Journal of
Polymer & Composites
ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 13, Special Issue 3, 2025
DOI (Journal): 10.37591/JoPC
https://journals.stmjournals.com/jopc
Review JoPC

Fabrication and Analysis of Al 7075 Based Metal Matrix Composites - A Review

Ravi Kant Tiwari[1,*], Satnam Singh[2]

Abstract

Aluminium 7075 alloys are extensively used in aerospace, marine, aviation, and automotive industries due to their superior mechanical properties, high strength-to-weight ratio, and low density. However, to further enhance their performance, aluminium-7075 metal matrix composites (AMMCs) are developed by incorporating various reinforcements. This paper focuses on the influence of reinforcements on the mechanical, tribological, and corrosion behavior of AMMCs. The study examines fabrication techniques, particularly the stir casting method, which is widely employed for integrating reinforcement particles such as silicon carbide (SiC), aluminum oxide (Al_2O_3), graphite (Gr), titanium dioxide (TiO_2), and bagasse ash into the aluminium matrix. The incorporation of these reinforcements significantly improves tensile strength, hardness, and wear resistance while reducing the coefficient of thermal expansion. Furthermore, enhanced corrosion resistance makes these composites suitable for harsh environmental conditions. A comparative analysis with conventional aluminium alloys highlights the superior properties of AMMCs, making them ideal for high-performance applications where strength, durability, and lightweight characteristics are crucial. The findings of this study provide valuable insights into the development of advanced aluminium composites, contributing to their broader adoption in engineering and industrial applications.

Keywords: Al 7075, aluminium metal matrix composites, reinforcement, stir casting, microstructural properties.

INTRODUCTION

Aluminium 7075 series alloys have been instrumental in reshaping the automotive, aerospace, and marine industries during the past 70 years [1]. These materials exhibit a remarkable strength-to-weight ratio [2]. Fuselages, lacrosse stick shafts, hang glider airframes, military guns, camping tools, turbo casings, missile tail cones, motorbike components, and automobile engine casings are just a few of the many uses for them. Researchers' quest to create materials that are high-performing, economical, and of superior quality has resulted in a shift from monolithic to composite materials because of the ongoing evolution of global needs [3], [4].

This development in alloy material is essential to addressing the needs of quickly changing technologies in various application domains. The ability of metal matrix composites (MMCs) to alter mechanical properties (such as compressive and tensile behavior), tribological features (such as thermal expansion and density), and other properties by varying the phases of filler material is the subject of current research interests. Differential forms of chemical composition are exhibited at the interfaces when more than two macro, micro, or nano components are blended or combined to form Aluminium Metal Matrix Composites (AMMCs)

***Author for Correspondence**
Ravi Kant Tiwari

[1]Research Scholar, Department of Mechanical Engineering, National Institute of Technology, Kurukshetra, Haryana, India
[2]Assistant Professor, Department of Mechanical Engineering, National Institute of Technology Kurukshetra, Haryana, India

Received Date: March 21, 2024
Accepted Date: August 06, 2024
Published Date: March 26, 2025

Citation: Ravi Kant Tiwari, Satnam Singh. Fabrication and Analysis of Al 7075 based Metal Matrix Composites - A Review. Journal of Polymer & Composites. 2025; 13(Special Issue 3): S1–S12p.

[5]. Because of the variable mechanical behaviour based on the matrix material's composition and the percentage change in reinforcement, AMMCs have shown promise in a variety of engineering domains and structural and functional applications.

MATERIALS AND METHODS

Both mechanical and tribological characteristics of AMMCs (aluminium metal matrix composites) that include one or more reinforcements are examined in this review of the literature as mentioned in Table 1. The fabrication method used in these investigations was stir casting, which is a well-known technique for producing composite materials. The improvement of both mechanical and tribological qualities is largely attributed to the addition of Al2O3 (alumina) as a reinforcement for aluminium alloy. Graphite reinforcing is essential because it gives aluminium better machinability and self-lubricating qualities. Furthermore, the addition of SiC particles works well, demonstrating aluminium’s increased hardness. The review specifically looks at using organic agricultural wastes as reinforcements, such as fly ash, bagasse ash, and coconut ash. Tensile strength, yield strength, and other important qualities are improved by these non-traditional materials. The review's latter sections go into detail on these investigations and offer insightful information about the different reinforcements' influence on AMMCs' mechanical and tribological characteristics.

Table 1. Reinforcements used in Aluminium Metal Matrix Composites.

Reinforcements	**Ref.**
TaC	[6]
Cenosphere	[7]
Gr	[8]
SiC	[9]
Al2O3	[10]
TiB2	[11]
B4C	[12]
SiN	[10]
ZrB2	[13]
TiC	[14]
SiO2	[15]
FA	[16]
Gr	[17]
TiO2	[18]
SiC + Gr	[19]
SiC + Al2O3	[20]
SiC + MoS2	[21]
SiC + FA	[22]
SiC + TiO2	[23]
SiC + B4C	[24]
SiC + RHA	[25]
Al2O3 + Gr	[10]
Al2O3 + B4C	[26]
Al2O3 + RHA	[27]
TiC + B4C	[28]
B4C + Gr	[29]
TiB2 + Gr	[30]
SiC + TiC	[31]

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

Hybrid Aluminium Matrix Composites' Reinforcements

Enhancing the characteristics of metal matrix composites requires the integration of reinforcements, and among the different forms that are available, the particulate form is the most used in aluminium matrix composites. Metals, ceramics, and waste materials from the agricultural and industrial sectors all fall under this category of reinforcement. Ceramic reinforcements, such as boron carbide (B4C), graphite (Gr), tungsten carbide (WC), silica (SiO2), titanium carbide (TiC) and silicon carbide (SiC), play a crucial role in metal matrix composites by greatly enhancing their hardness, strength, stiffness, and resistance to wear and erosion. To further broaden the selection of materials, metals like Cast Iron, Titanium, and Chromium are also included in reinforcements. In addition to promoting sustainability, the use of waste materials from industry and agriculture, such as bagasse ash, fly ash, rice husk ash, and red mud lowers the cost of composite materials. Furthermore, the strategic employment of two or more reinforcements in the matrix appears as a technique to attain optimum qualities while efficiently controlling costs in context with Hybrid Aluminium Matrix Composites. A very significant roles that reinforcements play in influencing the properties of hybrid aluminium matrix composites are summarized in this paragraph heading [32].

Stir Casting Method

To fabricate AMMCs (Aluminium Metal Matrix Composites), the stir casting technology in Figure 1 has revolutionized the world of materials engineering. Although its historical roots lie in early metallurgical processes that involved agitating molten metals to achieve homogeneity, its modern use in AMMCs gained importance because of the need for better reinforcement dispersion within the aluminium matrix [33]. To guarantee a uniform distribution, this technique involves adding reinforcing particles—such as ceramics or other materials—to the molten aluminium alloy and vigorously agitating the mixture. These constituents come together to form a composite material that has improved tribological, thermal, and mechanical qualities.

Because of its ease of use, adaptability, and affordability, the stir casting process is a recommended to synthesis AMMCs. Stir casting has advantages over other processes like powder metallurgy or in-situ procedures. These advantages include ease of use, scalability for large-scale manufacturing, and the ability to add a variety of reinforcement materials. The technique's capacity to accommodate different forms and dimensions adds to its appeal by facilitating the creation of specialized parts with precisely engineered material characteristics. Essentially, the stir casting is a fundamental component for developing aluminium metal matrix composites, offering a workable and effective means of attaining higher material properties for a range of engineering uses [34], [35].

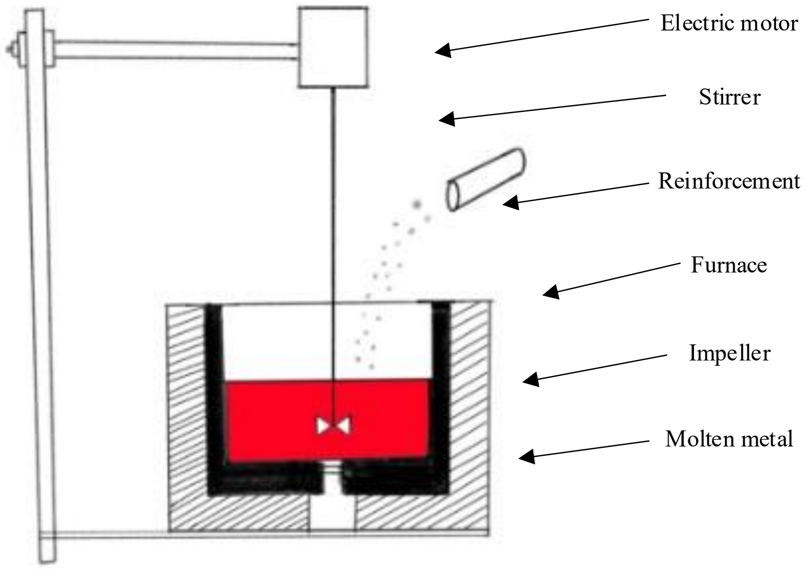

Figure 1. Stir casting process schematic diagram

Powder Metallurgy

As seen in Figure 2, there are three main steps in the powder metallurgy process: mixing, compacting, and sintering. The matrix material (continuous phase) and the reinforcing elements (discrete phases) are thoroughly blended during the mixing phase with the aid of toluene in order to prevent oxidation and zinc stearate as a lubricant [36]. The blended material is compressed enough during the compacting stage to produce a green compact with the appropriate porosity.

During the sintering process, for a long enough period of time, the temperature of the heated green compacts is kept above the melting point of the metal matrix, which promotes diffusion bonding. Compaction pressure, holding temperature, holding time, and other powder metallurgy process factors, as well as the reinforcement material, all affect the final product's qualities [37].

The optimal results in powder metallurgy are achieved by compaction at pressures between 600 and 700 MPa, sintering at a temperature between 520 and 600 °C, and sintering for three to four hours. When it comes to creating Metal Matrix Composites (MMC), powder metallurgy has several advantages over other methods, including reduced processing temperatures, lower energy consumption, and improved utilization of resources [38].

STRUCTURE ANALYSIS METHODS

This section uses elemental mapping with EDAX, SEM morphological analysis and optical microscopic picture to explain the microstructure.

Optical Microstructure Analysis

The microstructure studies of Metal matrix composites and their salient features are covered in this section. The characteristics of MMCs are improved by the homogeneous dispersion of reinforcement particles throughout the matrix. According to Kalkanlı and Yılmaz [39], Figure 3 illustrates how the reinforcing material is evenly distributed throughout the base material. The Al 7075 + SiC MMC composite's optical microstructure demonstrates the SiC particles' uniform dispersion inside the matrix and draws attention to the composites increased reinforcement percentage in the base matrix.

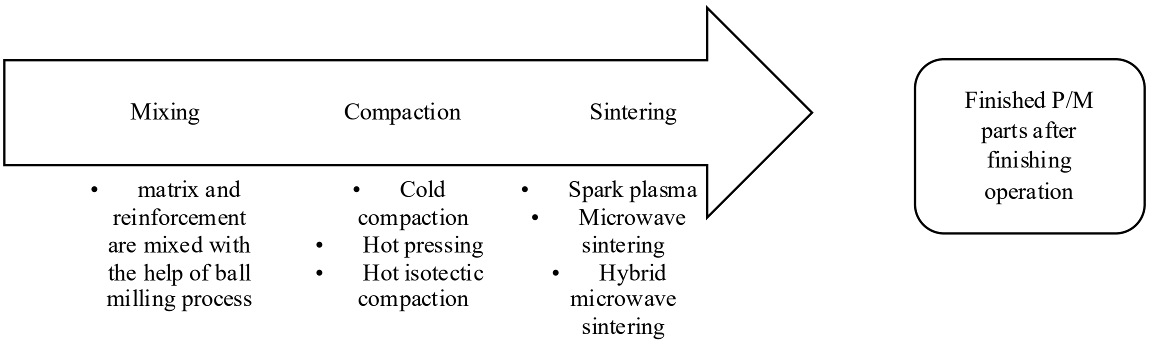

Figure 2. Processing diagram of powder metallurgy.

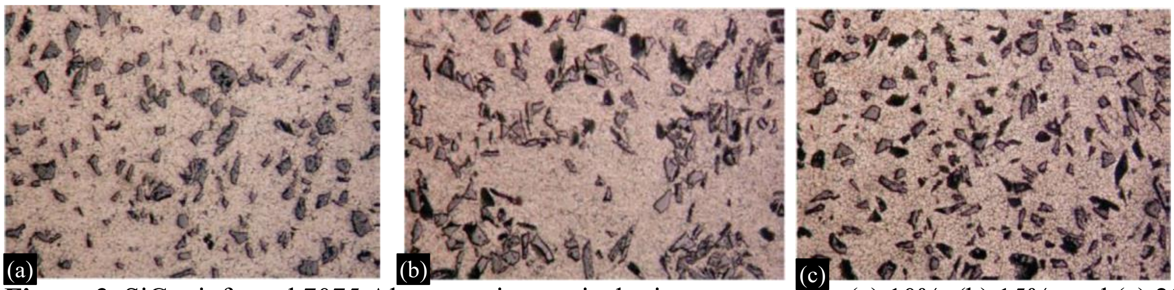

Figure 3. SiC reinforced 7075 Al composites optical microstructures at (a) 10%, (b) 15%, and (c) 20% weight percentage (200x)

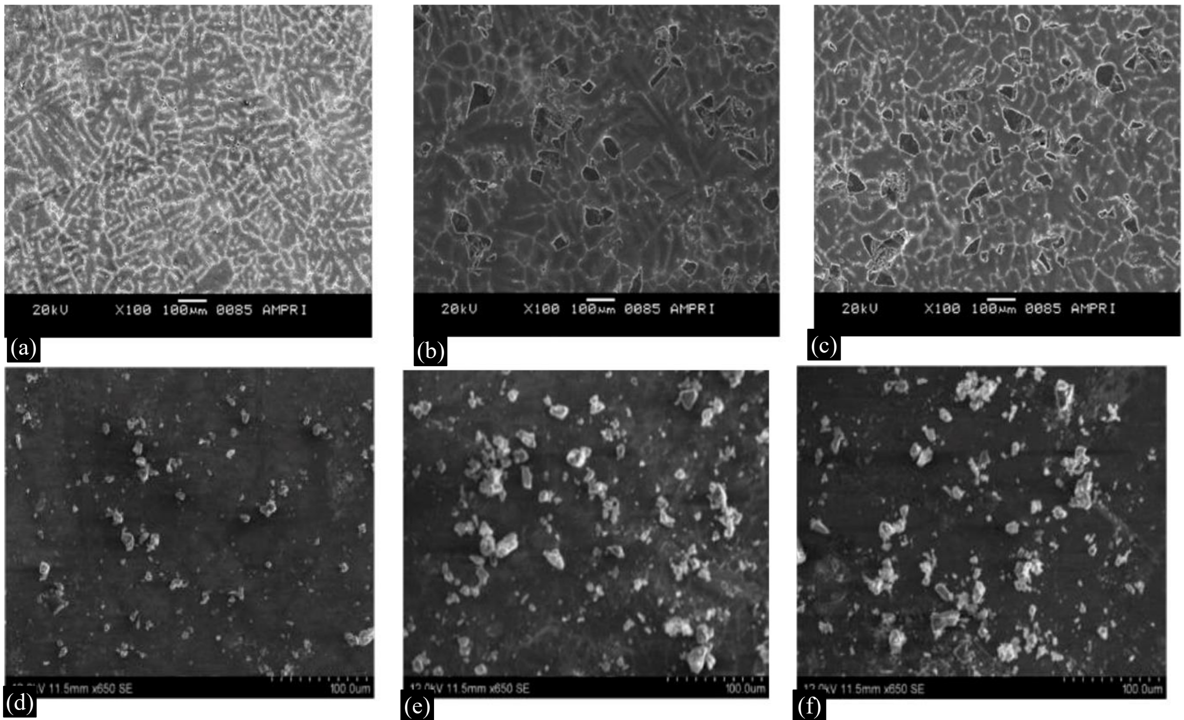

Figure 4. Scanning Electron Microscope image of (a) AA 7075, (b) AA 7075 with 10 weight percent SiC (20–40 μm), (c) AA 7075 with 15 weight percent SiC (20–40 μm), (d) AA 7075 with 15 weight percent SiC (25 μm), (e) AA 7075 with 15 weight percent SiC (50 μm) and (f) Al 7075 with 15 weight percent of SiC (75 μm)

Analysis of Scanning Electron Microscope

The surface morphology in tensile, tribological, and corrosion testing was examined using SEM images. Figure 3 displays images captured by SEM of the cast matrix Al 7075/SiC MMCs. The reinforcing particles are uniformly dispersed throughout the molten Al metal. The mean atomic number of the various phases that the metals include mostly determines the SEM image. SEM scans of the Al 7075/SiC with 0%, 10%, and 15% (20–40 μm) composite, as shown in Figure 4(a)–4(c), according to Bhushan et al. [40], show an even distribution of the reinforcements. The uniform distribution of Al 7075/15 weight percent SiC with varying particle sizes is shown in Figure 4(d), 4(e) and 4(f).

Analysis of Energy Dispersive X-Ray Spectroscopy

When materials are analysed using Energy-dispersive X-ray spectroscopy, or EDAX, specific details about the elements present are being revealed. The EDAX for the A7075 with basalt composite materials is displayed in Figure 4. Although these lines are weak, the solid diffraction lines of the Al phase with phases of Zn, Fe, and so forth make up the majority of the EDAX of Al 7075/7.5 weight percent of basalt composites.

MECHANICAL PROPERTIES

Here authors present the main conclusions on the tensile strength and the hardness data discovered. These findings also included the use of stress-strain to determine additional characteristics including ductility, elongation, and yield point.

Hardness

The literature claims that the E-10 ASTM Standard was followed when conducting the hardness tests. Use of a ball indenter with a standard 2.5 mm diameter and application of a load ranging from 10 to 35 kg for 20 to 30 seconds characterizes the most widely used Brinell hardness test. At multiple specimen locations, particle segregation effects were recorded through the acquisition of Brinell hardness number (BHN) readings [41].

SiC, Al2O3, B4C, and FA (fly ash) show increasing patterns in the review of hardness when the weight proportion of reinforcement in the aluminium base material rises [9], [10], [12], [17]. By reinforcing the aluminium matrix material with additional graphite (Gr) particles, hardness is decreased [42].

Tensile Strength

Tensile test was performed in compliance with the E-8M ASTM Standard at ambient temperature with the help of a UTM (universal testing machine). To comply with the E-8M standard, specimens must have gauge lengths that are five times larger than diameters [41]. The review of tensile behaviour is tabulated in Table 2. Tensile strength improves progressively with increases in weight proportion of reinforcement that is reinforced with aluminium base material for Gr, FA (fly ash), B4C, Al2O3, and SiC [9], [10], [12], [16], [17]. When fly ash is added, percentage elongation has been seen to randomly drop; in contrast, percentage elongation steadily increases upon the addition of graphite [42]. With the exception of fly ash, ultimate tensile strength (UTS) increases gradually as reinforcements are added. Random variations in UTS are observed with varying weight percentages of reinforcements due to the impacts of fly ash reinforcement as shown in Table 2 [17]. The inclusion of TaC improved the mechanical properties of the AA7075 matrix; the composite with 0.5 weight percent TaC had the greatest Ultimate tensile strength of 205 MPa, Yield Strength of 171 MPa, and 2.7 percentage elongation. The increase in Ultimate tensile strength, Yield strength, and percentage elongation was 35.7, 59.8, and 107.6 larger when compared with base alloy [43]. The tensile and flexural characteristics are improved by a higher amount of boron carbide. According to the findings, 5% B4C offers greater tensile and flexural strength than 2% B4C [44].

Similarly, stir casting was used by Senthilvelan et al. [45] to create Al 7075/ 10 wt.% SiC, B4C, and Al2O3 composites. Because Al/B4C composites have the strongest link between the reinforcement and matrix, their tensile strength has improved by 143%. On the other hand, weak interface and porosity result in 88% and 46% tensile strength for the Al + SiC and Al + Al2O3 composites respectively. After discussing the retrogagation-treated Al 7075 T6 alloy, Clark et al. [46] and Reda et al. [10] came to the conclusion that preaging material increases the electrical resistivity, tensile characteristics, and hardness. According to Kim et al. [47], aged Al 7075 makes the material harder.

Compressive Strength

A universal testing machine (UTM) was used to conduct compression tests as per E-9 ASTM Standard. For gauge length to diameter ratio compression specimens, the E 9 standard dimensions vary depending on the length option (short, medium, and long). A review of the compression test demonstrates how the compressive loads were progressively increased until the specimen failed, and its strain was recorded. When compared to graphite-reinforced composites, the impact of particle of Al2O3 reinforcement in AA exhibits an increase in compressive strength Table 2 [16], [49]. Because of the stronger reinforcement inserted into it, Titanium carbide reinforced aluminium composites has shown increased in compressive strength [6].

Table 2. Mechanical properties of Al 7075 MMCs.

S N.	Composition	UTS (MPa)	Tensile/yielding (MPa)	Compression (MPa)	Elongation (%)	Hardness	Refs.
1.	AA 7075	151±17	107±8	–	1.3±0.3	80 VHN	[43]
	AA 7075 with 0.1%TaC	166±21	124±11	–	1.7±0.2	85 VHN	
	AA 7075 with 0.2%TaC	179±15	139±9	–	2.0±0.4	88 VHN	
	AA 7075 with 0.3%TaC	190±18	152±12	–	2.3±0.3	91 VHN	
	AA 7075 with 0.4%TaC	199±22	163±10	–	2.5±0.5	93 VHN	

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

	AA 7075 with 0.5%TaC	205±26	171±15	–	2.7±0.6	96 VHN	
2.	AA 7075	–	–	160	–	99.96 RHN	[6]
	AA 7075 with 3%TiC	–	–	184	–	102.96 RHN	
	AA 7075 with 6%TiC	–	–	208	–	108.76 RHN	
	AA 7075 with 9%TiC	–	–	232	–	116.06 RHN	
3	AA 7075 with 3%Al_2O_3 with 2%B_4C	–	268	–	5.5	139 BHN	[44]
	AA 7075 with 8%Al_2O_3 with 2%B_4C	–	280	–	4.5	146 BHN	
	AA 7075 with 5%Al_2O_3 with 5%B_4C	–	275	–	4.7	142 BHN	
4	AA 7075	145	–	–	8.2	65 VHN	[48]
	AA 7075 with 3%TiB_2	195	–	–	7.5	80 VHN	
	AA 7075 with 6%TiB_2	240	–	–	5.0	95 VHN	
	AA 7075 with 9%TiB_2	100280	–	–	3.5	125 VHN	
5	AA 7075	210	–	265	–	115 BHN	[49]
	AA 7075 with 2%Al_2O_3	219	–	270	–	117 BHN	
	AA 7075 with 4%Al_2O_3	226	–	275	–	121 BHN	
	AA 7075 with 6%Al_2O_3	229	–	283	–	124 BHN	
	AA 7075 with 8%Al_2O_3	236	–	294	–	134 BHN	
6	AA 7075	–	–	–	–	67 VHN	[50]
	AA 7075 with 3%B4C	–	–	–	–	77 VHN	
	AA 7075 with 3%B4C with 5%SiC	–	–	–	–	82 VHN	
	AA 7075 with 3%B4C with 10%SiC	–	–	–	–	85 VHN	
	AA 7075 with 3%B4C with 15%SiC	–	–	–	–	88 VHN	
7	AA 7075	131.8	–	–	4.93	74 BHN	[51]
	AA 7075 with 2.5% cenosphere	133.6	–	–	5.12	81.9 BHN	
	AA 7075 with 5% cenosphere	138.9	–	–	5.13	89 BHN	
	AA 7075 with 7.5% cenosphere	146.1	–	–	5.22	96.3 BHN	
	AA 7075 with 10% cenosphere	–	–	–	5.17	100 BHN	

Tribological Behavior

The authors summarize the main conclusions about the tribological characteristics associated with various process parameters found in the literature in this section. Wear is the term for the phenomenon where material falls off one or both surfaces due to relative movement between them [39]. The surface's characteristics, which are established by the processing path, also influence the wear process [7]. Adhesive wear is created when two solid surfaces glide over one another under load [52]. High strength and toughness materials with high hardness also minimize wear [53]. Numerous studies have shown that improving the weight/volume ratio of reinforcing particles enhances the composites' resilience to wear [54]. Without any applied load condition, it is discovered that the coefficient of friction increases with a higher fraction of volume [55]. Also, the wear behavior of MMCs is enhanced by adding reinforcement, which also increases its specific strength and toughness, making it a great option for engineering applications [56], [57].

In comparison to other samples, the composite containing 8% titanium carbide and 4% silicon carbide had a higher microhardness value of 52.12 HV. Particles of silicon and titanium carbide are mixed into the matrix to increase wear resistance. The 4% silicon carbide and 4% titanium carbide AA 7075 composite has a lower coefficient of friction than the specimens. The dry sliding wear properties of squeeze-cast AA 7075 + SiCp + Titanium hybrid metal matrix composites were examined by Liu et al. [58]. The wear process is unaffected by the inclusion of Ti particles. These particles produce microzones that work in concert to release stress and cause deformation. Particles of Silicon Carbide are prevented from breaking and from developing cracks beneath by this type of impact. Adding Ti particles improves wear resistance at low loads.

With increasing load, the wear rate of 7075 AMCs grew significantly. Conversely, drop-in wear rate from 0.33 to 0.24 mm3/min when Al2O3 reinforcement was increased from 3% to 5%. At 1.5N load, additional increases in Al2O3 weight percentage significantly raise the wear rate to 0.0467 mm3/min [59]. The least wear rate of 0.7×10^{-3} mm3/min for a 20N load is shown by Al 7075 + 5 weight percent of Gr + 2 weight percent of Al2O3. The weight percentage of Al2O3 wear rate increased significantly [10] upon further increase. At 10N stress, the wear rate is considerably reduced to 0.049 mm3/min using Al 7075 MMCs plus 10 weight percent Al2O3 and 5 weight percent FA [60]. Al 7075 + 1 weight percent Mg + 4 weight percent SiC + 4 weight percent Al2O3 under a 40N load shows the least amount of wear rate of 0.0001 mm3/min. There was a reversal pattern, with wear rate decreasing as load increased [61].

When the weight percentage of Silicon Carbide increased, researchers saw an increase in wear rate [62]. It was noted that when the sliding distance increased, the wear rate increased [63]. At a sliding distance of 1000m, the minimum amount of wear is seen for AA 7075 + 9.5 weight percent Silicon Carbide [64]. When the weight percentage of Titanium Carbide 10 is increased, the wear rate decreases from 2.15 mm3 per km to 1.7 mm3 per km. It is imperative to conduct additional research on the effects of increasing the Titanium Carbide weight % to 15. AA 7075 MMCs considerably lower the wear rate to 200 mm^3 per min in addition to 10 weight percent FA and 6 weight percent Gr. Gr's hardness has increased its resistance to wear [65].

According to recent research, selecting the ideal tribological parameters, reinforcement quantity, reinforcement dispersion, and reinforcement type can all improve the tribological characteristics of MMCs.

CONCLUSION

1. Various fabrication techniques, including powder and liquid metallurgy routes such as stircasting method, have been employed successfully to produce aluminium metal matrix composites (AMMCs).
2. Although ductility has decreased, the increase in ceramic reinforcing particles, such as barium chloride, silicon carbide, alumina has significantly improved mechanical qualities including tensile strength, compressive strength, yield strength, hardness, flexural strength and hardness.

3. Incorporation of graphite as reinforcement has shown enhancements in tensile strength and ductility while decreasing hardness.
4. The mechanical and physical properties of AMMCs have significantly improved as a result of the use of organic reinforcement materials made from industrial waste, such as coconut shell ash fly ash, and rice husk ash. However, tribological properties have only slightly improved.
5. The AA7075 matrix alloy's wear rate and wear resistance are greatly increased by the addition of carbide particle reinforcement. The wear mechanism is mostly adhesive, resulting in a comparatively smoother worn-out surface.
6. Development of aluminium metal matrix composites has opened vast applications in sectors such as automobile, defense, military, and general engineering.
7. Composite materials such as Al7075/SiC, Al7075/TiC, and Al7075/B4C have demonstrated encouraging characteristics, including excellent wear resistance, high strength, and strong bonding b/w the matrix metal and reinforcement.
8. Powder metallurgy techniques have been particularly effective in fabricating these composites, with SiC-reinforced composites exhibiting exceptional hardness and TiC-reinforced composites displaying increased compressive strength due to dispersion strengthening.
9. AA7075/B4C composites' hardness rises as the percentage of B4C increases, which is explained by the alloy matrix's dispersion strengthening.
10. These findings underscore the potential and versatility of aluminium metal matrix composites in various industrial applications.

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