JENER Journal of Empirical and Non-Empirical Research
Volume 2, Issue 2, Page 17-32 | Article No. 4
DOI: 10.4898/jener.v2i2.a4
ISSN: 7895-9216
Journal homepage: https://jenerjournal.com
Journal email: editor@jenerjournal.com

JENER Journal
JENER Journal of Empirical and Non-Empirical Research

A Review of the Advancement and Challenges of 6xxx Series Aluminum Metal Matrix Composites for Automotive Application

Yesufikad Fentie Takele[1]

[1]Ministry of Industry, Manufacturing Industry Development Institute, Addis Ababa, Ethiopia

ARTICLE INFORMATION

Article history:
Published: February 2026

Keywords:
Advancements
Challenges
6xxx series AMMCs Automotive application
Stir casting

ABSTRACT

The need for lightweight, high-strength materials in automotive, aerospace, structural, and many more applications has led to innovative aluminum metal matrix composites (AMMCs). This offer benefits such as weight reduction, emissions control, increased fuel efficiency, and enhanced vehicle performance. The purpose of this paper is to examine studies on the fabrication and potential application of 6xxx composites. The review begins with a focus on the 6xxx series alloys, followed by a brief description of the processing technique. This review also thoroughly evaluates the physical, mechanical, and tribological properties of 6xxx composites. In addition to the stated characteristics, the advancement in automotive application has been envisioned. It also emphasizes the challenges that are currently encountered during the processing of AMMCs, such as inadequate wettability, agglomeration, and uneven dispersal. Furthermore, future research directions in the realm of aluminum based composites were suggested. Finally, the review found that the 6xxx alloys are emerging as viable composites in automotive applications. AMMCs of the 6xxx series can be strengthened by incorporating materials like SiC, B_4C, Al_2O_3, TiC, and so on to enhance their mechanical and tribological properties. Stir casting is preferred for AMMCs because of its simplicity, low cost, and ability to ensure uniform particle distribution within its limitations. As increasing reinforcement, the 6xxx alloy matrix composites mechanical and tribological properties enhanced to some extent, and further decreased. This review is a valuable resource for researchers, engineers, and industry experts aiming to set performance.

1. Introduction

The design and development of automotive components and structures involve careful consideration to meet the precise demands of their intended tasks. These components operate in demanding conditions, exposed to high stresses, elevated temperatures, and corrosive environments. However, the challenging nature of these operating conditions can gradually degrade the performance and integrity of automotive components, potentially leading to failure. Therefore, it becomes crucial to innovate materials that possess superior physical, mechanical, and tribological properties, in order to enhance the durability and reliability of automotive components and structures. The automotive industry has been relentlessly pursuing innovative lightweight materials that can contribute to improved fuel efficiency, reduced emissions (CO2), minimizing weight, and enhanced performance without compromising safety and structural integrity. Researchers are now not only focused on finding materials or composites that meet application needs but also prioritize eco-friendly, renewable, and degradable materials. In today's engineering applications, there is a growing demand for materials that offer a mix of lightweight properties, outstanding strength, and cost-effectiveness [1,2]

The pursuit of lightweight materials with high strength has driven the emergence of innovative aluminum-based metal matrix composites [3–5] Aluminum metal matrix composites (AMMCs) have gained significant attention for automotive applications [6]. AMMCs offer advantages such as weight reduction, lower emissions, increased fuel efficiency, and better overall vehicle performance and efficiency. Ongoing research on AMMCs seeks to improve their qualities and widen their applications. These AMMCs are widely used in a variety of industries, including aerospace, automotive, rail transport, marine, aircraft, construction, transmission, biomedical, nuclear, power, and electronics, where they provide unique properties and advantages that make them highly valuable [7]. These composites have exceptional properties [8], such as superior physical and mechanical properties [9], corrosion resistance [10], combining lightness with good strength [11], and possessing thermal stability, specific strength, and wear resistance [12]. Aluminum metal matrix finds extensive application in the automotive industry, particularly in components where wear resistance is crucial, such as valves, water coolants, cylinder linings, fan blades, pistons, rings, etc. [13]. They are also integrated in to brake plates and drums, chamber squares and liners, cylinders, crankshafts, associating poles, brake scissors, turbo warm exchangers, and so on [14].

Aluminum's popularity originates from its lightweight properties, ability to undergo strength-boosting heat treatment, and cost-effective manufacture as a high-performance material [15], supported by an impressive strength-to-weight ratio [16]. Furthermore, it has good thermal conductivity, a low coefficient of thermal expansion, great wear and corrosion resistance [17]. Among the various aluminum alloys, 6xxx series has emerged as extremely promising candidates for metal matrix composites (MMCs) in automotive applications, thanks to their outstanding combination of increased wear resistance and heat treatability [18–20]. These alloys have excellent mechanical qualities, formability, corrosion resistance, lightweight [21], as well as fracture and fatigue resistance [22]. They also have high corrosion resistance, cost-effectiveness, great thermal and electrical conductivity, amazing formability, and superior weldability [23].

The fabrication of AMMCs relies on factors such as the matrix and reinforcement materials, microstructure integrity, mechanical, electrochemical, and thermal properties [24]. The inclusion of reinforcements improves physical, thermal, chemical, and mechanical qualities while reducing weight, resulting in higher fuel efficiency [25]. Particulate-reinforced aluminum metal matrix composites have received attention for their improved mechanical and tribological properties [26], with particle reinforcements including TiB2, CNTs, , and graphite [27], SiC, Al203, TiC, and B4C [28], and TiC, WC, and Al2Cu [29]. Aluminum-Al203 structure providing considerable thermal conductivity [30]. Aluminum-SiC metal matrix composites meet the needs of the automotive, aerospace, and electrical industries [31].

Overall, the demand for high strength to weight ratio drive the development of advanced aluminum metal matrix composite. The 6xxx series aluminum alloys (Al–Mg–Si) are among the most widely used aluminum alloy due to their superior mechanical properties, excellent weldability, formability, and processing capabilities, low density, and corrosion resistance. Although many researchers have studied numerous 6xxx series composites, there is few review on 6xxx series composites advancement and application to the best of the author's knowledge. The main objective of this study is to review the various possible AMMCs fabricated through stir casting with 6xxx as the matrix material. The authors aim to discuss the recent advancement in 6xxx AMMCs, advanced automotive application, processing technique, and the physical, mechanical, and tribological properties of 6xxx AMMCs, existing challenges and future research direction. The subsequent sections of this work are organized as follows: Section 2 addresses 6xxx Series aluminum alloys. Section 3 explores processing techniques for 6xxx Series AMMCs. Section 4 examines the physical, mechanical, and tribological properties of 6xxx Series AMMCs. Section 5 examines the physical, mechanical, and tribological properties of 6xxx Series AHMMCs. Section 6 examine the advancement in automotive application. Section 7 discusses current challenges and potential research directions. Finally, concludes this review study.

2. 6xxx Series Aluminum Alloys

The 6xxx series aluminum alloys consist of a group of aluminum alloys that primarily incorporate magnesium and silicon as alloying elements [32]. Copper, magnesium, manganese, silicon, and zinc are some of the typical alloying elements incorporated in these alloys [33]. One of the notable characteristics of 6xxx series alloys is their precipitation hardening ability. Through heat treatment processes, the alloying elements form fine precipitates that enhance the mechanical properties and further improve the strength of the material [34]. The 6xxx series aluminum alloys (Al-Si-Mg) are well-known for their high strength-to-density ratio, low cost, ease of production, desirable physical qualities, and resistance to corrosion [35]. They are distinguished by their non-corrosive characteristics, low density, affordability, good thermal and electrical conductivity, excellent formability, and weldability. AA6xxx alloys are essential for applications in lightweight military vehicles, rockets, missiles, aircraft, and cars, serving both defense and civil purposes [36,37].

The 6xxx series AMMCs can be reinforced with various materials to enhance their mechanical properties. These reinforcements consist of materials such as SiC, B4C, Al2O3, TiC, Si3N4, BN, ZrO2, and others [37]. Silicon carbide (SiC) is used as reinforcement, which has high strength and stiffness and excellent thermal conductivity [38]. By utilizing the efficient stir casting technique, a composite was created by adding silicon carbide (SiC) to aluminum alloy 6063 in varying mass ratios of 5%, 7.5%, 10%, 12.5%, and 15% [39]. The addition of SiC, B4C, and graphite, to an aluminum matrix can significantly improve both the mechanical and tribological properties of the composite material [40]. Hardness and compressive strength increase with an increase in the wt% of TiC reinforcement on aluminum [41]. AA6061-B4C metal matrix composites (MMCs) were produced using an ultra-sonic assisted stir casting technique with varying B4C weight percentages (0, 2, 4, 5, 6, and 8%). The incorporation and distribution of B4C particles into the AA6061 matrix were successfully achieved up to 4 wt% B4C. The improvement of ultimate tensile strength (36.32%), specific compressive strength (43.92%), specific vickers hardness (53.41%), and specific brinell hardness (50.89%) [42]. AA6061 with B4C (5%, 10%, and 15%) and Gr (10%, 15%, and 20%), dual stir casting technique is employed. Particularly noteworthy is the successful dispersion of the reinforced materials, with minimal aggregation observed, especially in composites containing higher amounts of B4C and Gr [43]. AA6061, serving as a base material, reinforced with wt% of Al_20_3 particle size 24µm by vacuum stir casting. Composites showed significant improvements in wear resistance in contrast to the base alloys, due to the presence of alumina [44]. In case of AA6061, the hardness of the composite increases when the B_4C addition increases in the AA6061 [45]. Through stir casting, AA6063 was combined with 5% Al2O3, where Al2O3 played a crucial role for enhancing the micro hardness and toughness of the developed metal matrix composites [46].

3. Processing Techniques for 6xxx Series AMMCs

Various processes are used for the fabrication of metal matrix composites, including stir casting, infiltration, diffusion bonding, powder metallurgy, deposition technique, spray forming, and electroplating [47]. Main fabrication methods for aluminum metal matrix composites can be classified as solid-state and liquid state processing. Stir casting is the most common liquid-state process used for AMMCs because it is simple to operate, cost-effective, and provides uniform distribution of particles. Powder metallurgy is a solid state for fabrication; it provides uniform distribution of particles but is costlier than stir casting. Compo casting, squeeze casting, friction stir casting, spray casting, etc. are the other manufacturing processes used, but to a lesser extent [48]. From the different fabrication methods, stir casting, powder metallurgy, and centrifugal casting are the most common metal matrix composite fabrication methods because of their simplicity and cost-effectiveness [49]. The most viable method to develop AMMCs is stir casting and powder metallurgy [50]. As shown in Figure 1, stir casting is the favored way for producing aluminum metal matrix composites due to its simplicity, established process, cost-effectiveness, and mass-production capacity [51,52]. Stir casting is widely recognized for its versatility, market viability, and durability in the production of AMMCs [53]. Its adaptability is especially useful for manufacturing large, somewhat enclosed components [54,55]. However, challenges in fabrication through stir casting, such as poor wettability, agglomeration, clustering, uneven dispersal, and undesired chemical reactions between matrix and reinforcement, defines material properties [56]. The mechanical properties of composites are influenced by factors such as the weight percentage of reinforcement particles, preheat temperature, and melting temperature. The selection of appropriate reinforcement materials and the optimization of stir casting parameters pose challenges in the fabrication of new materials while maintaining desired mechanical properties [57]. Mechanical properties increase with increasing stirring speed and time in the composite because of the homogenous distribution of particle reinforcement in the aluminum matrix at maximum speed and time [58]. The study explores how the fabrication process of AA6061/zirconia nanocomposites is affected by ultrasonic-assisted stir casting conditions. The results show that specific processing factors affect grain refinement, homogeneous dispersion, and nanoparticle clustering [59].

Various research studies have highlighted the extensive use and suitability of the stir-casting method for crafting AA6061 composites [60], including AA6061/SiC/fly ash [61], AA6061 with Al2O3 and fly ash [62], AA6061 with different weight percentages of Silicon Carbide (SiC-40nm) [63], AA6061 with varying weight percentages of SiC, and more [64,65], AA6061 with SiC, Fly Ash, and Coconut Coir Ash have been examined [66]. Additionally, studies have been conducted on AA6063 with B4C + Graphite (Gr.) and B4C + Groundnut Shell Powder (GSA) [67], aluminum (6061-T6) with B4C [68], and the successful fabrication of an aluminum matrix hybrid composite involving AA6061, 7% Al2O3, and X wt% SiC (X = 10, 15, and 20%) was achieved using the stir casting method [69].

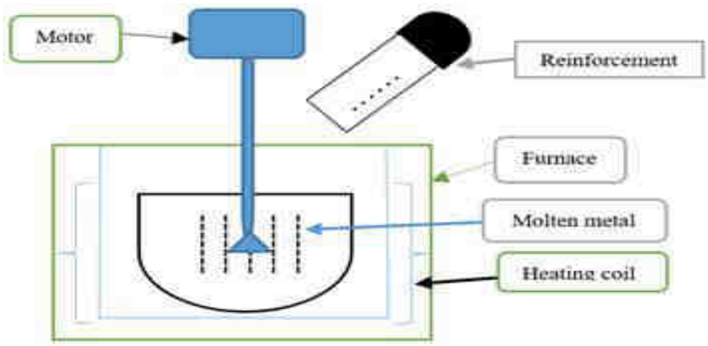

Figure 1. Schematic diagram of stir casting.

4. Physical, Mechanical, and Tribological Properties of 6xxx Series AMMCs

Aluminum metal matrix composites (AMMCs) are in high demand within the automotive, aerospace, and aviation industries due to their exceptional combination of properties. Researchers are actively exploring ways to further enhance these properties. Aluminum alloys are widely utilized in the automotive and aerospace sectors due to their low density, excellent mechanical characteristics, and low thermal coefficient of expansion compared to other metals and alloys. However, the production of AMMCs presents certain challenges that contribute to their complexity and cost. These challenges include issues such as inadequate wettability between the reinforcement phase and the molten metal, scattering, agglomeration of particles, and matrix interface debonding. This limitation hampers the effectiveness of traditional casting techniques [70]. The microstructure analysis of the AA6063-T6 hybrid composite, produced using the stir casting method, indicates the presence of minimal porosity within the composite structure as observed through FESEM analysis [71]. During the fabrication of AA6061/Graphene nano platelets (GNPs) composite using the bottom pouring stir casting method, an issue arises with the non-uniform distribution of GNPs within the composite [72]. Researchers have extensively investigated the incorporation of agricultural-industrial waste materials with synthetic reinforcements in hybrid metal matrix composites (HMMCs) and metal matrix composites (MMCs) using liquid metallurgy techniques. However, several challenges have been encountered in this process. These challenges include the non-homogeneous dispersion of reinforcement, the formation of porosity, and poor wettability [73]. The AA6061 alloy was reinforced with nano-sized SiC, Al2O3, and TiO2 particles. Morphological studies revealed a homogeneous distribution of the reinforcements, with nominal clustering as well as instances of agglomeration and cavities shrinking observed on the cermets [74]. AA6061 is a highly utilized aluminum alloy from the 6xxx series known for its exceptional properties, including formability, medium to good strength, excellent environmental resistance, low density, high elongation at break, and superior machinability. AA6061 is a popular choice as a matrix material, due to its ability to modify composite strength through appropriate heat treatment techniques [75]. The composites of AA6061 alloy exhibit superior performance and material characteristics when compared to the base alloy [76]. AA6061 composites are the most interesting engineering materials that have the ability to fulfill the demands of recent engineering applications used in the automobile, defense, aerospace, and marine industries [77].

4.1 Mechanical Properties of AMMCs

$Al_2 0_3$ (0-4 wt%) were added to an AA6061 alloy through stir casting technique. As the weight fraction of aluminum oxide particles increased in the aluminum matrix, the hardness, ultimate tensile strength, and compression strength of the composite of AA6061 alloy also increased. These enhanced mechanical properties make the developed metal matrix composite ideal for automotive applications, surpassing the performance of the AA6061 alloy alone [78]. The composite was fabricated from

AA6063/wt% SiC (2, 4, 6, and 8) with a 10μm average particle size by ultrasonic-assisted stir casting. Melting temperature of 750 0c, preheating temperature of 250 0c for one hour, and stirring speed of 500 rpm for 15 minutes. The mechanical properties of composites increase with an increase in the wt% of SiC up to 4% beyond reduction. The 4 wt% of SiC stir cast composite subjected to ultrasonic waves showed 51.17%, 67.52%, and 38.31% increases in UTS, yield strength, and hardness, respectively, compared with the base alloy [79]. As increasing reinforcement of SiC particles to AA6061 leads to an increase in the hardness value of the composite. The maximum hardness value of 110Rb was obtained with the inclusion of 15 wt% SiC in AA6061 [80]. AA6063 is reinforced with nano SiC wt% of (1, 1.5, and 2) by the ultrasonic-assisted stir casting method. The particle size of SiC is 23nm. The micro hardness (HRF) values are 54.423, 64.926, and 68.006 with respective increments in wt%. observed excellent distribution of nano SiC, which results in better mechanical properties [81].

4.2 Tribological Properties of AMMCs

AA6061 alloys have traditionally been extensively utilized in the automobile industry. However, these alloys have certain limitations, including moderate strength and wear resistance. To overcome these drawbacks, modern approaches involve incorporating ceramic reinforcements such as silicon carbide and graphite into the matrix of the aluminum alloy. By doing so, the strength and wear resistance properties of the composite material are significantly enhanced [82]. The AA6061 with 6 wt% Al_20_3 composite displayed excellent wear resistance [83]. When produced through stir casting, the AA6061-SiC composite demonstrates a lower volumetric wear rate compared to pure AA6061, showcasing the enhanced wear resistance property, due to the presence of silicon carbide in the aluminum matrix. This phenomenon can be attributed to the role of SiC in carrying the applied load and stresses, thereby preventing plastic deformation and reducing the wear rate. The increase in the overall strength of the composite with higher SiC percentages, also contributes to the decrease in wear rate [84]. AA6061-SiC composites with varying SiC content (3%, 6%, 9%, and 12%) and a constant volume fraction of graphite (5%) were fabricated using the stir casting method. The unreinforced alloy exhibits lower wear resistance compared to the aluminum metal matrix composite (AMMC). Increasing the reinforcement in a material leads to an increase in wear resistance [85].

Stir casting is used to produce the Al203-reinforced AA6061 metal matrix composite. The composition is AA6061- Al_20_3 (l-2%, 4%) with particle sizes of 24–32 micrometers. The melting temperature is 780 ^{0}c, preheating temperature of reinforcement is 400 ^{0}c, the die is preheated to 200 ^{0}c and the stir speed is 600 rpm. AA6061 has hardness (68 HV), ultimate tensile strength (125 Mpa), %elongation (5.8), and compression strength (22610 N/m^2), AA6061/2% Al203 has hardness (75 HV), Ultimate tensile strength (143 Mpa), %elongation (4.27), and compression strength (24030 N/m^2), AA6061/4% Al203 has hardness (81 HV), Ultimate tensile strength (164 Mpa), %elongation (3.03), and compression strength (24660 N/m^2). Hardness, ultimate tensile strength, and compression strength increase within increase reinforcement, but %elongation decreases. This developed metal matrix composite can be used in aircraft fittings, couplings, brake pistons, hydraulic pistons, and valve parts [86].

AA6061/3.5%, 7%, and 10.5% of B_4C reinforcement by stir casting. The stirring speed is 700 rpm for 10 minutes, the stirrer blade angle is 30 ^{0}, and the melting temperature is 760 ^{0}c. The AA6061/3.5% B_4C, hardness (67.6 HV), tensile strength 176.49 Mpa), yield strength 149.94 Mpa), and % elongation (6.43). The AA6061/7% B_4C hardness (70 HV), tensile strength (186.09 Mpa), yield strength (147.83 Mpa), and %elongation (6.60). The AA6061/10.5% B_4C hardness (59.3 HV), tensile strength (141.98 Mpa), yield strength (94.81 Mpa), and % elongation (9.14). Hardness and tensile strength increase up to AA6061/7% B4C and further decrease. Yield strength decreases as reinforcement increases. where %elongation increases as reinforcement increase [87]. Hardness and tensile strength increase up to AA6061/7% B_4C further decrease, yield strength decrease as reinforcement increases, and percent of elongation increase as reinforcement increases.

5. Physical, Mechanical, and Tribological properties of Aluminum Hybrid Metal Matrix Composites (AHMMCs)

AA6061 has moderate strength, good corrosion resistance, and toughness compared to other aluminum alloys. AA6061 is reinforced with 5% SiC, 5% Al_20_3, and 5% fly ash (15%), 7.5% SiC, 7.5% Al_20_3 & 5%fly ash=20%), and (10%SiC,10% Al_20_3 & 5%fly ash=25%) by stir casting. Tensile strength increases up to 25% with reinforcement. yield strength and hardness increase up to 20% of reinforcement and decrease further [88]. The combination of AA601/5% Al203, AA601/5%Al203, 8%BA (bagasse ash) (37 m), AA6061/% Al203,8%BA (53 μm), and AA6061/5% Al203,8%BA (75 μm) by stir casting. The hybrid composite gave better mechanical properties than the base material by using smaller particle size reinforcement; however, increasing particle size decreases mechanical properties [89]. In the AA6061 matrix, titanium diboride (TiB2) reinforcement addition ranged from 0 to 6 wt%, while a fixed graphite reinforcement of 4 wt% was added through stir casting. The ultimate tensile strength (UTS) of the AA6061-TiB2-Gr aluminum hybrid metal matrix composites (AHMMCs) increased by 64% as the content of TiB2 particles increased from 0 to 6 wt%. Additionally, the increase in hardness of the Al6061-TiB2-Gr HMMCs resulted in enhanced strength, as demonstrated by effective load distribution from the matrix to the reinforcement particulates. It was observed that the percent elongation of the HMMCs decreased by 29% as the TiB2 content increased from 0 to 6 wt% [90].

The composition of composites is AA6063+5% fly ash, AA6063+5% SiC, and AA6063+5% fly ash +5% SiC by stir casting. Hardness at AA6063+5%flyash +5% SiC is 100 BHN, among others, so it can be used for automotive and aircraft industries where hardness is an important property for design components [91].

Composites prepared AA6061/0.5wt%SiC+1.5wt%B4C and AA6061/1.5wt%SiC+1.5wt%B4C ceramic nanoparticles by using conventional stir casting. The enhanced wear properties of composites are achieved because of the addition of SiC and B_4C nanoparticles [92].

Fabrication of AA6061/2%SiC3%$Zr0_2$ AA6061/4% SiC3%Zr02 and AA6061/6% SiC3%Zr02 through stir casting involved a matrix melting temperature of 740 ^{0}c, stirring speed of 350 rpm, and preheated temperature set at 300 ^{0}c. The hardness, tensile strength, compressive strength, and impact energy all demonstrated an increase with the rise in the weight percentage of SiC and

Zr02 reinforcement. AA6061/6%SiC3%ZrO_2 shows a hardness value of 95.5 BHN, 39% improved from the matrix material, tensile strength value of 384.4 MPa, improved by 20.4%, compressive strength value of 255.47 MPa, improved by 24.2% from the matrix. The prepared AA6061/6%SiC3%ZrO_2 composite had better mechanical and metallurgical properties, this combination was recommended for automotive and aerospace component applications [93].

AA6061 is reinforced with SiC & Al_2O_3 through stir casting. Tensile strength and hardness were improved at 7.5% SiC and 7.5% Al_2O_3 in the AA6061 matrix material. Fracture toughness and ductility were continuously decreased by adding SiC & Al_2O_3 to the AA6061 matrix material [94]. Metal matrix composites of AA6061/SiC/Al_2O_3 by bottom pouring stir casting process. AA6061 is preheated to 300 ^{0}c, melting temperature 750^{0}c, preheating reinforcements at 300^{0}c for 60 min, stirrer speed 650 rpm for 10 min, impeller stage is one, impeller angle 29^{0}c. The AA6061 tensile strength (106.1N/mm^2), and hardness (28 HV). The AA6061/5%SiC tensile strength (108.8N/mm2), and hardness (30 HV). The AA6061/7% SiC tensile strength (121.4N/mm2), and hardness (32HV). The AA6061/5%SiC3% Al_2O_3 tensile strength (134.3N/mm2), and hardness (35HV). The tensile strength, and hardness of the composite increase as reinforcement increases due to uniform particle distribution. An optical micrograph sho ws a uniform distribution of reinforcement. The wear rate decreases or wear resistance increases when the amount of reinforcement increases [95].

AA6061 was reinforced with wt%10 of (5% Zr02+5% Al203) average particle size 55-65 micrometers in order to attain good bonding with the metal matrix by stir casting. The experimental result shows an increase in hardness, tensile strength, wear resistance, and reduced corrosion rate [96].

AA6061 metal matrix reinforced with Al_2O_3, bagasse ash by vacuum-assisted stir casting. Used Mg, Al_2O_3 particle size 53 µm, BA particle size 38 micrometers, pouring temperature 700 ^{0}c, reinforcement preheated temperature is 400 ^{0}c, mold temperature 210±10 0c, and stirring speed 500±10 rpm for 5-7 minutes. The composition is AA6061- 5%Al_2O_3, has a tensile strength (138.5 MPa), ductility (8.2%), hardness (30.2 HV), compressive strength (310 MPa), impact (6.9 J), density (2.747g/cc^3), and porosity (0.94%). AA6061- 5%Al_2O_3 4%BA, having tensile strength (146.8 MPa), ductility (8.6%), hardness (32.8 HV), compressive strength (347 MPa), impact (6.4 J), density (2.711g/cc^3), and porosity (1.2%). AA6061- 5%Al_2O_3 6%BA, having tensile strength (151.1 MPa), ductility (7.4%), hardness (35.2 HV), compressive strength (380 MPa), impact (5.8 J), density (2.705g/cc^3), and porosity (1.5%). AA6061- 5%Al_2O_3 8%BA, having tensile strength (141.9 MPa), ductility (5.9%), hardness (28.4 HV), compressive strength (411 MPa), impact (5.2 J), density (2.665g/cc^3), and porosity (2.26%). Tensile strength and hardness show increments up to AA6061- 5%Al_2O_3 6%BA, further decreasing; however, the decreased values of hardness and tensile strength are higher than the single matrix. Ductility shows a decrease as reinforcement increases but increases at AA6061- 5%Al_2O_3 4%BA. Compressive strength showed an increment as reinforcement increased. Impact and density decrease as reinforcement increases. Porosity increases when reinforcement increases. Microstructural analysis shows the presence of Al_2O_3 & BA in AA6061 and a fairly uniform distribution up to Al6061- 5%Al_2O_3 6%BA but further voids and clustering are observed. The microstructure, as depicted in Figure 2, makes it evident that Al2O3 and BA are present inside the metal matrix and are distributed pretty uniformly within the AA6061. Nonetheless, samples containing a larger weight percentage of BA showed some pores and particle clumping. Additionally, it showed that up to 6 wt% of BA, the cast samples Al 6061/A l2O3/BA had a homogenous and fair distribution with little agglomeration; above this, considerable particle clustering and voids were found [97].

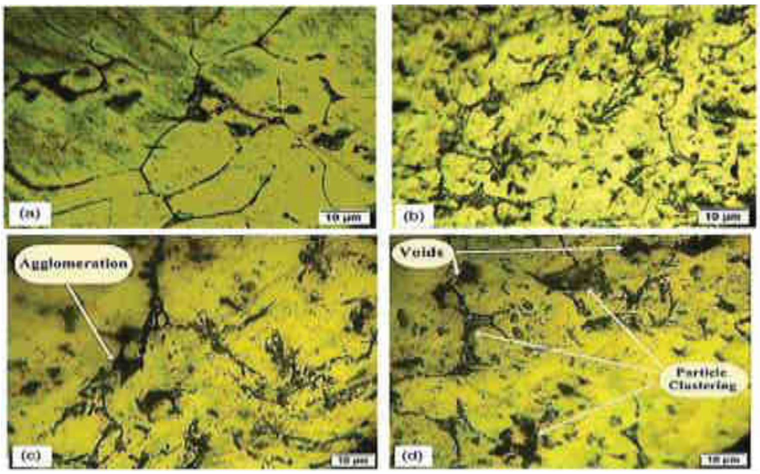

Figure 2. Optical microscopic photomicrograph of reinforced AA6061/Al203/BA with 5 |%Al203 and 4, 6, and 8wt% BA at 600x(a) AA6061+5wt%Al203 (600x), (b) AA6061+5wt%Al203 +4wt%BA(600x), (c) AA6061+5wt%Al203 +6wt%BA(600x), and (d) AA6061+5wt%Al203 +8wt%BA(600x) [97].

AA6103 is reinforced with Al203 and SiC by stir casting. The composition of composites is, AA6103/1% Al203/2%SiC, AA6l03/1%Al203+4%SiC, A6l03/1%Al203+6%SiC, A6l03/1%Al203+8%SiC. The microstructure shows a fairly uniform distribution of reinforcements. The density of composites decreases with an increase in reinforcement because of the volatile nature of ceramic particles. The hardness of composites increases with an increase in reinforcement materials. The wear rate increases with an increase in load. At higher load wear rate of the composites was higher due to a higher coefficient of fric tion. At higher reinforcement content, wear rate is lower because ceramic particles provide a lubricating film on the counter surface, which lowers the coefficient of friction, and lowers the wear rate of composite [98]. AA6061 is reinforced with Zn, Gr, Si, and Cr by stir casting. AA6061 has tensile strength (310.7 N/mm^2), yield strength (275.7 N/mm^2), % elongation (18.2), wear (0.0046), and hardness (94.6 N/mm^2). AA6061 reinforced with 0.5% Zn, 0.5% Gr, 0.5% Si, and 0.5% Cr at a temperature of 923 ^{0}c, tensile strength (324 N/mm^2), yield strength (283 N/mm^2), % elongation (19.5), wear at 300 rpm (0.0037), and hardness (96 N/mm^2). AA6061 reinforced with (1% Zn, 1% Gr, 1% Si, and 1% Cr) at temperature 1027 ^{0}c, tensile strength (316 N/mm^2), yield strength (279 N/mm^2), % elongation (18.4), wear at 300 rpm (0.0039), and hardness (96.8 N/mm^2). AA6061 reinforced with (1.5% Zn, 1.5% Gr, 1.5% Si, and 1.5% Cr at a temperature of 1140 ^{0}c, tensile strength (377 N/mm^2), yield strength (321 N/mm^2), % elongation (18), wear at 300 rpm (0.0042), and hardness (96.3 N/mm^2). All mechanical and tribological properties were improved at AA6061 reinforced with (0.5% Zn, 0.5% Gr, 0.5% Si, and 0.5% Cr), but the hardness value was better at AA6061 reinforced with (1% Zn, 1% Gr, 1% Si, and 1% Cr). To determine the morphology of the composite, scanning electron microscopy (SEM) was used to examine its surface. The surface of the composite samples is shown in Figure 3, below, which reveals that there was no particle segregation of silicon, zinc, graphite, or chromium, indicating that the mixture was homogeneous [99].

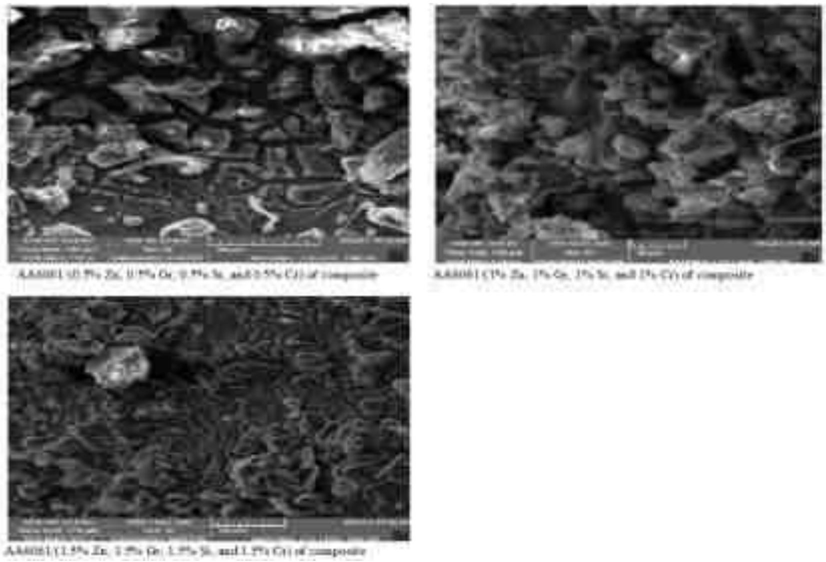

Figure 3. SEM image of AA6061 reinforced with (0.5% Zn, 0.5% Gr, 0.5% Si, 0.5% Cr, (1% Zn, 1% Gr, 1% Si, and 1% Cr) , 1.5% Zn, 1.5% Gr, 1.5% Si, and 1.5% Cr) composite [99].

The hybrid metal matrix composite of AA6063/SiC and AA6063/SiC/Gr combination by stir casting. SiC particle size is 37µm preheated at 650 ^{0}c for 120 min, and Gr particle size is 40 µm preheated at 1000^{0}c for 120 min. melting temperature is 760^{0}c$\pm$100^{0}c, stirrer speed 500 rpm for 10–20 min. 1-2wt% Mg has been added. The mold was preheated at 300^{0}c for 30 minutes. The melt was degasified by using solid hexachloroethane (C_2Cl_6). The AA6063/2.5% SiC/2.5% Gr tensile strength is 164.38 MPa, and the density (2.66 gm/cc). The AA6063/5%SiC/5%Gr tensile strength is 190.48 MPa, and its density (is 2.64 gm/cc). The AA6063/7.5%SiC/7.5%Gr tensile strength (200.32 MPa) and density (2.63 gm/cc). The AA6063/5%SiC tensile strength (142.46 MPa) and density (2.7 gm/cc). The AA6063/10%SiC tensile strength (160.84 MPa) and density (2.71 gm/cc). The AA6063/15%SiC tensile strength (184.26 MPa) and density (2.73 gm/cc). The tensile strength increases as SiC/Gr increases, whereas density decreases as wt% SiC/Gr increases. The tensile strength increases as the wt% of SiC increases, and the density increases as the wt% of SiC increases. SEM analysis showed a uniform distribution of SiC and Gr in the matrix without any tunneling or voiding effects. SiC/Gr composites could be used as light weight engineering materials. With the help of a scanning electron microscope (SEM) as shown in Figure 4, the microstructure of AMMCs shows that the SiC particles (black) are spread out almost evenly, with some clustering. The cast specimen likewise shows negligible porosity (2%). The dispersion of SiC particles is readily seen in the 5-wt% SiC composite. Furthermore, the presence of SiC can be seen in Figure 2, indicating that the particle mixture was homogeneous due to the absence of SiC particle segregation. No voids were discovered during SEM analysis. The matrix contains graphite particles (gray and white), which are evenly dispersed and appear to be well bound [100].

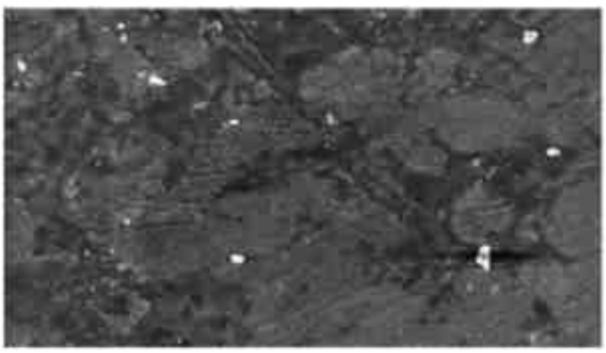

Figure 4. SEM images of (AA6063/5% SiC composite) [100].

The composite produced by AA6063 is reinforced by SiC and TiC by stir casting. The composition is AA6063/1% SiC1%TiC, AA6063/1% SiC1.5%TiC, AA6063/1% SiC2%TiC, and AA6063/1% SiC2.5%TiC. The density of composites decreases with an increase in reinforcement content due to the volatile nature of ceramic particles. The hardness of composites increases with increased reinforcement. The wear rate of composites increases with increasing loads. At higher reinforcement content, the wear rate is lower because ceramic particles provide a lubricating film on the counter surface, which lowers the coefficient of friction, lowers the wear rate of the composite [101].

As shown in Table 1, the mechanical properties of aluminum composites are significantly influenced by the level of reinforcement. Hardness, compressive strength, and ultimate tensile strength increase with, while elongation decrease [86]. In AA6061/7%B4C composite , hardness, tensile strength, and yield strength increase initially but decline beyond this reinforcement level [87]. Hardness, tensile strength, and wear resistance generally improve with reinforcement [95]. However, AA6061-5%Al_2O_3 - 6%BA composites, compressive strength and porosity increase, and while density, ductility, and impact strength as reinforcement level rise [97]. Hardness increase with reinforcement but eventually decline, at AA6061 reinforced with AA6061 - 1.5% Zn, 1.5% Gr, 1.5% Si, and 1.5% Cr tensile strength and yield strength decrease as reinforcement increase, while elongation decrease and wear resistance improve [99]. Tensile strength increases as reinforcement increases up to AA6063/7.5%SiC7.5%Gr but further decreases, and density decreases up to AA6063/7.5%SiC7.5% Gr further increases [100].

Table 1. Summary of physical, mechanical, and tribological properties of 6xxx AMMCs and AHMMCs.

Composition	Fabrication method	Hardness	Tensile strength	Compressive strength	Ultimate tensile strength	Yield strength	Density (g/cc^3)	Ductility	Porosity	Impact	Percent of elongation	Wear rate	Ref.
AA6061	stir casting	68 HV		23810 N/m2	123 Mpa						5.8		[86]
AA6061/2% Al2O3		75 HV		24030 N/m²	143 Mpa						4.27		
AA6061/4% Al2O3		81 HV		24080 N/m²	164 Mpa						3.03		
AA6061/3.5% B_4C	stir casting	67.6 HV	176.49 Mpa			149.94 Mpa					6.43		[87]
AA6061/7% B_4C		70 HV	186.09 Mpa			147.83 Mpa					6.60		
AA6061/10.5% B_4C		59.3 HV	141.98 Mpa			94.81 Mpa					8.14		
AA6061	stir casting	28 HV	106.1N/mm²									The wear rate decreases as reinforcement increases	[95]
AA6061/5%SiC		30 HV	108.8N/mm²										
AA6061/7% SiC		32HV	121.4N/mm²										
AA6061/5%SiC3% Al_2O_3		35HV	134.3N/mm²										
AA6061- 5%Al_2O_3	Vacuum-assisted stir casting	30.2 HV	138.5 MPa	310 MPa			2.747	8.2%	0.94%	6.9 J			[97]
AA6061- 5%Al_2O_3 4%BA		32.8 HV	146.8 MPa	347 MPa			2.711	8.6%	1.2%	6.4 J			
AA6061- 5%Al_2O_3 6%BA		35.2 HV	151.1 MPa	380 MPa			2.705	7.4%	1.5%	5.8 J			
AA6061- 5%Al_2O_3 8%BA		28.4 HV	141.9 MPa	411 MPa			2.665	5.9%	2.26%	5.2 J			
AA6061	stir casting	94.6 N/mm²	310.7 N/mm²			275.7N/mm²					18.2	0.0048	[99]
AA6061- (0.5% Zn, 0.5% Gr, 0.5% Si, and 0.5% Cr)		98 N/mm²	324 N/mm²			283 N/mm²					19.5	0.0037	
AA6061 - (1% Zn, 1% Gr, 1% Si, and 1% Cr)		96.8 N/mm²	316 N/mm²)			279 N/mm²					18.4	0.0039	
AA6061 - (1.5% Zn, 1.5% Gr, 1.5% Si, and 1.5% Cr)		96.3 N/mm²	377 N/mm²			321 N/mm²					18	0.0042	
AA6063/2.5% SiC/2.5% Gr	stir casting		164.38MPa				2.66						[100]
			190.48MPa				2.64						
AA6063/5%SiC/5%Gr			200.32MPa				2.63						
AA6063/7.5%SiC/7.5%Gr			142.46MPa				2.7						
AA6063/5%SiC			160.84MPa				2.71						
AA6063/10%SiC			184.26MPa				2.73						
AA6063/15%SiC													

6. Advancements in Automotive Application

Composite materials exhibit superior mechanical properties compared to conventional materials. The exceptional resistance to corrosion and wear exhibited by AMMCs positions them as highly promising materials for a wide range of applications, including structural, automotive, marine, and aerospace industries [102], due to its low production cost and desirable mechanical characteristics [103]. SiC and Al_2O_3-based aluminum composites have improved strength and damping properties compared to steel-based IC engine mounts. With their mechanical properties and vibration characteristics, the AA6061-SiC and AA6061-Al_2O_3 AMMCs mounts are suitable for engine mount vibration isolation. Moreover, the AA6061-SiC mounts are able to exhibit better performance than the Al6061-Al_2O_3 mounts [104]. Aluminum is commonly used in the production of pistons [105]. In operation, pistons are subjected to cyclic gas pressure and inertial stresses that they must endure [106]. According to Rashmita, Sumi Singh et al. [107] the AA6061–B4C–SiC composite is considered ideal material for pistons due to its superior properties.

Aluminum demonstrates excellent performance under pressure [108]. Substituting the conventional connecting rod material with Al-Cu-Mg/bean pod ash nanoparticle biocomposites, led to a fuel efficiency enhancement of 0.36%. This change not only provided good strength and reduced weight, but also induced stress in the structure, resulting in improved fuel efficiency [109]. In this setup, AA6061 (90%) served as the matrix, with the addition of 10% boron carbide through powder mixing [110]. The composite derived from aluminum alloy and silicon carbide exhibits an array of characteristics: durability, high corrosion resistance, exceptional thermal and electrical conductivity, good reflective properties, and more [111]. The components utilized in the production of crankshafts must possess strength, durability, and the ability to endure elevated levels of stress and temperature. Aluminum finds application in crankshaft manufacturing [112]. A camshaft is a cylindrical shaft with oblong moving elements known as cams, designed to transform rotational motion into linear motion. Silicon carbide particles have superior properties, such as higher modulus of elasticity, hardness, lower thermal expansion coefficient, and higher density compared to aluminum. When combined with aluminum alloys, these reinforced materials become highly desirable due to their enhanced properties [113]. As a result, aluminum-silicon alloy is rapidly used for its greater strength-to-weight ratio, increased wear resistance, lower density, and lower thermal expansion coefficient [114]. Aluminum alloys are the most widely used materials to manufacture the cylinder block [115- 118]. Al-Si alloys are preferable materials for cylinder block manufacture, subject to performance requirements and manufacturability issues [119]. The combination of aluminum with cast iron is employed to craft cylinder blocks that comply with carbon emission standards [120]. The aluminum alloy A6061 is specifically utilized in cylinder block fabrication [121], because they have low specific gravity, ease of fabrication, corrosion resistance, and high thermal conductivity [122]. Aluminum alloy matrix-based hybrid composites are reinforced with silicon carbide and graphite particles to enhance strength [123]. In automotive applications, aluminum matrices reinforced with silicon carbide (SiC), aluminum oxide (Al2O3), graphite, and carbon are utilized for body structures [124].

An automobile drive shaft is an important component of a vehicle. Composite shafts provide better mechanical properties in comparison with steel shafts. In addition, the total weight of the shaft made of composite is lower in comparison with a s teel shaft, which helps improve fuel consumption. The research also emphasizes the significance of advancing composite materials as a key area of focus [125]. Industrial vehicle transmission shafts made of composite materials (particularly carbon fibers) result in a final weight savings of up to 30 % compared to identical components made of steel with equal static and dynamic performance [126]. By using composite materials, about 81% of weight savings are achieved and the vehicle weight is reduced when compared to a steel shaft [127]. R. Siva et al. [128] studied spur gears are made from AA6061 composite with varying weight percentages of titanium carbide (TiC) with a grain size of 40 µm. Metal matrix composite (MMC) brake discs provided better thermal and mechanical performance [129]. MMC have the possibility of substituting cast iron (Cx-24) for brake discs. The MMC limit is not less than 240 MPa (that is not less than the strength of CX-24) is achieved in a wide range of alloying components content and reinforcements [130]. AMMCs are valid for replacing existing materials for brake disc applications [131,132] According to P K Dinesh Kumar and S Darius Gnanaraj, automotive brake discs significantly contribute to vehicle weight, making lightweight aluminum discs a promising alternative to traditional cast iron or steel [133] Dong Tan et al. [134] fabricated lightweight hybrid composite brake discs using friction-stir processing, combining an A357/SiC top layer with an AA6082 aluminum alloy base. These discs exhibit excellent wear and friction performance, with thermally stable SiC particles enhancing wear resistance, particularly at high temperatures. Their superior performance demonstrates their readiness to replace heavier iron and steel brake discs. K. Vinoth Babu et al. successfully fabricated an Al-SiC composite brake disc using the centrifugal casting technique .M. M. A. Baig et al. [135] highlighted that the AA6061-Al2O3 composite offers superior wear resistance and enhanced friction stability, making it an excellent material for brake disc applications [136]. Aluminum matrix with Al2O3 exhibit exceptional mechanical and physical attributes, yielding excellent outcomes [137]. Additionally, an aluminum, silicon carbide, and fly ash hybrid composite by stir casting for brake disc [138].The 6xxx series, such as AA 6061, AA 6063, and AA 6082, are reported alloys for the brake disc matrix material [139]. AA6061 is reinforced with titanium diboride (TiB_2) particles [140,141], A6061/Al2O3 [142], AA6061/Alumina/Graphite [143], AA6061 matrix composite reinforced with rice husk ash (RHA) with a large amount of silica contained [144]. The brake system is composed of many different parts, including brake pads, a master cylinder, wheel cylinders, and a hydraulic control system. The brake pads are an important component in the braking system of an automobile [145]. Brake pads are designed for friction stability, durability, and the minimization of noise and vibration. The type of brake pads depends on the material from which they are made. Aluminum reinforced with zirconium oxide, silicon carbide, titanium oxide, graphite, coconut fiber, and phenolic resin, a metal matrix composite used for brake pads [146]. Natural fibers like palm kernel can replace asbestos in reinforcing friction composites for brake pad applications [147]. S. Anoop, S.et al. [148] studied the dry sliding wear behaviour of AA6082–SiC composite for brake pad application. A.A. Agbeleye et al. [149] investigated aluminum 6063 alloy–clay (Al–clay) composites for brake pad applications. A vehicle's wheel is an important component of its overall performance. It gives efficient movement for objects over a surface. Alloy wheels reduce the weight of the vehicle. W hen the weight of the rim is reduced, the overall efficiency will increase. AA6061-T4 and the magnesium alloy AZ80 are used for the wheel rim for the purpose of a weight reduction of nearly 58.33 % without any compromise on the safety parameters of the rim. Considering the cost of the material, it is found that aluminum alloy is comparatively cheaper than magnesium alloy [150].

Figure 2. Automotive application of 6xxx series metal matrix composites.

7. Existing Challenges and Future Research Directions

The existing AMMCs and AHMMCs physical, mechanical, and tribological properties are demanded. However, the production of AMMCs poses specific challenges that contribute to their complexity and cost. These challenges encompass issues such as inadequate wettability between reinforcements and molten metal, agglomeration, and debonding at the matrix interface, uneven distribution of particles, porosity, clustering, and voids. This hampers the effectiveness of traditional casting techniques and can lead to poor composite performance. While based on the Vickers hardness values of B4C (4000 kg/mm2), SiC (3000 kg/mm2),

and Al_2O_3 (1365 kg/mm2) [151], one might expect that the hardness of AA6061/3.5% B_4C would surpass that of AA6061-2% Al_2O_3 and that AA6061-5% SiC would be greater than AA6061-5% Al_2O_3, but the actual results contradict these assumptions. Specifically, the hardness values are as follows: AA6061-3.5% B_4C (67.6 HV) [87], AA6061-2% Al_2O_3 (75 HV) [86], AA6061-5% SiC (30 HV) [95], and AA6061-5% Al_2O_3 (30.2 HV) [97], which were produced using stir casting. This discrepancy underscores the impact of factors such as stir casting parameters and other fabrication conditions on aluminum metal matrix composite fabrication, emphasizing the need for additional research to fully understand these results.
Developing techniques to enhance the wettability between the reinforcement phase and the molten metal is crucial for improving the bonding and overall performance of AMMCs. Exploring surface modification methods, interfacial engineering techniques can help address this challenge. Advancements in careful selection of matrix and reinforcement materials, process optimization, including refining the casting parameters and optimizing the stirring and solidification processes, can aid in minimizing porosity formation. Developing innovative processing methods and considering advanced fabrication techniques like additive manufacturing is crucial to ensuring a uniform distribution of reinforcement materials. Moreover, from the author's perspective, multi-scale modeling, and analysis integrating with coding may be used to resolve the composite properties. This numerical analysis with varying parameters should be employed, as this may significantly save research expense and time. Models to predict the composite properties should be develop.

8. Conclusion

The review concluded that the demand for lightweight, high-strength materials has driven the development of AMMCs. These composites provide advantages such as weight reduction, emissions control, improved fuel efficiency, and heightened vehicle performance. Notably, aluminum-magnesium-silicon alloys are emerging as promising options for AMMCs in automotive applications. The 6xxx series aluminum alloys exhibit impressive precipitation hardening abilities that enhance mechanical characteristics when subjected to heat treatment procedures. Renowned for their high strength-to-density ratio, cost-effectiveness, corrosion resistance, thermal and electrical conductivity, formability, and weldability, these alloys are indispensable for multiple industry applications. Within the 6xxx series, aluminum matrix composites can be strengthened by incorporating materials such as SiC, B_4C, Al_2O_3, TiC, etc. to enhance their mechanical and tribological properties. Various fabrication methods, including stir casting, infiltration, diffusion bonding, powder metallurgy, deposition techniques, spray forming, and electroplating, are used to create metal matrix composites. AMMCs are commonly manufactured using solid-state and liquid-state processes. Stir casting, a popular liquid-state technique, is preferred for AMMCs due to its simplicity, cost-effectiveness, and ability to ensure uniform particle distribution. Despite its benefits, challenges like poor wettability, agglomeration, and uneven dispersal can impact material properties. Factors like reinforcement particle weight percentage, preheat temperature, and stirring speed and time play a role in influencing the mechanical properties of composites. Aluminum alloys, like AA6061, are favored in the automotive and aerospace industries for their lightweight, excellent mechanical characteristics, and low thermal expansion. However, producing AMMCs from these alloys poses challenges like wettability, particle scattering, agglomeration, and matrix debonding. Despite complexities, AMMCs derived from AA6061 are in high demand for diverse engineering applications across automotive, defense, aerospace, and marine industries. As increasing reinforcement, the 6xxx composites hardness, tensile strength, compressive strength, ultimate tensile strength (UTS), yield strength, and wear resistance show increments up to a certain limit, further decreasing, whereas density, ductility, percent of elongation, and porosity show decreasing up to a certain limit, further increasing. Porosity increases when reinforcement increases. Increasing particle size decreases mechanical properties. The density of composites decreases with an increase in reinforcement because of the volatile nature of ceramic particles. At higher reinforcement content, wear rate is lower because ceramic particles provide a lubricating film on the counter surface, which lowers the coefficient of friction and lowers the wear rate of composite. Composite materials, specifically 6xxx aluminum metal matrix composites (AMMCs) and (AHMMCs), offer superior mechanical properties, making them ideal for a wide range of applications in structural, automotive, marine, and aerospace industries. In the automotive industry, aluminum 6xxx AMMCs and HAMMCs are utilized in components like brake plates and drums, chamber blocks, pistons, crankshafts, connecting rods, camshafts, and cylinder blocks, wheel rims, brake pads, and drive shafts to enhance performance and reduce weight.

Conflict of interest

The authors declare no conflict of interest.

Ethical approval

This work does not require any ethical statement.

Reference

[1] T. Arunkumar, T. Selvakumaran, R. Subbiah, K. Ramachandran, and S. Manickam, "Development of high-performance aluminium 6061/SiC nanocomposites by ultrasonic aided rheo-squeeze casting method," *Ultrason. Sonochem.*, vol. 76, p. 105631, Aug. 2021, doi: 10.1016/j.ultsonch.2021.105631.

[2] V. Mohanavel, K. Rajan, S. Suresh Kumar, G. Vijayan, and M. S. Vijayanand, "Study on mechanical properties of graphite particulates reinforced aluminium matrix composite fabricated by stir casting technique," in *Materials Today: Proceedings*, Elsevier, Jan. 2018, pp. 2945–2950. doi: 10.1016/j.matpr.2018.01.090.

[3] A. Abebe Emiru, D. K. Sinha, A. Kumar, and A. Yadav, "Fabrication and Characterization of Hybrid Aluminium (Al6061) Metal Matrix Composite Reinforced with SiC, B4C and MoS2 via Stir Casting," *Int. J. Met.*, vol. 17, no. 2, pp. 801–812, Apr. 2023, doi: 10.1007/s40962-022-00800-1.

[4] V. Jurwall, A. Pandey, and A. K. Sharma, “A Review on Fabrication and Characteristics of Metal Matrix Composites Fabricated By Stir Casting A Review on Fabrication and Characteristics of Metal Matrix Composites Fabricated By Stir Casting,” *Mater. Sci. Eng.*, vol. 377, p. 012125, 2018, doi: 10.1088/1757-899X/377/1/012125.
[5] A. Kumar, R. C. Singh, and R. Chaudhary, “Recent progress in production of metal matrix composites by stir casting process: An overview,” in *Materials Today: Proceedings*, Elsevier, Jan. 2020, pp. 1453–1457. doi: 10.1016/j.matpr.2019.10.079.
[6] A. K. Sharma, R. Bhandari, A. Aherwar, R. Rimašauskiene, and C. Pinca-Bretotean, “A study of advancement in application opportunities of aluminum metal matrix composites,” *Mater. Today Proc.*, vol. 26, pp. 2419–2424, 2020, doi: 10.1016/j.matpr.2020.02.516.
[7] P. Samal, P. R. Vundavilli, A. Meher, and M. M. Mahapatra, “Recent progress in aluminum metal matrix composites: A review on processing, mechanical and wear properties,” *J. Manuf. Process.*, vol. 59, no. September, pp. 131–152, 2020, doi: 10.1016/j.jmapro.2020.09.010.
[8] K. Singh, H. Singh, S. Vardhan, and S. Mohan, “Materials Today : Proceedings Mechanical study of Al 7050 and Al 7075 based metal matrix composites : A review,” *Mater. Today Proc.*, vol. 43, pp. 673–677, 2021, doi: 10.1016/j.matpr.2020.12.601.
[9] P. K. Gupta and R. K. Srivastava, “Fabrication of ceramic reinforcement aluminium and its alloys metal matrix composite materials: A review,” *Mater. Today Proc.*, vol. 5, no. 9, pp. 18761–18775, 2018, doi: 10.1016/j.matpr.2018.06.223.
[10] A. Nirala, S. Soren, N. Kumar, V. K. Dwivedi, and D. R. Kaushal, “A comprehensive review on stir cast Al-SiC composite,” *Mater. Today Proc.*, vol. 21, no. xxxx, pp. 1610–1614, 2020, doi: 10.1016/j.matpr.2019.11.240.
[11] H. Singh and G. S. Brar, “Characterization and Investigation of Mechanical Properties of Composite Materials used for Leaf Spring,” *Mater. Today Proc.*, vol. 5, no. 2, pp. 5857–5863, 2018, doi: 10.1016/j.matpr.2017.12.183.
[12] S. Baskar, V. Vijayan, S. Saravanan, A. V. Balan, and A. Godwin Antony, “Effect of Al2O3 aluminium alloy and fly ash for making engine component,” *Int. J. Mech. Eng. Technol.*, vol. 9, no. 12, pp. 91–96, 2018.
[13] N. E. Udoye, O. S. I. Fayomi, and A. O. Inegbenebor, “Assessment of wear resistance of aluminium alloy in manufacturing industry-a review,” *Procedia Manuf.*, vol. 35, pp. 1383–1386, 2019, doi: 10.1016/j.promfg.2019.09.007.
[14] P. Dev and M. S. Charoo, “ScienceDirect Application of Hybrid Aluminum Matrix Composite in Automotive Industry,” *Mater. Today Proc.*, vol. 18, pp. 3189–3200, 2019, doi: 10.1016/j.matpr.2019.07.195.
[15] S. Ravindran, N. Mani, S. Balaji, M. Abhijith, and K. Surendaran, “Mechanical behaviour of aluminium hybrid metal matrix composites - A review,” *Mater. Today Proc.*, vol. 16, pp. 1020–1033, 2019, doi: 10.1016/j.matpr.2019.05.191.
[16] O. C. Olorunyolemi, O. A. Ogunsanya, A. A. Akinwande, O. A. Balogun, and M. Saravana Kumar, “Enhanced mechanical behaviour and grain characteristics of aluminium matrix composites by cold rolling and reinforcement addition (Rice husk ash and Coal fly ash),” *Proc. Inst. Mech. Eng. Part E J. Process Mech. Eng.*, Sep. 2022, doi: 10.1177/09544089221124462.
[17] P. D. Srivyas and M. S. Charoo, “Role of Fabrication Route on the Mechanical and Tribological Behavior of Aluminum Metal Matrix Composites - A Review,” *Mater. Today Proc.*, vol. 5, no. 9, pp. 20054–20069, 2018, doi: 10.1016/j.matpr.2018.06.372.
[18] N. M. Siddesh Kumar, Dhruthi, G. K. Pramod, P. Samrat, and M. Sadashiva, “A Critical Review on Heat Treatment of Aluminium Alloys,” *Mater. Today Proc.*, vol. 58, pp. 71–79, Jan. 2022, doi: 10.1016/j.matpr.2021.12.586.
[19] Z. H. Zhao, Q. Q. Chen, Q. F. Zhu, W. Q. Liu, and G. S. Wang, “Study on the ageing process of the 6xxx series aluminum alloy wires for overhead conductors,” in *Materials Science Forum*, Trans Tech Publications Ltd, 2017, pp. 347–355. doi: 10.4028/www.scientific.net/MSF.877.347.
[20] D. Maisonnette, D. Bardel, V. Robin, D. Nelias, and M. Suery, “Mechanical behaviour at high temperature as induced during welding of a 6xxx series aluminium alloy,” *Int. J. Press. Vessel. Pip.*, vol. 149, pp. 55–65, Jan. 2017, doi: 10.1016/j.ijpvp.2016.12.004.
[21] U. B. Kuruveri, D. B. Panemangalore, S. B. Kuruveri, M. John, and P. L. Menezes, “Surface Modification of 6xxx Series Aluminum Alloys,” Jan. 2022, *Multidisciplinary Digital Publishing Institute*. doi: 10.3390/coatings12020180.
[22] K. Jebabalan and M. S. Dennison, “Solid-State Welding of Aluminium Alloys,” in *Materials Horizons: From Nature to Nanomaterials*, Springer Nature, 2023, pp. 105–122. doi: 10.1007/978-981-19-7146-4_6.
[23] K. K. Pius, N. O. Ongwen, M. Mageto, V. Odari, and F. M. Gaitho, “Mechanical Properties of Al–Mg–Si Alloys (6xxx Series): A DFT-Based Study,” *Alloys*, vol. 2, no. 3, pp. 213–226, Sep. 2023, doi: 10.3390/alloys2030015.
[24] P. Garg, A. Jamwal, D. Kumar, K. K. Sadasivuni, C. M. Hussain, and P. Gupta, “Advance research progresses in aluminium matrix composites: manufacturing & applications,” *J. Mater. Res. Technol.*, vol. 8, no. 5, pp. 4924–4939, 2019, doi: 10.1016/j.jmrt.2019.06.028.
[25] P. S. Shanker, “ScienceDirect ICMPC 2017 A review on properties of conventional and metal matrix composite materials in manufacturing of disc brake,” *Mater. Today Proc.*, vol. 5, no. 2, pp. 5864–5869, 2018, doi: 10.1016/j.matpr.2017.12.184.
[26] B. Rajwinder Singh Gill a and P. S. S. C, “Materials Today : Proceedings Effect of different types of reinforcement on tribological properties of aluminium metal matrix composites (MMCs) – A review of recent studies,” *Mater. Today Proc.*, vol. 56, pp. 3094–3101, 2022, doi: 10.1016/j.matpr.2021.12.211.
[27] A. Verma, S. Singh Chauhan, and S. Prakash Dwivedi, “Review paper on thermal expansion and tribological behavior of composite materials,” *Mater. Today Proc.*, no. xxxx, 2022, doi: 10.1016/j.matpr.2022.11.073.
[28] M. Ravikumar, H. N. Reddappa, and R. Suresh, “ScienceDirect Aluminium Composites Fabrication Technique and Effect of Improvement in Their Mechanical Properties - A Review,” *Mater. Today Proc.*, vol. 5, no. 11, pp. 23796–23805, 2018, doi: 10.1016/j.matpr.2018.10.171.

[29] S. N. N. Kumar, R. M. Devarajaiah, and T. R. Prabhu, "Materials Today : Proceedings Review on aluminium based functionally graded composites," *Mater. Today Proc.*, no. xxxx, 2020, doi: 10.1016/j.matpr.2020.06.307.
[30] S. Venugopal and L. Karikalan, "A review paper on aluminium-alumina arrangement of composite materials in automotive brakes," *Mater. Today Proc.*, vol. 21, no. xxxx, pp. 320–323, 2020, doi: 10.1016/j.matpr.2019.05.452.
[31] P. K. Jain, P. Baredar, and S. C. Soni, "Development of silicon carbide particle reinforced aluminium 6101 metal matrix composite using two-step stir casting," *Mater. Today Proc.*, vol. 18, pp. 3521–3525, 2019, doi: 10.1016/j.matpr.2019.07.281.
[32] S. Singh, S. Kumar, and B. Pesic, "The Corrosion Behavior of 5xxx and 6xxx Aluminum Alloys with Trace Calcium," in *Minerals, Metals and Materials Series*, Springer Science and Business Media Deutschland GmbH, 2021, pp. 198–205. doi: 10.1007/978-3-030-65396-5_29.
[33] V. Kumar, H. Mehdi, and A. Kumar, "Effect of silicon content on the mechanical properties of aluminum alloy," *Int. Res. J. Eng. Technol.*, vol. 2, no. 4, pp. 1326–1330, 2015.
[34] M. Baruah and A. Borah, "Processing and precipitation strengthening of 6xxx series aluminium alloys: A review," *Int. J. Mater. Sci.*, vol. 1, no. 1, pp. 40–48, Jan. 2020, doi: 10.22271/27078221.2020.v1.i1a.10.
[35] H. Torres, T. Caykara, H. Rojacz, B. Prakash, and M. Rodríguez Ripoll, "The tribology of Ag/MoS2-based self-lubricating laser claddings for high temperature forming of aluminium alloys," *Wear*, vol. 442–443, p. 203110, Feb. 2020, doi: 10.1016/j.wear.2019.203110.
[36] E. Fahri Ozdogru, "The Effect of Chemical Composition on EN AW 6XXX Series Aluminum Alloys," in *Recent Advancements in Aluminum Alloys [Working Title]*, IntechOpen, 2023. doi: 10.5772/intechopen.110218.
[37] R. Pandiyarajan, P. Maran, S. Marimuthu, and K. Arumugam, "Mechanical and metallurgical characterization of friction stir welded AA6061- ZrO2-C hybrid MMCs," *Mater. Today Proc.*, vol. 19, pp. 256–259, Jan. 2019, doi: 10.1016/J.MATPR.2019.06.760.
[38] A. P. Kumbhar, R. T. Vyavahare, and S. G. Kulkarni, "Vibrational response and mechanical properties characterization of aluminium alloy 6061/Sic composite," *AIP Conf. Proc.*, vol. 1966, 2018, doi: 10.1063/1.5038715.
[39] J. Singh, C. S. Jawalkar, and R. M. Belokar, "Analysis of Mechanical Properties of AMC Fabricated by Vacuum Stir Casting Process," *Silicon*, vol. 12, no. 10, pp. 2433–2443, Oct. 2020, doi: 10.1007/s12633-019-00338-8.
[40] N. Subramani, R. Haridass, S. Pramodh, A. Prem Anand, and N. Manikandan, "Mechanical strength analysis of Al6061&Al2024 based metal matrix composite prepared through stir casting method," in *Materials Today: Proceedings*, Elsevier, Jan. 2021, pp. 4513–4517. doi: 10.1016/j.matpr.2021.05.417.
[41] U. Pandey, R. Purohit, P. Agarwal, and S. Kumar, "ScienceDirect Study of Fabrication , Testing and Characterization of Al / TiC Metal Matrix Composites through different Processing Techniques," *Mater. Today Proc.*, vol. 5, no. 2, pp. 4106–4117, 2018, doi: 10.1016/j.matpr.2017.11.671.
[42] S. Gudipudi, S. Nagamuthu, K. S. Subbian, and S. P. R. Chilakalapalli, "Enhanced mechanical properties of AA6061-B4C composites developed by a novel ultra-sonic assisted stir casting," *Eng. Sci. Technol. an Int. J.*, vol. 23, no. 5, pp. 1233–1243, Oct. 2020, doi: 10.1016/j.jestch.2020.01.010.
[43] M. Yunus and R. Alfattani, "Assessment of Mechanical and Tribological Behavior of AA6061 Reinforced with B4C and Gr Hybrid Metal Matrix Composites," *Coatings*, vol. 13, no. 9, p. 1653, Sep. 2023, doi: 10.3390/coatings13091653.
[44] P. Mandloi, B. Dhakar, V. Pare, and S. Manepatil, "Experimental investigation of wear properties of AA6061 + Al2O3 metal matrix composite fabricated by vacuum stir casting method," in *Materials Today: Proceedings*, Elsevier, Jan. 2022, pp. 55–61. doi: 10.1016/j.matpr.2022.03.312.
[45] K. Rajkumar, P. Rajan, and J. M. A. Charles, "Microwave Heat Treatment on Aluminium 6061 Alloy- Boron Carbide Composites," *Procedia Eng.*, vol. 86, pp. 34–41, 2014, doi: 10.1016/j.proeng.2014.11.008.
[46] D. Chandra, N. R. Chauhan, and S. Rajesha, "Hardness and toughness evaluation of developed Al metal matrix composite using stir casting method," in *Materials Today: Proceedings*, Elsevier, Jan. 2019, pp. 872–876. doi: 10.1016/j.matpr.2019.12.026.
[47] B. C. Kandpal, N. Johri, N. Kumar, and A. Srivastava, "Effect of industrial/ agricultural waste materials as reinforcement on properties of metal matrix composites," *Mater. Today Proc.*, vol. 46, pp. 10736–10740, 2021, doi: 10.1016/j.matpr.2021.01.575.
[48] N. Panwar and A. Chauhan, "Fabrication methods of particulate reinforced Aluminium metal matrix composite-A review," in *Materials Today: Proceedings*, Elsevier, Jan. 2018, pp. 5933–5939. doi: 10.1016/j.matpr.2017.12.194.
[49] S. N. Tekale and D. R. Dolas, "Materials Today : Proceedings Study of fabrication methods and various reinforcements with aluminium for automotive application – A review," *Mater. Today Proc.*, vol. 62, pp. 2768–2773, 2022, doi: 10.1016/j.matpr.2022.01.343.
[50] S. Lal, R. Sehrawat, and N. Sharma, "Materials Today : Proceedings A short review on the developments of aluminium matrix composites," *Mater. Today Proc.*, no. xxxx, 2023, doi: 10.1016/j.matpr.2023.02.012.
[51] A. Ramanathan, P. K. Krishnan, and R. Muraliraja, "A review on the production of metal matrix composites through stir casting – Furnace design, properties, challenges, and research opportunities," *J. Manuf. Process.*, vol. 42, no. April, pp. 213–245, 2019, doi: 10.1016/j.jmapro.2019.04.017.
[52] A. Coyal, N. Yuvaraj, R. Butola, and L. Tyagi, "An experimental analysis of tensile, hardness and wear properties of aluminium metal matrix composite through stir casting process," *SN Appl. Sci.*, vol. 2, no. 5, pp. 1–10, May 2020, doi: 10.1007/s42452-020-2657-8.

[53] A. Kumar, R. Bhandari, and C. Pinca-bretotean, “Materials Today : Proceedings A systematic overview on fabrication aspects and methods of aluminum metal matrix composites,” *Mater. Today Proc.*, no. xxxx, 2020, doi: 10.1016/j.matpr.2020.11.899.
[54] V. Mohanavel and M. Ravichandran, “IOP Conference Series : Materials Science and Engineering Role of Stir Casting in development of Aluminium Metal Matrix Composite (AMC): An Overview Role of Stir Casting in development of Aluminium Metal Matrix Composite (AMC): An Overview,” 2021, doi: 10.1088/1757-899X/1116/1/012022.
[55] L. Singh, S. Kumar, S. Raj, Shivam, and P. Badhani, “Aluminium Metal Matrix Composites: Manufacturing and Applications,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1149, no. 1, p. 012025, 2021, doi: 10.1088/1757-899x/1149/1/012025.
[56] D. K. Sharma, D. Mahant, and G. Upadhyay, “Manufacturing of metal matrix composites: A state of review,” *Mater. Today Proc.*, vol. 26, no. xxxx, pp. 506–519, 2019, doi: 10.1016/j.matpr.2019.12.128.
[57] C. S. Shyn, R. Rajesh, and M. D. Anand, “Review of aluminium 6061 metal matrix composites fabricated using stir casting method and applications,” in *AIP Conference Proceedings*, American Institute of Physics Inc., Feb. 2021. doi: 10.1063/5.0036169.
[58] N. Ashok, A. Johnson Santhosh, A. Diriba Tura, H. Beyene Mamo, E. A. Lemma, and L. E. Melaku, “Effect of stirring speed and time on the mechanical properties of Al8011-SiC metal matrix composites,” *Mater. Today Proc.*, vol. 64, pp. 194–199, 2022, doi: 10.1016/j.matpr.2022.04.364.
[59] A. Gacem *et al.*, “Optimization and Mechanical Characteristics of AA6061/Zirconia Nanocomposites Fabricated by Ultrasonic-Aided Stir Casting Method,” *J. Nanomater.*, vol. 2022, p. 15, 2022, doi: 10.1155/2022/2453412.
[60] A. Kareem, J. A. Qudeiri, A. Abdudeen, T. Ahammed, and A. Ziout, “A review on aa 6061 metal matrix composites produced by stir casting,” *Materials (Basel).*, vol. 14, no. 1, pp. 1–22, 2021, doi: 10.3390/ma14010175.
[61] S. Sachinkumar, S. Narendranath, and D. Chakradhar, “Studies on microstructure and mechanical characteristics of as cast AA6061/SiC/fly ash hybrid AMCs produced by stir casting,” in *Materials Today: Proceedings*, Elsevier, Jan. 2020, pp. A1–A5. doi: 10.1016/j.matpr.2020.01.266.
[62] Y. Yashpal, N. Panwar, M. M. Goud, and S. Kant, “Experimental investigation of AA6061-Al2O3-Fly ash composite produced by using stir casting method,” in *Materials Today: Proceedings*, Elsevier, Jan. 2018, pp. 28413–28419. doi: 10.1016/j.matpr.2018.10.127.
[63] A. Thirugnanasambandam, N. Joy, A. Mariadhas, K. S. S. Raja, A. K. Tiwari, and B. V. S. Krishna, “Study on mechanical properties of aluminium 6061 / SiC composite by single and double stir casting process,” in *AIP Conference Proceedings*, American Institute of Physics Inc., Dec. 2020. doi: 10.1063/5.0034127.
[64] M. A. Taha, R. A. Youness, and M. A. Ibrahim, “Evolution of the physical, mechanical and electrical properties of sic-reinforced al 6061 composites prepared by stir cast method,” *Biointerface Res. Appl. Chem.*, vol. 11, no. 2, pp. 8946–8956, 2021, doi: 10.33263/BRIAC112.89468956.
[65] A. P. Reddy, P. V. Krishna, and R. N. Rao, “Mechanical and wear properties of aluminum-based nanocomposites fabricated through ultrasonic assisted stir casting,” *J. Test. Eval.*, vol. 48, no. 4, 2020, doi: 10.1520/JTE20170560.
[66] R. Devanathan, J. Ravikumar, S. Boopathi, D. Christopher Selvam, and S. A. Anicia, “Influence in Mechanical Properties of Stir Cast Aluminium (AA6061) Hybrid Metal matrix Composite (HMMC) with Silicon Carbide, Fly Ash and Coconut coir Ash Reinforcement,” in *Materials Today: Proceedings*, Elsevier, Jan. 2019, pp. 3136–3144. doi: 10.1016/j.matpr.2020.03.450.
[67] P. Kumar Singh, A. Thakur, R. Rana, and R. Lal, “Development and characterization of AA6063 matrix composite reinforced with B4C, graphite and groundnut shell powder,” *Mater. Today Proc.*, vol. 78, pp. 667–674, Jan. 2023, doi: 10.1016/j.matpr.2022.12.186.
[68] K. Kalaiselvan, N. Murugan, and S. Parameswaran, “Production and characterization of AA6061-B4C stir cast composite,” *Mater. Des.*, vol. 32, no. 7, pp. 4004–4009, Aug. 2011, doi: 10.1016/j.matdes.2011.03.018.
[69] S. Senthil Murugan, V. Jegan, and M. Velmurugan, “Mechanical properties of SiC, Al2O3 reinforced aluminium 6061-T6 hybrid matrix composite,” *J. Inst. Eng. Ser. D*, vol. 99, no. 1, pp. 71–77, Jun. 2017, doi: 10.1007/s40033-017-0142-3.
[70] A. Malik, N. S. Jammoria, R. Bhat, P. Saxena, M. I. U. Haq, and A. Raina, “Nanocomposites and tribology,” in *Nanomaterials for Sustainable Tribology*, CRC Press, 2023, pp. 25–51. doi: 10.1201/9781003306276-2.
[71] O. Sharma, P. Gupta, and T. Kumar, “Characterization of AA6063-T6/SiC/Walnut shell powder hybrid composite fabricated by electromagnetic stir-casting process with vacuum,” *Mater. Today Proc.*, vol. 76, pp. 630–635, Jan. 2023, doi: 10.1016/j.matpr.2022.10.247.
[72] S. Rawal, T. Das, A. M. Sidpara, and J. Paul, “Fabrication and characterization of Al/GNPs composite by bottom pouring stir casting,” *Mater. Lett.*, vol. 327, p. 133002, Nov. 2022, doi: 10.1016/j.matlet.2022.133002.
[73] P. K. Sonker, T. Jackson Singh, and Y. Kumar Verma, “Effect of reinforced diverse synthetic and agricultural-industrial waste materials on the microstructural and mechanical performance of hybrid metal matrix composite,” *Mater. Today Proc.*, Jul. 2023, doi: 10.1016/j.matpr.2023.06.313.
[74] T. Arunkumar, V. Pavanan, V. A. Murugesan, V. Mohanavel, and K. Ramachandran, “Influence of Nanoparticles Reinforcements on Aluminium 6061 Alloys Fabricated via Novel Ultrasonic Aided Rheo-Squeeze Casting Method,” *Met. Mater. Int.*, vol. 28, no. 1, pp. 145–154, Jan. 2022, doi: 10.1007/s12540-021-01036-0.
[75] N. K. Chandla, S. Kant, and M. M. Goud, “Mechanical, tribological and microstructural characterization of stir cast Al-6061 metal/matrix composites—a comprehensive review,” *Sadhana - Acad. Proc. Eng. Sci.*, vol. 46, no. 1, pp. 1–38, Dec. 2021, doi: 10.1007/s12046-021-01567-7.

[76] R. Nandal, A. Jakhar, and R. Kumar Duhan, "Review on synthesis of AA 6061 metal matrix alloy using stir casting method," *Mater. Today Proc.*, vol. 78, pp. 462–468, Jan. 2023, doi: 10.1016/j.matpr.2022.10.268.
[77] S. Raja, M. Ravichandran, B. Stalin, and V. Anandakrishnan, "ScienceDirect A Review on Tribological , Mechanical , Corrosion and Wear Characteristics of Stir Cast AA6061 Composites," *Mater. Today Proc.*, vol. 22, pp. 2614–2621, 2020, doi: 10.1016/j.matpr.2020.03.392.
[78] S. Sivananthan, V. Rajalaxman Reddy, and C. Samson Jerold Samuel, "Preparation and evaluation of mechanical properties of 6061Al-Al2O3 metal matrix composites by stir casting process," in *Materials Today: Proceedings*, Elsevier, Jan. 2020, pp. 713–716. doi: 10.1016/j.matpr.2019.06.744.
[79] S. P. V.G. and S. K. Subbu, "Effect of ultrasonic treatment during stir casting on mechanical properties of AA6063-SiC composites," *Mater. Chem. Phys.*, vol. 294, no. November 2022, p. 126977, 2022, doi: 10.1016/j.matchemphys.2022.126977.
[80] P. Prajulraj and R. Sridhar, "Experimental investigation on mechanical and morphological properties of AA 6061 reinforced with silicon carbide," in *Materials Today: Proceedings*, Elsevier, Jan. 2020, pp. 2041–2047. doi: 10.1016/j.matpr.2020.07.501.
[81] A. P. Rath, S. K. Patel, and N. Deep, "Synthesis and characterisation of silicon carbide nanoparticulate reinforced metal matrix composite," *Mater. Today Proc.*, vol. 33, no. xxxx, pp. 5419–5424, 2020, doi: 10.1016/j.matpr.2020.03.136.
[82] T. Karuppusamy and S. Bhaskar, "Study on Ageing Behaviour of Silicon Carbide, Graphite Reinforced Hybrid Al6061 Composites," in *AIP Conference Proceedings*, American Institute of Physics Inc., Nov. 2022. doi: 10.1063/5.0109460.
[83] G. B. Veeresh Kumar, R. Pramod, C. S. P. Rao, and P. S. S. Gouda, "Artificial Neural Network Prediction on Wear of Al6061 Alloy Metal Matrix Composites Reinforced With-Al2o3," *Mater. Today Proc.*, vol. 5, no. 5, pp. 11268–11276, 2018, doi: 10.1016/j.matpr.2018.02.093.
[84] C. B. Prabhakar, S. Hanumanthe, H. S. Naik, and J. Valder, "Effect of content of SiC on Al 6061 processed through stir casting," in *AIP Conference Proceedings*, American Institute of Physics Inc., May 2020. doi: 10.1063/5.0006825.
[85] M. B. Chennaiah, "Tribological and Mechanical Properties of Al 6061/SiC/ GO Hybrid Composites Produced with Stir Casting," *Artic. J. Mines Met. Fuels*, 2023, doi: 10.18311/jmmf/2023/35445.
[86] S. Sivananthan, V. Rajalaxman Reddy, and C. Samson Jerold Samuel, "Preparation and evaluation of mechanical properties of 6061Al-Al2O3 metal matrix composites by stir casting process," *Mater. Today Proc.*, vol. 21, no. xxxx, pp. 713–716, 2020, doi: 10.1016/j.matpr.2019.06.744.
[87] S. Sathiyaraj, A. Senthilkumar, P. M. Ameen, R. Sundar, and V. Saseendran, "Materials Today : Proceedings Experimental investigations on mechanical properties of Al-B4C metal matrix composites," *Mater. Today Proc.*, no. xxxx, 2020, doi: 10.1016/j.matpr.2020.11.017.
[88] C. H. Gireesh, "Experimental Investigation on Mechanical Properties of an Al6061 Hybrid Metal Matrix Composite," *J. Compos. Sci.*, pp. 1–10, 2018, doi: 10.3390/jcs2030049.
[89] Yashpal, C. S. Jawalkar, S. Kant, N. Panwar, M. D. Sharma, and H. S. Pali, "Effect of particle size variation of bagasse ash on mechanical properties of aluminium hybrid metal matrix composites," *Mater. Today Proc.*, vol. 21, no. 2020, pp. 2024–2029, 2020, doi: 10.1016/j.matpr.2020.01.319.
[90] G. B. V. Kumar *et al.*, "Effects of addition of Titanium Diboride and Graphite Particulate Reinforcements on Physical, Mechanical and Tribological properties of Al6061 Alloy based Hybrid Metal Matrix Composites," *Adv. Mater. Process. Technol.*, vol. 8, no. 2, pp. 2259–2276, Apr. 2022, doi: 10.1080/2374068X.2021.1904370.
[91] D. Chandra, N. Ram, and S. Rajesha, "Materials Today : Proceedings Hardness and toughness evaluation of developed Al metal matrix composite using stir casting method," *Mater. Today Proc.*, vol. xxx, no. xxxx, 2019, doi: 10.1016/j.matpr.2019.12.026.
[92] S. Das, M. Chandrasekaran, S. Samanta, P. Kayaroganam, and J. Paulo Davim, "Fabrication and tribological study of AA6061 hybrid metal matrix composites reinforced with SiC/B4C nanoparticles," *Ind. Lubr. Tribol.*, vol. 71, no. 1, pp. 83–93, 2019, doi: 10.1108/ILT-05-2018-0166.
[93] V. B. Nathan, R. Soundararajan, C. B. Abraham, E. Vinoth, and J. K. Narayanan, "Study of mechanical and metallurgical characterization of correlated aluminium hybrid metal matrix composites," *Mater. Today Proc.*, vol. 45, no. xxxx, pp. 1237–1242, 2021, doi: 10.1016/j.matpr.2020.04.643.
[94] S. P. Dwivedi, A. K. Srivastava, N. K. Maurya, R. Sahu, A. Tyagi, and R. Maurya, "Microstructure and mechanical behaviour of Al/SiC/Al2O3hybrid metal matrix composite," *Mater. Today Proc.*, vol. 25, no. xxxx, pp. 789–792, 2019, doi: 10.1016/j.matpr.2019.09.023.
[95] Gangaraj and K. Manjunath, "Characterisation of Aluminium Metal Matrix Composites reinforced with SiC (Carborundum) & Al2O3 (Corundum)," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1189, no. 1, p. 012009, 2021, doi: 10.1088/1757-899x/1189/1/012009.
[96] S. J. James, M. Ganesan, P. Santhamoorthy, and P. Kuppan, "Development of hybrid aluminium metal matrix composite and study of property," in *Materials Today: Proceedings*, Elsevier, Jan. 2018, pp. 13048–13054. doi: 10.1016/j.matpr.2018.02.291.
[97] N. K. Chandla, Yashpal, S. Kant, M. M. Goud, and C. S. Jawalkar, "Experimental analysis and mechanical characterization of Al 6061/alumina/bagasse ash hybrid reinforced metal matrix composite using vacuum-assisted stir casting method," *J. Compos. Mater.*, vol. 54, no. 27, pp. 4283–4297, 2020, doi: 10.1177/0021998320929417.
[98] S. Hossain *et al.*, "Fabrication, microstructural and mechanical behavior of Al-Al2O3-SiC hybrid metal matrix composites," *Mater. Today Proc.*, vol. 21, no. xxxx, pp. 1458–1461, 2020, doi: 10.1016/j.matpr.2019.10.089.

[99] C. Elanchezhian, B. Vijaya Ramanth, G. B. Bhaskar, and M. Vivekanandhan, "An investigation of the mechanical properties of hybrid composites in applications of automotive industry," *Mater. Today Proc.*, vol. 16, pp. 875–882, 2019, doi: 10.1016/j.matpr.2019.05.172.

[100] B. S. Babu, P. Prathap, T. Balaji, D. Gowtham, S. D. S. Adi, and R. Divakar, "Materials Today : Proceedings Studies on mechanical properties of aluminum based hybrid metal matrix composites," *Mater. Today Proc.*, no. xxxx, 2020, doi: 10.1016/j.matpr.2020.07.342.

[101] A. Kumar, M. Yeasin Arafath, P. Gupta, D. Kumar, C. Mustansar Hussain, and A. Jamwal, "Microstructural and mechano-tribological behavior of Al reinforced SiC-TiC hybrid metal matrix composite," *Mater. Today Proc.*, vol. 21, no. xxxx, pp. 1417–1420, 2020, doi: 10.1016/j.matpr.2019.08.186.

[102] N. Radhika, M. Sam, M. Sathishkumar, V. Kavimani, and A. Pramanik, "Periodic advancement of aluminium metal matrix composites: tribo-mechanical performance, corrosion properties, challenges and future," Jul. 02, 2024, *Taylor & Francis*. doi: 10.1080/2374068X.2023.2216397.

[103] S. Hemalatha, R. Ramakrishna, and D. Srinivasa Rao, "Mechanical characterization of aluminum-boron carbide composites," *Mater. Today Proc.*, Jul. 2023, doi: 10.1016/j.matpr.2023.07.047.

[104] T. Ramachandran, S. Surendarnath, and R. Dharmalingam, "Materials Today : Proceedings Structural and suitability analysis of aluminium metal matrix composites for IC engine mountings," *Mater. Today Proc.*, no. xxxx, 2020, doi: 10.1016/j.matpr.2020.07.145.

[105] A. R. Anugu, N. V. T. Reddy, and D. Venkateswarlu, "Materials Today : Proceedings Theoritical modelling and finite element analysis of automobile piston," *Mater. Today Proc.*, no. xxxx, 2020, doi: 10.1016/j.matpr.2020.08.741.

[106] V. S. Shaisundaram, S. Ramasubramanian, and R. Srinath, "Materials Today : Proceedings Design and analysis of composite materials based piston," *Mater. Today Proc.*, vol. 69, no. 2022, pp. 783–785, 2023, doi: 10.1016/j.matpr.2022.07.211.

[107] Rashmita, S. Singh, A. Kumari, and S. Aggarwal, "Optimization of piston material with aluminium alloy based metal matrix composites," *Mater. Today Proc.*, Sep. 2023, doi: 10.1016/j.matpr.2023.09.019.

[108] K. Mayandi, R. M. Reddy, B. J. H. Vardhan, and Y. A. Babu, "STATIC AND THERMAL ANALYISIS OF PISTON USING ANSYS WITH VARIOUS MATERIALS," *Int. Res. J. Mod. Eng. Technol. Sci.*, no. 05, pp. 3035–3044, 2021.

[109] V. S. Aigbodion, "Bean pod ash nanoparticles a promising reinforcement for aluminium matrix biocomposites," *J. Mater. Res. Technol.*, vol. 8, no. 6, pp. 6011–6020, 2019, doi: 10.1016/j.jmrt.2019.09.075.

[110] M. U. Shah, B. A. Haider, and M. O. Farooq, "Design , Testing and Manufacturing of a Metal Matrix Composite Connecting Rod," *ResearchGate*, no. February, pp. 0–4, 2020, doi: 10.6084/m9.figshare.12612233.

[111] D. Banerjee, J. N. Biswal, and N. Sethy, "Behavioral Analysis of Connecting Rod Made from Aluminum Alloy and Micro Silicon Carbide Composite," *(UGC List. Journal)*, no. 4, pp. 37–43, 2019.

[112] A. Suresh, G. Rahul, N. S. Akhil, A. R. Reddy, P. L. B. Sai, and C. S. Reddy, "Materials Today : Proceedings Analytical investigation of crankshaft performance using stainless steel and aluminium," *Mater. Today Proc.*, vol. 64, pp. 374–381, 2022, doi: 10.1016/j.matpr.2022.04.720.

[113] T. Kumar Gupta, D. Mangal, and A. Gupta, "Impact of material properties on the dynamics of cam shaft," *Mater. Today Proc.*, vol. 47, no. xxxx, pp. 4083–4091, 2021, doi: 10.1016/j.matpr.2021.06.310.

[114] N. Srimath, C. J. Thomas Renald, and S. Yuvaraj, "Comparison Study of Aluminum Camshafts alloyed with different ratio of Silicon," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1100, no. 1, 2022, doi: 10.1088/1755-1315/1100/1/012023.

[115] R. G. Kolhe, P. V Kokate, S. D. Kashid, and A. Kadu, "Static , Modal & Thermal Analysis of Engine," *IJERT*, vol. 9, no. 08, pp. 185–190, 2020.

[116] R. Bambura, M. Šolc, M. Dado, and L. Kotek, "applied sciences Implementation of Digital Twin for Engine Block Manufacturing Processes," *Appl. Sci.*, 2020.

[117] E. N. Aw-, E. N. Aw-, and A. Hydrogen, "applied sciences Deterioration of Property of Aluminum Alloys (EN AW - 1050A ," *Appl. Sci.*, 2022.

[118] A. Silva-magalhães, L. Cederqvist, J. De Backer, E. Håkansson, B. Ossiansson, and G. Bolmsjö, "A Friction Stir Welding case study using Temperature Controlled Robotics with a HPDC Cylinder Block and dissimilar materials joining," *J. Manuf. Process.*, vol. 46, no. September, pp. 177–184, 2019, doi: 10.1016/j.jmapro.2019.08.012.

[119] S. C. Eze, D. S. Yawas, and E. T. Dauda, "Comparative Analysis of Some Models of Motorcycle Aluminum Engine Blocks Using Weighted Property Method (WPM).," *Int. J. Eng. Res. Appl.*, vol. 12, no. 6, pp. 22–29, 2022, doi: 10.9790/9622-1206022229.

[120] A. Malakizadi and L. Nyborg, "ScienceDirect Machining of bi-metallic aluminium-grey cast iron engine block – process optimisation by means of FEM," *Procedia CIRP*, vol. 117, pp. 323–328, 2023, doi: 10.1016/j.procir.2023.03.055.

[121] M. Subbiah, S. Balamurugan, K. Jayakumar, and R. Karthick, "Materials Today : Proceedings Analysis of engine cylinder block with fins by varying different materials," *Mater. Today Proc.*, vol. 72, pp. 2039–2043, 2023, doi: 10.1016/j.matpr.2022.08.079.

[122] S. Durgam, A. Kale, N. Kene, and A. Khedkar, "Thermal analysis of fin materials for engine cylinder heat transfer enhancement Thermal analysis of fin materials for engine cylinder heat transfer enhancement," *Mater. Sci. Eng.*, 2021, doi: 10.1088/1757-899X/1126/1/012071.

[123] R. S. Rana and R. Purohit, "Materials Today : Proceedings Synthesis & analysis of mechanical and tribological behaviour of silicon carbide and graphite reinforced aluminium alloy hybrid composites," *Mater. Today Proc.*, no. xxxx, 2020, doi: 10.1016/j.matpr.2020.02.650.

[124] D. D. Bhambure, "A REVIEW ON ADVANCE COMPOSITE MATERIAL FOR AUTOMOTIVE BODY APPLICATION," *Int. Res. J. Eng. Technol.*, vol. 07, no. 02, pp. 2926–2930, 2020.
[125] A. A. Feroz, D. Chawla, and R. Kumar, "Materials Today : Proceedings To study and analyze the design of drive shafts for automobiles using composite material through empirical review on literature," *Mater. Today Proc.*, vol. 56, pp. 3820–3822, 2022, doi: 10.1016/j.matpr.2022.01.309.
[126] L. Solazzi, D. Bertoli, and L. Ghidini, "Static and dynamic study of the industrial vehicle transmission adopting composite materials," *Compos. Struct.*, vol. 316, no. August 2022, p. 117042, 2023, doi: 10.1016/j.compstruct.2023.117042.
[127] S. K. S. Nadeem, G. Giridhara, and H. K. Rangavittal, "ScienceDirect A Review on the design and analysis of composite drive shaft," *Mater. Today Proc.*, vol. 5, no. 1, pp. 2738–2741, 2018, doi: 10.1016/j.matpr.2018.01.058.
[128] R. Siva, K. A. Vimalson, P. Yogeshkumar, N. Joy, M. Sangeetha, and K. Bantha Navas, "Study on optimization of spur gear performance with titanium carbide incorporated aluminium matrix composite," in *Materials Today: Proceedings*, Elsevier, Jan. 2021, pp. 3686–3691. doi: 10.1016/j.matpr.2020.10.804.
[129] C. Sasikumar, P. K. G, R. Sundaresan, and A. Ramakrishnan, "Materials Today : Proceedings Experimental analysis of Al-AlN-B 4 C hybrid composite material for automobile disk brake," *Mater. Today Proc.*, vol. 45, pp. 3674–3677, 2021, doi: 10.1016/j.matpr.2021.01.954.
[130] I. Romanov, E. Chernyshov, and A. Romanov, "Materials Today : Proceedings Assessment of the possibility for substituting cast iron in vehicle brake disc with Aluminum-Based Metal-matrix composite material produced by internal oxidation," *Mater. Today Proc.*, no. xxxx, 2019, doi: 10.1016/j.matpr.2019.07.224.
[131] P. Sivaprakasam, E. Abebe, R. Čep, and M. Elangovan, "Thermo-Mechanical Behavior of Aluminum Matrix Nano-Composite Automobile Disc Brake Rotor Using Finite Element Method," *Materials (Basel).*, vol. 15, no. 17, 2022, doi: 10.3390/ma15176072.
[132] P. Sadagopan, H. K. Natarajan, and P. K. J, "Study of silicon carbide-reinforced aluminum matrix composite brake rotor for motorcycle application," pp. 1461–1475, 2018, doi: 10.1007/s00170-017-0969-7.
[133] P. K. Dinesh Kumar and S. Darius Gnanaraj, "Aluminium-Silicon based Metal Matrix Composites for brake rotor applications: a review," *Eng. Res. Express*, vol. 5, no. 2, p. 022002, Apr. 2023, doi: 10.1088/2631-8695/ACCDB6.
[134] D. Tan *et al.*, "Evaluation of the wear resistance of aluminium-based hybrid composite brake discs under relevant city rail environments," *Mater. Des.*, vol. 215, p. 110504, Mar. 2022, doi: 10.1016/j.matdes.2022.110504.
[135] M. M. A. Baig, A. M. Al-Qutub, I. M. Allam, F. Patel, and A. S. Mohammed, "Tribological Performance of Sub-Micron Al2O3-Reinforced Aluminum Composite Brake Rotor Material," *Arab. J. Sci. Eng.*, vol. 46, no. 3, pp. 2691–2700, 2021, doi: 10.1007/s13369-020-05179-x.
[136] K. Vinoth Babu, S. Marichamy, P. Ganesan, D. Madan, M. Uthayakumar, and T. P. D. Rajan, "Processing of functionally graded aluminum composite brake disc and machining parameters optimization," in *Materials Today: Proceedings*, Elsevier, Jan. 2020, pp. 563–567. doi: 10.1016/j.matpr.2019.06.707.
[137] R. Balaji, M. Nadarajan, A. Selokar, S. S. Kumar, and S. Sivakumar, "ScienceDirect Modelling and analysis of Disk Brake under Tribological behaviour of Al-Al2O3 Ceramic Matrix Composites / Kevlar ® 119 composite / C / Sic-Carbon Matrix Composite / Cr-Ni-Mo-V steel .," *Mater. Today Proc.*, vol. 18, pp. 3415–3427, 2019, doi: 10.1016/j.matpr.2019.07.269.
[138] A. Chatterjee *et al.*, "Fabrication and Characterization of SiC-reinforced Aluminium Matrix Composite for Brake Pad Applications," *Metals (Basel).*, vol. 13, no. 3, 2023, doi: 10.3390/met13030584.
[139] T. Review, "Aluminium-Silicon based Metal Matrix Composites for brake rotor applications : a review Aluminium-Silicon based Metal Matrix Composites for brake rotor applications : a review," *Eng. Res. Express*, vol. 5, p. 022002, 2023.
[140] S. Venkatachalam, S. Baskaran, R. S. Karrthik, D. B. T. G. Raj, and T. R. Kumar, "Titanium diboride reinforced aluminum composite as a robust material for automobile applications," *AIP Conf. Proc.*, vol. 2128, no. July, 2019, doi: 10.1063/1.5117922.
[141] L. Mercy, K. Kutuva, and N. Joy, "Study of aluminium metal matrix composite material characteristics for potential use in disc brake rotor Study of Aluminium Metal Matrix Composite Material Characteristics for Potential Use in Disc Brake Rotor," vol. 080006, no. December, 2020.
[142] M. M. A. B. A. M. Al, Q. I. M. Allam, F. Patel, and A. Samad, "Tribological Performance of Sub - Micron Al 2 O 3 - Reinforced Aluminum Composite Brake Rotor Material," *Arab. J. Sci. Eng.*, vol. 46, no. 3, pp. 2691–2700, 2021, doi: 10.1007/s13369-020-05179-x.
[143] M. Kumar and A. Megalingam, "Tribological characterization of Al6061/alumina/graphite/redmud hybrid composite for brake rotor application," *Part. Sci. Technol.*, vol. 37, no. 3, pp. 261–274, 2019, doi: 10.1080/02726351.2017.1367747.
[144] J. P. Harshad, C. P. Narendra, P. P. Sbhash, S. Ganesh, Akshay, and S. Mahamandre, "Casting of Aluminium Alloy with Rice Husk Ash for Disc Brake Rotor," *GRD Journals-Global Res. Dev. J. Eng.*, vol. 3, no. 5, pp. 73–83, 2018.
[145] C. Pinca-Bretotean1, A. L. Craciun1, C. Preda2, and and A. K. Sharma3, "Physico-mechanical and tribological characteristics of composites used for brake pads Physico-mechanical and tribological characteristics of composites used for brake pads," *J. Phys.*, vol. 1781, p. 012032, 2021, doi: 10.1088/1742-6596/1781/1/012032.
[146] O. Access, "Aspects regarding manufacturing technologies of composite materials for brake pad application Aspects regarding manufacturing technologies of composite materials for brake pad application," pp. 0–9, doi: 10.1088/1757-899X/294/1/012003.
[147] S. Pujari and S. Srikiran, "Experimental investigations on wear properties of Palm kernel reinforced composites for brake pad applications," *Def. Technol.*, vol. 15, no. 3, pp. 295–299, 2019, doi: 10.1016/j.dt.2018.11.006.

[148] S. Anoop, S. Natarajan, and S. P. K. Babu, "Analysis of factors influencing dry sliding wear behaviour of Al / SiC p – brake pad tribosystem," *Mater. Des.*, vol. 30, no. 9, pp. 3831–3838, 2009, doi: 10.1016/j.matdes.2009.03.034.

[149] A. A. Agbeleye, D. E. Esezobor, S. A. Balogun, J. O. Agunsoye, J. Solis, and A. Neville, "Tribological properties of aluminium-clay composites for brake disc rotor applications," *J. King Saud Univ. - Sci.*, vol. 32, no. 1, pp. 21–28, Jan. 2020, doi: 10.1016/j.jksus.2017.09.002.

[150] K. Loganathan and S. K. V. Siva, "Materials Today : Proceedings Design and optimization of aluminium alloy wheel rim in automobile industry," *Mater. Today Proc.*, no. xxxx, 2023, doi: 10.1016/j.matpr.2023.01.207.

[151] Ş. Karabulut, H. Karakoç, M. Bilgin, H. Canpolat, G. M. Krolczyk, and M. Sarıkaya, "A comparative study on mechanical and ballistic performance of functionally graded Al6061 composites reinforced with B4C, SiC, and Al2O3," *J. Mater. Res. Technol.*, vol. 23, pp. 5050–5065, Mar. 2023, doi: 10.1016/j.jmrt.2023.02.116.