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Review Article

A Systematic Review on the Mechanical, Tribological, and Corrosion Properties of Al 7075 Metal Matrix Composites Fabricated through Stir Casting Process

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Aluminium alloy components are used in lightweight engineering applications and lack mechanical properties, wear resistance, and corrosion resistance. When hard reinforcement particulates are dispersed in the aluminium matrix alloy, aluminium matrix composites (AMCs) are formed. This new material exhibits enhanced properties such as better specific stiffness, specific strength, corrosion resistance, elastic modulus, wear resistance, and lightweight. AMCs have many favorable properties compared to their alloy and extensive applications. Especially, in the space industry, where weight reduction and an increase in modulus are prevalent, the strength-to-weight ratio is more important. This study focuses on the tribological, mechanical, and corrosion properties of Al 7075 metal matrix composites (MMCs) reinforced with one or more particulates such as aluminium oxide (Al_2O_3), boron carbide (B_4C), titanium carbide (TiC), silicon carbide (SiC), titanium dioxide (TiO_2), and titanium diboride (TiB_2). In AMCs, the reinforcements are incorporated by either the solid or liquid metallurgy route. The study addresses the findings and shortcomings in the preparation of MMCs with reinforcements and their improvement in corrosion resistance, wear resistance, mechanical properties, and lower coefficient of thermal expansion than the Al 7075 base alloy. A comprehensive survey of reinforcement particulates in MMCs and their influences are outlined from the literature, encompassing recent research trends to enhance the structural properties.

1. Introduction

Airplane and automotive sectors have faced more technological disputes in meeting consumer obligations. Weight reduction is the foremost task among manufacturers. Decreased weight in airplanes can reduce fuel consumption, enhance payload [1], improve performance, and lower emissions [2]. Additionally, the material has ameliorated properties like corrosion, mechanical, wear, and so on, reducing maintenance and repair costs and increasing service life. Reducing weight and cost is essential for aircraft and automobiles. Thus, the need arises to search for suitable advanced material [3, 4]. During the last few decades, researchers have focused on composite materials to develop advanced materials to meet customer requirements. The researchers did a comprehensive review of polymer MMCs [5].

The materials used for constructing airplanes and automobiles ought to have a lightweight, high specific strength, resistance against high temperature, fatigue load, corrosion and crack, and low wear rate [6]. Previously, alloy steels were generally used for airplanes and automotive components. The benefits of ferrous metals are broad availability and inexpensiveness; and drawbacks include substantial weight, a higher wear rate, and lesser corrosion resistance. Nonferrous metals have low densities compared to ferrous metals, and there has been broad interest in using aluminium, magnesium, titanium, and so on for various applications. Among the various nonferrous materials, Magnesium (Mg) is a lightweight metal but is restricted in airplane production because it quickly seizes fire [7, 8]. Titanium (Ti) expends an equivalent weight to Mg, costing 20 to 30 times more than Aluminium (Al).

The tensile strength of pure Al is about 90 MPa, and its strength can be increased by about two times by rolling or other cold working processes. By alloying with other metals or using heat treatment processes, the tensile strength can be increased to the strength range of structural steel. Aluminium alloy (AA) is often used because it is more robust than most magnesium alloys [9]. Different manufacturing methods fabricate aluminium alloys by adding alloying elements such as copper, manganese, silicon, magnesium, zinc, and lithium to improve their properties.

1.1. Aluminium Matrix Composites. Aluminium matrix composites (AMCs) are a type of MMC that provide a superior combination of physical, mechanical, and thermal properties compared to monolithic materials. Due to their higher performance and environmental benefits, AMCs are used in the aerospace and automobile industries for the benefits of lower fuel consumption and noise. Moreover, the selection of reinforcement and fabrication techniques of AMCs can offer a wide variety of commercial applications [10]. The usage of reinforcement and matrix materials in composites is represented in Figures 1(a) and 1(b).

To the authors' best knowledge, the mechanical, tribological, and corrosion properties of AA 7075-MMCs with different reinforcements were rarely found in the literature. This article investigates the mechanical, tribological, and corrosion properties of Al 7075 MMCs reinforced with different particulates. In this paper, the authors mainly focus on reinforcing Al 7075 alloys with SiC, B_4C, Al_2O_3, etc., by stir casting and analyzing their properties through tensile tests, friction and wear tests, and corrosion tests. The results from the literature are compared to show the variations in properties of MMCs in a comprehensive manner. Due to its potential application and studies, the authors limit the review of Al-based MMCs to Al_2O_3, SiC, Gr, etc. Table 1 shows review articles related to various aluminium alloy composites. From the review, the production of Al-MMCs with different manufacturing techniques and studied their mechanical or wear or corrosion properties. Review papers on Al 7075 are minimal and study their mechanical and wear properties only. This review article discussed the origin of AMCs, the fabrication (stir casting) method compared with other techniques, different reinforcement types, mechanical properties, wear properties, and corrosion properties.

2. Fabrication Methods of AMCs

This section presents an outline of the different fabrication methods of Al-based MMCs and their advantages and disadvantages. The properties of Al, Mg, and Ti are presented in Table 2. The properties of different aluminium alloys and their applications are represented in Table 3.

In Table 3, the heat-treatable aluminium 2xxx and 7xxx series alloys have higher strengths than other aluminium alloy series and are applicable for aerospace and automobile applications. Table 4 provides a comparative study of various manufacturing processes of Al-MMCs. Manufacturing AMC on an industrial scale can be classified as

(i) Liquid state process: spray casting, infiltration, and stir casting
(ii) Solid-state process: powder metallurgy and diffusion bonding processes

Various techniques have been used to develop composite materials. From these available techniques, stir casting (liquid metallurgy) is the best way to produce the composite owing to its low cost, simplicity, and mass production [22]. Aluminium-zinc (Al-Zn) alloys are used widely in automobiles due to their lightweight, castability, mechanical properties, and corrosion resistance. They are widely utilized in various applications [23]. They are ready to cast using all standard casting techniques [24].

Numerous studies on hybrid Al-MMCs reinforced with more than one reinforcement, such as boron carbide (B_4C), alumina (Al_2O_3), titanium carbide (TiC), silicon carbide (SiC), and graphite (Gr), show an enhancement in properties as compared to the base alloy and single reinforcement composites. Adding a little weight/volume fraction of reinforcement to MMCs improves the mechanical and thermal properties. In the liquid metallurgy technique, the homogeneous dispersal of particles into the matrix is the challenging step, affecting the properties and quality of the composites directly. The matrix and reinforcement have an interfacial strength, which determines the properties of MMCs.

In stir casting, the gases are entrapped during melting and mixing/stirring, producing gas bubbles and porosity [25]. The porosity amount depends on the matrix and reinforcement type, weight/volume fraction, and process parameters. The reinforcement particle distribution in the molten metal depends on the geometry, location, stirring parameter of the stirrer, and melting temperature [26]. Al-MMCs were prepared with powder metallurgy (PM) route with different wt.% of SiC reinforcements. An increase in SiC ratio by 5 wt.% enhanced hardness by 14%. The compressive strength is maximum with 25 wt.% of SiC [27]. The Al_2O_3 and collagens were reinforced with Al-MMCs using the stir casting method. They found that there were 38.25% and 45% enhancements in tensile strength (TS) and hardness for the Al + 5% collagen + 5% Al_2O_3 composite, respectively. Though composite material's density, toughness, and ductility were decreased by 0.16%, 25%, and 24.24%, respectively [28]. Mg_2Zn matrix alloy reinforced with Al_2O_3 fabricated through the PM route. Mg alloy composite with

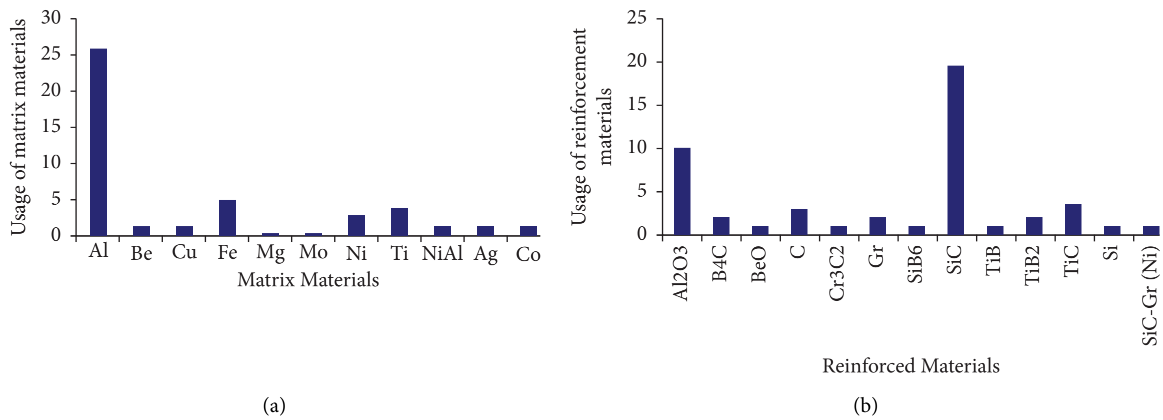


FIGURE 1: Usage of (a) matrix and (b) reinforcement materials in MMCs [11].

TABLE 1: Previous review articles based on aluminium composites.

S. no.	Studies	Materials	Ref.
1	Stress corrosion cracking and its factors	7xxx	[12]
2	Corrosion behavior in a deep-sea environment	Al 5083 H111, Al 6082 T6, Al 7075 T651, and Al 8090 T81	[13]
3	Development of MMCs with optimum furnace processing parameters	Different Al alloys	[14]
4	Different fabrication methods of MMCs and their mechanical properties	Different Al alloys	[15, 16]
5	Mechanical properties of MMCs	Al 7050 and Al 7075	[17]
6	Mechanical properties of hybrid MMCs	Different Al alloy	[18]
7	Tribological properties of MMCs	Different Al alloy	[19]
8	Review based on types of reinforcement	Different Al alloy	[20]

TABLE 2: Properties of Al, Mg, and Ti [7].

Properties	Al	Mg	Ti
Crystal structure	FCC	hcp	hcp
Density@20°C	2.70 (g/cm^3)	1.74 (g/cm^3)	4.4 (g/cm^3)
Coefficient of thermal expansion 20–100°C	23.6 10^{-6}/C	25.2 10^{-6}/C	8.5 10^{-6}/C
Elastic modulus (MPa)	68.9×10^6	44.1×10^6	110×10^6
Tensile strength (MPa)	320 (for A380)	240 (for AZ91D)	434
Melting point (°C)	660	650	1660

TABLE 3: Comparison of aluminium alloy properties [9].

S. no.	Alloy		UTS (MPa)	Yield strength (MPa)	Advantages	Applications
1	Nonheat treatable alloys	1xxx	105	25	High electrical conductivity, formability, corrosion resistance, and low strength	Chemical and electrical components
2		3xxx	180	69	High corrosion resistance, formability, indivisibility, and moderate strength	Packaging, heat transfer, and roofing applications
3		5xxx	145	35	Outstanding corrosion resistance, toughness, weldability, and sufficient strength	Construction, automobile, cryogenic, and shipbuilding
4	Heat treatable alloys	2xxx	220	95	High strength at elevated and room temperatures	Transportation and aircraft and applications
5		4xxx	170	165	Good flow attributes and moderate strength	Pistons and intricate shaped forgings
6		6xxx	124	55	Superior corrosion resistance, outstanding extrudability, and sufficient strength	Building, automobile, and shipbuilding
7		7xxx	228	103	Exceptional high toughness and very high strength versions	Automotive and aerospace

Table 4: Comparative study of various manufacturing techniques of MMCs [21].

S. no.	Method	Range of size and shape	Advantages	Disadvantages
1	Stir casting	Larger size and extensive range	Low cost, less reinforcement damage, and very high metal yield (>90%)	Vol. fraction range up to 30%
2	Squeeze casting	Limited by preform shape, up to 2 cm height	Relatively expensive and volume fraction range up to 45%	Serious damage to reinforcement, meager metal yield
3	Powder metallurgy (PM)	Controlled size and a wide range	Very high metal yield and volume fraction range up to 30 to 70%	High-priced and reinforcement fracture
4	Spray casting	Larger size and limited shape	Metal yield is medium	High-priced
5	Infiltration process	Restricted size and limited by preform shape	Vol. fraction is more	High-priced

8 wt.% of Al_2O_3 exhibits the highest TS of 191 MPa. The least weight loss (9%) and corrosion rate (2.5 mm/year) were obtained with a 2 wt.% Al_2O_3 [29].

Al 7005 composite reinforced with fly ash (FA) (5 wt.%, 6 wt.%) and S-glass fiber (5 wt.%) was fabricated through a stir casting route. They found that Al 7005 + 6 wt.% of fly ash exhibited enhanced corrosion resistance compared to other composites. During the corrosion test, the fly ash particles remain inactive and act as a physical fence with corrosive medium [30]. An aluminium hybrid MMCs was produced using the stir casting method and investigated the mechanical and tribological properties [31].

AA7075-Y_2O_3 (0.5 wt.%) composites were successfully produced through the PM (ball milling and hot pressing) route. The fabricated composite exhibits enhanced hardness and TS of 164% and 90%, respectively [32]. The combination of PM and ball milling was utilized to produce the multi-walled carbon nanotubes (MWCNTs)-reinforced AMCs. After 8 hrs of ball milling, hardness was increased by 160%, and after 2 hrs of milling, density increased by 99.96% from the base composite. This result ensures that the employed PM method effectively produces MMCs with enhanced mechanical properties [33].

A summary of various fabrication methods for different AAs explored by various researchers is given in Table 5. Various reinforcement materials are added to enhance the properties of AAs. The addition of one or more particulates into the AA has also been studied and is listed in Table 6.

3. Methods of Structure Analysis

This section describes the microstructure using an optical microscopic image, SEM morphological analysis, and elemental mapping using EDAX.

3.1. Optical Microstructure Analysis. This section discusses the microstructure observations of MMCs and their key characteristics. Equal dispersion of reinforcement particles into the matrix enhances the properties of the MMCs. According to Kalkanlı and Yılmaz [83], the reinforcement material is evenly distributed in the base material, as illustrated in Figure 2. The optical microstructure of the Al 7075 + SiC MMC composite shows that the SiC particles are equally dispersed in the matrix and reveals the composite that increases the content of reinforcement in the base matrix.

3.2. Scanning Electron Microscope (SEM) Analysis. The following section addresses the SEM analysis of various MMCs in the literature. SEM images were used to analyze surface morphology in tensile, tribological, and corrosion studies. The scanning electron microscope (SEM) images of the cast matrix Al 7075/SiC MMCs are presented in Figure 3, and the reinforcement particles are distributed evenly in the Al molten metal. The SEM image depends mainly on the mean atomic number of various phases present in the metals. According to Bhushan et al. [84] SEM images of the Al 7075/SiC with 0%, 10%, and 15% (20–40 μm) composite show an even distribution of the reinforcements, as illustrated in Figures 3(a)–3(c). Figures 3(d)–3(f) present the uniform distribution of Al 7075/15 wt.% of SiC with different particle sizes.

3.3. Energy-Dispersive X-Ray Spectroscopy Analysis. Energy-dispersive X-ray spectroscopy (EDAX) analysis reveals detailed information about the elements present in materials. Figure 4 shows the EDAX of A7075/basalt composite materials. The EDAX of Al 7075/7.5 wt.% of basalt composites is composed mainly of solid diffraction lines of Al phase with Zn, Fe, and so on phases but with weak diffraction lines.

4. Mechanical Properties Research

In this section, the authors report the key findings about the hardness and tensile strength results found in the literature. From this study, other properties such as ductility, elongation, and yield point were also found by using stress-strain.

4.1. Hardness. The composite containing a higher volume percentage of reinforcement exhibits superior hardness. According to Baradeswaran et al. adding Al_2O_3 fragments into the Al 7075 matrix improves the hardness values, as shown in Figure 5. Hard reinforcement particles increase the load-carrying capability of the MMC, constrain the matrix deformation by restricting the movement of disruption, and increase the strength of the composites [76].

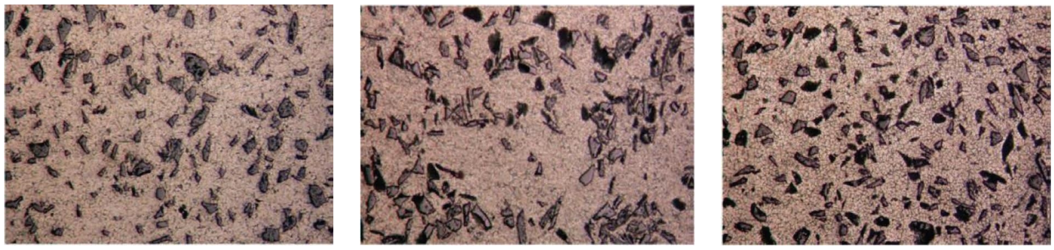
4.2. Tensile Strength. Hybrid composites of Al 7075 exhibit improved tensile strength (TS) compared to the base composite. The presence of hard reinforcement particles

Table 5: Fabrication methods for various Al-MMCs.

S. no.	Ref.	Matrix	Fabrication method	Properties studied
1	[34]	1060	Powder metallurgy	Wear
2	[35]	1100	Accumulative roll bonding	Elongation, microhardness, and TS
3	[36]		Stir casting	Yield strength, TS, and % elongation
4	[37]	2009	Powder metallurgy	Corrosion
5	[38]	2011	Stir casting	Wear
6	[39]	2014	Squeeze casting	Wear and friction
7	[40]	2024	Squeeze casting	Hardness and wear
8	[41]		Stir casting	Wear
9	[42]		Pressure infiltration	Bending strength
10	[43]		Powder metallurgy	Wear
11	[44]		Vortex method and applied pressure	Hardness and TS
12	[45]	2124	Powder metallurgy	Fatigue behavior
13	[46]	2219	Liquid metallurgy	Wear
14	[47]	2618	Squeeze casting	Wear
15	[48]	5052	Pressure less infiltration	TS
16	[49]	5059	Stir casting	Hardness and wear
17	[50]	6061	Stir casting	Hardness, ultimate TS, and wear
18	[51]		Vacuum hot pressing	TS
19	[52]	6063	Liquid metallurgy	Wear
20	[53]	6351	Stir casting	Wear
21	[54]	7005	Compo casting	TS, hardness, and fracture
22	[55]	7055	Powder metallurgy	Fatigue behavior
23	[56]	7075	Stir casting	Ultimate TS and hardness
24	[57]		Liquid casting	TS, hardness, and wear
25	[58]	8090	Spray deposition	Wear

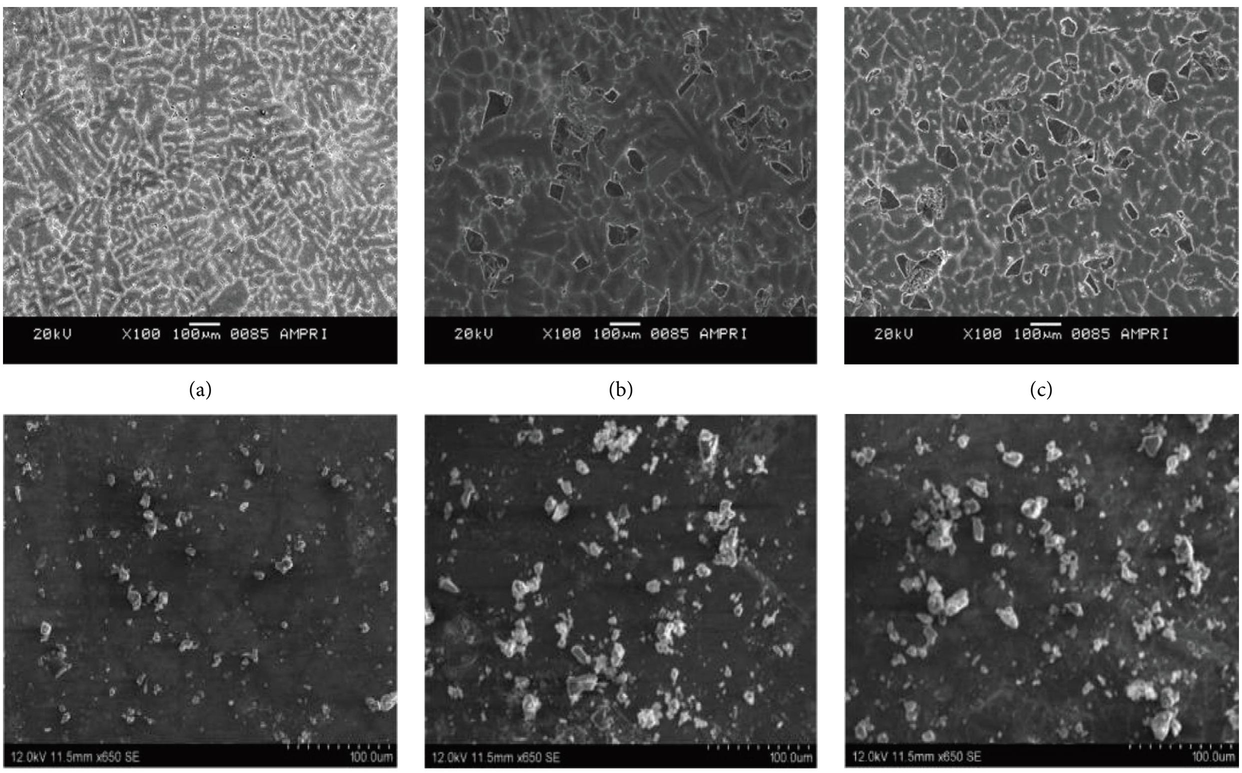
Table 6: Various reinforcement materials used in Al-MMCs.

Reinforcements	Ref.
Gr	[59]
SiC	[60]
Al_2O_3	[61]
TiB_2	[62]
B_4C	[63]
SiN_4	[61]
ZrB_2	[53]
TiC	[64]
SiO_2	[65]
FA	[66]
Gr	[67]
TiO_2	[68]
SiC + Gr	[69]
$SiC + Al_2O_3$	[70]
$SiC + MoS_2$	[71]
SiC + FA	[72]
$SiC + TiO_2$	[73]
$SiC + B_4C$	[74]
SiC + RHA	[75]
Al_2O_3 + Gr	[76]
$Al_2O_3 + B_4C$	[77]
Al_2O_3 + RHA	[78]
$TiC + B_4C$	[79]
B_4C + Gr	[80]
TiB_2 + Gr	[81]
SiC + TiC	[82]



(a) (b) (c)

Figure 2: The optical microstructures of (a) 10 wt.%, (b) 15 wt.%, and (c) 20 wt.% SiC reinforced 7075 Al composites (200x).



(a) (b) (c)

(d) (e) (f)

Figure 3: SEM image of (a) Al 7075 [84], (b) Al 7075/10 wt.% of SiC (20–40 μm) [84], (c) Al 7075/15 wt.% of SiC (20–40 μm) [84], (d) Al 7075/15 wt.% of SiC (25 μm) [85], (e) Al 7075/15 wt.% of SiC (50 μm) [85], and (f) Al 7075/15 wt.% of SiC (75 μm) [85].

improves the strengthening effect of the composites. In Al 7075 hybrid MMCs, the hard reinforcement particles are scattered consistently, resulting in the act of block-off for dislocation movement. It reduces the rupture of the composite material [87]. Increasing hard reinforcement increases the TS and reduces the fracture of the composite by stress transfer from the Al matrix to the reinforcements. This is due to the orowan mechanism [88], bypassing serious obstacles where dislocation is limited around a reinforcement, which improves TS. Figure 6 presents an SEM image of the Al 7075 fractured surface and its stress-strain curve.

During tensile testing, when applying load on the material, the high local stress concentration will be generated around the particles, enhancing debonding or breaking of SiC particles, as shown in Figure 7 [89]. Al-MMCs reinforced with hard ceramic parts rapidly change conventional materials in different applications [90]. The Al/SiC particles are more rigid than the other ceramic particles and provide a very effective barrier to subsurface shear [91]. Deaquino et al. [92] fabricated Al 7075/graphite composites by hot extrusion and mechanical alloying. Increasing the milling time and Gr wt.% refines the grain size and increases the dislocation density. The addition of graphite particles reacts with Al and forms Al_4C_3 during the extrusion and sintering processes, which enhances the TS of the composite by interrupting the dislocation motion.

Rogal et al. [93] studied the microstructure characterization of the Al 7075 alloy after the thixo forming process. After the formation of semisolid metal, the globular microstructure is obtained, and the size of the average globules is 60–90 μm, whereas the process temperature is 615°C and

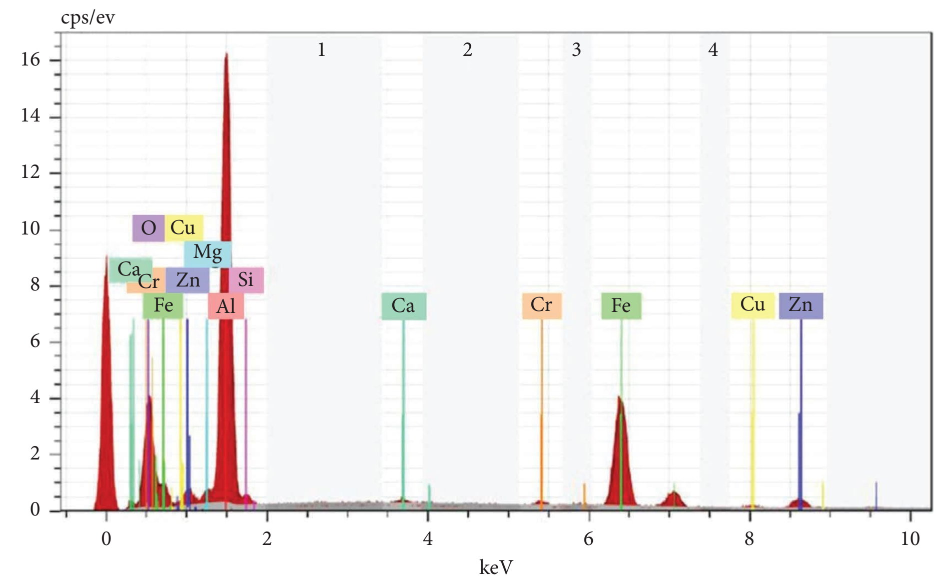


Figure 4: EDAX analyses of Al 7075 and composite with 7.5 wt.% basalt reinforcement [86].

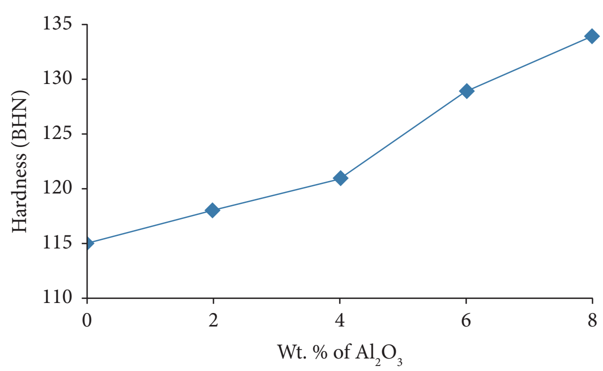
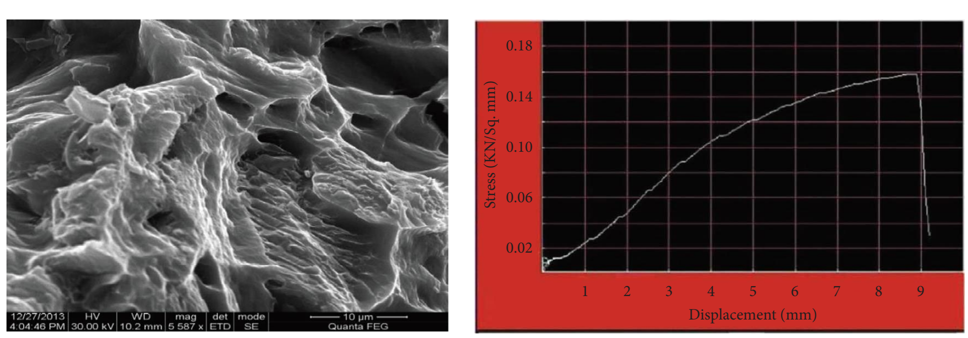


Figure 5: Hardness of Al 7075 MMC with/Al_2O_3 + 5 wt.% of Gr [76].



(a)

(b)

Figure 6: (a) SEM image of Al 7075 fractured surface. (b) Al 7075 stress-strain curve [80].

the piston velocity is 1.5 m/s. Thixo formed microstructure samples show 19% eutectic, 12% Cu, and 77% Al (all in wt.%). Qu et al. [94] have studied the properties of spray-formed Al 7075 alloys under various heat treatment processes and reported that tiny and disconnected precipitates at grain boundaries improve the alloy's corrosion resistance

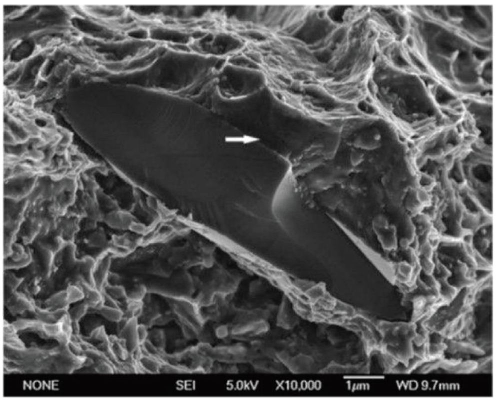


Figure 7: SEM micrographs of the nucleation of cracks result from the breaking of SiC particles [89].

and ultimate tensile strength. The Al-MMCs treated with the U-RRA-H process show higher properties than the T6, T73, and conventional RRA processes.

Similarly, Senthilvelan et al. [95] developed Al 7075/10 wt.% SiC, B_4C, and Al_2O_3 composites using the stir casting method. Al/B_4C composites show a tensile strength improvement of 143% due to the most robust bonding between reinforcement and matrix. However, in the Al/Al_2O_3 and Al/SiC composites, 88% and 46% tensile strength are obtained because of weak interface and porosity. Clark et al. [96] and Reda et al. [97] have deliberated on the retrogagation-treated Al 7075 T6 alloy and reported that preaging material improves the electrical resistivity, tensile properties, and hardness. Kim et al. [98] have reported that aged Al 7075 improves the hardness.

Baradeswaran and Perumal [57] examined the wear and mechanical properties of Al 7075/Gr composites developed by the liquid casting technique. The flexural strength and hardness decrease when raising the Gr content by 5 wt.%. The wear property increases compared to the other samples with increasing sliding distance, sliding speed, and graphite content (up to 5 wt.%). The composite's wear rate rises with increasing load. Lee and Kwon [99] have fabricated Al 7075/SiC composites by a pressureless infiltration process and reported that the composites exhibit higher strength values than the base alloy in all the treated conditions. The addition of Mg improves the wettability and TS.

Chen et al. [100] developed Al 7075 hybrid composite reinforced with 40 vol.% SiC particle and 5 vol.% Ti particle by the squeeze casting process. Casted hybrid Al-MMCs have a TS of 622 MPa and considerable plasticity of 1.2%. The addition of Ti particles improves crack propagation resistance and plastic deformation. The TS of MMC was enhanced due to the good interfacial bonding between Ti reinforcement and the base matrix. Kannan and Ramanujam [101] fabricated Al 7075 hybrid nanocomposites using squeeze and stir casting techniques and analyzed the microstructural and mechanical characterization. The hardness and ultimate TS increase when both single and hybrid composites expand the reinforcements. The hardness of hybrid and single-reinforced nanocomposite by stir casting is improved by 81.1% and 63.7% respectively, while a single-reinforced squeeze cast nanocomposite improves up to 90.5%. The ultimate TS of the nanocomposite is also detected up to 60.1%, 73.8% and 92.3% in the same series of composites compared to base alloy respectively.

In the same way, Lu et al. [102] studied the mechanical and thermophysical properties of Al 7075/SiC/Cr hybrid MMC produced through squeeze casting. Thermophysical and mechanical properties are enhanced by the addition of Cr particles into the 50% SiC composite. 50% SiC + 5% Cr composite show ductile-brittle fracture mode, but 50 SiC composite exhibits brittle fracture mode. Adding Cr particles decreases the dislocation density, forming a good interface between Al matrix and Cr particles and improving fracture toughness and interface conductance. The hybrid composite material has good thermophysical properties and the highest bending strength. Baradeswaran and Perumal [76] studied the wear and mechanical performance of Al 7075/Al_2O_3/5 wt.% of Gr hybrid MMC fabricated through stir casting. In a wear process, the Gr particles act as a solid lubricant and reduce the friction coefficient of the composites. Table 7 shows the mechanical properties of MMCs compared to the base metal.

Al 7075-MMCs reinforced with 1 wt.% of Mg and 1–4 wt.% of Al_2O_3 were fabricated by stir casting and found an augmentation in hardness and TS. 4 wt.% of Al_2O_3 exhibits an increase in 50% and 6.25% of hardness and TS, respectively. On the contrary, % elongation was decreased by 51.16% [109]. Al 7075 with 6 wt.% of Al_2O_3 exhibits an increase of 37.5% and 24.44% hardness and TS, respectively [110]. Al 7075 with 10 wt.% of SiC, Al_2O_3, and B_4C exhibits an increase of 25.52%, 16.98%, and 43.75% hardness and 45.51%, 88.71%, and 143.34% increase in TS, respectively and % elongation also significantly decreased [95]. The heat-treated (500°C) Al-MMCs with 2 wt.% of Al_2O_3 increased the hardness and TS by 61.84% and 60.71%, respectively. Al 7075 + 2% Al_2O_3 + 4% SiC (500°C) exhibits superior properties than Al 7075 and Al 7075 + 2% Al_2O_3. Mechanical properties are slightly dropped with a further increase in the heat treatment temperature. Al-MMCs with 2 wt.% of Al_2O_3 produced through squeeze casting exhibited enhanced properties than all [101].

Al-MMCs with 5 wt.% of SiC and 5 wt.% of CB exhibited a 16.36% and 19.32% rise in hardness and TS. On the other hand, the same MMCs process with FSP yields a 105.98% increase in TS and % elongation to 5.83% [111]. Al 7075 with 5 and 10 wt.% of SiC exhibited a 69.23% and 84.61% increase in hardness and TS, respectively [112]. Al 7075 with 6 wt.% of SiC exhibited a 58.33% and 77.77% increase in hardness and TS, respectively [113]. During the casting of Al-MMCs, different sizes of SiC particles were reinforced. Al-MMCs + 10 wt.% of 75 μm SiC particles exhibited better mechanical properties than other particle sizes. It increased the 22.58% and 8.25% hardness and TS, respectively [114]. Al-MMCs with 15 wt.% of SiC exhibit 10.52%, 17.64% hardness, and TS, respectively. The specimen with heat treatment significantly increases the TS (61.76%) [83].

Al-MMCs with 5 wt.% of TiC increased the hardness by 70% [115]. Al-MMCs with 7.5 wt.% TiC + 7.5 wt.% of SiC increased by 18.11% and 27.77% hardness and TS [116]. Al-

Table 7: Mechanical properties of Al 7075 MMCs.

S. no.	Composition	Density (g/cm^3)	Hardness	UTS (MPa)	Elongation (%)	Ref.
1	Al 7075	—	83 VHN	368.5	—	[103]
	Al 7075 + 1.5% Gr	—	113 VHN	413	—	
	Al 7075 + 15% SiC	—	120 BHN	230	—	
	Al 7075 + 15% Al_2O_3	—	140 BHN	240	—	
	Al 7075 + 15% B_4C	—	160 BHN	260	—	
	Al 7075 + 15% TiB_2	—	150 BHN	250	—	
2	Al 7075	—	127 BHN	114	13.8	[104]
	Al 7075 + 3% CSFA	—	134 BHN	121	13.5	
	Al 7075 + 3%CSFA + 12% B_4C	—	169 BHN	177	9.8	
3	Al 7075 (cast)	—	62 VHN	100	7	[105]
	Al 7075 (hot rolled)	—	70 VHN	250	13	
	Al 7075 + 10% TiB_2 (cast)	—	78 VHN	160	5	
	Al 7075 + 10% TiB_2 (hot rolled)	—	82 VHN	400	11	
4	Al 7075	—	65 VHN	145	8.2	[56]
	Al 7075 + 3% TiB_2	—	80 VHN	195	7.5	
	Al 7075 + 6% TiB_2	—	95 VHN	240	5	
	Al 7075 + 9% TiB_2	—	125 VHN	100280	3.5	
5	Al 7075	2.804	70 BHN	—	—	[106]
	Al 7075 + 2% albite	2.796	80 BHN	—	—	
	Al 7075 + 4% albite	2.793	90 BHN	—	—	
	Al 7075 + 6% albite	2.787	100 BHN	—	—	
	Al 7075 + 8% albite	2.784	115 BHN	—	—	
	Al 7075 + 10% albite	2.78	110 BHN	—	—	
6	Al 7075	2.75	74 BHN	131.8	4.93	[107]
	Al 7075 + 2.5% cenosphere	2.67	81.9 BHN	133.6	5.12	
	Al 7075 + 5% cenosphere	2.52	89 BHN	138.9	5.13	
	Al 7075 + 7.5% cenosphere	2.47	96.3 BHN	146.1	5.22	
	Al 7075 + 10% cenosphere	2.41	100 BHN	143.2	5.17	
7	Al 7075	—	120 HV	166	—	[108]
	Al 7075 + 2% steel powder	—	131 HV	180	—	
	Al 7075 + 4% steel powder	—	139 HV	185	—	
	Al 7075 + 6% steel powder	—	155 HV	170	—	

MMCs with 5 wt.% of TiC with 10 hours of milling exhibit high hardness and TS [117]. Al-MMCs with 6 wt.% of BA and 5 wt.% of Gr had 100 BHN hardness and 300 MPa TS [118].

From Table 7, it was observed that Al 7075 + 15 wt.% B_4C offers 160 BHN hardness and 260 MPa UTS. Along with 12 wt.% of B_4C and 3 wt.% of CSFA, hardness increased to 169 BHN, but UTS decreased to 177 MPa. The particle size of B_4C played a significant role in hardness. The small particle size (20 μm) provides enhanced hardness values [119]. The addition of albite, cenosphere, and steel powder significantly enhances the mechanical properties of Al 7075 AMCs. When the reinforcements are added beyond a significant level, they form a cluster and significantly affect the mechanical properties [106].

Recent studies have shown that by choosing suitable reinforcement and optimizing for optimum reinforcement dispersion, the mechanical characteristics of MMCs can be further enhanced. Impressive improvements in the hardness and mechanical properties were seen. Heat-treated MMCs also improve the mechanical properties of the composites.

4.3. Tribological Properties. In this section, the authors report the key findings about the tribological properties related to different process parameters in the literature. Relative movement between two surfaces can cause the material to fall off one or both surfaces, called wear [83]. The wear process also depends on the nature of the surface, which is determined by the processing route [120]. Two solid surfaces slide over one another with load, which forms adhesive wear [121]. High-hardness materials reduce wear with high strength and toughness [122]. Many researchers have reported that increasing the wt./vol. fraction of reinforcement particles improves the wear resistance of the composites [123]. At a higher vol. fraction, the coefficient of friction is found to be higher without any applied load condition [124]. Adding reinforcement to MMCs improves the wear behavior, increasing the stiffness and specific strength, making it an ideal contender for engineering applications [125, 126].

Material wear resistance is determined by strength, hardness, ductility, toughness, reinforcing material type, wt./vol. fraction, and particle size and shape [65, 127, 128]. MMCs reinforced with higher bond strength particles and matrix support can prevent crack initiation and improve wear resistance [129, 130]. Several researchers examined the wear characteristics of Al-MMCs with various reinforcement materials. The commonly used AMCs are reinforced with hard ceramic particles (like SiC, Al_2O_3 [131]) or soft particles (such as Gr [132]). Venkataraman and

Sundararajan [133] studied the sliding friction and wear characteristics of 7075 AA and SiC particle-reinforced AMCs under dry conditions. Experimental observations show a strong correlation between friction and wear in the mechanical mixed layer (MML). The oxidation mechanism was established from the microphotograph of the worn surface.

Daoud et al. [134] developed Al 7075/Al_2O_3 MMCs through compression casting technology. The presence of the reinforcement creates a fine structure in the MMC. The pressure applied during the extrusion process increases the bond strength at the interface between the matrix and the Al_2O_3, thus reducing superfluous porosity at the interface of the particles. As the vol. fraction of Al_2O_3 rises, the hardness of the composite material increases linearly. Compression casting compounds show better wear resistance than base alloys because Al_2O_3 acts as a load-carrying element during sliding.

In the same way, Michael et al. [135] considered the wear characteristics of the Al 7075/TiB_2 composites developed. TiB_2 particles do not develop intermetallic compounds and are dispersed evenly in the matrix. TiB_2 particles and matrix material bonding and wear resistance are more due to the absence of pores and inclusions. The worn surface at room temperature exhibits parallel grooves, delamination, and grooves through the worn surface. By increasing the reinforcing agent content and the wear transition temperature to 210°C, the wear resistance of the MMC is lowered. TiB_2 particles can resist metal flow and subsurface deformation at 240°C.

Baradeswaran and Perumal [136] explored the mechanical and wear behavior of Al 7075/B_4C composites developed by casting and used K_2TiF_6 as a fluxing agent to increase the wettability during the casting process. Adding reinforcing particles will increase the hardness because it will hinder the movement of dislocations. Compared with the base alloy, adding B_4C particles enhances the mechanical properties. Compared with the base alloy, the compound Al 7075 + 10% vol. of B_4C, their wear rate is reduced by 11%. The MML developed on the worn surface controls the wear characteristics, and composites reached a coefficient of friction (CoF) of 0.32.

Baydoğan et al. [137] analyzed the wear characteristics of retrogression and reaging (RRA) on Al 7075. Under dry sliding conditions, the alloy treated at 220°C shows better resistance against wear than the Al 7075 alloy. However, due to the lubricating effect, RRA with 30 g/l NaCl + 10 g/l HCl solution-treated alloys has lower wear resistance than Al 7075 T6 alloy. Dasgupta and Meenai [138] also developed Al 7075/SiC composites using stir casting and analyzed the sliding wear properties. The composites show appreciably enhanced wear properties compared to the base matrix. The RRA-treated composites exhibit better resistance against wear than T6 heat-treated composites.

Lakshmipathy and Kulendran [139] developed Al 7075/SiC and Al 6061/Al_2O_3 MMCs through stir casting and studied the wear behavior. Increasing reinforcement (SiC, Al_2O_3) improves the hardness of the composites, and 20 wt.% reinforced composites have 50 BHN (SiC) and 37 BHN (Al_2O_3). Composite impact strength decreases when increasing reinforcements. Al with 20 wt.% reinforced composites show enhanced wear properties than base matrix, in which Al 7075/SiC is better than all. The wear rate rises with the load, and the surface temperature increases with increased reinforcement.

Pradeep et al. [82] produced Al 7075/SiC/TiC hybrid MMC through the powder metallurgy route. The composite with 8% TiC and 4% SiC has a higher microhardness value of 52.12 HV than other samples. Adding SiC and TiC particles into the matrix improves the wear resistance. The Al 7075 composite with 4 wt.% SiC and 4 wt.% TiC shows a lower CoF than specimens. Liu et al. [140] examined the dry sliding wear characteristics of Al 7075/SiCp/Ti hybrid MMCs developed by squeeze casting. The addition of Ti particles does not influence the wear mechanism. These particles form microzones that develop synergistic deformation and stress release effects. This type of effect obstructs the formation of cracks beneath and the cracking of SiC particles. At low loads, incorporated Ti particles improve the wear resistance.

Similarly, Kumar and Dhiman [69] developed Al 7075/SiC/Gr hybrid MMCs by stir casting. The specific wear rate reduces with increasing the transition speed (4 m/s) and load. Transition speed increased to 6 m/s, reducing the specific wear rate by forming the tribolayer. The composite-specific wear rate decreases with an expansion in the sliding distance at low load (20–40 N) and low speed (2–4 m/s). With the rise in the sliding distance, the specific wear rate increases with increasing load and speed. The amalgamation of Gr, formation of iron oxide, work-hardening of the specimen surface, and miniature lubricant layer formation between the contact surfaces increase the wear resistance.

The wear rate of 7075 AMCs significantly increased with the load. On the other hand, by increasing the reinforcement of Al_2O_3 from 3% to 5%, the wear rate decreased from 0.3309 to 0.2467 mm^3/min. Further increases in Al_2O_3 wt.% considerably increase the wear rate to 0.0467 mm^3/min at 1.5 N load [141]. Al 7075 + 5 wt.% of Gr + 2 wt.% of Al_2O_3 exhibits the least wear rate of 0.0007 mm^3/min for a 20 N load. Further increasing the wt.% of Al_2O_3 wear rate was considerably increased [76]. Al 7075 MMCs + 10 wt.% of Al_2O_3 + 5 wt.% of FA significantly decrease the wear rate to 0.049 mm^3/min at 10 N load [142]. Al 7075 + 1 wt.% of Mg + 4 wt.% of SiC + 4 wt.% of Al_2O_3 with a 40 N load exhibits the least wear rate of 0.10×10^{-3} mm^3/min. A reverse trend of a decrease in wear rate with an increase in load was observed [143].

A rise in wear rate with an expansion in wt.% of SiC was found [144]. It was noticed that the wear rate boosted with an expansion in sliding distance [145]. Al 7075 AMCs + 9.5 wt.% of SiC exhibit the least wear rate with a sliding distance of 1000 m [146]. An increase in wt.% of TiC (10 wt.%) reduces the wear rate from 2.15 mm^3/km to 1.7 mm^3/km [147]. The impact of TiC wt.% has to be further explored by increasing the wt.% to 15. Al 7075 MMCs, along with 10 wt.% FA and 6 wt.% Gr, significantly decrease the wear rate to 200 mm^3/min. The wear resistance has been enhanced due to the hardness of Gr [148]. The addition of B_4C along with Gr considerably increases the wear resistance [80].

Recent studies have shown that the tribological properties of MMCs can be further enhanced by choosing the proper reinforcement, amount of reinforcement, reinforcement dispersion, and optimum tribological parameters.

5. Corrosion Properties

In this section, the authors report the key findings about the corrosion properties of MMCs as found in the literature. Yue et al. [149] examined the corrosion cracking resistance of Nd-YAG laser surface-treated Al 7075 T651 alloy prepared in air and nitrogen gas environments. Corrosion is severely attacked with intergranular cracks in the untreated specimen at the grain boundaries. In air-treated specimens, long-stress corrosion cracks and a less number of large corrosion pits are found at interdendritic boundaries. A few short-stress corrosion cracks appear on the alloy surface in the nitrogen-treated specimen. Superior corrosion resistance is achieved on the laser-melted surface due to the formation of the AlN phase, an electrical insulator. The preheated reinforcement particles with a range of 500°C produce uniformly distributed reinforced composites and reduce agglomeration when the nanoreinforcement particles' presence does not exceed 2%.

Varma and Vasquez [150] analyzed the corrosive wear characteristics of Al 7075 MMCs reinforced with Al_2O_3 particles. Pitting corrosion can occur in both alloys and composites. Al 7075/Al_2O_3 composites show better corrosive wear than the base alloy, while solutionizing composites reveals significant grain growth. Zhou et al. [151] examined the corrosion properties of Al 7075 with thin electrolyte layers in 1 M sodium sulfate solutions and a pH of 5. The oxygen reduction current of 110 μm is more significant at −1.1 V and measured from the potentiodynamic polarization. The electrochemical impedance spectroscopy results reported that the corrosion rate increases when the immersion time between 0 hr and 96 hr increases, independent of the electrolyte layer.

Karunanithi et al. [152] developed an Al 7075/TiO_2 composite by powder metallurgy route and studied the corrosion behavior of 3.5 wt.% NaCl. The corrosion potential moves in the noble-gas direction, and the corrosion current density increases with the accumulation of TiO_2 particles. The current density is determined using the TAFEL curve, with a minimum for the base alloy and a maximum for 30 vol.% TiB_2 reinforced composites. The current density values for 5 and 10 vol.% TiB_2 reinforced composites are in the same range. Increasing the reinforcement particles increases the pitting damage observed by SEM analysis. Nagaswarupa et al. [153] fabricated an Al 7075/Zr composite using stir casting, and the stress corrosion studies were done using seawater. Zr is an inert material that does not involve a galvanic effect. Therefore, the composite material is less susceptible to corrosion, mass loss, and pit formation than the base alloy. Increasing the reinforcement material improves the TS and bonding strength.

El-Amoush [154] investigated the corrosion behavior of hydrogenated Al 7075 T6 alloy in a 0.5 M NaCl solution with a pH of 3.56. Increasing the precharged hydrogen time increases the pitting and severity of the attack. Pitting is lower compared to the nonhydrogenated alloy material. Huang et al. [155] studied the electrochemical behavior of Al 7075-T73 alloy and its cooled rolled components. It is reported that the anodized, cooled, and rolled Al 7075-T73 alloys show higher corrosion resistance compared to the base alloy. Microcell approaches are viable for characterizing and understanding localized corrosion in microstructurally complex alloys.

Recent studies have shown that the corrosion properties of Al 7075 MMCs can be further enhanced by choosing the suitable reinforcement, amount of reinforcement, and reinforcement dispersion.

6. Summary and Future Direction

(i) Numerous obstacles must be optimized to increase the application of MMCs, such as reinforcement vol./wt.%, reinforcement size/shape/type, operating temperature, and development method, to develop advanced materials for a wide range of structural and frictional applications

(ii) According to the literature, it was found that hybrid nanocomposites offer a wide range of possible industrial uses

(iii) The exact composition with different manufacturing methods will lead to the development of advanced MMCs

(iv) Further studies in thermal properties and heat treatment of MMCs with different reinforcements will improve the thermal applications

(v) The secondary processing methods in MMCs are the main problem

(vi) Further advancements in research are required to combine MMCs easily, and specialized tool innovations are required for machining MMCs

7. Conclusions

An extensive literature study has been performed for various AMCs and different reinforcements. Based on the study, the following conclusions have arrived.

(i) Developing AMCs with different reinforcement particles improves the properties of the materials required in different application areas such as aerospace, automobiles, military, and general structural applications.

(ii) Most researchers use the liquid metallurgy technique for developing composite materials. This technique is cost effective, simple, and absent of size limitations, and it can be used for mass production.

(iii) The review found that adding hard reinforcement particles enhances the mechanical, tribological, and corrosion properties of MMCs compared to the base alloy.

(iv) The composite material's properties increased when the reinforcement particles increased, irrespective of the manufacturing process.
(v) Hybrid MMCs have better mechanical, tribological, corrosion, and thermal properties than single-reinforced composites and base alloys.
(vi) In the case of hybrid MMC, adding a small amount of two or more reinforcement particles provides better properties than increasing the single reinforcement in the matrix.

Nomenclature

AMCs: Aluminium matrix composites
Al_2O_3: Aluminium oxide
Al-Zn: Aluminium-zinc
BA: Bagasse ash
B_4C: Boron carbide
BHN: Brinell hardness number
CB: Carbon black
COF: Coefficient of friction
EDAX: Energy-dispersive X-ray spectroscopy
FA: Fly ash
FSP: Friction stir processing
Gr: Graphite
MML: Mechanical mixed layer
MMCs: Metal matrix composites
PM: Powder metallurgy
RRA: Retrogression and reaging
HRB: Rockwell hardness
SEM: Scanning electron microscope
SiC: Silicon carbide
TS: Tensile strength
TiC: Titanium carbide
TiB_2: Titanium diboride
TiO_2: Titanium dioxide
UTS: Ultimate tensile strength
VHN: Vickers hardness number
wt.%: Weight %
Y_2O_3: Yttrium oxide.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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