile and smooth alloy matrix triggered fine micro-cracks to be begun at less stress values. The micro-cracks grew quickly, leading to macroscopic deficiency and less tensile strength. Garg et.al [22] mentioned that there was diminish in ductility with raise in SiC wt.% within Al 6061/fly ash/SiC composites.

### 2.4 Toughness

Toughness is a material's potential to withstand cracking. If a substance breaks down, it is brittle. If it doesn't break when undergoing an impact load, it is tough. Md. Habidur et.al [1] noticed from with raising SiC reinforcement in AMMCs, hardness, tensile strength and wear-resistance enhanced but toughness had decreased. Ravesh et al. [22] mentioned toughness of Al6061/fly ash/SiC was enhanced with the increment of reinforcement. This is owing to sufficient reinforcement distribution within alloy matrix and there was greater bond between reinforcement and base metal. The peak toughness acquired at the composite comprising 5 wt.% fly-ash and SiC 10 wt.%. Aluko et al. [23] revealed from circumferential notch tensile test that fracture- toughness was enhanced with the raising vol.% of SiC or else with the help of ageing treatment. But Park et.al [24] mentioned that toughness value had

diminished with raising 5 to 30 vol.% of Al<sub>2</sub>O<sub>3</sub> reinforcement. The principal reason for this is owing to reduction in spacing among nucleated micro-voids of inter-particulates. Alaname et.al [25] disclosed that Bamboo Leaf Ash (BLA) and SiC reinforced Al/Mg/Si composite's fracture-toughness was enhanced as BLA proportion raised. This is because raising existence of silica which was smooth than SiC. The hybrid composite's fracture toughness found to be inferior than single reinforcement which has 10 wt.% SiC in aluminium.

## 2.5 Wear Resistance

Wear rate is the volume loss per unit distance. Shanmuga Sundaram et.al [3] had studied wear rate by using pin-on-disc test on Al7075-SiC composite with elaborated sliding-speed and differing load. At 1 m/sec sliding-velocity and 20 N load, the composite material which was precipitated heat-treated (6 hrs T6 aged) displayed greater wear-resistance and also elaborated that by doubling load there was 26% enhancement wear rate and by raising sliding velocity there was 21% wear enhancement and also clarified that irrespective of load and velocity heat-treated composite's wear resistance enhanced by ageing. Saini et.al [9] explained Al 359/Gr/SiC wear behaviour and results had shown reinforced matrix's wear resistance raised with conditions of sliding distance, loading and greater sliding-speed and also mentioned that graphite diminishes wear-resistance at greater loading than SiC because it has extreme lubricant property. It was also concluded from SEM analysis that Al 359/SiC surface had big sized cracks, voids, groove and also confirmed that these were viewed very fine within Al/Gr/SiC than Al/SiC composites.

Natarajan et.al [26] linked 356 Al/SiC 25 composite's wear properties with gray cast-iron sliding material towards the friction material of the automotive. It has been discovered that the composite's wear resistance was greater than standard gray cast-iron and was very appropriate for brake drum material. But, due to existence of hard particulates of SiC, it was not used for lining components. Mahajan et.al [27] and Thirumalai et.al [28] taken reinforcements of B<sub>4</sub>C and TiC and revealed that till some wt.% the wear-resistance was raised. Manikandan et.al [29] explained Al 7075/B<sub>4</sub>C, Al 7075/SiC and Al 7075/Al<sub>2</sub>O<sub>3</sub> composite's wear characteristics with differing sliding distance and load by test performing on pin-disc and mentioned that due to hardness and heat-resistance of B<sub>4</sub>C, the Al 7075/B<sub>4</sub>C composite had disclosed better wear-resistance. In contrast to others, Muthu et.al [30] discovered 7075 Al-fly-ash 5%- SiC 3% dry sliding properties and noted that there was diminishing wear-rate and enhanced density when SiC incorporated to

Al7075. Both properties were diminished in fly-ash context and also noted with increasing sliding speed 2 m/sec to 3 m/sec wear-rate enhanced.

Abouelmagd [31] examined AMMCs wear behaviour and hot-deformation which were generated by powder-metallurgy method and disclosed that compressive strength, hardness were enhanced with raising addition of Al<sub>4</sub>C<sub>3</sub>, Al<sub>2</sub>O<sub>3</sub> reinforcement to alloy matrix. In the context of Al/Al<sub>4</sub>C<sub>3</sub>, there was enhancement of wear-resistance. Kumar et.al [32] found the effectiveness of nano particulates of silicon graphite in Al2024 and mentioned that wear-resistance was enhanced by SiC incorporation but with graphite particulates incorporation furthermore enhanced and there was good bond within composites which was revealed by XRD analyser. Rahman et.al. [14] noticed from their research that mass loss for Al/SiC was lower in compared to aluminium which was in pure form. This is owing to softness of pure Al. The incorporated SiC safeguards the alloy matrix against more wear. At SiC 20 wt.% the peak wear-resistance was attained.

From literature-survey, it is clearly understood that with adding Graphite, SiC wear-resistance could be enhanced. The MMCs were guarded with SiC which were predominant on external substances layer and also if the MMCs were conducted at higher loads, the particulates of graphite tend to diminish the rate of wear.

## 3 Thermal Properties of MMCs

The material's thermal properties were those features which are associated with its heat conductivity. In another sentence, when heat moves through it, substances possess these properties. Thermal-resistivity or conductivity, thermal-expansion coefficient, thermal-diffusivity and specific-heat capacity were few of essential properties of thermal. The evaluation and characterization of this kind of properties plays crucial role. The investigation and observation of thermal properties are conducted at elevated temperature, room-temperature too.

### 3.1 Coefficient of Thermal Expansion (CTE)

CTE is described as Change in dimensions of material accompanying with alteration in the temperature. In automobile applications temperature variations occur so that less CTE substances recommended. D. Sujan et.al [13] observed the values of CTE were shortened as reinforcement proportion raising. S. Cem okumus et.al [33] found there was reduction in CTE by raising graphite with 45 and 53 µm grain size of SiC and also found that values of CTE raised with increment of temperature and when temperature goes 200 to 250°C beyond it got reached saturation as it relies on

proportion of graphite. The greater the proportion of graphite reduces the temperature of saturation and raising proportion of graphite had led the refining of grain for eutectic-silicon, aluminium as well, that is why it shown less CTE. In addition to, incorporation of much proportion of graphite given the dimension stability for MMCs. Arpon et.al [34] investigated the evaluation of CTE between 50 to 300°C and revealed that the CTE was varied with temperature change and reduced with raising vol.% of reinforcement. Manivannan et.al [35] reported that there was a decrease in thermal-contact resistance i.e. it reduces CTE which was in turn, improves the substance thermal diffusivity and conductivity by adding Carbon Boron Nitride (CBN) contents in matrix metal,.

S.A Mohan Krishna et.al [36] observed that CTE of Al 6061/Gr/SiC hybrid MMCs got reduced with further addition of graphite, SiC in equal proportion and CTE values were raised with increment of temperature till 300°C. The general reason for reduction of CTE is owing to the less CTE values for graphite and SiC, in comparison to aluminium-base matrix material.

### 3.2 Thermal Conductivity (TC)

Thermal Conductivity (TC) is the material's property that depicts the capacity for heat conductivity. It may also be described as heat-transfer rate by unit material's thickness per unit area per unit difference of temperature. One of the main compensations of aluminium is its TC is approximately thrice to steel. Aluminium is a significant substance in applications of cooling or heating such as heat exchangers.

S. Cem Okumus et.al [33] found that TC was reduced as the amount of graphite content increased in Al matrix and the raising test temperature also resulted in gradual reduction on TC. Moreover it was also stated that there was a decrease of TC when the grain size of SiC particles were reduced, because reducing SiC's particulate size, the interface characteristics among SiC and matrix Al could ascribed. Manivannan et.al [35] investigated on Al6061/CBN, Al6061/SiC and Al6061/Al<sub>2</sub>O<sub>3</sub> MMCs. From this, it is observed that Cubic Boron Nitride (CBN) contents in the Al matrix have tremendous raise in both TC and heat transfer coefficient than Al/SiC, Al/Al<sub>2</sub>O<sub>3</sub> fillers. S.A Mohan Krishna et.al [36] mentioned that TC values were reduced with raising incorporation of graphite, SiC in equal proportion within 6061 Al and concluded that there was no enhancement of TC of AMMCs by using graphite and SiC as reinforcements and also mentioned that only single SiC reinforcement enhanced the TC of AMMCs. The reason for reduction in TC values may be the less TC values of reinforcement particulates. Krishna et.al [37] researched on 6061 Al/Gr/SiC MMCs

with help of software ANSYS and disclosed that reduction in TC due to graphite incorporation. Sateesh et.al [38] researched on effect of moisture, also it effects fiber reinforced composites.

## 4 Conclusion

The intention of this review is to throw a light on the impact of various reinforcements including different percentages and a range of reinforcement's size in aluminium metal matrix composites. The following facts were revealed by the number of researchers on AMMCs.

The value of hardness was improved as SiC reinforcement was increased but the hardness was reduced as graphite content was increased. The 359 Al/SiC MMCs hardness was higher compared to 359 Al/Gr MMCs. This is owing to graphite softness and lubricant properties. The peak hardness values were attained at the 25 wt.% SiC. Al/SiC MMCs displayed higher tensile strength, hardness in comparison with Al/Si<sub>3</sub>N<sub>4</sub> and Al/Al<sub>2</sub>O<sub>3</sub> MMCs.

The peak tensile strength values were obtained at 20 wt.% of SiC and ductility was reduced as SiC reinforcement was increased. In the context of fly-ash, the tensile strength and ductility were reduced significantly until 10 wt.% of reinforcement.

For the MMCs which are reinforced with fly-ash 5 wt.% and SiC 10 wt.% acquired the greatest toughness value. The hybrid Al/Si/Mg hybrid MMCs had a greater fracture toughness than single reinforcement of Al 10 wt.% SiC MMCs.

The CTE values are raised as the increasing temperature and also values of CTE were gradually reduced as the incorporation of graphite, SiC reinforcement increased. By adding Carbon Boron Nitride (CBN) contents in matrix metal, there is decrease in the CTE value which was in turn, improvise the substance's thermal diffusivity and conductivity.

As amount of graphite content increases, TC values were shortened and also raising test temperature resulted in a continuous reduction in TC values. By reducing SiC grain size, there is a decrease in TC because reducing SiC grain size outcomes in wider area of surface among SiC and Al matrix.

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