Review Article

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Effect of Reinforcement Addition on Mechanical Behavior of Al MMC - A Critical Review

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ABSTRACT

Composites are in high demand in the industry right now because of their low weight, wear resistance, stiffness, and high strength. The functional and structural characteristics were enhanced in response to industrial requirements. Metal matrix composites (MMCs) have been popular in engineering structural applications due to their high specific strength and are rapidly being viewed as a viable alternative to traditional materials, especially in the automobile sector. Particulate reinforcement is one of the ways for improving the composites' strength, ductility, and toughness. The market for Aluminium Hybrid Metal Matrix Composites has risen in recent years as a result of their improved mechanical characteristics, which meet the needs of sophisticated technical applications. The choice of an appropriate mix of reinforcing materials has a significant impact on the performance of these materials. Carbon Nanotubes, Silicon Carbide, Boron Carbide are best among the reinforcing materials. The mechanical, morphological, and tribological evaluations of these five reinforcements were thoroughly investigated in this study.

Keywords: Metal matrix composites; Reinforcements; Carbon nanotubes.

1. INTRODUCTION

Owing to their superior mechanical, thermal, surface, and other properties, metal matrix composite (MMC)-based low-weight alloys have a wide variety of applications in today's world (whether the area is structural or non-structural) (Shuvho *et al.* 2020). Most MMCs have been discovered to have superior properties when compared to single metal matrices. These MMCs may be tailored to have exceptional durability, ductility, tensile modulus, thermal conductivity, and other properties (Manikandan *et al.* 2020). In industry, the most prevalent composites are Metal Matrix Composites (MMCs). According to a recent study Advanced Materials, MMCs outperform both Polymer Matrix and Ceramic Metal Composites (PMC and CMC).

- Increased temperature capabilities
- Improved radiation resistance
- Increased transverse stiffness and strength
- Less moisture absorption
- Increased thermal and electrical conductivity
- Improved processability
- Reduced outgassing
- Increased fire resistance

The primary advantage of composite materials is that they are both lightweight and sturdy. By selecting the correct combination of matrix and reinforcing material, a composite that exactly suits the demands of a certain application may be constructed (Kumar Sharma *et al.* 2020). Many composites give for creative freedom since they may be moulded into complicated designs. The following are the most beneficial properties of composite materials:

- Young's modulus is high.
- High fatigue resistance, especially at high emperatures
- High tensile strength and stiffness
- High-quality durability
- High thermal conductivity and electrical conductivity
- Low concentrations
- High wear resistance (Kumar *et al.* 2020c)

The construction of composite materials, as well as associated design and production processes, represents a major improvement in the engineered materials field (Aktar Zahid Sohag *et al.* 2020). Composites offer unrivalled motorised tribological properties that were tailored to meet the demands of a certain application (Balokhonov *et al.* 2020). Composites are made up of two or more separate components that are insoluble in each other and vary in shape or chemical makeup (Hossain *et al.* 2020). A composite is made up mostly of two parts. One of the components is a matrix, while the other is reinforcement. While the macrostructure is homogenous, the microstructure is heterogeneous (Kumar *et al.* 2020a). For missile conical tips and exit pieces, rocket heat shields, and other applications, carbon fibres were first developed in the late '60s. These materials are now often employed in aircraft braking systems, sophisticated plane components as well as composite materials for both structural and non-structural reasons (Zhang *et al.* 2020). Metal matrix nanocomposites (MMCs) contain carbon black, carbon nanotubes, and other nanofibers to achieve certain properties (Ferdosi Heragh *et al.* 2020). The MMC matrix may be used in high-strength applications thanks to the addition of micro fibres to it (Abbas *et al.* 2020). However, as compared to metals and PMCs, MMCs have certain disadvantages, such as higher end cost, relatively immature technology, and complex production techniques (Sharma *et al.* 2020).

2.0 REVIEW ON VARIOUS REINFORCEMENTS USED IN AMMC'S

Because the reinforcing phase is stronger than the matrix, it is referred to as such. The following characteristics are expected of reinforcement (the reinforcing phase) (Coyal *et al.* 2020).

- Good process ability
- High Young's modulus
- Good mechanical and chemical compatibility
- Low density
- Good thermal stability
- High compression and tensile strength
- Economic efficiency

Organic nonmetal components (such as ceramic particles and carbon fibres) can frequently provide acceptable combinations of the following properties. Continuous, aligned fibres are the most effective reinforcing type, and they are extensively used, particularly in high-performance applications (Gayathri *et al.* 2020). MMCs are often distinguished by their reinforcing characteristics. The reinforcing phase might be fibrous, plate-like, or equiaxed (equal dimensions in all directions), with sizes ranging from 0.1mm to more than 100mm (Nayak *et al.* 2020). The five forms of MMC reinforcements used include continuous fibers, short fibers, whiskers, equiaxed particles, and linked networks (Kumar *et al.* 2020b).

2.1 Carbon Nanotubes Reinforcement

Carbon nanofiber and carbon nanotube reinforced composites have seen a significant increase in research in the last few years. CNTs are attractive reinforcing materials for composites because of their exceptional mechanical qualities, very low thermal expansion (CTE0), and high thermal conductivity (Preethi *et al.* 2021). A number of studies on the thermal characteristics of CNT-reinforced polymer-based composites have recently been published. It has been shown that CNTs can withstand temperatures up to 2700 K in an argon atmosphere or in a vacuum (Savina *et al.* 2021).

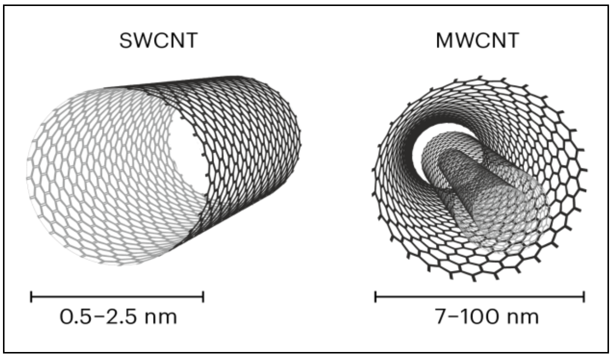

Fig. 1: Carbon nanotube

The carbon nanotubes can be used in various formations which are depicted in the image above. The characteristics and properties of CNT reinforcements are tabulated below.

Table 1. Properties of carbon nanotubes

Parameter	SWCNTs	MWCNTs
Key parameters		
Typical diameter	1 to 2nm	7 to 100 nm
Typical length	Upto 1mm	Up to 1 mm
Aspect ratio	Upto 10000	50–4000
Mechanical properties		
Elastic modulus	1000 to 3000 GPa	300 to 1000 GPa
Tensile strength	50 to 100GPa	10 to 50 GPa
Density	1400	1800 g/dm^3
Electronic structure properties		
Thermal conductivity at 300K	3000 to 6000 W/(m K)	2000 to 3000 W/(m K)
As an anti-static additive, the minimum effective dose	0.01%	0.5%

It was shown that adding up to 15% single walled carbon nanotubes (SWNTs) to the hot pressed nano-Al matrix dropped the CTE by up to 66%, demonstrating that CNTs with the correct composition may drastically reduce composite CTE. An aluminium matrix composite augmented with MWNTs was studied to understand more about its thermal expansion behaviour. Particle dispersion in an Al alloy (AA7075) and MWCNTs composite was studied by (Manickaraj *et al.* 2023b) using the FSP method. Without any agitation, twisted carbon nanotubes are used as reinforcements. To improve CNT dispersion in the Al-alloy matrix, tool rotation frequency and shoulder penetration depth were raised from 1500 to 2500 rpm. Experimental evidence from SEM and TEM shows that the multiwall structure of CNTs is preserved in the Al alloy stir zone's lamella region. Al-alloy matrix CNTs should be evenly distributed in many passes.

The AA7075 alloy and carbon nanotubes were used in the work of Ebrahimzad *et al.* (2017). FSP caused grain refinement and homogenous distribution of CNTs, according to microstructural changes. Tensile characteristics increased dramatically, whereas elongation qualities decreased significantly. The treated composite including CNTs has a micro hardness of 20% higher than the basic Al matrix, whereas the processed AI has a micro hardness of 10% higher. Tensile and wear resistance may be improved by 20% by employing FSP with the following parameters: Tool rotating speed of 1200rpm, feed rate of 40mm/min, and 0.6g of CNT in the surface coating Composite grain size decreased significantly as a consequence of the FSP's dynamic recrystallization An Al1060 composite with CNT reinforcement was studied by (Zhang *et al.* 2019).

Adding CNTs to an Al composite is simpler when the volume % is smaller, but as the volume fraction rises, the CNTs separate. The harder the Al composite matrix becomes, the more CNTs it contains. Composite matrix wear resistance increases dramatically when CNT volume proportions in excess of 5 percent are used. It was practically unchanged when the CNT percentage was substantially larger. It was shown that CNT-reinforced Al1060 composites (Ebrahimzad *et al.* 2017) with changing energy inputs may be made by Shuai Zhang and colleagues (Zhang *et al.* 2019). As previously proven, the mechanical and microstructure characteristics of MMCs are influenced by FSP process parameters, hence the impacts of energy input on these aspects are examined. Composites with varying CNT dispersion and mechanical characteristics may be made using a variety of energy sources. Energy inputs increased, and the grain size shrank.

Prakash *et al.* (2020) are among those who have contributed to this effort. In order to effectively synthesise Al with CNTs composites with stacking defects, high-strain-rate hot rolling and Spark Plasma Sintering (SPS) may be utilised. The resulting microstructure and its impact on mechanical characteristics can then be comprehensively examined. Al matrix containing carbon nanotubes (CNTs) aids in the creation of stacking defects. From 0.5 to 1.0 vol percent of CNT, density functional theory simulation shows that the density of stacking faults increases owing to a condensed Al/CNT composite materials' fault energy stacking. The purpose of this work by Syahid *et al.* (2020) was to employ stir casting to investigate the effect of pouring temperature on the mechanical strength and microstructure of AA6061 (CNT). At a concentration of 0.1 percent by weight, CNT is poured at 700 °C, 730 °C, and 760 °C. Mechanical equipment was used to conduct tensile, hardness, and impact force tests. The highest hardness and tensile strength were 78HV and 80.97 MPa at 700 °C pouring temperature. Lower pouring temperatures lead to finer grain size, which increases strength.

Nayak *et al.* (2020) coworkers to conduct this study, the TiC content is altered from 0.5 to 2 percent at 0.5 percent intervals, while the CNT concentration is fixed at 0.5 percent. In-depth studies of composites' microstructures and mechanical behaviour were conducted. Adding extra reinforcement makes it easier to distribute the particles evenly. The composite density drops due to the volatile nature of the reinforcing particles. Reinforcing components enhance the toughness of composites. Composites wear more slowly at lower loads and with more reinforcement.

Zhang and his colleagues (Zhang *et al.* 2020) used high-energy ball milling and polymer pyrolysis chemical vapour deposition (PPCVD) to create an MMC powder with a CNT-Al composition of 1wt%. A cold gas dynamic spray (CGDS) was utilised to spray-coat MMC powder in order to maintain the AZ91 Mg alloy. This demonstrates that CGDS coatings maintained their stoichiometry and that the CNT and Al4C3 phases observed in the feedstock powder were effectively retained in MMC coatings.

According to Yoo *et al.* (2020) chemical vapour deposition was used to develop a unique one-dimensional template-grown coaxial SiC including carbon nanotubes in this instance. The surface of commercial multiwalled carbon nanotubes (MWCNTs) was coated with Fe_2O_3 using a molecular-level mixing approach to aid the creation of SiC on CNT templates. The Fe-CNTs were sintered with Al6061 alloy and then changed into SiC to make Al6061-SiC nanocomposites employing CNT nanotubes. When 5 vol% SiC was coupled with CNT, the yield strength improved by 46 percent and the Young's modulus increased by 58 percent. This investigation also resulted in a 31 percent reduction in wear and a 45 percent reduction in friction. The most prevalent materials used in the automotive, aerospace, and marine industries are aluminium and its alloys with carbon nanotube reinforcement. Spreading reinforcing particles during SPD may enhance mechanical and tribological properties (Suk, 2021).Carbon nanotubes are added to Al alloys to generate AMCs, which improves their tribological and mechanical characteristics (Fitch *et al.* 2021).

2.2 Silicon Carbide Reinforcement

Previously, researchers concentrated on the silicon carbide addition to increase the aluminium mechanical and tribological characteristics and related alloys. To make composites, the stir casting technique necessitated a significant amount of labour (Surya *et al.* 2022). By increasing content and lowering particle size, silicon carbide particles have been discovered to increase the aluminium mechanical strength and its alloys.

Table 2. Works done with Carbon Nanotubes with Metal Matrix Composites

Process / Technique	Benefits / Process outcomes	Reference
Adding 15% single-walled carbon nanotubes (SWNTs) to hot-pressed nano-Al	CTE was reduced by up to 66%.	Tang *et al.* (2021)
Use FSP settings of 1200 rpm tool rotation speed, 40 mm/min feed rate, and 0.6g CNT to enhance tensile characteristics.	The composites' grain size has been reduced.	Ebrahimzad *et al.* (2017)
With different energy inputs, CNT-reinforced aluminium composites (Al1060) have been studied.	The grain size shrank as the energy inputs increased	Zhang *et al.* (2019)
CNTs composites with stacking faults were effectively produced using SPS and high-strain-rate hot rolling.	The presence of carbon nanotubes (CNTs) aids the creation of stacking faults in the Al matrix. The density of stacking faults increases as CNTs are increased from 0.5 to 1.0 vol %.	Prakash *et al.* (2020)
incorporate CNTs using the stir casting technique and evaluate the influence of pouring temperature on AA6061's mechanical strength and microstructure based on this method (CNT)	At 700 °C, the maximum values of hardness and tensile strength were 78 HV and 80.97 MPa, respectively.	Syahid *et al.* (2020)
A chemical vapour deposition technique was used to produce one-dimensional template-grown coaxial SiC with carbon nano tubes	Young's modulus was increased by 58 percent and yield strength was increased by 46 percent. Wear rate was lowered by 31%, and the friction coefficient was reduced by 45%.	Yoo *et al.* (2020)

Fig. 2: Silicon carbide

The appearance of silicon carbide is depicted in Fig. 2 and its properties are tabulated in Table 3.

Table 3. Silicon carbide characteristics

Property	Values
Melting Point °C	2200 to 2700
Thermal expansion coefficient (micron/m °C)	4.0
Density(g/ cm^3)	3.1
Fracture Toughness	4.6
Hardness(k g/mm^2)	2800
Color	Black
Poisson's ratio	0.14

In fabrication, stir casting is said to be problematic in the preparation of Al-SiC reinforced MMCs because it causes unwanted reactions, gas dissolution, and variances in densities and thermal expansion coefficient, leading in wettability limitations (Agrawal *et al.* 2021). Powder metallurgy is a well-established and effective method for producing Al-SiC MMCs. Powder metallurgical processes, for example, are ideally adapted to the reinforcing phase's low molten metal wettability. Furthermore, using powder metallurgical techniques, a number of research on the preparation and process parameters optimization for the Al-SiC MMCs synthesis could be discovered (Saravanan *et al.* 2020). Zakaria (2014) investigated SiC-strengthened Al composites microstructure and conductivity produced using the PM technique and note dthat adding strengthening reduces corrosion. Sivananthan *et al.* (2020) investigated stir-cast AlMMCs utilising Al 6061 alloy and SiC particles with SiC weight percentages ranging from 0 to 4. By increasing the weight percent of SiC particles in 6061 aluminium alloy, compression strength, resistivity, and tensile strength were all improved. The ductility of aluminium 6061 alloys reduces from 0 to 4 weight percent SIC in the matrix, lowering their use. Compression resistance is a property of a material. The mechanical qualities of 6061 aluminium alloys are projected to improve by up to 12 percent, 25 percent, or 25.6 percent, respectively. Dhanashekar *et al.* (2020) investigated the mechanical properties and wear characteristics of SiC-reinforced AA6061 composites produced by powder metallurgy. According to a study, composite hardness and compressive strength have improved as reinforcement levels have increased. The distribution of material particles in the composites was uniform. When the SiC concentration of a composite is greater, it has a reduced wear rate. In the microstructure of the composite, there is a distinct link between the matrix and reinforcing particles. As the percentage of SiC particles in composites grew, compression strength and hardness increased.

Sarapure *et al.* (2020) used the AlMMc Taguchi technique to investigate corrosion behaviour. Stir casting was used to make the parts, which were made of Al6061 reinforced with SiC at weights of 0%, 2%, and 4%. The Taguchi technique and a design experimental approach were utilised to perform statistical evaluations of AlMMC corrosion characteristics. According to a research, composite materials are more corrosion resistant than monolithic 6061 alloys. According to study, corrosion and weight loss/area both decrease considerably with time. AlMMCs outperformed monolithic unreinforced matrix alloys in terms of corrosion resistance. The influence of SiC particle weight percent on the physical and thermal characteristics of an Al6061/SiCp composite was examined by (Zare *et al.* 2019). SiC and 6061 were employed as reinforcement materials, and powder metallurgy was used in the manufacturing process. Experiments have shown that increasing the reinforcing material reduces CTE. The number of crystalline defects at phase boundaries increased as the composite SiC component in samples increased, lowering thermal conductivity.

The microstructure, hardness, and corrosion characteristics of aluminum-based composites including silicon carbide (SiC) and ferrotitanium (TiFe) particles were investigated by (Akinwamide *et al.* 2021). Microstructural development, micro hardness, and nano hardness parameters of as-cast specimens were examined. Electrochemical testing was carried out on the specimens in a 3.5wt percent sodium chloride (NaCl) solution using potentiodynamic and potentiostatic procedures. The hardness of reinforced specimens was increased by qualities such as an effective load transfer mechanism between the reinforcements and matrix, as well as a limitation on dislocation movement inside the composite (micro and nano). According to potentiodynamic polarisation, the specimens with 5% SiC + 2% TiFe and 5% SiC added had the greatest gain in corrosion resistance. The hybrid composites were created by Squeeze casting A356 alloy reinforced with Al_2O_3, SiC, and Gr particles at varying weight percentages, according to Kumar and his colleagues.

The structural and mechanical properties of the composites were investigated, including density, microstructural characterisation, hardness, tensile strength, yield strength, and elongation percent. The density of the composite increased as the weight % of reinforcement increased. Microstructural and X-ray diffraction investigations revealed that the A356 matrix alloy and reinforcements such as Al_2O_3, SiC, and Gr. The hardness and tensile strength of A356/3wt% Al_2O_3/3wt% SiC/3wt% Gr were equally impressive, measuring 119BHN and 315MPa, respectively.

Karthik Pandiyan *et al.* (2021)used stir casting processes to make composites using AA6061 as the matrix and SiC at various weight percentages. SiC was added to the AA6061 T6 matrix at weighted rates of 0, 5, 10, and 15% in the AA6061 T6 matrix. Density, tensile strength, compression strength, hardness, and impact strength were all measured first.

Table 4. Works done with Silicon Carbide in Metal Matrix Composites

Process/ Technique	Benefits / Process outcomes	Reference
Al composites microstructure and conductivity with SiC strengthening were investigated utilising the PM manufacturing process.	Reinforced material reduces the corrosion rate	Zakaria, (2014)
By using varying weight percentages of Al 6061 alloy enhanced with SiC particles in the stir casting process	Percentage increases in compression strength, hardness tensile strength and ductility.	Sivananthan *et al.* (2020)
SiC reinforced AA6061 composites manufactured by powder metallurgy with various weight percent	Increasing the SiC particle weight percent resulted in an increase in compression strength, hardness, and density in the composites	Dhanashekar *et al.* (2020)
Stir casting process for fabrication and taguchi approach for statistical analysis with SiC at 0%, 2%, and 4% weight	Experiments find that they have high resistance for corrosion As time passes, the corrosion rate and weight loss/area decreases significantly	Sarapure *et al.* (2020)
The weight proportion of SiC particles in Al6061/SiCp composites may alter their physical and thermal characteristics.	Thermal conductivity diminishes when crystalline defects on phase borders grow.	Zare *et al.* (2019)
Studied the as-cast specimen's microstructural evolution, micro hardness, and nano hardness characteristics of SiC reinforcements.	From the potentio dynamic polarization, the specimens supplemented with particles of 5% SiC +2% TiFe and 5% SiC showed the greatest enhanced corrosion resistance	Akinwamide *et al.* (2021)
By employing the squeeze casting process, the hybrid composites were made from A356 alloy reinforced with Al_2O_3, SiC, and Gr particles in various wt%.	Three-quarters Al_2O_3/3 quarters SiC/three-quarters Al Gr had a hardness of 119BHN and a tensile strength of 315MPa.	Senthil Kumar *et al.* (2021)
Stir casting methods were used to make composites using AA6061 as the matrix and SiC in various weight percentages	When the SiC concentration of the AA6061 T6 matrix was raised, the density values rose. When SiC was added to AA6061 T6 at 15% weight percent, there were considerable improvements in tensile, compressive, and impact strengths as well as hardness values.	Karthik Pandiyan *et al.* (2021)

Dry sliding wear was used to study the tribological behaviour of the synthesized composites. Tribological wear studies were performed on the AA6061 T6 matrix with 5, 10, and 15% SiC by weight. The density values grew as the SiC concentration of the AA6061 T6 matrix increased. When SiC was added to AA6061 T6, the maximum tensile strength, compression strength, impact strength, and hardness all rose by 15%. According to the findings, Silicon Carbide reinforcement lowers corrosion and enhances compressive strength, hardness, ductility, and tensile strength. Powder metallurgy is the best method for fabrication of composite. Thermal conductivity diminishes when the number of crystalline flaws increases at the phase boundaries.

2.3 Boron carbide reinforcement

Boron carbide (B4C) is a useful reinforcing material that has 2.52 g/cm^3 density and 427GPa elastic modulus. Aluminum is a commonly accessible, light-weight foundation material for matrix that is reactive to B4C under the right processing circumstances (Manikandan *et al.* 2020). Composites have been proposed for usage as a structural neutron absorber, armour plate materials, and a computer hard disc substrate (Meignanamoorthy *et al.* 2021).

Fig. 3: Boron carbide

The Boron carbide reinforcing material is displayed above, and the different boron carbide properties are summarized as follows.

Table 5. Boron carbide properties

Properties	Boron Carbide (B4C)
Boiling point	3500 °C
Melting point	2763 °C
Appearance	Crystalline solid
Molecular Weight	55.25 g/mol
Specific Gravity	2.1
Density	2.52g/cm^3
Thermal Conductivity	28 W/m-K @ 30 °C
Color	Black
Knoop Hardness	2750 kg/mm^2

Boron carbide (B4C) is very hard owing to its boron-carbon ceramic composition. It has a high density of 2.51 g/cm^3 and is regarded as one of the most durable materials on the market. Boron carbide is a common neutron absorber in nuclear power reactors because of its ability to absorb neutrons that produce long-lived radionuclides (Gao *et al.* 2020). Aluminum-reinforced boron carbide composites are notable for their great strength and toughness. These features suggest that B4C and aluminium composite materials have a lot of potential in the industrial industry (Singh *et al.* 2021). The manufacturing of aluminium composites reinforced with boron carbide is hampered by many intrinsic flaws in boron carbide as a single form, such as its brittleness and the need for high heat treatment temperatures due to its high melting point. The brittleness problem is solved by using boron carbide as reinforcement in an aluminium matrix composite (Manohar *et al.* 2021).

The tensile performance of hybrid composites may be enhanced by using a certain proportion of reinforcements. To attain optimal tensile characteristics in Al2014 composites, it is advised that 6 percent boron carbide and 8 percent copper coated basalt fibre be used. B4C/Al nanocomposites made using the PM technique were found to have the highest hardness and compression strength, according to (Alihosseini *et al.* 2017; Kaviti *et al.* 2018) investigated the microstructure and mechanical behaviour of mechanically alloyed and PM-fabricated AA6061—Al_2O_3 nanocomposites.

Bodukuri *et al.* (2021) investigated the mechanical behaviour of B4C/SiC/Al powder metallurgic composites. Soundararajan *et al.* (2017) produced and analysed x-ray diffraction of a mechanically alloyed Al_2O_3 reinforced nanocomposite. Ravichandran *et al.* (2022) discovered reinforcing particles in Al–TiO_2–Gr composites using microstructure and EDAX analysis (Ravichandran *et al.* 2022). Hassan *et al.* (2012) observed that the weedy micro galvanic interaction between reinforcement particles and alloy improved the corrosion resistance of powder metallurgy-fabricated Cu-30Zn brass composites (Hassan *et al.* 2012). Iqbal *et al.* (2017), who studied the mechanical properties of Al_2O_3 and Gr-added hybrid composites, concluded that combining these two materials considerably improves AMC performance. Si-3.5 wt% Al-8.5 wt% Al-8.5 wt% Al-8.5 wt% Al-8.5 wt% Akçamlı *et al.* (2021) developed Cu matrix composites that were considerably enhanced in mechanical performance by adding B4C particles. When employing the PM technique to create Al6061-Al_2O_3-SiC-CeO_2 composites, (Chaudhary *et al.* 2021) observed that increasing the reinforcement weight percent enhances the mechanical behaviour of the composite substantially. Karakoç *et al.* (2018) discovered that adding additional reinforcing particles to Al6061/SiC/B4C hybrid composites manufactured using the PM technique increased mechanical characteristics.

Table 6. Works done with Boron Carbide in Metal Matrix Composites

Process / technique	Benefits / process outcomes	Reference
Behavior and characterization using PM technique	Composites produced have high hardness and compression strength	Alihosseini *et al.* (2017)
Mechanical alloying and PM were used to study the structure and behaviour of AA6061-Al_2O_3.	Mechanical qualities are constantly improving.	Kaviti *et al.* (2018)
Powdered B4C/SiC/Al was used to create a metallurgic composite.	The mechanical behaviour of powder metallurgic composites was investigated, and the findings were assessed.	Bodukuri *et al.* (2021)
Mechanical alloying was used to study the x-ray diffraction of an Al_2O_3 reinforced nanocomposite.	The thermal characteristics of the composite have been enhanced thanks to the nano composite.	Soundararajan *et al.* (2017)
Al–TiO_2–Gr composites microstructure and EDAX analysis	The reinforcement particles were strewn over the matrix.	Ravichandran *et al.* (2022)
Cu-30Zn Brass with and without SiC reinforcement was tested for corrosion characteristics.	As a consequence of the weedy micro galvanic combination, the composites' corrosion resistance enhanced.	Hassan *et al.* (2012)
Investigated the mechanical properties of Al+Gr+Al_2O_3	improves the mechanical behaviour of AMCs	Iqbal *et al.* (2017)
8.5 wt% Al in construction Si-3.5 wt% Si-3.5 wt% Si-3.5 wt% Composites with a copper matrix	adding B4C particles improves the mechanical performance of the composites significantly.	Akçamlı *et al.* (2021)
PM approach to make Al6061-Al_2O_3-SiC-CeO_2 composites	increasing the reinforcing weight percent improves the composite's mechanical behavior significantly	Chaudhary *et al.* (2021)

They were tested for microstructure, density, and hardness before being employed, in addition to tensile and compressive strength testing and dry sliding wear characteristics. The microstructure reveals a homogeneous distribution of microscopic particles in its microstructure since it has no holes in its framework or composite (Nagaral *et al.* 2021). The presence of boron carbide in the Al2024 alloy matrix is shown by XRD. The B4C particle-reinforced composites with a 44-meter diameter had greater hardness, tensile strength, and compression strength than the Al2024 alloy. Metal composites are not much lighter than Al2024 alloys (Pakdel *et al.* 2018). In the tension-shattered surface, fault lines are readily evident. The wear resistance of the Al2024 alloy was also increased by including 44-m-sized particles into the cast alloy. The wear behaviour of Al2024 alloy and its composites is affected by sliding speed and load. The wear loss of Al2024 alloy and its boron carbide-reinforced composites increased as load and speed increased. Wear resistance has been enhanced, as shown by SEM photos of worn surfaces and wear debris (Guo *et al.* 2012).

2.4 Graphene reinforced metal matrix composite

It's one layer thick when it comes to graphene. The honeycomb structure, which has a sp2-hybridized two-dimensional structure, is fascinating to many individuals all over the globe. Graphene, according to the strongest substance yet tested, is the ideal material for a wide range of future applications. Due to the intense reactivity of metals, the significant density difference between graphene and metal matrix, and the greater interfacial contact area compared to carbon nanotubes, graphene dispersed metal matrix composites cannot be made using traditional metallurgical processes.

Metal matrix composites may be made via semi-powder metallurgy, a well-known solid-state process. Graphene-based metal matrices may be made using this technology (Güler *et al.* 2020). Aluminium oxide is created during the sintering process when aluminium is oxidised. Because of a substantial coefficient of thermal expansion mismatch, dislocations are encountered at interfaces between graphene and matrix materials, reinforcing the composite matrix. The appearance of graphene for the reinforcement in a metal matrix composite is depicted above. The unique characters of graphene in reinforcement with a MMC is tabulated below.

Fig. 4: Graphene

Table 7. Graphene unique physical properties as reinforcements

Charge-carrier-mobility	200000 $cm^2/V \cdot s$ (approximately)
Thermal-conductivity	5000 $W/m \cdot K$ (approximately)
Transparency	97.4% (approximately)
Specific-surface-area	2630 m^2/g (approximately)
Young's modulus	1 TPa (approximately)
Tensile strength	1100 GPa (approximately)
Bandgap	Zero

When dispersing GNFs, Al-GNPs, and Mg-1 percent A-1 percent Sn alloys using a mechanical agitator, the first category used ethanol, while the second group used acetone. According to the results of the X-ray mapping, the GNPs are evenly distributed throughout the composites (Song *et al.* 2020). By using electrodeposition to build the next generation of Cu-Gr composites, researchers hope to improve both the materials' mechanical and electrical properties. Researchers combined nickel sulphate solution with 1 g/L GO nanosheets floating in water to make graphene/Ni composites. GO nanosheets were pushed atop the cathode surface by magnetic stirring, preventing them from sinking. Fig. 3 shows Ni/Graphene that was held at 55 °C by an autonomous heat management system (c). Furthermore, the low temperature of the electro deposition method preserves the Gr/Go properties throughout the composite production process.

For the Mg-Gr composite, GNFs were injected into a 700 °C Mg melt and ultrasonicated for 15 minutes with an amplitude of 60 micrometres. When treating GNFs in liquid molten state, ultrasonic processing is frequently regarded as the best option (Bartolucci *et al.* 2011). However, SEM image failure has been seen (Bartolucci *et al.* 2011). Milling graphene to the Al particle during milling in a high-energy attritor with stearic acid to reduce agglomeration and milling cycles that add some refinement may result in graphene adhering to the Al particle during milling (Kumar *et al.* 2014). To establish a long-lasting dispersion of Gr in ethanol with a low melting point, the solvent exchange approach may be applied (Kusuma *et al.* 2021). This is essential for the production of composites and other Gr-based products.

Rajaganapathy *et al.* (2020) and colleagues, for example, are working on graphene-based aluminium matrix composites with titanium particles (AA 6082). The features of graphene and titanium were investigated by increasing the weight percentages in which they appeared. For example, when mixed with 1 percent Ag Nanoparticles and Jatropha oil, the mechanical and tribological performance of AA6082 Aluminum Matrix Composites with G and 3 percent Ti was proven to be better. Sharma *et al.* (2021) investigate the compositional performance of Al-GNP composite surfaces using an enhanced FSP approach. Rather of a single huge groove, GNPs are injected into an aluminium matrix via a succession of microscopic channels (MCRF) (SCRF). This strategy resulted in a 14 percent reduction in friction and wear rates when compared to utilising the SCRF app. A proposed reinforcement filling approach for SCRF-produced composites improves particle dispersion in the matrix, changing the wear mode from adhesion to abrasion. GNPs and graphene oxide (GO) are being investigated in separate research programmes.

GNFs are currently dispersed into the matrix via chemical, mechanical, and electrode deposition methods (Repeto *et al.* 2020). To achieve the composite's even properties, a uniform distribution of the second phase is necessary.

Table 8. Review on Graphene used as Reinforcement with MMC

Process/ technique	Benefits/ process outcomes	Reference
Ultrasonically dispersed in ethanol using a mechanical agitator	GNFs and Al-GNPs were separately ultrasonically dispersed in acetone	Tabandeh-Khorshid *et al.* (2020)
Cu-Gr composites, made by electrodeposition	improve mechanical qualities while maintaining electrical properties	Song *et al.* (2020)
Electrodeposition procedure for graphene/ Ni composites	characteristics of Gr/Go are protected	Azimi *et al.* (2021)
Ultrasonic processing for processing GNFS	SEM image failure in molten metal dispersion has been seen	Bartolucci *et al.* (2011)
High-energy attrition milling using a Zoz	Al and graphene might react during the milling process.	(Kumar *et al.* 2014)
Solvent exchange approach	used for days as a distributed solution in composites and Gr-based products	Kusuma *et al.* (2021)
Researchers studied the effect on mechanical properties when the graphene and titanium reinforcement weight percentages were increased.	The mechanical and tribological characteristics of aluminium matrix composites supplemented with 3% G and 3% Ti were improved.	Rajaganapathy *et al.* (2020)
Using a modified friction stir processing (FSP) method, we evaluate the surface performance of Al-graphene nanoplatelet composites (GNPs).	Increases particle dispersion in the matrix Abrasive mode of wear in SCRF composites created by modifying the adhesion mode of wear Lowering degradation rates.	Sharma *et al.* (2021)

2.5 Fiber reinforced composites

This kind of MMC is comprised of both matrix and fibres. The matrix holds all of the reinforcements in place with the help of fibres. Asbestos, carbon, glass, aluminium and tungsten are some of the most common fibre materials(Nithyanandhan *et al.* 2022).

Fig. 5: Carbon fiber

Fig. 6: Glass fiber

There are wide range of fiber reinforcements available for composites. For illustration just two widely used and advantageous fibers are depicted above.

Table 9. Carbon fiber properties

Specific gravity	1.79
Tensile strength, MPa	3900
Length(mm)	12
Diameter(μm)	10 to 13
Elongation at break(%)	15
Density(g/cm³)	1.785
Tensile modulus GPa	225

The properties of carbon as fiber is tabulated above and the characters of glass fiber is tabulated below. Both are highly used fibers and similarly large varieties of fiber are used.

Table 10. Property glass fiber

Property	Value
Appearance	white
Density(g/cm^3)	0.91
Tensile strength	> 600 MPa
Fire reaction flame-resistant	
Melting point	12000 ºC
Crack elongation (%)	10 minimum
Elastic modulus	> 3500 MPa

They may be either continuous or discontinuous and have a diameter of less than 20 mm in fiber-reinforced MMC. Before the composite is made, the fibres might be arranged in a certain pattern or pre-woven. Unidirectional or bidirectional orientation of continuous fibres is possible (all fibres aligned in two directions, typically perpendicular to each other). In either a single-direction or random arrangement, discontinuous fibres can be used. On the other side, industrial technology is used to change continuous fibres into a variety of reinforcing forms, allowing for greater through-thickness strength and ease of manufacture. Glass fibre, carbon fibre, boron fibres, silicon carbide fibres, alumina fibres, aramid fibres, and high density polyethylene fibres are examples of brittle ceramic or carbon fibre reinforcements.

Optimal load transmission is achieved when continuous fibres are employed, since the fibre ends do not offer complete stress support.. The fiber's "end effect" is to blame. While continuous fibres have a much lower aspect ratio, they nonetheless have a significant impact because of their high aspect ratio. The greatest mechanical qualities and commercial potential may be found in continuous fiber-reinforced MMCs. Aluminum-based composites may be manufactured using a variety of production processes (Bielinski *et al.* 2021). Fiber-reinforced MMCs have good heat conductivity, low coefficient of thermal expansion, specific stiffness, and strength. Boron-aluminum tubular struts, the first continuous fibres to be utilised in space, have been successfully employed for the first time. (Manickaraj *et al.* 2023a) investigated Ti-matrix and Al-matrix composite specimens using the push-out test. The fibres were oriented perpendicularly in order to create the composite. The contact behaviour of the SiC/Al combination had almost all friction. The MMCS interface was carefully inspected due to the efficacy of the push-out test.

Teke *et al.* (2020) created it to explain the outcomes of push-out research. For composites with chemically connected surfaces, the load–displacement data revealed a change in slope. There was just a little difference in the slope of composites with frictionally coupled fiber–matrix connections. Shetty *et al.* (2021) claims that shear lag analysis on a single fibre push-out test may be used to quantify sliding friction magnitude stress at the interface of CMCs. Shear strength decreases dramatically over the length of the fibre. Slippage stress may be underestimated if fibre transverse expansion is not taken into consideration.

Researchers (Mao *et al.* 2018) used the shear lag analysis model to see how well it predicted the mechanical features of a contact. The BEM and SLA were utilised to compute the fiber–matrix contact coefficient of friction. Between the two statistics, there was a 15% difference. Interfacial residual radial stress was found to vary by just 1%. Interfacial stresses were found to be uniform across the specimen thickness in both SLA and BEM. There was a 20% difference in maximum push-out force between BEM and SLA. During the investigation, the friction coefficient, fiber-to-matrix modulus ratio, and fibre volume % all varied dramatically. With the initial push force, no temperature change was seen in composites having a mullite matrix. As the temperature rises, the second push stress increases. CMCs have been shown to have lower stress levels than titanium matrix composites (TMCs). Field-aided sintering samples with discontinuous fibres showed adequate toughness, according to (QU *et al.* 2011).

According to Zasadzińska *et al.* (2020), composites containing 1, 2, and 5% glass fibres were manufactured using aluminium powder extrusion consolidation as a reference material. Compression testing was used to assess the microstructure, density, electrical properties, inflexibility, and sensitivity to plastic treatment of all materials. Electrical conductivities measured using the rule of combinations and glass fibre content showed that samples containing 5wt. percent GF had higher electrical conductivities (30.6MS/m) than those produced through extrusion. To boost the strength of Al7005, a high-strength alloy, fly ash and S-glass fibres (Swamy *et al.* 2021) were used as reinforcing components. There were four different samples: Al7005, Al7005, +5% GF, Al7005, +6% FA, and Al7005, plus 5% GF. A variety of extrusion ratios were used to test extrusion properties (ER: 5.32:1, and 2.66:1). The corrosion resistance of Al7005 +6% FA is the greatest. When extrusion ratios were raised in a gravimetric study, corrosion rates were lowered due to better corrosion passivation and improved features. Because to flakes, enhanced corrosion fit, and micro-cracks, as-cast composites have a greater corrosion rate than extrusion composites.

Carbon, aramid, boron, and polypropylene fibres are among the high-performance fibres used in advanced composites. Since carbon fibre is becoming more popular, manufacturers are reacting by creating carbon fibres that can be used with a greater variety of resins and manufacturing processes. Optimized sizing for high-speed material manufacturing is now available from high-performance fiber suppliers.

Table 11. Review on Polymer used as Reinforcement with MMC

Process/ Technique	Benefits / Process outcomes	Reference
eject test on Ti-matrix and Al-matrix specimens	Interface investigation is carried out using push out test	Manickaraj *et al.* (2023a)
Push-out experiments for analysis of materials	Slow changes occur in the slope of composites	Teke *et al.* (2020)
Push-out test on a single fibre	The amount of sliding friction stress at the CMCs contact was calculated.	Shetty *et al.* (2021)
Shear lag analysis model, BEM and SLA	Frictioncoefficient at the fiber–matrix interface is calculated and there is change in the ratio of fiber to matrix modulus, and fiber volume fraction	Mao *et al.* (2018)
Field aided sintering process	They had a suitable quantity of toughening	Qu *et al.* (2011)
Aluminium powder extrusion consolidation produced additional material for the glass fibre composites, which were used in their production.	The samples electrical conductivity created by metallurgical synthesis is greater than that calculated using the rule of mixtures.	Zasadzińska *et al.* (2020)
A high-strength alloy called Al 7005 was reinforced using industrial wastes such fly ash (FA) and S-glass fibres (GF).	As the extrusion ratio rose, the corrosion rates decreased, which might be attributable to improved corrosion passivation and features. A greater number of microcracks and corrosion fits were found in cast composites compared to extruded composites.	Swamy *et al.* (2021)

3. SUMMARY

The materials which is to be chosen for the reinforcement must be studied thoroughly based on the force needed to be withstand based on the material applications. Carbon nanotubes have an extraordinarily high heat conductivity, thus allowing them to be employed for thermal management in metal matrix carbon nanotubes. The silicon carbide adding to the Metal Matrix Composite enhances the density of dislocations at the particle–matrix contacts. Reinforcement of Boron Carbide particles in aluminium matrix increases ultimate stress, breaking load, maximum displacement, and flexural strength. Graphene has an advanced specific surface area and a lower inclination to weave than carbon nanotubes, making it easier to disseminate into a matrix while also increasing mechanical qualities such as strength and stiffness. Generally, loads are carried mostly in longitudinal directions by fibers which transmits stresses among fibers and thus to protect material from mechanical and environmental damage.

- Reinforcing more numbers of reinforcement with required composition is the best way to obtain the optimum material matrix composite. Reinforcing more number of composite allows to obtain the physical and mechanical properties of many particulates as per the requirement of the composites application.
- The components impacting the homogeneity of reinforcement dispersion of reinforcement in manufacturing are impacted by different tool profiles. The improved hardness of the metal is due to more even reinforcement dispersion within the matrix. For most composites with a large number of FSP passes, Friction Stir Processing allows for a superior fabrication process. The tool rotation speed, number of FSP passes, feed rate, and reinforcement amount provided to matrix are all important process elements that must be carefully chosen in order to get a flawless composite.
- There are huge studies made in the metal matrix composite to enhance its various properties. Still there is a need to focus on bringing up reinforcements with low economic cost and low weight without compromising the mechanical and tribological strength of the material.

4. CONCLUSION

The numerous reinforcements mechanical and tribological properties utilized in Metal Matrix Composites were carefully examined in this survey. Carbon Nanotubes were discovered to be a commonly utilized reinforcement for a broad range of applications. Because of its sp2-hybridized two-dimensional honeycomb structure, graphene has unique features and is the strongest material with great thermal stability. Silicon Carbide is another popular reinforcing material. Boron Carbide was found to be the toughest material used as a reinforcement which enhances the strength efficiently. Fibers are also widely used reinforcement now-a-days wide range of materials are used as fiber reinforcement. Thus the most used reinforcement materials have been evaluated and the works were discussed briefly in this research.

5. FUTURE SCOPE

Due to its superior required properties, metal matrix composites have a diverse variety of uses, which motivates further research. The matrix phase and reinforcement in composites are determined by the composites intended use. The characteristics of the composites were also impacted by the fabrication process. It would be significant to conduct additional study on hybrid processing methods and the development of current and novel processing routes for the hybrid AMNCs fabrication in order to improve their characteristics. Also, for the manufacturing of AMNCs, there is a lot of scope for creative reinforcing material combinations. Despite the fact that the metal-matrix grain size is one of the most fundamental elements in defining the mechanical characteristics of AMNCs, many prior research have failed to take appropriate grain size measurements.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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