STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 13, Special Issue 1, 2025
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Review JoPC

An Overview of The Impact of Reinforcement on Mechanical and Thermal Characteristics of Aluminum Alloy Composites

Dhruv kumar[1,*], Subodh Barthwal[2], Praveen Pachauri[3]

Abstract

Aluminum is utilized extensively in the domains of aerospace, electronic technology, electric module packing, automotive body structure, solar and wind energy management, and so on because of its better potential for weight reduction. Strength of aluminum is very less so application is limited where high strength is needed. Aluminum alloy which have greater potential for weight reduction as well as high strength to weight ratio have ability to overcome these problem. Aluminum alloy have major application in aerospace, shipbuilding, and automotive industries, it is able to provide the greater mechanical characteristics needed by modern technologies but high wear rate and not able to withstand high temperature. So it is very necessary to reinforcement some nanomaterial which improve the overall characteristic of material. In this investigation a thorough summary of the recent development of nanomaterial and its effect on aluminum alloy is studies through powder metallurgy route. This study also contributes to the understanding of material behavior and supports the development of high-performance aluminum alloys for innovative engineering solutions.

Keywords: Metal matrix composite, aluminum alloy, nano particles, powder metallurgy

INTRODUCTION

Metal matrix composites that are known as metal nanocomposites, are a type of cutting-edge materials which produce lightweight, high-strength composite materials using reinforcing particles [1]. Aluminum alloys have excellent strength-to-weight ratios and exceptional mechanical qualities, they are often lightweight and used extensively in the automotive, aerospace, aeronautical and electronics sectors [2]. Aluminum alloys can be made using additional alloying, heat treatment, thermomechanical processing, and extreme plastic deformation, among other methods, to improve their qualities. Furthermore, aluminum alloys have some drawbacks is their poor resistance to corrosion and abrasive wear [3]. Therefore, in order to reinforce aluminum and its alloy, various innovative techniques and materials are needed. These Al alloy limitations can be effectively addressed by using metal matrix composites which are made with aluminum alloy and supplemented with ceramic, intermetallic, or refractory material.

Aluminum matrix composites are made of pure aluminum or an alloy of it, and because of their exceptional properties, they are being used more and more in industrial applications, applications related to mechanics, materials, and tribology. This resulted in the creation of Aluminum matrix composites that integrate a variety of reinforcement elements into a matrix made of every conceivable aluminum alloy in order to obtain unique desired

***Author for Correspondence**
Dhruv Kumar

[1]Research Scholar, Department of Mechanical Engineering, Amity School of Engineering and Technology, Greater Noida, Uttar Pradesh, India
[2]Assistant Professor, Department of Mechanical Engineering, Amity School of Engineering and Technology, Greater Noida, Uttar Pradesh, India
[3]Professor, Department of Mechanical Engineering, Government Polytechnic Siwan, Bihar, India

Received Date: May 16, 2024
Accepted Date: June 01, 2024
Published Date: December 06, 2024

Citation: Dhruv Kumar, Subodh Barthwal, Praveen Pachauri. An Overview of The Impact of Reinforcement on Mechanical and Thermal Characteristics of Aluminum Alloy Composites. Journal of Polymer & Composites. 2025; 13(Special Issue 1): S240–S249p.

qualities. There are nine different kinds of aluminum, and four of them are referred to as heat treatable aluminum alloys because they can precipitately strengthen, improving their mechanical properties. [4, 5].

Copper, zinc, magnesium, and manganese are among the metals that are alloyed with aluminum to provide it with increased mechanical strength for specific uses. The aluminum alloys series is determined by the alloying components. The series categories that are feasible are 1xxx to 9xxx. There are two further categories for aluminum alloys: heat-treatable alloys and non-heat-treatable alloys. Alloys that can be heat-treated are those whose strength is increased through precipitation hardening [6]. The aluminum series 1xxx (Al), 2xxx (aluminum-copper), 3xxx (Al-Mn), 4xxx (Al-Si), 5xxx (Al-Mg), 6xxx (aluminum-magnesium-silicon), and 7xxx (aluminum-zinc-magnesium) [7].

Heat treatable Al-alloys can have a reinforcing phase added to them to increase the overall strength of the composite and enhance its mechanical qualities even further. Typically Al-Alloy, metal matrix composites (MMC) are man-made materials consisting of two or more distinct phases: a secondary reinforcing phase and a continuous metallic component called the matrix. The reinforcement as fibers or particles in the secondary phase can be continuous or intermittent. An enhancement of the material's mechanical characteristics results from the introduction of this phase into the matrix [8]. In comparison to unreinforced alloys, metal matrix composites have better characteristics [9].

Compared to continuous fiber reinforced MMCs, the qualities of discontinuously reinforced aluminum MMCs with particles or short fibers are not as great; unless, these materials are more cost-effective to produce since they are easier to construct and offer greater manufacturing flexibility [10,11]. The most important parameter that influence the metal matrix composites are its type, size, shape, and weight fractions. However, it has been observed on a regular basis that the manufacturing routes have a major impact on the last products [12].

Currently, metal matrix nanocomposites employ a broad range of reinforcing agents. With their diverse mechanical, chemical, and thermal properties, these nanomaterials which include carbides (B_4C[13], SiC[14], TiC[15], WC[16]), oxides (TiO_2[17], ZrO_2[18], Al_2O_3[19]), and carbon-based nanomaterials (Graphene[20], CNT[21]) give unique qualities to their respective composites.

Many review papers are available on fabrication of aluminum with reinforcement of micro and nano particles and their effect on mechanical and wear behavior but limited study was done on aluminum alloy based metal matrix nano-composites. In this paper we tried to review the fabrication process of aluminum alloy based composites with reinforcement of micro and nano particles.

FABRICATION PROCESS

Metal matric composites can be produced using a variety of manufacturing processes, each with unique benefits, drawbacks, and uses. When creating composites, manufacturing techniques are also helpful in determining the qualities and attributes that support application selection. Selection of the manufacturing method is based on a number of parameters, including component development, desired qualities, and material type. Metal matrix composites are typically produced using both liquid and solid state techniques. Solid state processing includes low temperature production techniques like as diffusion bonding and powder metallurgy. Strong interfacial reactions are avoided, and the undesirable counteraction connecting the reinforcement and matrix is managed by the powder metallurgy (PM) approach. Nevertheless, the procedure has limitations on scale and is costly. Moreover, certain drawbacks such as reinforcements breaking during powder metallurgy processing.

Usually, both liquid and solid state methods are used to create MMCs. Stir casting, squeeze casting, spray coating, ultrasonic aided casting, and fragmented melt deposition are examples of liquid casting techniques. The process involves combining the reinforcing elements with the molten metal, filling the mold cavity with the absorbed solution, and then waiting for it to solidify [22-23]. Because stir casting is so affordable, it's always the best choice. Stir casting has several notable advantages. It's a more flexible and straightforward approach than the others. Stir casting process is perfect for near-net form components and performs well in large volume production. Large material selection, excellent matrix–particle bonding, simpler control over matrix structure, cheap processing costs, flexibility in large-scale manufacturing, and remarkable productivity for near-net-shaped components are just a few of the many noteworthy advantages of the stirring process. A few disadvantages of stir casting aluminum metal composites are low wettability and an uneven distribution of reinforcing material. [24]. The schematic diagram of stir casting is shown in Figure 1.

Powder metallurgy and diffusion bonding are two examples of low temperature manufacturing techniques used in solid state processing. The study of processing metal powders, such as their creation, characterization, and transformation into functional engineering components, is known as powder metallurgy. It is a versatile manufacturing technique that can produce a large variety of novel materials, microstructures, and characteristics. Because powder metallurgy can produce complicated parts with close tolerances at a reasonable cost, it is a desirable manufacturing process. Significant interfacial reactions are prevented by the powder metallurgy method by regulating the undesirable counteraction that connects the reinforcement and matrix. However, the process is expensive and has scalability restrictions [25]. The flow chart to convert raw material into finished product is shown in Figure 2. The process involve to produced finished product from micro/nano powder are production of powder, mixing and blending of powder, compaction of powder and sintering of compacted specimen. Various process involved and its method are shown in Figure 3.

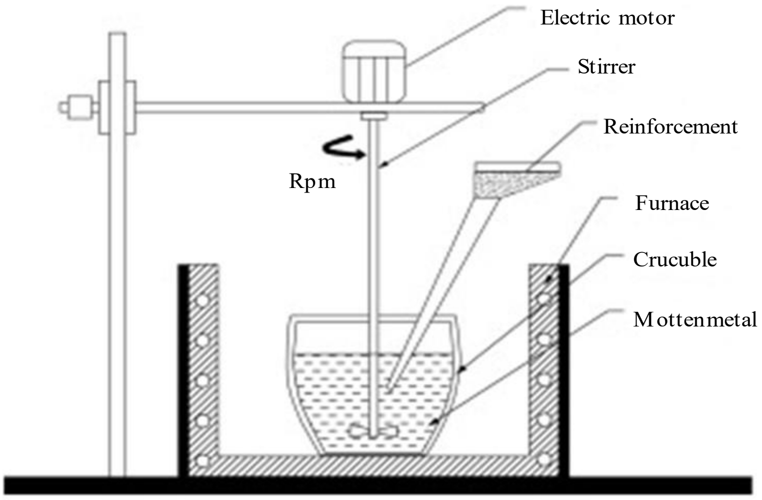

Figure 1. Schematic diagram of stir casting technique [24].

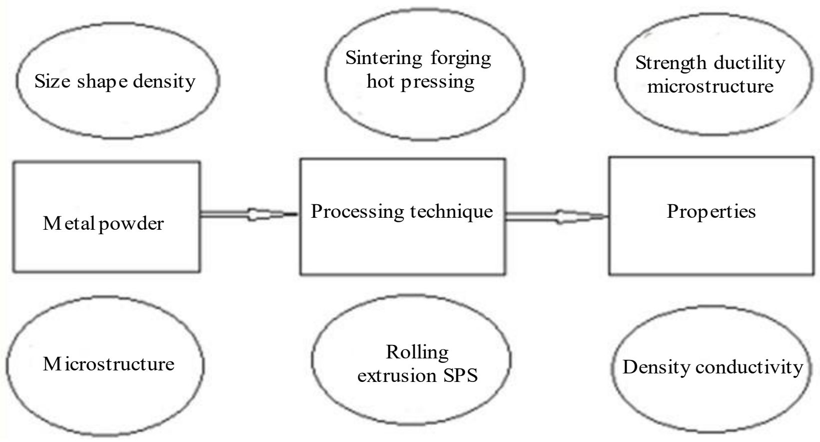

Figure 2. Flow chart of converting raw materials to finished through powder metallurgy.

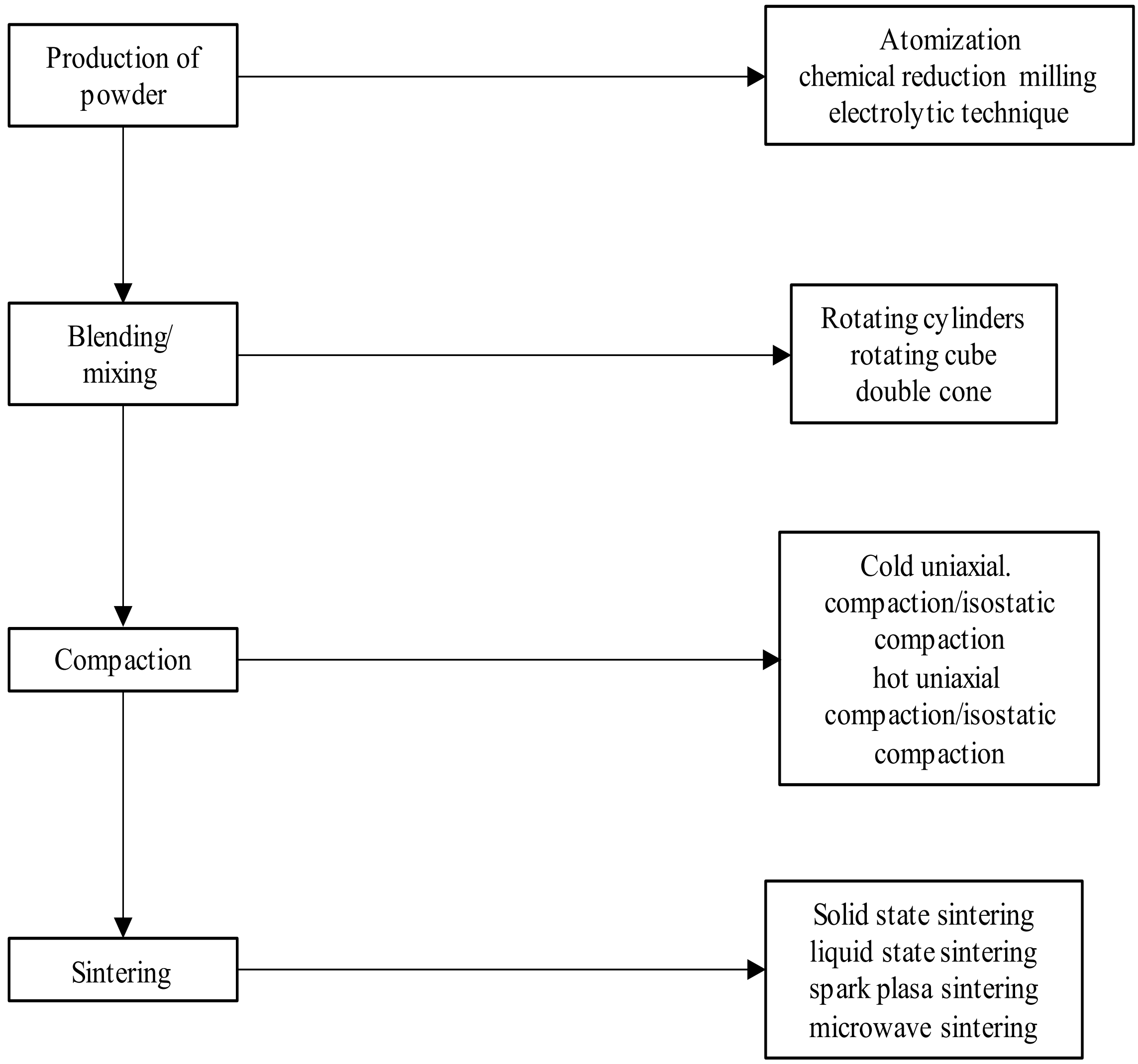

Figure 3. Process involved in powder metallurgy.

Powder metallurgy's initial phase involves weighing the mixtures composition and preparing the powder that will be used as a component in the subsequent processing stages. For example, metal or metal alloy powders need to be blended with reinforcement.

The next step involves compacting blended powders using either cold isostatic pressing or uniaxial pressing to create a "green form". Green form or the resulting green body, is around 80% dense. The green body is heated to the appropriate processing temperature in an inert atmosphere during the third step of sintering to create a sintered body. Generally, the theoretical density of the sintered body is 100% [26]. Schematic diagram of spark plasma sintering is shown in Figure 4.

REINFORCEMENT MATERIAL AND EFFECT ON MECHANICAL PROPERTIES

Many fabrication techniques have been used to successfully reinforce different materials in an Al matrix, including B_4C, TiC, Graphene, SiC, carbon nano-tube (CNT), Al_2O_3, ZrO_2, boron carbide, and marble dust. The mechanical, wear, and thermal behavior of the created aluminum alloy composites are all greatly impacted by the addition of these additional constituents. Due to these materials advantages over other materials, Al_2O_3, SiC, and B_4C are the most commonly utilized materials for reinforcement. Table 1 shows the summary of various aluminum alloy with reinforcement material, fabrication technique and effect on manufacturing properties.

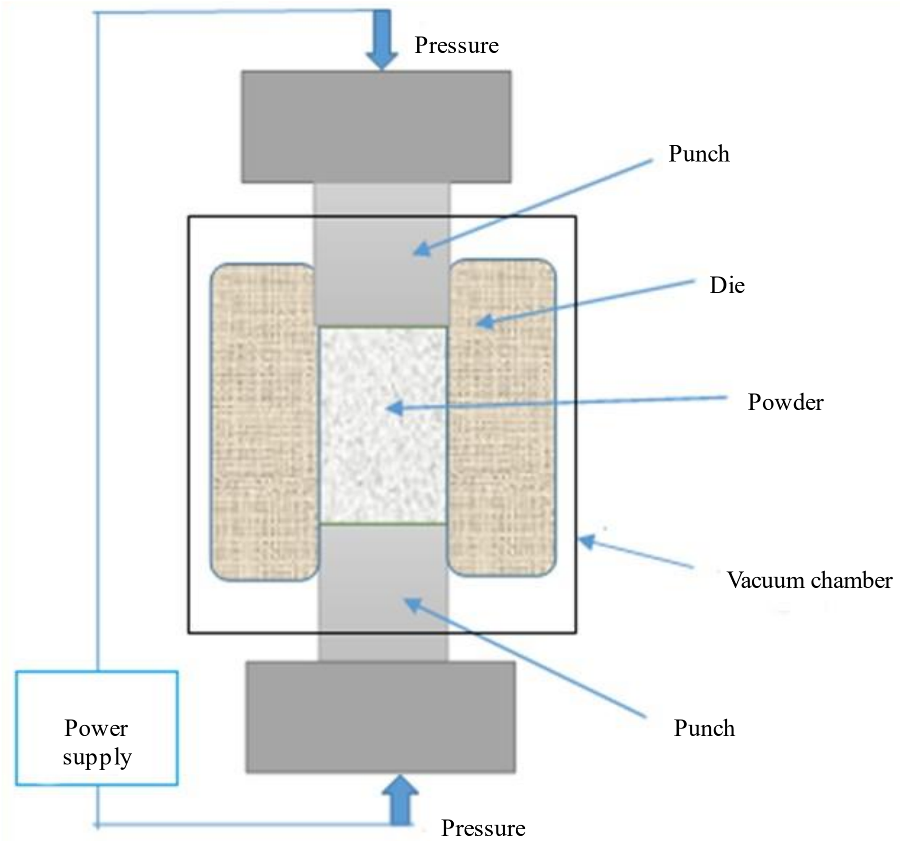

Figure 4. Schematic diagram of spark plasma sintering.

INFLUENCE OF NANOPARTICLE ON WEAR BEHAVIOR AND HIGH TEMPERATURE

A wide variety of reinforcing agents are used in metal matrix nanocomposites nowadays. These particles can significantly enhance mechanical qualities, such as strength and resistance against abrasion, erosion, and other wear phenomena. Their composition varies, ranging from carbides to oxides to carbon-based compounds, etc. Their chemical and thermal properties give their composites unique characteristics. Wear behavior depend on various parameter such a load, velocity, weight reduction, and coefficients of friction and wear rate. By incorporating ceramics into aluminum matrix, hybrid composites with significantly better wear resistance than conventional aluminum alloys can be produced. The increased resistance to wear is critical in situations where mechanical components are subjected to rolling, sliding, or collision under high loads and temperatures [44,45]. Al_2O_3 is a commonly utilized ceramic reinforcement due to its exceptional mechanical and tribological characteristics. High degrees of hardness, thermal stability, and wear resistance are displayed by the material. Alumina can be employed in circumstances where it will be exposed to corrosive environments because of its beneficial chemical inertness. [46It provides a good compatibility in terms of coefficient of thermal expansion (CTE) with the aluminum matrix, which reduces the magnitude of thermal mismatch stresses. Because of its outstanding wear resistance, high hardness, and excellent thermal stability [47]. The material's increased melting point and capacity to maintain its mechanical properties at high temperatures demonstrate its remarkable resilience to thermal deterioration. SiC exhibits advantageous properties like a high heat conductivity and a low coefficient of friction. The material showed favorable compatibility with the aluminum matrix and chemical inertness. SiC is widely used in applications like brake systems and cutting tools where excellent wear resistance and thermal stability are crucial. Because of its unique properties, zirconia (ZrO_2) is a ceramic reinforcement that is extensively used [48]. The material exhibits high hardness levels, excellent wear resistance, and remarkable thermal stability. Because of its remarkable fracture toughness, zirconia can endure cracking and breakage better than other materials. The substance is capable of going through a phase change from the monoclinic to the tetragonal or cubic phase, which will increase its toughness. Composites based on zirconia have proven useful in many industrial applications, including as cutting tools, seals, and bearings. A ceramic substance known as titanium dioxide (TiB_2) offers a special blend of outstanding hardness, great wear resistance, and noteworthy thermal stability. With a high melting point and remarkable thermal stability, the material can withstand high temperatures without losing its mechanical integrity. It is well known that TiB_2 has favorable chemical inertness. It is widely used as a reinforcing agent in hybrid composites for a number of purposes, such as wear-resistant parts and high-temperature cutting tools. With a high melting point and remarkable thermal stability, the material can withstand high temperatures without losing its mechanical integrity. It is well known that TiB_2 has favorable chemical inertness. It is widely used as a reinforcing agent in hybrid composites for a number of purposes, such as wear-resistant parts and high-temperature cutting tools [49]. A ceramic reinforcement with remarkable lubricating qualities, low friction coefficients, and heat stability is called boron nitride (BN). Solid lubricants are often used in high-temperature tribological applications. It is crucial to recognize that the choice of ceramic reinforcement depends on the specific requirements of the tribological application, which include variables like temperature range, load conditions, and environmental elements [50]. To achieve specific tribological properties for a given application, other ceramic materials and their dispersion within the aluminum matrix might be investigated further. Ceramic composites like Boron Carbide (B_4C) are well known for their remarkable hardness, outstanding wear resistance, and superior thermal stability. Compared to other materials, this one exhibits low friction coefficient and is renowned for its extraordinary hardness [51]. Since boron carbide is chemically inert, it offers significant protection against chemical deterioration in harsh environments. The material has a noticeable melting threshold and maintains its mechanical properties at high temperatures. In tribological applications involving high temperatures, boron carbide is a material that is commonly used. These applications cover, but are not limited to, wear-resistant components exposed to hostile environments, abrasive coatings, and cutting instruments.

Table 1. Aluminum alloy, types of reinforcement, fabrication route and effect on manufacturing properties.

Al Alloy	Reinforcement	Fabrication route	Effect on manufacturing properties	References
Al 6061	B_4C/BN	Powder metallurgy	Al_2O_3 particles make the top surface harder, which reduces erosion rate. It was discovered that erosion wear decreased as the weight percentage of B_4C reinforcement increased.	[27]
Al 7075	SIC	Powder metallurgy	Al Alloy with 15% SiC have superior mechanical properties, have better hardness, toughness, and flexural strength.	[28]
Al 7076	Graphene titanium diboride particulate	Pressure-less vacuum sintering process, Ball milling	Al/10% TiB2/4% GNPs' wear resistance and microhardness enhanced by 71.3% and 17.6%, respectively.	[29]
Al 7075	ZrO_2	Spark plasma sintering (SPS)	Wear resistance improved, tensile strength, density, hardness, elongation, and wear rate have risen. Abrasive wear change to adhesive wear as the wear mechanism.	[30]
AA6061	Aluminium nitride ,Aluminium oxide (Al_2O_3),silicon carbide	Stir-casting method	In comparison to the base alloy, the properties of density, hardness, impact strength, void content, flexural strength, and tensile strength were higher.	[31]
6005A T6 Al alloy	MSS powder with the TiC powder	Circular oscillating laser	TiC enhances wear resistance and the substrate's hardness by a 4.5–7.8%	[32]
AA6061	Marble dust	Stir casting	5w% percent marble dust has good mechanical and sliding wear resistance qualities as compare to 3 and 7w% .	[33]

AlSi10Mg powders	Carbon nanotubes (NC7000) 10nm in diameter and 15nm in length	Advanced powder processing (Mixed Ball-Milling technique)	The mixed ball mill technology allows for the customization of the interfacial bonding structure despite the heterogeneous grain structure.	[34]
Al powder (30 µm)	Si size 2-3µm, CNT 10–50 µm length and 100–150 nm of diameter.	Powder metallurgy	By adding of Sic wettability of the Al/CNTs interface is increased and improved its interface bonding.	[35]
AA 5083	Boron carbide with particle size of 3 µm and titanium di boride particle size of 2–3 µm both 99 % purity.	Friction stir processing rout	The composite with 75% TiB2 + 25% B4C hybrid reinforcement exhibits the highest mechanical performance. There is a hybrid reinforcement particles which are evenly dispersed throughout the stirring zone and free of micro flaws.	[36]
A356	SiC (2% 4% and 6% weight fraction)	Stir casting	Increase compressive strength. 6% SICp tensile strength increase by 4 % It has been noted that as the SiCp weight percentage in A356 increases, the impact strength and elongation property values droop.	[37]
Al7075	TIC (3%wt, 6 wt%, and 9 wt%)	Stir casting	Process variables include stirrer time, rpm, and compressive strength, which was raised to 232 MPa while maintaining a 15-minute stirring duration and a 600 rpm stirring speed.	[38]
Al6262	Al-0% Bagasse,Al-2% Bagasse, Al-5% Bagasse	Stir casting	Bagasse powder enhances the mechanical and tribological characteristics of the reinforced Al alloy because it is uniformly dispersed throughout the base metal.	[39]
AA7075	AA7075 with 2% TiC, AA7075 with 4% TiC, AA7075 with 2% TiC + 2% MoS2, AA7075 with 4% TiC 4% + 2% MoS2	Stir casting	Enhanced machinability. In AA7075, discontinuous chips replace continuous sheared chips in terms of shape. The hard TiC component of composite contributes to their increased surface roughness compared to base AA7075.	[40]
AA 7075	20–60µm SIC powder was obtained by ball milling which are made of tungsten carbide and produce nano size particle with size of 30–80 nm	Friction stir processing	Poor mechanical and ductility, which are improved by friction stir casting, nano composites have greater corrosion resistance than micro composites due to their superior wear resistance, improved hardness, uniform SiC particle distribution, refined matrix grain size, and improved bonding between the particles and matrix.	[41]
AA5083	AA5083 powder (44 – 58 µm), µB4C(1-7)	Powder mettalurgy	Larger B4C particles were shown to accelerate abrasive wear, whereas AA5083 alloy with ultrafine grains was shown to increase hardness by 56% and resist abrasive wear by 7%.	[42]
A6063	TIC	Stir casting	The maximum impact strength reduced by 31% and elongation of composites is also reduced to 35% by increase the titanium carbide. Highest values for density, hardness, and tensile strength were 7.8%, 20%, and 19.55.	[43]

CONCLUSIONS

This research examines the wear characteristics of metal matrix nanocomposites, namely those that have lightweight metal matrices, such as aluminum, reinforced by a range of nanomaterials with a variety of reinforcement types, including carbon-based allotropes like carbon nanotubes (CNTs) and graphene, as well as oxides, carbides, nitrides. The effect of various reinforcing nano-particles on its physical properties of nanocomposites is studied. This paper presents the impact of several manufacturing and processing techniques, base material types, reinforcement types, metal matrix nanocomposites' sizes, and percentages. The suitability of hybrid composites made of aluminum and ceramic reinforcement for high-temperature tribological applications in automobile parts, aircraft systems, and manufacturing was examined. In key components such as gas turbines, bearings, seals, engine parts, brake systems, and cutting tools, composite materials present prospects for enhanced functionality, increased efficiency, and extended service life.

REFERENCES

1. Kumar A, Pal K, Mula S. Simultaneous improvement of mechanical strength, ductility and corrosion resistance of stir cast Al7075-2% SiC micro-and nanocomposites by friction stir processing. Journal of Manufacturing Processes. 2017 Dec 1;30:1-3.
2. Kim CS, Cho K, Manjili MH, Nezafati M. Mechanical performance of particulate-reinforced Al metal-matrix composites (MMCs) and Al metal-matrix nano-composites (MMNCs). Journal of Materials Science. 2017 Dec;52:13319-49.
3. Nieto A, Yang H, Jiang L, Schoenung JM. Reinforcement size effects on the abrasive wear of boron carbide reinforced aluminum composites. Wear. 2017 Nov 15;390:228-35.
4. Rashed HMMA, Rashid Bazlur AKM. Heat Treatment of Aluminum Alloys. Comprehensive Materials Finishing, Volume 2 (2017).
5. Barthwal S, Lim SH. A durable, fluorine-free, and repairable superhydrophobic aluminum surface with hierarchical micro/nanostructures and its application for continuous oil-water separation. Journal of Membrane Science. 2021 Jan 15;618:118716.
6. Esmaeili S, Lloyd DJ, Jin H. A thermomechanical process for grain refinement in precipitation hardening AA6xxx aluminum alloys. Materials letters. 2011 Mar 31;65(6):1028-30.
7. Apostol F, Mishin Y. Interatomic potential for the Al-Cu system. Physical Review B. 2011 Feb 25;83(5):054116.
8. Barthwal S, Barthwal S, Singh NB. Nanocomposites and Their Sensing Properties. InNanocomposites 2022 Dec 22 (pp. 223-260). Jenny Stanford Publishing.
9. Reddy AC, Zitoun E. Matrix Al-alloys for silicon carbide particle reinforced metal matrix composites. Indian journal of Science and Technology. 2010 Dec 1:1184-7.
10. Barthwal S, Uniyal S, Barthwal S. Nature-Inspired Superhydrophobic Coating Materials: Drawing Inspiration from Nature for Enhanced Functionality. Micromachines. 2024 Mar 13;15(3):391.
11. Mavhungu ST, Akinlabi ET, Onitiri MA, Varachia FM. Aluminum matrix composites for industrial use: advances and trends. Procedia Manufacturing. 2017 Jan 1;7:178-82.
12. Barthwal S, Barthwal S, Singh NB. Bioinspired Superhydrophobic Nanocomposite Materials: Introduction, Design, and Applications. InNanocomposites 2022 Dec 22 (pp. 429-481). Jenny Stanford Publishing.
13. Mohankumar V, Kapilan S, Karthik A, Bhuvaneshwaran M, Santulli C, Kumar DT, Palanisamy S, Fragassa C. A Hybrid Design of Experiment Approach in Analyzing the Electrical Discharge Machining Influence on Stir Cast Al7075/B_4C Metal Matrix Composites. Metals. 2024 Feb 7;14(2):205.
14. Alam MT, Arif S, Ansari AH. Mechanical behaviour and morphology of A356/SiC nanocomposites using stir casting. InIOP conference series: materials science and engineering 2017 Aug 1 (Vol. 225, No. 1, p. 012293). IOP Publishing.
15. Bauri R, Yadav D, Suhas G. Effect of friction stir processing (FSP) on microstructure and properties of Al–TiC in situ composite. Materials Science and Engineering: A. 2011 May 25;528(13-14):4732-9.

16. Liu CY, Wang Q, Jia YZ, Zhang B, Jing R, Ma MZ, Jing Q, Liu RP. Evaluation of mechanical properties of 1060-Al reinforced with WC particles via warm accumulative roll bonding process. Materials & Design. 2013 Jan 1;43:367-72.
17. Barthwal S, Kim YS, Lim SH. Fabrication of amphiphobic surface by using titanium anodization for large-area three-dimensional substrates. Journal of colloid and interface science. 2013 Jun 15;400:123-9.
18. Hemanth J. Development and property evaluation of aluminum alloy reinforced with nano-ZrO2 metal matrix composites (NMMCs). Materials Science and Engineering: A. 2009 May 15;507(1-2):110-3.
19. Barthwal S, Singh B, Singh NB. Electrical Conductivity and Mechanical Hardness of Al2O3-1wt% MWCNT Nanocomposite Synthesized by Ball Milling Method. Journal of Scientific & Industrial Research. 2019 Aug;78:532-4.
20. Tjong SC. Recent progress in the development and properties of novel metal matrix nanocomposites reinforced with carbon nanotubes and graphene nanosheets. Materials Science and Engineering: R: Reports. 2013 Oct 1;74(10):281-350.
21. Barthwal S, Barthwal S, Singh B, Singh NB. Multifunctional and fluorine-free superhydrophobic composite coating based on PDMS modified MWCNTs/ZnO with self-cleaning, oil-water separation, and flame retardant properties. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 2020 Jul 20;597:124776.
22. Srinivasan DR, Devi DN, Bhagavathula UR, Kumar BK, Sonkhaskar YM, Sivasubramanian P. Nitriding treatment for improvement of eroded surfaces by electroerosion. Materials Today: Proceedings. 2023 Jul 26.
23. Reddy RM, Venkataramanamurthy VP, Laxmaiah G, Syed K, Sonkhaskar YM, Sivasubramanian P. Evaluation of cryogenic cooling in cnc machining of martensitic stainless steel aisi 440c. Materials Today: Proceedings. 2023 Jul 22.
24. Arsha AG, Manoj V, Raag LA, Akhil MG, Rajan TP. Metallic nanocomposites for automotive applications. In Nanotechnology in the Automotive Industry 2022 Jan 1 (pp. 163-198). Elsevier.
25. Chaira D. Powder metallurgy routes for composite materials production. Materials Science, Engineering Heliyon 2021.
26. Garg P, Gupta P, Kumar D, Parkash O. Structural and mechanical properties of graphene reinforced aluminum matrix composites. J. Mater. Environ. Sci. 2016 Feb;7(5):1461-73.
27. Chand S, Chandrasekhar P. Influence of B4C/BN on solid particle erosion of Al6061 metal matrix hybrid composites fabricated through powder metallurgy technique. Ceramics International. 2020 Aug 1;46(11):17621-30.
28. Surya MS, Prasanthi G. Manufacturing, microstructural and mechanical characterization of powder metallurgy processed Al7075/SiC metal matrix composite. Materials Today: Proceedings. 2021 Jan 1;39:1175-9.
29. Kumar JL, Gurusamy P, Gayathri N, Muthuraman V. Influence of graphene nanoplates and titanium diboride particulate on wear and interfacial bonding properties of sintered aluminium alloy composites. Diamond and Related Materials. 2024 Apr 1;144:111035.
30. Zhang JD, Zhang L, Ma HZ. Effect of ZrO2 additions on the microstructure, mechanical and wear properties of ZrO2/7075 aluminium alloy composite. Materials Today Communications. 2023 Dec 1;37:107437.
31. Yadav R, Meena A, Lee SY, Park SJ. Experimental tribological and mechanical behavior of aluminium alloy 6061 composites incorporated ceramic particulates using Taguchi analysis. Tribology International. 2024 Apr 1;192:109243.
32. Cao F, Cui H, Song X, Gao L, Liu M, Qiao Q, Kong H. Fabrication of multi-scale TiC and stainless steel composite coatings via circular oscillating laser towards superior wear and corrosion resistance of aluminum alloy. Journal of Materials Science & Technology. 2024 Apr 1;177:191-204.
33. Tejyan S, Lal C, Ror CK, Singh V. Influence of marble waste reinforcement on mechanical properties and sliding wear behavior of an aluminium alloy metal matrix composite. Journal of Engineering Research. 2023 Aug 6.

34. Nateq B, Haddad-Sabzevar M, Sajjadi SA, Pellizzari M. Interfacial structure-property relationship in a carbon nanotube-reinforced aluminum alloy matrix composite fabricated by an advanced method. Materials Characterization. 2023 Sep 1;203:113159.
35. Zhang X, Li X, Wang J, Li B, Liu L, Hou X, Li S, Ji X, Gao L, Li S. Stimulating adequate strengthening effect through alloying regulation for powder metallurgy CNTs reinforced aluminum matrix composites. Journal of Materials Research and Technology. 2024 Jan 1;28:1725-33.
36. Rao DS, Simhadri TS. Improvements in mechanical properties of aluminium alloy-titanium di boride and boron carbide hybrid composite produced through friction stir processing route. Materials Today: Proceedings. 2021 Jan 1;45:5231-6.
37. Sunitha K, Gurusami K, Rajeswari N, Kathikraja A, Saravanan L. Investigation of mechanical properties of SiC particle reinforced Aluminium A356/LM25 alloy composite. Materials Today: Proceedings. 2022 Jan 1;66:1983-7.
38. Scaria CT, Pugazhenthi R. Effect of process parameter on synthesizing of TiC reinforced Al7075 aluminium alloy nano composites. Materials Today: Proceedings. 2021 Jan 1;37:1978-81.
39. Palanivendhan M, Chandaradass J, Philip J. Fabrication and mechanical properties of aluminium alloy/bagasse ash composite by stir casting method. Materials Today: Proceedings. 2021 Jan 1;45:6547-52.
40. Dhulipalla A, Kumar BU, Akhil V, Zhang J, Lu Z, Park HY, Jung YG, Zhang J. Synthesis and machining characteristics of novel TiC ceramic and MoS2 soft particulate reinforced aluminium alloy 7075 matrix composites. Manufacturing Letters. 2020 Apr 1;24:82-6.
41. Kumar A, Pal K, Mula S. Simultaneous improvement of mechanical strength, ductility and corrosion resistance of stir cast Al7075-2% SiC micro-and nanocomposites by friction stir processing. Journal of Manufacturing Processes. 2017 Dec 1;30:1-3.
42. Nieto A, Yang H, Jiang L, Schoenung JM. Reinforcement size effects on the abrasive wear of boron carbide reinforced aluminum composites. Wear. 2017 Nov 15;390:228-35.
43. Kumar KR, Kiran K, Sreebalaji VS. Micro structural characteristics and mechanical behaviour of aluminium matrix composites reinforced with titanium carbide. Journal of Alloys and Compounds. 2017 Nov 5;723:795-801.
44. Praveen Kumar M, Mangalaraja RV, Karazhanov S, de Oliveira TF, Sasikumar M, Murugadoss G, Mubarak S, Palanisamy S, Kumaresan N. An overview of noble-metal-free nanostructured electrocatalysts for overall water splitting. Materials Technology for the Energy and Environmental Nexus, Volume 1. 2023 Sep 1:3-1.
45. Barthwal S, Barthwal S. Engineering a robust, multifunctional superhydrophobic/oleophobic microporous aluminum surface via a two-step chemical etching process. Surfaces and Interfaces. 2024 Mar 1;46:103933.
46. Barthwal S, Lim SH. Robust and chemically stable superhydrophobic aluminum-alloy surface with enhanced corrosion-resistance properties. International Journal of Precision Engineering and Manufacturing-Green Technology. 2020 Mar;7(2):481-92.
47. Ashwath P, Xavior MA. Processing methods and property evaluation of Al2O3 and SiC reinforced metal matrix composites based on aluminium 2xxx alloys. Journal of Materials Research. 2016 May;31(9):1201-19.
48. Hvizdoš P, Duszová A, Puchý V, Tapasztó O, Kun P, Dusza J, Balázsi C. Wear behavior of ZrO2-CNF and Si3N4-CNT nanocomposites. Key Engineering Materials. 2011 Apr 30;465:495-8.
49. Sheelwant A, Narala SK, Shailesh P. Synthesis and tribological evaluation of aluminum-titanium diboride (Al-TiB2) metal matrix composite. Materials Today: Proceedings. 2020 Jan 1;28:651-8.
50. Podgornik B, Kosec T, Kocijan A, Donik Č. Tribological behaviour and lubrication performance of hexagonal boron nitride (h-BN) as a replacement for graphite in aluminium forming. Tribology International. 2015 Jan 1;81:267-75.
51. Sharath BN, Madhu KS, Venkatesh CV. Experimental study on dry sliding wear behaviour of Al-B4C-Gr metal matrix composite at different temperatures. Applied Mechanics and Materials. 2019 Dec 2;895:96-101.

