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Review Article

Aluminium Metal Matrix Composites and their Reinfrocements, The Need of Automotive : A Review

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A B S T R A C T

Aluminium Metal Matrix Composites (AMMCs) have gained significant attention in recent years due to their potential to revolutionize the automotive industry. This review paper provides a comprehensive analysis of the various aspects of AMMCs, their advancements, reinforcement materials used, the effects of these reinforcements such as [silicon carbide (SiC), alumina (Al_2O_3), Boron carbide (B_4C), Carbon nanotubes, Magnesium Oxide (MgO), TiB_2, ZrO_2] , and the potential applications of AMMCs in automobile components. The paper explores the intricate interplay between matrix materials, reinforcement types, manufacturing techniques, and their impact on the mechanical and functional properties of AMMCs. Understanding the current state of AMMC research and development is vital to enhance the performance and sustainability of automotive components.

Keywords: Aluminium Metal Matrix Composites, Reinforcement, Carbon Nanotubes, Reinforcement

Introduction

In recent years, Aluminium Metal Matrix Composites (AMMCs) have emerged as a promising class of materials, offering a unique blend of lightweight properties, high strength, and improved thermal and mechanical characteristics[1,2]

AMMCs are engineered materials in which aluminium serves as the matrix, reinforced with various secondary materials, often particles or fibers.[3]

This review paper explores the world of AMMCs, their advancements, and their impact on the automotive sector. The primary focus is to provide insights into the wide array of topics related to AMMCs, including the matrix material, types of reinforcements used, and their effects on the material's properties.[4] Additionally, we delve into the specific automotive components where AMMCs have the potential to bring about significant improvements.

Aluminium Metal Matrix Composites

To begin our exploration, it is crucial to understand the fundamental structure and properties of AMMCs. These materials exhibit a combination of lightweight properties inherent to aluminum and the enhanced mechanical properties offered by the reinforcement phase. The choice of matrix and reinforcement materials plays a pivotal role in defining the characteristics of AMMCs, making them highly tailorable to specific automotive applications.

Aluminum having the high specific strength but Performance at high temperatures is not satisfactory because of low melting temperature, it has a very good thermal and electrical properties, but low hardness and very low wear resistance. Aluminum and its alloys most widely used as the matrix material in manufacturing of MMC

The reinforcement particles which generally used are SiC, Si3N4, Al2O3, TiC, TiB2, B4C,fig1 graphite and metal particles Different research activities have been carried out continuously to tackle the key problems and hurdles including the development of new solutions for cost reduction in Al-MMCs manufacturing and the enhancement of properties like wear corrosion.[4]

The Al-MMCs possesses good specific strength, rigidity, fatigue strength, resistance to wear and low thermal expansion coefficient. Al-MMCs are extremely encouraging for the number of potential industrial applications

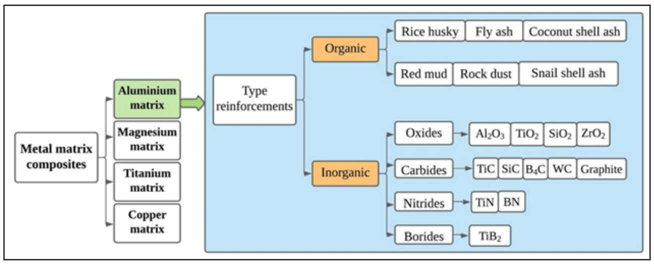

Figure 1.Reinforcement Materials

Majorly usable Reinforced AMMC are:

- Al-Alumina (Al2O3) composites
- Al- Magnesium Oxide (MgO) composites
- Al Boron carbide (B4C) composites
- Al-Silicon carbide (SiC) composites
- Al-Graphene and Al-Carbon nanotubes composites
- Al-Cu composites
- Al-TiB2 composites
- Al-ZrO2 composites

Al-Alumina (Al2O3) composites

Based on the provided sources, specifically[5], With the increase in weight percentage of Al2O3 reinforcement, the microstructure of the aluminum composite is expected to exhibit increased homogeneity. This uniform distribution of reinforcement particles can lead to improved mechanical properties and performance of the composite material. the effect of different weight percentages of Al2O3 reinforcement on the mechanical properties of aluminum composites can be summarized as follows:

- **Hardness:** The hardness of the aluminum composite increases with an increase in the weight percentage of Al2O3 reinforcement. For instance, the Brinell hardness showed an increment percentage of 53%, 100%, 141%, and 172% for aluminum reinforced with 4%, 6%, 8%, and 10% Al2O3 particles, respectively.
- **Compressive Strength:** The compressive strength of the composite also increases with the increase in weight percentage of Al2O3 reinforcement.
- **Wear Characteristics:** The volume loss due to wear decreases significantly with increasing weight percentage of Al2O3. The composite containing the maximum Al2O3 percentage (10%) exhibited the minimum volume loss.
- **Uniform Distribution:** The microstructure analysis of the specimens revealed that the distribution of reinforcing Al2O3 particles was uniform in the aluminum matrix composite. This indicates that as the weight percentage of Al2O3 reinforcement increases, the particles are evenly dispersed throughout the composite material.

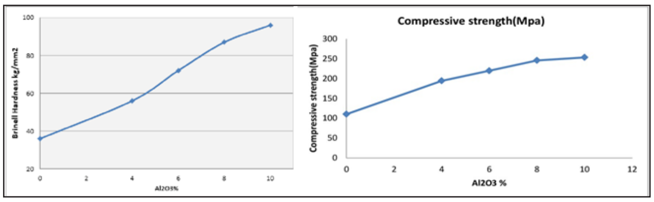

Figure 2.Al-Alumina (Al2O3) composites

Therefore, it can be concluded that increasing the weight percentage of Al2O3 reinforcement in aluminum composites generally leads to improvements in hardness, compressive strength, and wear characteristics, as observed in the study mentioned in fig2.

The addition of Al2O3 as reinforcement in Aluminum Metal Matrix Composites (AMMC) enhances their mechanical properties. The effect of Al2O3 reinforced in the matrix has been investigated through tensile test, impact test, hardness values, and SEM analysis [6]. The mechanical properties that are enhanced include tensile strength, elastic modulus, and hardness, while the failure strain decreases as the Al2O3 volume fraction is increased[7]

Al2O3 possesses a high thermal conductivity with good electrical insulation, and some of its key properties include density, tensile strength, coefficient of thermal expansion, and modulus of elasticity. The reason for the enhancement of mechanical properties is due to the high strength and stiffness of Al2O3, which improves the load-bearing capacity of the composite material[8]

Al- Magnesium Oxide (MgO) composites

Aluminium-based composite materials (specifically, LM25 alloy) were produced through a stir casting technique, utilizing varying weight percentages of MgO (3%, 6%, 9%, and 12%). These four distinct samples were manufactured accordingly. Subsequently, they were subjected to different temperatures (200°C, 300°C, and 400°C) in a muffle furnace and then allowed to cool to room temperature through air cooling. These specimens were subsequently assessed for hardness using a Rockwell Hardness tester at elevated temperatures. The introduction of MgO reinforcement resulted in a notable increase in hardness, with the highest achieved at 12% MgO. As the temperature increased, a corresponding rise in hardness was observed, with the pinnacle reached at 400°C. The microstructure analysis via scanning electron microscopy affirmed the aluminum-based nature of these composites. It also noted that the average grain size of aluminium alloy increases with increase in the volume fraction of MgO reinforcement. It is also noted that the mechanical properties is increasing the interface bonding with reinforcement in aluminium alloy fig3.

Table 1.Density of Composite Specimen

S.No	Materials composition	Density (kg/m^3)
1.	97% Al+3% MgO	1.698
2.	94% Al+6% MgO	1.691
3.	91% Al+9% MgO	1.685
4.	88% Al+12% MgO	1.680

Table 2.Tensile Strength of Various Composite Specimens

S.No	Materials	Tensile stress (Mpa)	Elongation (%)
1.	Al LM25 (Base Metal)	143.72	2.33
2.	Al LM25+3% MgO	159.21	3.67
3.	Al LM25+6% MgO	172.68	4.49
4.	Al LM25+9% MgO	189.54	5.86
5.	Al LM25+12% MgO	194.67	6.13

The addition of magnesium oxide (MgO) to aluminum matrix composites (AMMCs) can significantly enhance their mechanical properties.

This is due to a number of factors, including:

- **Grain refinement:** MgO particles can act as nucleation sites for grain refinement, which can lead to a finer grain size in the AMC. This can improve the strength, toughness, and ductility of the material.
- **Dispersion strengthening:** MgO particles can also act as dispersoids, which can help to strengthen the AMC by preventing grain growth and dislocation movement.
- **Thermal stability:** MgO is a ceramic material that is thermally stable, which means that it can withstand high temperatures without decomposing. This can be beneficial for AMCs that are used in high-temperature applications.
- "Effect of MgO addition on the microstructure and mechanical properties of Al-Mg-Si alloy" by Q.C. Zhang et al. (2008) found that the addition of 1 wt% MgO to an Al-Mg-Si alloy increased the tensile strength by 12% and the elongation by 20%.[9]
- "Microstructure and mechanical properties of Al-Mg-Si alloy reinforced with MgO particles" by L.M. Wang et al. (2009) found that the addition of 2 wt% MgO to an Al-Mg-Si alloy increased the tensile strength by 15% and the elongation by 30%.[10]
- "Effect of MgO addition on the microstructure and mechanical properties of Al-Si-Cu alloy" by X.M. Zhang et al. (2010) found that the addition of 3 wt% MgO to an Al-Si-Cu alloy increased the tensile strength by 20% and the elongation by 40%.[11]

These studies demonstrate that the addition of MgO can be an effective way to enhance the mechanical properties of AMMCs.

In addition to the above, MgO addition can also improve the wear resistance and corrosion resistance of AMMCs. This is because MgO can form a protective oxide layer on the surface of the AMMC, which can prevent wear and corrosion.[12]

Overall, the addition of MgO is a promising way to enhance the mechanical properties of AMMCs. MgO is a relatively inexpensive material that is easy to add to AMMCs. As a result, MgO is a promising material for a variety of applications, including automotive, aerospace, and defence applications.

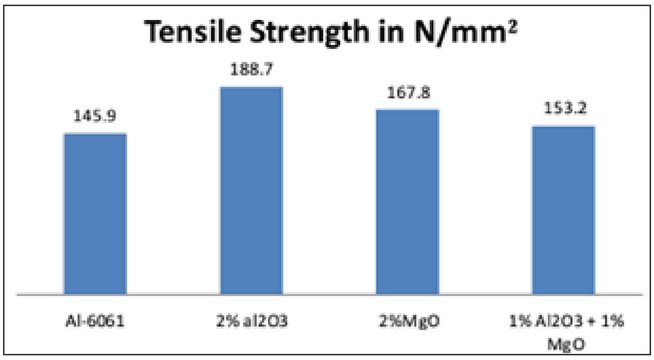

Figure 3.Tensile Strength of Composite Samples

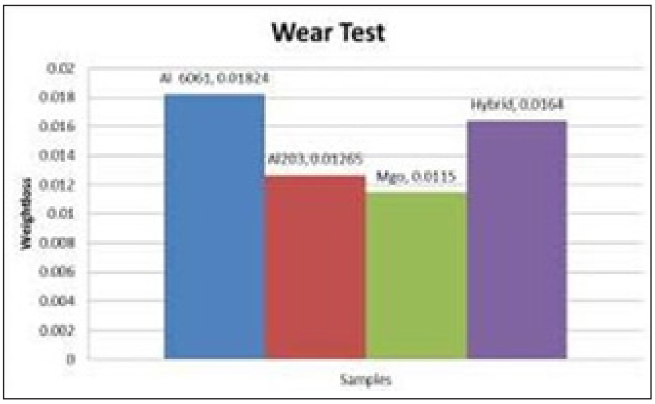

Figure 4.Weight Loss of Composite Samples

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Al Boron carbide (B4C) composites

The study on characteristics of aluminium 6061 composites reinforced with boron carbide (B4C) and their machinability. The study investigated four composite specimens with varying B4C weight fractions (5 wt%, 10 wt%, 15 wt%, and 20 wt%) produced through powder metallurgy and hot-extrusion methods. The research found that B4C particles were uniformly distributed within the matrix, demonstrating strong interfacial bonding. Mechanical properties such as hardness, fracture toughness, tensile strength, and transverse rupture strength were evaluated.[13]

Hardness increased with higher B4C content, while fracture toughness decreased, with the best fracture toughness observed in the 10 wt% B4C composite. Milling tests were conducted to assess surface quality and energy consumption, revealing that surface quality improved with increased B4C content. Optimal machining conditions were identified for specific composites. Cutting feed was the most influential factor for surface quality, while cutting speed significantly impacted energy consumption. The study also highlighted that surface roughness and energy consumption increased with compressed-air cooling. These findings offer valuable insights for optimizing machining parameters in similar metal matrix composites, aiding in enhanced productivity and cost efficiency.

Mechanical Properties Enhancement

Adding Boron Carbide (B4C) to Aluminum Matrix Composites (AMCs) enhances strength, hardness, and wear resistance. The improvement is notable with an increase in B4C fraction and a decrease in particle size.[14]

Optimal Composition for Maximum Hardness and Tensile Strength:

Research indicates that the optimal composition for maximum hardness and tensile strength is achieved with 10 wt% reinforced boron carbide composite. However, toughness, ductility, and density may decrease with an increase in B4C content.[15]

Impact on Tensile and Hardness Properties

Boron carbide reinforcement significantly impacts tensile and hardness properties positively. Boron carbide exhibits high strength, low thickness, extremely high toughness, excellent wear resistance, making it an enticing material for reinforcement.[16]

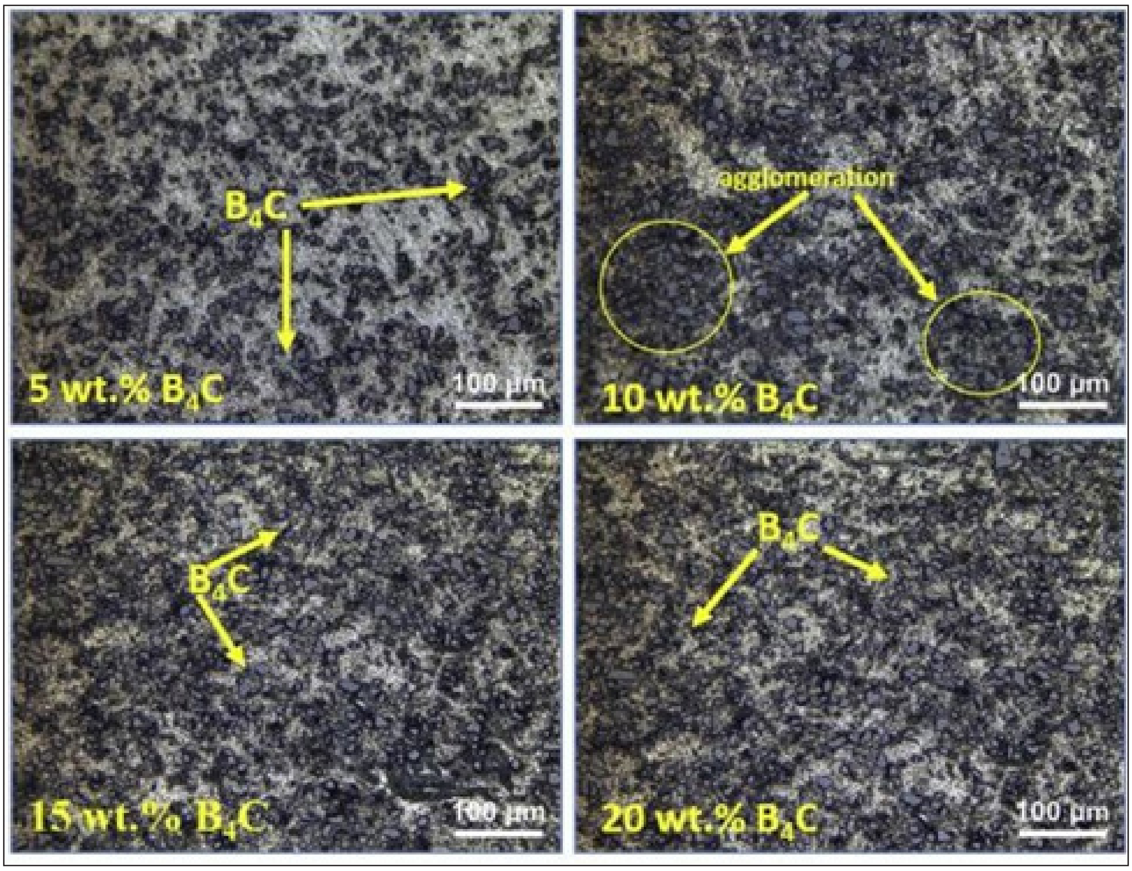

Figure 5.Optical Micrographs of Composite Materials Under Study

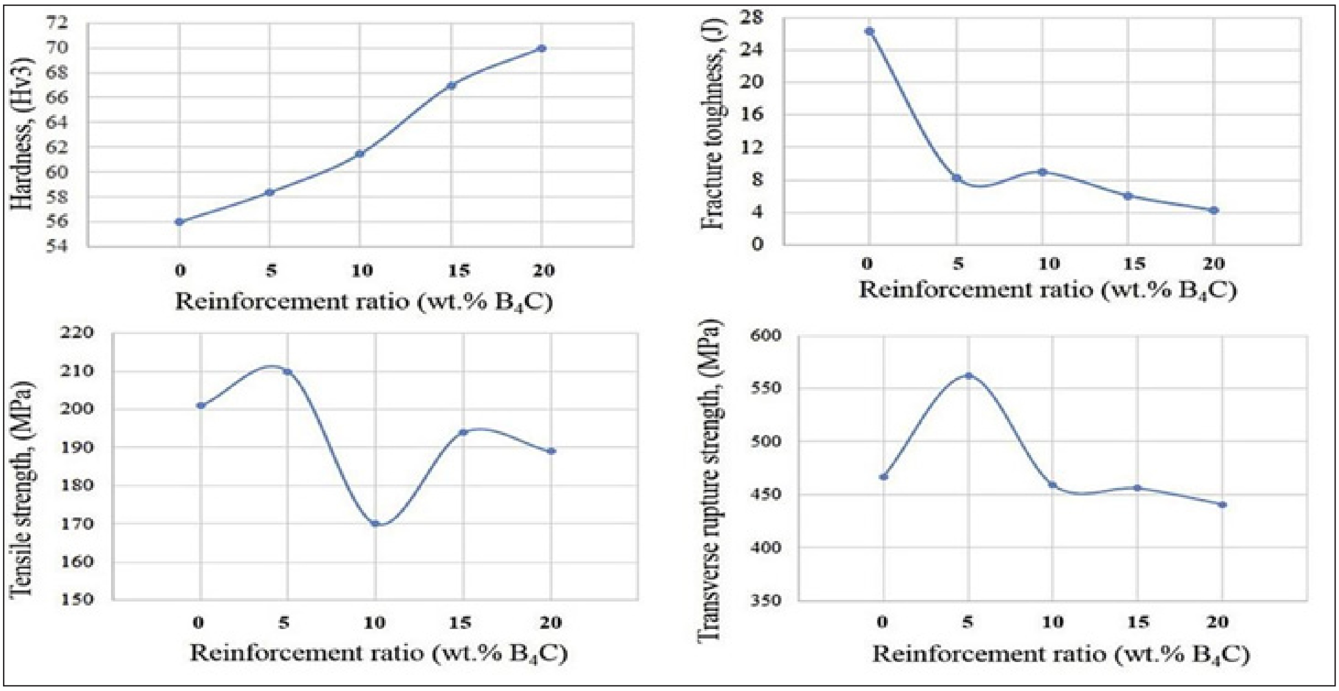

Figure 6.Mechanical Properties of Composite Materials Under Study

Comparison with Other Reinforcement Materials

Boron carbide stands out as a superior ceramic reinforcement material due to its lower density compared to other commercial reinforcing particles like SiC, TiB2, and Al2O3.[17]

Effectiveness in Wear Resistance

Aluminum-B4C composites prove effective in enhancing wear resistance properties with improved hardness and tensile strength, validating their suitability for practical applications.[18]

Correlation of Wear Resistance with B4C Content

Studies show that an increase in B4C content correlates with an increase in wear resistance, providing valuable insights into the relationship between composition and properties.[19]

Al-Silicon carbide (SiC) composites

- Al-SiC is one of the important AMMCs which exhibits attractive physical and mechanical properties, suitable for engine and brake parts
- The SiC particles become embedded within the aluminum matrix, creating a mechanical interlocking effect
- This interlocking provides a strong physical connection between the SiC particles and the aluminum matrix, enhancing the overall strenght of the composite.
- The optimization of these factors is crucial to achieve a strong and uniform bond between SiC particles and the aluminum matrix, resulting in enhanced mechanical properties of the AMMC

Hardness shows good when silicon carbide is employed at 4.5% weight. Hardness value increase with the increase of silicon carbide but it decrease when increase in graphite. Hence to obtain an optimum hardness of the desired number, both the reinforced material can be used in proper proportions.

Tensile test result shows that elevation in mechanical property when they are compared with cast iron. Hardness test shows that improvement of hardness value up to 40% due to the good cohesion between metal matrix and reinforcement phase. Other reinforced materials such as graphite and alumina show better results pertaining to tensile strength when compared to Silicon carbide.

Aluminum-silicon (Al- SiC) composites are commonly used in automobile components due to their good strength, wear resistance, and low cost. Aluminum-silicon (al-si) alloys offer advantages such as Lower weight, Good thermal conductivity & Improved wear resistance.

Al-Graphene and Al-Carbon nanotubes composites

Graphene and Carbon Nanotubes (CNTs) reinforcement in Aluminum Matrix Composites (AMCs) has gained significant attention for combining the ductility and toughness of metals with the high strength and elastic modulus of carbon-based materials.

Mechanical Properties Enhancement

Studies show a notable enhancement in mechanical properties such as yield strength, microhardness, ductility, and wear resistance when incorporating Graphene and CNTs into Aluminium Matrix Composites.[23-25] The incorporation of graphene and CNTs in the aluminium matrix significantly improved tensile strength. Studies have reported increased tensile strength values, with a notable example reaching 236MPa.[26] Graphene-reinforced aluminium composites exhibited improved hardness properties. For instance, the maximum hardness reported was 83 HV . The value of the microhardness of the MWCNTs reinforced Al–MMCs were measured with the variation of MWCNTs ranging from 0 wt.% to 9 wt.%.[27] It was observed that hardness increased up to 151 HV for 6 wt.% of MWCNTs and then dropped to 140 HV at 9 wt.% MWCNTs. The samples with 6 wt.% MWCNTs showed a 350 % increase in hardness as compared to the original Al sample.[28]

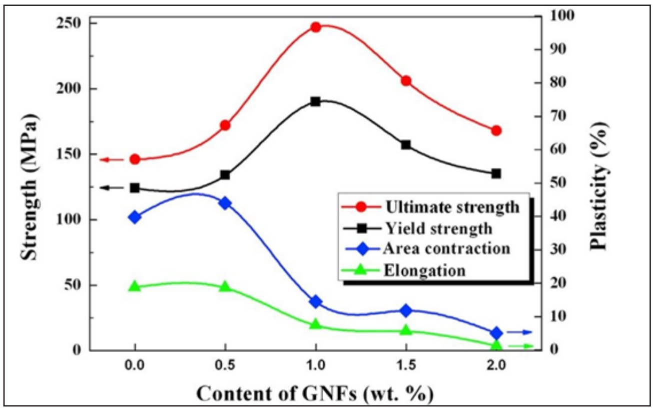

Figure 7.Content of GNFs(wt.%)

Microstructure Analysis

SEM analysis revealed a refined microstructure in the composites, highlighting the effective dispersion of graphene and CNTs in the aluminium matrix. Detailed images can be found in the respective research articles.[29] Microstructure analysis reveals improved wear resistance, corrosion resistance, and mechanical strength in Aluminium Matrix Composites with the addition of Graphene and CNTs.[30]

Graphical Representation of Mechanical Properties

Graphs illustrating changes in hardness, toughness, tensile strength, and wear resistance provide a visual understanding of the positive impact of Graphene and CNTs reinforcement.[31]

Reasons for Enhancement

The inclusion of Graphene and CNTs is attributed to the unique properties of these materials, including high strength, lightweight, and excellent electrical and thermal conductivity.[32]

Aluminum-copper (Al-Cu) AMMCs

Tailored Microstructure: The addition of copper to the aluminum matrix can harden the alloy by solid solution and subsequent precipitation hardening, leading to a tailored microstructure that enhances the mechanical performance of the composite.[33]

Al-Cu composites exhibit enhanced mechanical properties, including increased tensile strength, hardness, and wear resistance compared to unreinforced alloys[34]

The use of microwave sintering techniques for preparing Al-Cu composites has been reported to offer advantages in terms of time and energy savings, making the manufacturing process more efficient,[35] Offered high strength, wear resistance, and thermal stability. These composites are employed in the production of engine components, brake systems, and structural parts of vehicles.

Aluminum-diboride (Al-TiB2) AMMCs

The effect of different weight percentages of TiB2 reinforcement on aluminum composites can be inferred from related studies on similar reinforcement materials. While specific information on TiB2 reinforcement is not available in the provided sources, we can draw general conclusions based on related studies:[36-38]

- **Mechanical Properties:** Typically, increasing the weight percentage of TiB2 reinforcement in aluminum composites leads to improvements in mechanical properties such as hardness, tensile strength, and compressive strength. The mechanical properties tend to increase with higher weight percentages of reinforcement up to a certain threshold.
- **Microstructure:** Varying weight percentages of TiB2 reinforcement are likely to influence the microstructure of aluminum composites. Higher weight percentages may result in a more uniform distribution of reinforcement particles within the matrix, potentially enhancing the overall mechanical performance of the composite material.
- **Optimal Percentage:** There is usually an optimal weight percentage of reinforcement that maximizes the mechanical properties of aluminum composites. Beyond this optimal percentage, further addition of reinforcement may not lead to significant improvements or could even have adverse effects on certain properties.
- **Impact Strength:** Typically, the impact strength of composite materials tends to improve with the addition of reinforcement up to an optimal percentage. Beyond this optimal percentage, the impact strength may not increase further or could even decrease due to factors such as agglomeration of reinforcement particles or changes in the microstructure.

In conclusion, while specific data on TiB2 reinforcement is not available in the provided sources, it can be expected that different weight percentages of TiB2 reinforcement in aluminum composites may follow similar trends observed in studies with other reinforcement materials, leading to enhancements in mechanical properties and microstructural changes within the composite material.

Aluminum- (Al-ZrO2) AMMCs.

- **Mechanical Properties Enhancement:** Addition of zirconium dioxide (ZrO2) reinforcement to aluminum

(Al) metal matrix composites (MMCs) enhances mechanical properties.[39]

- **Tensile Strength:** Incorporating 10% Zirconia and 10% fly ash into the composite increased tensile strength by 278 MPa.[40]
- **Wear Resistance:** ZrO2 reinforcement enhances wear resistance due to its high hardness and toughness. However, specific numerical data on wear resistance enhancement was not provided in the available sources.
- **Hardness:** The addition of ZrO2 significantly increases hardness, with a reported increase of 94 HV (Vickers Hardness) for 10% Zirconia reinforcement.[41]

Conclusion

- Aluminum-Alumina (Al2O3) composites are used for making suspension components such as control arms, knuckles, and other parts due to their high strength and low weight.
- Boron Carbide (B4C) is also used as a reinforcement material for aluminum metal matrix composites (AMMCs) in brake pads and brake rotors due to its high wear resistance, high strength-to-weight ratio, elevated temperature toughness, and high stiffness.
- The addition of graphite as a solid lubricant can also improve the tribological characteristics.
- Based on the provided search results, various Aluminum Metal Matrix Composites (AMMCs) and reinforcement particles are used for making engine components. For instance, Boron carbide (B4C) and graphite are used as reinforcement particles for aluminum metal matrix composites (AMMCs) in engine components such as pistons, cylinder liners, and other parts due to their high wear resistance, high strength-to-weight ratio, elevated temperature toughness, and high stiffness
- Nanosize Al2O3 reinforcement in Si-rich aluminum MMC is also used to enhance the tribological performance of engine components.

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