Materials Physics and Mechanics. 2022;50(3): 439-458
Research article
http://dx.doi.org/10.18149/MPM.5032022_8

Submitted: August 30, 2022
Approved: September 20, 2022
Accepted: October 18, 2022

Effect of reinforcements on mechanical and tribological behavior of magnesium-based composites: a review

Dinesh Kumar✉**, Satnam Singh, Surjit Angra**

Department of Mechanical Engineering, National Institute of Technology Kurukshetra-136119, Haryana, India

✉ dinesh_61900120@nitkkr.ac.in

Abstract. The challenges faced in the development of light materials, motivate researchers to produce materials with improved characteristics, which have wide applications in the biomedical, automotive, defense, and aviation industries. The limited availability of monolithic or natural materials on the earth can be another reason to develop a newer version of metals, alloys, and composites. These developed materials should have enhanced physical, mechanical, and tribological properties. The present article discusses the effect of numerous reinforcements with different weight/volume percentages on the hardness, tensile strength, corrosion, and wear resistance of Mg-based metal matrix composites (Mg-MMCs). It has been observed that the hardness and tensile strength of Mg-MMCs range from 34-152.7 HV and 45-240 MPa, respectively, and its corrosion current density reduces from 549.21-1.923 μA cm^{-2}. This research paper also focused on the effect of various wear and friction process parameters such as applied load (10-80 N), sliding distance (100-2000 m), sliding velocity (1-3 m/s), sliding time (5-30 minutes), and the effect of different weight/volume reinforcement percentages (0-25%) on the performance of Mg-MMCs during wear and friction phenomenon. The material loss during wear measurement and coefficient of friction (COF) of Mg-MMCs ranges from 0.0174 -0.09 g and 0.90-0.0234, respectively.

Keywords: MMC, magnesium, bio-medical, tensile strength, hardness, corrosion, wear, friction

Acknowledgements. *No external funding was received for this study.*

Citation: Kumar D, Singh S, Angra S. Effect of reinforcements on mechanical and tribological behavior of magnesium-based composites: a review. *Materials Physics and Mechanics*. 2022;50(3): 439-458. DOI: 10.18149/MPM.5032022_8.

1. Introduction

Over the recent years, rapid transformation in social inevitabilities and requirements contributes to the various progressive genera of materials through enhanced properties achieved from alloys, metals, and non-metals [1]. Material adoption is a vital part of our everyday needs and in the advancement of every nation [2]. As of now, how materials are being utilized for the betterment of our daily needs is genuinely enough to know the significance of designing that material in our life [3].

New materials have to create with quick production and assembly needs among worldwide industries [4]. The evolved material should have improved properties over monolithic materials [5]. The necessity for enhanced properties can be fulfilled with

Publisher: Peter the Great St. Petersburg Polytechnic University

composites [6]. The combination of two or more materials is identified as a composite. Matrix and reinforcements can be called two portions of the composites. The matrix material should be metal, whereas reinforcement can be metal or non-metal [7]. When the metal and its alloy are used as matrix material, then the fabricated composite is known as metal matrix composite (MMC). Metal matrix composites have mostly improved properties by adding some reinforcement weight/volume percentage [8]. The types of composites are represented in Fig. 1. The pictorial view of the constituents of the hybrid metal matrix composite is shown in Fig. 2.

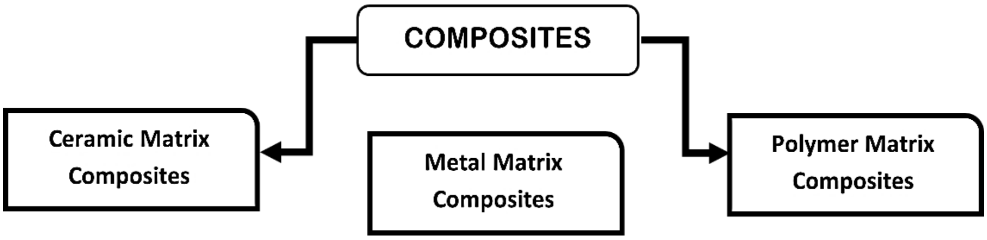

Fig. 1. Classification of composite materials

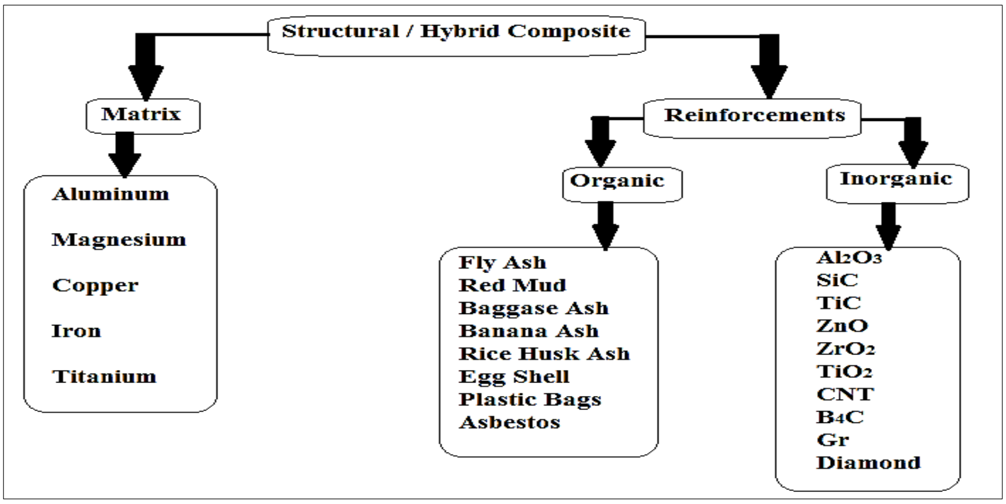

Fig. 2. Constituents of hybrid composites [9]

Iron (Fe), zinc (Zn), aluminum (Al), copper (Cu), titanium (Ti), and magnesium (Mg) are being utilized as matrix materials in MMCs. Each metal matrix has its importance regarding its application. Mg is the most used lightweight material for various applications. It is the eighth most abundant material in the earth’s crust and one-third and one-sixth lighter than aluminum and titanium, respectively [10]. The Mg applications include biomedical (such as orthopedic, cardiovascular, and other transplants) [11], automotive (like gearbox, steering column, seat frames, drivers' airbags, and fuel tank covers) [12], and other (laptops, cameras, luggage storage products, power tools, and household) [13]. The Mg-MMC's demand consistently increases due to artificial implants. To fulfill this demand for patients with bone injuries and degeneration caused by the normal process of aging, injuries, and accident, we required biomedical materials to bring back into the functionality of the part [14-16].

Mg-MMCs have shown tremendous potential in orthopedic and other implant applications to address the problems. The elastic moduli of Mg-MMCs closer to natural bone is also the main reason for its adaptation in bio-medical industries [17]. The Mg-MMCs also have enhanced mechanical properties (like hardness, tensile strength, compressive strength, flexural strength, etc.) and tribological properties (Corrosion, friction, and wear) compared to base Mg and it's alloy [17-19]. The high strength stiffness and light-in-weight makes Mg an important material for use in aviation and automotive applications [20], however, its high manufacturing cost restricts the use of Mg as a matrix material. To overcome these factors, homogeneity and reinforcement are used and tried to make an inexpensive using fast dispersion process to manufacture Mg-MMCs composites. Metal and ceramic particulates are among the furthermost traditionally used reinforcements in composites [21,22].

2. Material used and methods of fabrication

The study focuses on magnesium and its alloy used as a matrix material for the fabrication of composites. Due to the high damping and vibration coefficient, low density, and high strength of the magnesium, the Mg-based composites have great potential to use in structural elements in automotive, aerospace, and bio-medical industries [23]. The various kinds of reinforcements in different proportions can be added during the synthesis of Mg-MMCs [24]. The commonly used composite fabrication methods are:

1. Stir Casting
2. Powder Metallurgy (PM)
3. Friction stirs processing (FSP)

Stir casting. The fabrication of discontinuous particle reinforced MMCs use the stir casting technique. The process is affected by many influencing parameters on which the mechanical and microstructure of the composite depends. The two-step stir casting technique was used to produce a composite of aluminum alloy and alumina oxide by Alaname et al. The Al6063 was preheated at 250°C, then the preheated form of matrix material is put into a graphite furnace and heated up to 750°C to convert into a molten state. Then the stirrer with 300 rpm for 10 minutes was used for uniform dispersion of the reinforcement into the molten matrix. After that, the molten metal was poured into a sand mould for solidification [25]. Figure 3 describes the stir casting setup.

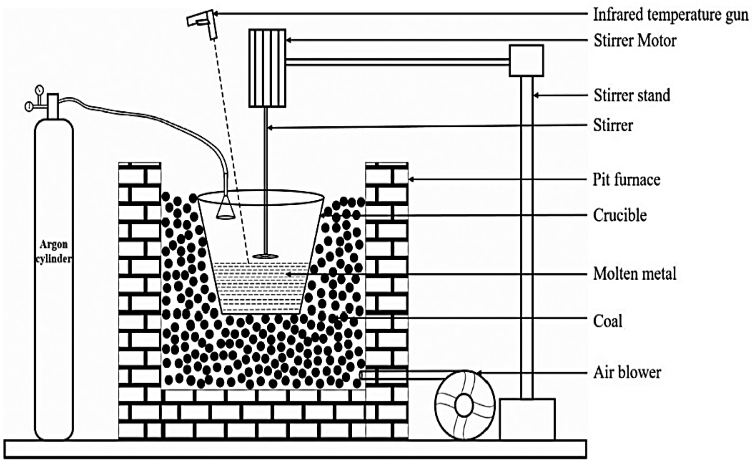

Fig. 3. Stir Casting Setup [26]

Meher et al. adopted a stir casting process to fabricate the magnesium composite for manufacturing the components of the automotive and aerospace sectors. The 4, 6, and 8 weight percentage of TiB_2 was added to the RZ5 magnesium alloy. The mechanical properties were enhanced with TiB_2 at 8 weight percentage addition in the base metal [26]. Kumar and Sozhamannan discuss the characterization of magnesium-based matrix composites in the study. The stir cast samples of graphene 0.5, 1 and 1.5 wt.% and magnesium alloy were prepared. The preheating of the die was done at 300ºC and the stirrer speed was used at 450-500 rpm to avoid the casting defects in the samples. The strong interfacing between graphene and magnesium alloy was observed during microstructure analysis [27].

Powder metallurgy. Sintering, blending, and compacting are the three steps involved in powder metallurgy. First of all the base metal or compound powders are blended appropriately then afterward passed through the high-pressure die then at high temperature it was sintered for the legitimate holding of particles [28]. Singh et al. concluded in their study that the heating of the magnesium powder and Sic powder was done at 400ºC thereafter desired shape was given by passing the material through the die and punch for 60 minutes at 150 rpm, then room temperature was maintained at the molten metal [29]. The extruded rods were cut into a length of 150 mm and after that using a muffle furnace the internal stress was released from the prepared rods. Ghasali et al. observed the higher bending strength and microhardness of the sintered magnesium/ B_4C composites [30]. Kumar et al. studied the influence of sintering temperature, milling time, and compaction pressure on magnesium-based composite during powder metallurgy processing technique. The improvement was noticed in the hardness and density of the composite [31]. The graphical representation of powder metallurgy process is mentioned in Fig. 4.

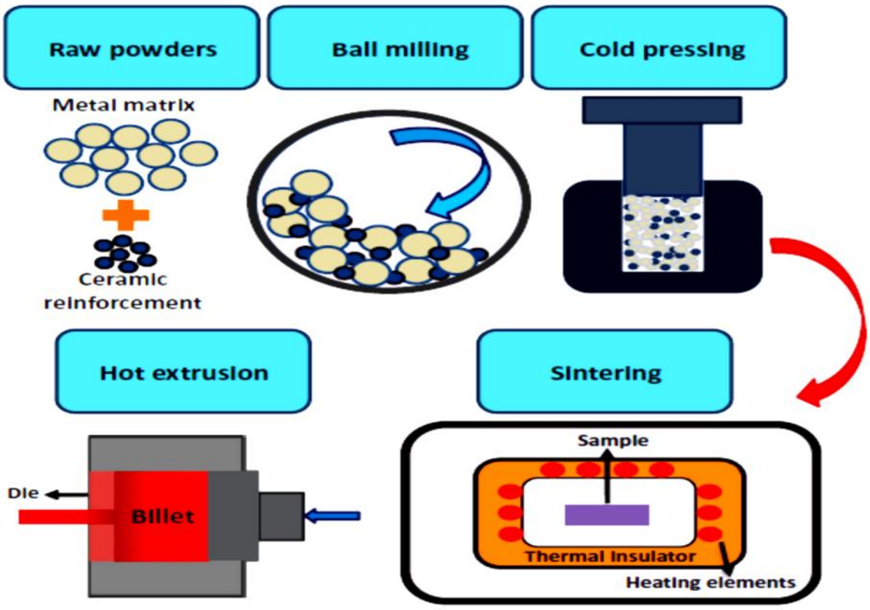

Fig. 4. Powder Metallurgy [32]

Friction stir processing. When the modification in surface property is required during the manufacturing of metal matrix then the friction stir technique is utilized. The structural advancement by plastically deformation during the advancement of non-consumable apparatus into the work-piece is done by this process [33,34]. During the progression, a turning or rotating pin type of tool is progressed on the surface of the work-piece. Due to frictional resistance, heat is generated which is the main reason for plastic deformation between the surface of the work-piece and tool pin [35]. Dinaharan et al. utilized FSP to fabricate Mg MMC's of AZ31/Ti-6Al-4V. The H13 steel material cylindrical shaped tool of diameter 24 mm was used in the processing of composite fabrication. The height of the tool tip was 5.7 mm with the threaded profile. The effect of transverse speed, tilt angle, and tool rotation speed was studied on the mechanical properties of the composite [36].

Pandey et al. studied the influence of FSP on the strength and wear of magnesium and SiC nano-composites. The enrichment was seen in the mechanical and metallurgical properties of the produced nano-composite. The homogenous mixture of the SiC was observed in SEM analysis [37]. The 19.72% and 77.5% increment was noticed for the micro-hardness and compressive strength of the AZ31/graphene/MWCNT composites.

The MWCNT with 1.6 vol.% and 0.3 vol.% of graphene was found optimized at the rotation speed of 1400 rpm [38]. Figure 5 shows the process parameters and response parameter of friction stir processing.

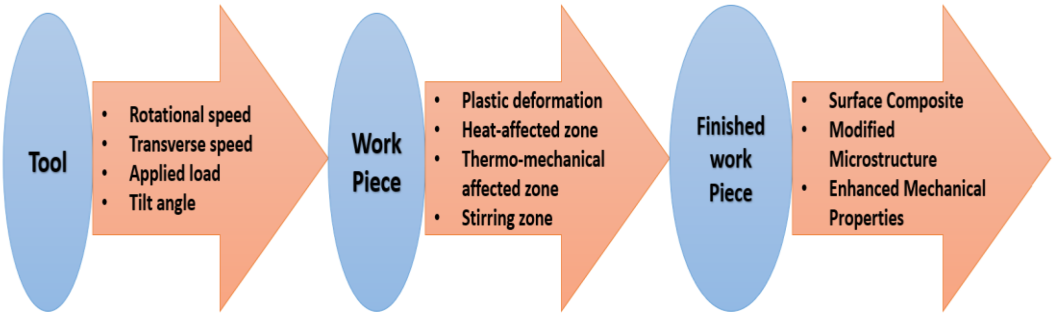

Fig. 5. Friction stir process [10]

3. Effects of different reinforcements on mechanical properties of Mg-MMCs

Effect on hardness. The resistance to indentation and abrasion of the material is called hardness. The Brinnel, Rockwell, and Vickers are commonly used machines for testing hardness. The experimental work concluded that increment in the hardness of Mg-MMCs of 10 wt.% titanium carbide (TiC) when reinforced in the matrix of RZ5 magnesium alloy, fabricated using the self-propagating high-temperature technique [39]. Authors have produced Mg-MMCs with reinforcement of 0.5 wt. % of Al_2O_3 and 8 wt. % of Tio_2 with AZ61 Mg alloy using laser cladding (LC). It has been observed that hardness increases as wt.% of reinforcements increases due to the particle grain size refinement of Al_2O_3 and Tio_2 in matrix material [40].

The research work concluded that the increase in value of Vickers hardness (HV) for Mg alloy AZ91 fabricated using stir casting technique when reinforced with TiO_2 having 2 wt.% and graphene 0.5 wt.%. The increment in hardness of Mg-MMCs was due to the solid lubrication behavior of graphene for consistent mixing in a matrix material [41]. In this work, the effect of calcium reinforcement (0.2 Vol.%) in Mg alloy matrix when fabricated with friction stir processing (FSP) was studied. It was also noticed that the hardness increased to 73.7 ± 9.9 HV from 60.98 ± 5.3 HV. The grain refinement and texture effect are the main reasons behind the hardness value increment [42].

The value of Vickers hardness increased to 106 from 34 when pure magnesium is reinforced with SiC using FSP at tool pin rpm of 1300 was observed. The reason behind that was reduced grain size and low dislocation movement. The SiC has hard particles, which increases the high load-bearing capability of the composite [43]. The fabrication of Mg-MMCs when reinforced with 5wt.% $Al_2O_3$and 8 wt.% SiC particles in AZ31 Mg alloy. The hardness value was reported to increment 75.16 HV from 64.53 HV, which principally increases the load-bearing capability due to SiC particles present in the Mg-MMCs [44]. Figure 6 shows the comparison of different Mg-MMCs.

When matrix metal AZ91 was reinforced with 10 wt% Al_2O_3 and 5 wt.% SiC, the hardness value expanded by 25% compared to without reinforcement, the Mg-MMC was fabricated using the powder metallurgy (PM) technique. The increment in hardness was observed from 36.3 HV to 45.39HV, as reported in this work [45]. The authors observed the increase in hardness when ZrO_2 was reinforced in the matrix of Mg alloy AZ91D. The authors concluded that hardness increased to 31% compared to Mg alloy due to uniform strain deformation and proper distribution of reinforcement particles [46]. The 28% improvement in the hardness was noticed when stir-cast Mg-MMCs reinforced with zinc oxide (0-5 wt.% ZnO) to Mg alloy [6]. 143.6 HV was reported in Mg-MMC and 112.3 HV in

Mg alloy [47]. Table 1 shows the summary sheet for the hardness of some researchers for magnesium-based composites.

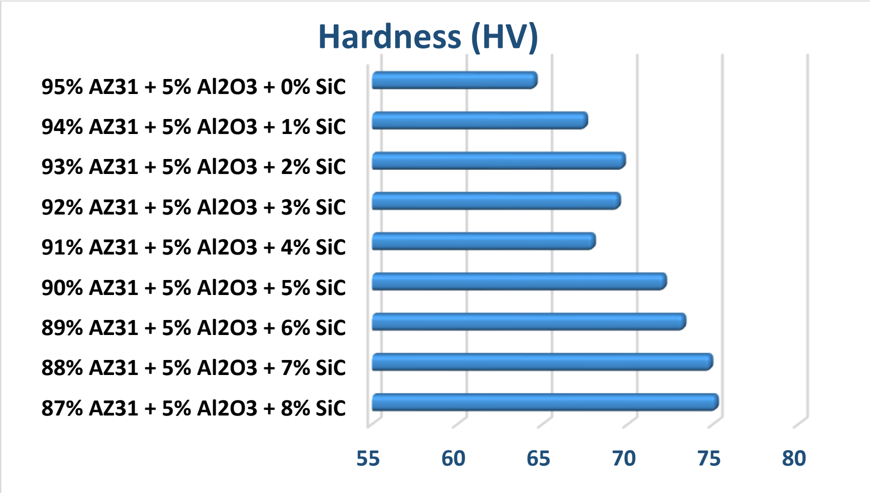

Fig. 6. Hardness of different Mg-MMCs [44]

Table 1. Hardness summarized sheet of Mg-MMCs

S No	Reinforcement	Method	Hardness		Ref.
			Mg Alloy	Mg-MMC	
1	Nano Y_2O_3 0.7 Wt. %	Microwave Sintered	35 HV	45 HV	[21]
2	B_4C 9 Wt.%	Stir Casting	42 HR	78 HR	[48]
3	Nano BN 2.5 Wt. %	Microwave Sintered	48±1 HV	57±2 HV	[49]
4	B_4C 5 Wt. %	Stir Casting	88±10 HV	61±11 HV	[32]
5	Nano CNT 0.1 Wt. %	Microwave Sintered	48±1 HV	61.8±8.6 HV	[50]
6	TiO_2 15 Wt. %	Stir Casting	55.9 BHN	72.4 BHN	[51]
7	$Niti_p$ 10 Vol. %	Friction Stir Processing	35±5 HV	152.7 HV	[52]

Effect on tensile strength. In industries, mechanical testing has great importance before producing or developing any material. The testing also leads to cost reduction without comprising the quality during production. The tensile strength concludes the functionality of the manufactured products. Jayabharthy et al. and Mehra et al. also reported the enhancement of tensile strength increment in the stir-casted Mg-MMCs. The values of Tensile strength of Mg-MMCs were 149.1 MPa and 195 MPa as compared to Mg alloy (84.3 MPa and 179 MPa respectively) [39,41]

The microwave sintering process was used to produce a composite with 2 wt.% of nano Y_2O_3 reinforcement in the Mg alloy matrix. The study reported that tensile strength was increased to 85% (130 MPa to 240 MPa) with 2 wt.% nano Y_2O_3 in the matrix material. The enhancement of tensile strength was attributed to uniform particle dispersion, grain refinement, and increment in extrusion ratio [21]. The effect of variation with B_4C particles in pure Mg on tensile strength was studied by fabricating samples of Mg-MMCs using the stir casting technique. The authors observed that tensile strength increased from 45 MPa to

84 MPa with an increment of reinforcement in Mg matrix. The decrement in porosity, grain size, and nearly uniform distribution of B_4C particles can be the reason for the increment in the tensile strength of MMC's[48].

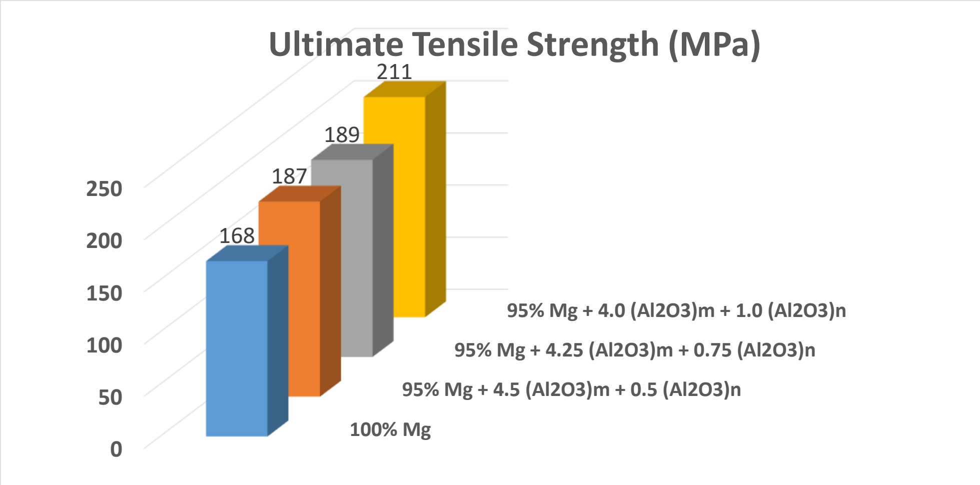

Fig. 7. Ultimate tensile strength of Mg-MMCs at different Reinforcements [53]

The fabrication of MMC's was completed using SiC (0.5 vol.% and 1 vol.%) in pure Mg by powder metallurgy. The maximum tensile strength was reported at 1 vol.% of SiC particles in Mg-MMC. The increment in tensile strength was 18% (172 MPa to 203 MPa) compared to monolithic magnesium. The smaller size and lower volume fraction of reinforcement in the MMC are attributed to the enhancement of tensile strength [54]. The powder metallurgy technique was utilized for the fabrication of MMC's by submicron and nano Al_2O_3 (4 to 4.5 vol.% and 0.5 to 1 vol.% respectively) in pure Mg using the powder metallurgy technique. The increment in tensile strength was observed to be 26% (168 MPa to 211 MPa) as compared to pure magnesium (as shown in Fig. 7) [53]. Table 2 shows the summary sheet for the tensile strength of some researchers for magnesium-based composites.

Table 2. Tensile strength summarized sheet of Mg-MMCs

S. No	**Reinforcement Percentage**	**Method**	**Tensile Strength (MPa)**		**Ref.**
			Mg Alloy	**Mg-MMC**	
1	2 Y_2O_3	Microwave sintered	130	240	[21]
2	5 B_4C	Microwave sintered	65	112	[30]
3	5 B_4C	Spark plasma sintered	65	191	[30]
4	10 Tic	Stir casting	179	195	[39]
5	1 TiO_2 + 0.5 Gr 2 TiO_2+ 0.5 Gr	Stir casting	84.3	149.1	[41]
6	B_4C	Stir casting	45	84	[48]
7	0.5 SiC 1 SiC	Powder metallurgy	172	203	[54]
8	4 $(Al_2O_3)_m$ + 0.5 $(Al_2O_3)_n$	Powder metallurgy	168	211	[55]
9	0.66 TiO_2	Powder metallurgy	194	197	[56]
10	0.7 Y_2O_3 + 0.3 nano Cu	Microwave sintered	244	270	[57]
11	0.7 SiC + 0.3 nano CNT	Powder metallurgy	155.8	195.4	[58]
12	1 CNT + 1.5 TiB_2	Stir casting	213.96	389.67	[59]

The Mg-MMCs with 5 vol.% of B_4C reinforcement in magnesium matrix using microwave sintering (MS) and spark plasma sintering (SPS) process were prepared. The comparative analysis for tensile strength reported that 191 MPa tensile strength was observed in SPS process and 112 MPa in MS process. The study also shows that a 71% increment of tensile strength was reported using SPS process as compared to MS process. The presence of pores and microcracks formation decreases the tensile strength of microwave-sintered Mg-MMCs [30]. Hassan et al. used the powder metallurgy method to fabricate the Mg-MMCs of nano TiO_2 (0, 0.58, and 0.66 Vol.%) reinforcement in pure magnesium powder. The tensile test samples were prepared according to ASTM E8M-15a standard. Results reported that 2% (194 MPa to 197 MPa) increment of tensile strength by adding 0.66 vol.% nano TiO_2 in the Mg matrix material [56]. Authors reported the effect on tensile strength of reinforcements (Y_2O_3 0.7 Wt.% Nano Cu 0.3 Wt.%) hybrid microwave sintered in Mg powder at different temperatures. The 270 MPa value of ultimate tensile strength was achieved at 25ºC in (Mg/0.7 Y_2O_3/0.3 Cu) MMC [57]. The powder metallurgy technique was used to produce Mg-MMCs with reinforcements of Sic 0.7 Wt.% / Nano CNT 0.3 Wt.%. The 25.4 % increment in tensile strength (155.8 MPa to 195.4 MPa) was noticed compared to monolithic magnesium [58]. The 7% increment in tensile strength was reported for AZ91D/1.5wt.% CNTs/1.5 wt. % TiB_2 hybrid composite [59].

From the literature, it can be concluded that the increase in grain particle size causes porosity which reduces the load-bearing capacity. The chances of non-uniform dispersion of reinforcement particles are also there which causes high surface roughness, hence reducing the mechanical properties of the Mg-MMCs [56-60].

4. Effect of different reinforcements on tribological behavior of Mg-MMCs

Effect on corrosion characteristics. From a technical point of view, the proper selection of the process and material for the particular product cannot be decided without corrosion testing. The corrosion testing calculates the failure and life of the material. Thus, in order to find the corrosion rate of the Mg-MMCs, the corrosion current density (μA cm^{-2})/current potential (V) was noted, the greater the corrosion current potential/density greater the corrosion rate in the fabricated Mg-MMCs.

The immersion test was performed on the base and AZ91D-ZrO2 composite material samples ranging from 72 to 168 hours. Initially, at 72 hours, the increment in corrosion starts, and after immersion of 168 hours, it was found that the corrosion rate was reduced. The corrosion potential in the samples was decreased due to the fine dispersion of the reinforcement in the composite. The corrosion current density of MMC was increased to 1.05% (MMC corrosion current density 1.923 μA cm^{-2}) compared to the base metal. This enhancement of corrosion resistance makes the MMC biodegradable [46].

The investigation of Mg-Al_2O_3-SiC hybrid composite in which Al_2O_3 and SiC were used as reinforcement with magnesium matrix using powder metallurgy method. The effect on corrosion resistance was examined under the anodization and immersion process, and surface treatment was carried out using cerium oxide. The authors concluded that surface treatment enhances the corrosion resistance in both the MMCs, but Al_2O_3 particles help in achieving better corrosion resistance compared to SiC particles [61].

The liquid state processing (Stir casting) was used to fabricate Mg-MMCs of AZ41-samarium (sm) (x = 0%, 1%, 2%, and 3%) as alloy and reinforcement, respectively. The electrochemical impedance spectroscopy (EIS) and Tafel polarization (TP) methods were used to analyze corrosion behavior under NaCl solution in 3.5 wt. %. The research concluded that the corrosion resistance was increased due to an increment in the sm reinforcement compared to AZ41 Mg alloy. At 1wt.% of sm, the corrosion rate was 18.7 μA cm^{-2} which has been reported the best compared to AZ41, sm 2 wt.%-AZ41, and sm 3 wt.%-AZ41 (34.6, 25.7, and 23.2 μA cm^{-2} respectively). This enhancement was due to hydrogen evolution, which increases the soaking time and enhances the corrosion resistance of Mg-MMCs compared to Mg alloy [62].

The authors reported in their study that Mg Alloy/ 4wt.% of glass microsphere (GM), MMC was fabricated using stir casting to analyze the effect of corrosion behavior. EIS technique was utilized in the presence of 0.5m H_2SO_4 solution for corrosion characteristics of the developed Mg MMC's. The corrosion rate was enhanced by reinforcing the GM particle to the Mg alloy. The potential corrosion value (-1.16 V) and corrosion resistance (2.61 μA cm^{-2}) have been reported in the study. The deterioration and large crack formation decrease the corrosion resistance of the fabricated Mg MMC's [63]. The investigation was accomplished for the corrosion behavior of Mg/ zinc oxide (ZnO). ZnO powdered particles (5, 10, and 20 wt.%) were mixed with pure Mg metal matrix to form Mg-MMC's samples. The immersion test and electrochemical surface measurement were done to evaluate the corrosion behavior through Hank's solution. During the trial, reinforced particles were uniformly dispersed in the Mg matrix, which enhance corrosion resistance and mechanical properties in the developed Mg-MMC. The corrosion resistance of Mg-MMC was noticed as 95.02 μA $cm^{-2,}$ which was one-sixth of Mg alloy (549.2l μAcm^{-2}) [64].

Effects on wear and coefficient of friction. The interaction between two surfaces causes material loss. The loss and deformation are the results of mechanical action. It can be determined by the volume and mass loss of the material element.

Ting lei et al. investigated the COF and wear behavior of Mg/ zinc oxide (ZnO). The loss of material and COF in Mg-based MMC has been observed to be lower as compared to Mg alloy. The intense binding action of ZnO particles and low porosity is the reason for the enhancement of COF and wear resistance in Mg-MMCs. The analysis was done and found that Mg alloy had an average material loss of 0.85 mg and 0.18 mg was found in Mg-MMC sample. Figure 8 shows the wear loss comparison between the Mg alloy and Mg-MMC [64]. Khatkar et al. fabricated the AZ91D-xSiC-xGr hybrid composite, AZ91 alloy as matrix and reinforcements were SiC (3 and 5 wt. %) and Gr (0, 3, and 5 wt. %) with stir casting technique. The wear test had been performed on a pin on disc apparatus and concluded that the wear rate has been decreased as the percentage of Sic and Gr particles increased. The 0.0079 mm^3/m wear rate of Mg-MMC has been achieved at Sic-5 wt. % and Gr-5 wt. % as reinforcement in the Mg alloy. The delamination and oxidation of SiC particles increase the wear rate in Mg-MMC and decrease the coefficient of friction (COF) [65]. The effect of Sic and graphene oxide (Go) on Mg AZ91 alloy was studied. The wear damage was reduced due to fewer cracks and debris on the worn surfaces by adding Sic and GO particles in the Mg alloy. The graphene oxide gives the best result for wear loss; the volume loss of GO/Mg alloy has been reduced to 0.31 times compared to Mg alloy [66].

The powder metallurgy method was adopted to fabricate Mg-B_4C (0, 1.5, 3.5, and 10 wt. %) MMC's samples. The increment in wear resistance has been seen as the percentage of the B_4C reinforcement (0 to 10 wt. %) increases. The wear resistance was improved by 33 % with 10 wt.% of B_4C in the Mg-MMCs. This is due to the strong bonding of particles and the higher hardness of Mg-MMC's [67]. The wear resistance has increased 5.7 times in the Mg-SiC-Al_2O_3 composite. This increment in the wear resistance was due to the homogenous and uniform dispersion of SiC and Al_2O_3 particles in the fabricated composite. The Al_2O_3 particle gives better results compared to SiC particles in the composite [68].

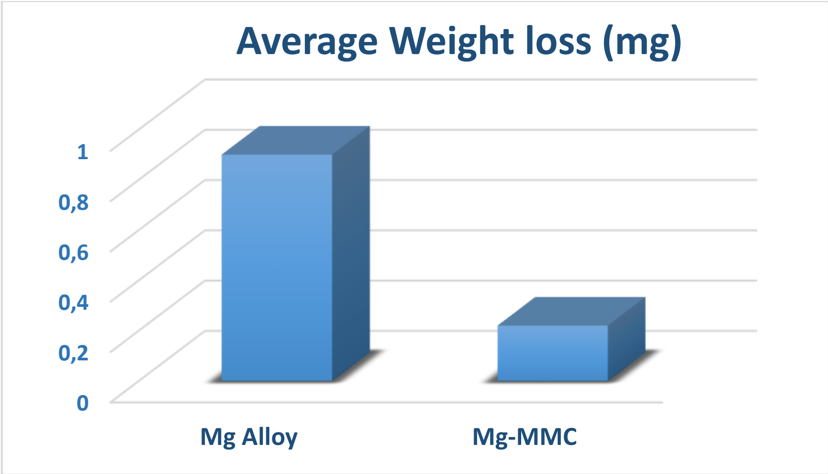

Fig. 8. Material loss determines the COF of Mg alloy and Mg-MMC [64]

The spark plasma sintering techniques were adopted to fabricate Mg-Ni composite. The wear resistance was low because of the softness present in the Mg-alloy. The enhancement in the wear resistance has been noticed just by adding 1.5 wt.% of Ni micro-sized particles in the Mg-alloy [69]. The study shows the improvement of wear resistance and COF at 3 wt. % of Sic particles present in Mg alloy-xSiC (x= 1, 3, and 5 wt. %) composite. The wear loss of 0.0174 g and 0.90 COF was noticed in Mg-MMCs and 0.0218 g (wear loss) and 0.24 (COF) in Mg alloy as shown in Fig. 9. The enhancement of particle distribution and breaking of the intermetallic phase was the reason for improved friction and wear properties in the Mg-MMC [70]. The research work shows the 150% and 350% increment to wear resistance in the fabricated Mg-SiC_p (Nano and Micro) MMC as compared to Mg alloy. The COF values are 0.0248, 0.0242, and 0.0234 for Mg alloy, Mg micro-composite, and Mg nano-composite, respectively. Due to nano SiC particles present in Mg nano-composite, strong bonding and uniform dispersion are the reason for the COF's decrement and increment in wear resistance [71]. The adhesive and abrasive wear was analyzed in AZ91-B_4C (15 Vol. %) Mg-MMCs. The friction stir processing was used in the fabrication of Mg-MMC. The outcome showed the enhancement of abrasive and adhesive wear in AZ91-B_4C composite due to delamination and oxidation of the reinforcement. In Mg-MMC, wear and friction resistance of 60% and 40% (respectively) were observed compared to Mg alloy [72].

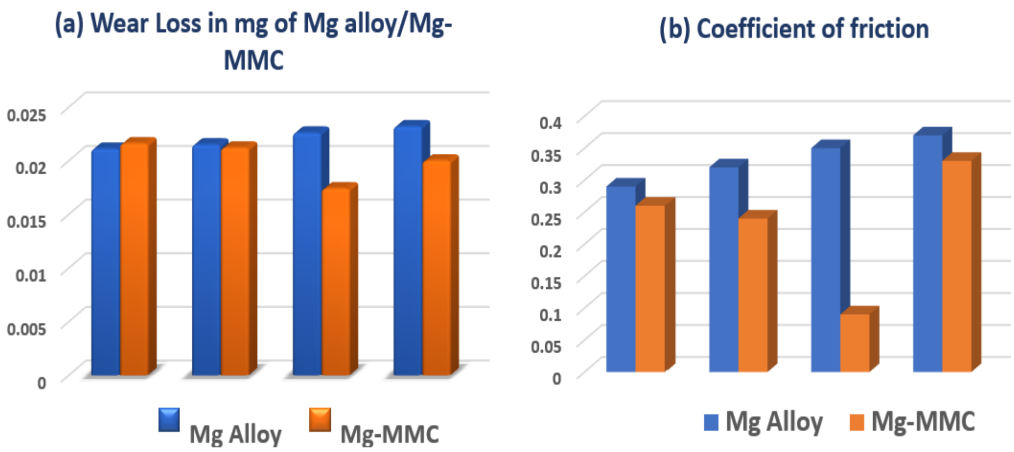

Fig. 9. Wear loss & COF of Mg alloy and Mg-MMCs [70]

The wear loss in RZ5-TiB_2 composite has gradually decreased due to the presence of TiB_2 reinforcement in Mg-MMCs. The strong bonding and wettability of TiB_2 particles increased the wear resistance and decreased the friction coefficient in the fabricated composite. The wear loss and COF were noticed as 306.87 mg and 0.469 respectively for RZ5 alloy and 183.23 mg (wear loss) and 0.402 (COF) in the Mg-MMCs with 8 wt. % of TiB_2 reinforcement particles [73]. The Mg-xB_4C-xMoS_2 composite using the powder metallurgy method was fabricated. The reinforcements were taken as 0, 5, and 10 wt.% each. The best results for wear resistance have been achieved on B_4C-10 wt. % and MoS_2- 5 wt. %. The optimization of reinforcement stated that B_4C-10 wt. % contribute 78.06 % to the increment of wear resistance and decrement in COF in the Mg-MMC [74].

The common reasons for the reduction in surface characteristics are: oxidation, adhesion, abrasion, erosion, delamination, and ploughing formation on Mg-MMCs samples [72-75].

However, the effect of process parameters also affects the wear and friction of the fabricated MMC. The critical process parameters in measurements of friction and wear are; applied load, sliding velocity, sliding time, sliding distance, and reinforcement percentage. The effects of the parameters are discussed below:

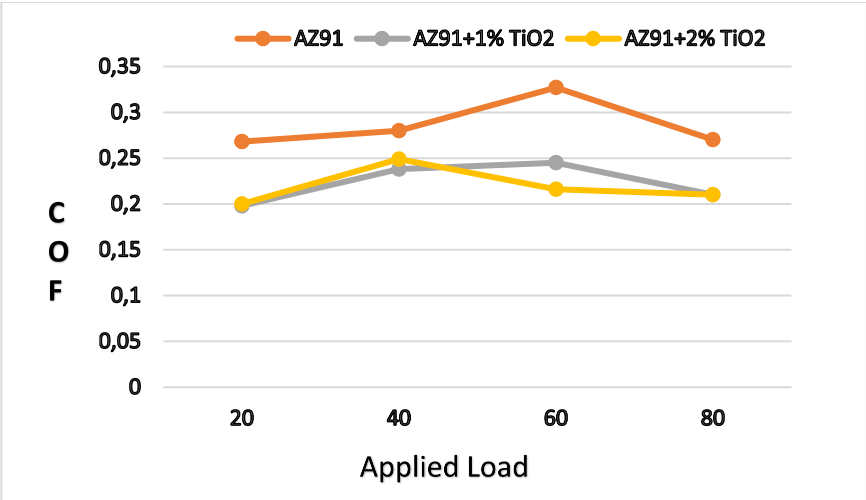

Fig. 10. COF with different applied loads [41]

Applied load effect on wear and friction. The friction and wear are predominantly dependent on the load applied during the testing of the composite. The outcomes indicate that the co-efficient of friction and wear resistance has increased as the average load was increased during analysis on the pin and disc wear test apparatus. The typical range for applied load is 10-80 N during COF and wear resistance measurement[51,76-80]. Figure 10 shows the COF of Mg-MMCs at different applied loads.

Sliding velocity effect on wear and friction. The friction and wear are also affected by sliding velocity during testing. The literature reported that sliding velocity could be in the range of 1-3 m/s and decrement in the wear rate happens by increments up to 3 m/s sliding velocities. On the other hand, the wear rate increases as we increase the sliding velocity beyond 3 m/s in the Mg-based composite [41,78,81-83].

Sliding time effect on wear and friction. The sliding time also affects the wear and friction in the composite material. As the sliding time increases, the material loss and higher friction also take place in the mg-based composite. The sliding time can be from 5 minutes to 30 minutes during the wear test of Mg-MMCs [39,65,84,85].

Sliding distance effect on wear and friction. The wear characteristic of the Mg-based composite had been analyzed. It was noticed that the increment in the sliding distance also increases the friction and wear in the composite as shown in Fig. 11. The sliding distance was listed to be in the range of 100-2000 m and correspondingly increased the wear rate and COF [86-88].

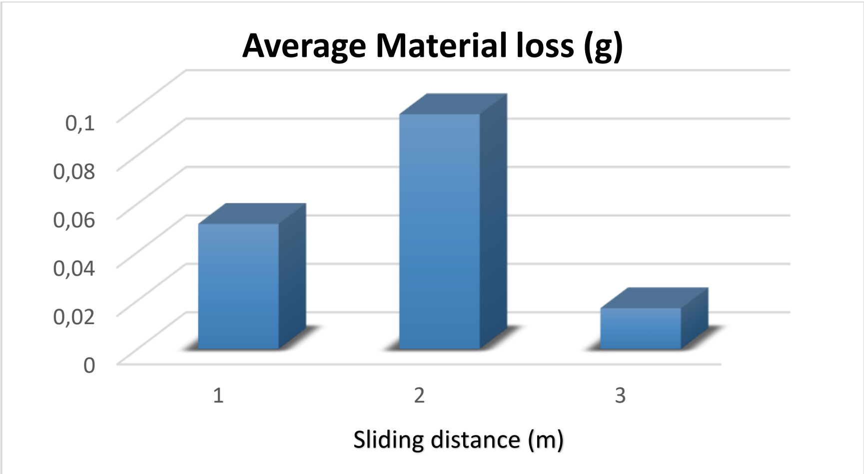

Fig. 11. Wear loss of Mg-MMC with sliding distance [89]

Reinforcement percentage effect on wear and friction. The weight percentage of the reinforcements affects the physical and mechanical properties of the composite. However, the reinforcement weight percentage also influences tribological properties like friction and wear. The decrement in the wear rate has been observed as the weight percentage of the reinforcement increases in the Mg-based composite. The excessive increment in the weight percentage of reinforcement leads to crack formation and deterioration, which causes wear and friction increment [89-91].

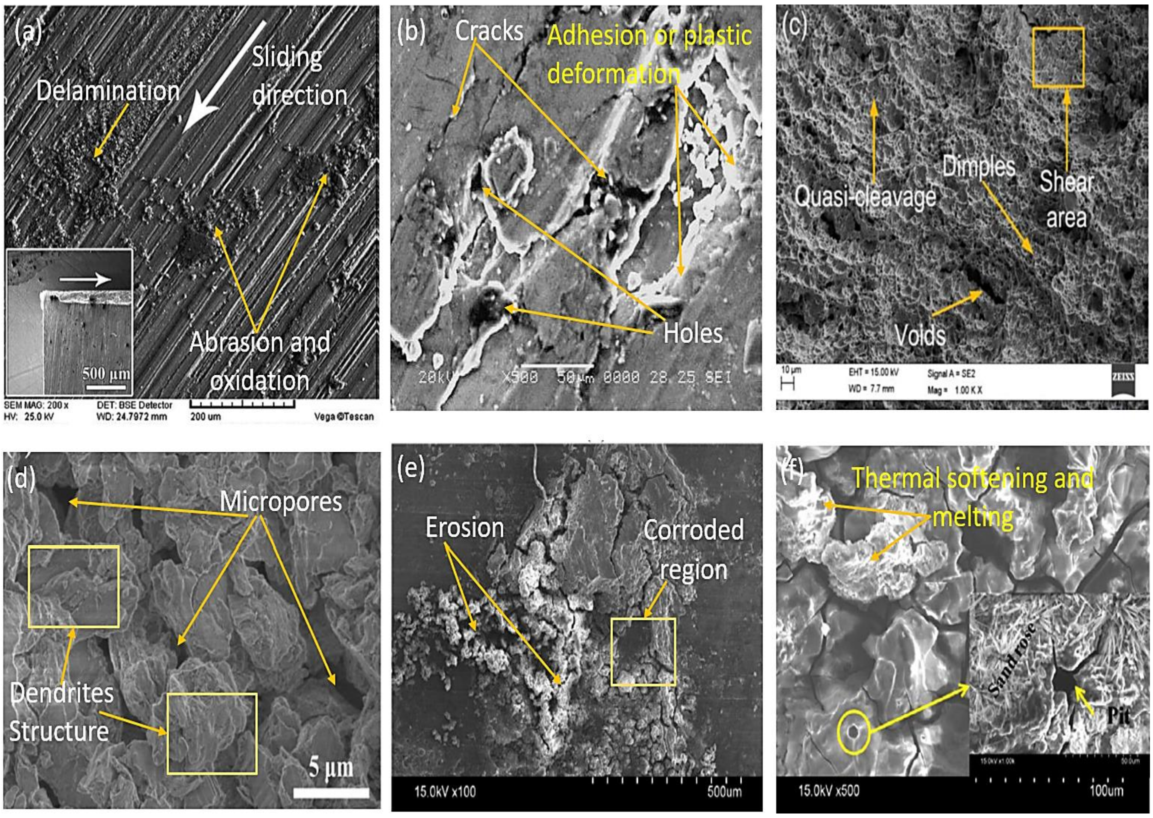

Fig. 12. SEM images represent the worn-out mechanisms for wear and corrosion

Mechanisms controlling the tribological behavior of Mg-MMCs. The current review article discusses the tribological behaviors of Mg-based composites. The degradation factors like delamination, oxidation, adhesion, abrasion, plastic deformation, erosion, cracks, and pit holes occurred during wear and corrosion examination. Figure 12 shows the graphical representation of degradation factors as reported in different research articles. Dey and Pandey observed the wear defects of AZ91 alloy reinforced with 2wt.% of Praseodymium as a rare earth element. The abrasion, oxidation and delamination were observed as primary wear mechanisms during the investigation as represented in Fig. 12 (a) [92].

Figure 12 (b) shows the plastic deformation, cracks, and holes during the dry sliding wear test of ZE41alloy as casted magnesium alloy [93]. The dimple, voids, and shear zone as major wear mechanisms were reported by Gupta and Wong in magnesium nano-reinforced composites as mentioned in Fig. 12 (c) [94]. Jiang et al. prepared a composite of AZ91D/ZnO to observe the corrosion behavior under NAOH solution. The microstructure behavior after the salt spray test was shown in Fig. 12 (d). The micropores and dendritic structure were the main corrosion mechanism observed during the investigation of Mg-MMCs surface [95]. The erosion, thermal softening, and melting of Mg-MMCs surface were shown as the mechanism in Fig. 12 (e) and 12 (f), respectively [96][97].

However, these degradation factors can be controlled by implementing the following suggestion in various studies. Moharana and Senapati suggested introducing a lubricant film and separating the mating surfaces in the study [98]. The wear defects can also be controlled with the help of heat treatment and making the wear surface hard. Various processes such as ion implantation, vapor deposition, hard chromium plating, and diffusion heat-treatment are developed for hard-facing surfaces [99-101].

The wear surface should be made fracture resistant because fracture resistance plays a significant role in the wear resistance of the material. In many cases, the fracture was the reason for wear progress. Also, the use of ceramic and carbide, etc. reinforcement addition led to fracture problems and causes higher material loss in the magnesium matrix composite surface [67,70,102]. Flores et al. concluded that surface erosion led to corrosion in the Mg-MMCs [103]. The liquid erosion, slurry erosion, and cavitation damage the surface and result in corrosion on the surface of the Mg-MMCs [104]. So, it is necessary to make the surface of Mg-MMCs erosion-resistant.

Abhijit and Krishna reported delamination wear caused due to metal-to-metal interfacing of two materials during sliding [92]. This type of wear can be avoided by providing some plating and diffusion hardening between the interfacing surfaces of Mg-MMCs [105]. The wear surfaces should also be fatigue resistant. The surface fatigue also led to wear in rolling elements and power transmission devices, where repeated line and point contact is made [106]. This causes stress between the interfacing surfaces and causes pits and cracks on the Mg-MMCs surface. The use of flame induction casing, electron beam casing, and laser hardening of the Mg-MMCs prevents stress formation and enhances the fatigue resistance, and correspondingly, improves the wear resistance of the Mg-MMCs [39].

5. Conclusion

In this research paper, the effect of different reinforcements on mechanical and tribological properties are discussed, and based on the discussion following conclusion are drawn:

- Magnesium has wide applications in the automotive and bio-medical industries due to its low density and high in strength to weight ratio. In general terms of manufacturing, the Mg-MMCs are more flexible, reliable, economical, eco-friendly, and biodegradable materials.
- Stir casting, friction stir processing, and powder metallurgy are the common processes to fabricate these composites.

- The hardness and tensile strength of Mg-MMCs largely depend upon uniform dispersion and grain refinement of the reinforcement particles. The hardness and tensile strength for commonly used Mg-MMC's range from 34-152.7 HV and 45-240 MPa respectively.
- The corrosion resistance of Mg-MMCs can be enhanced with the proper homogenous distribution of reinforcement particles. The corrosion current density is directly proportional to corrosion resistance and it reduces in the range of 549.21-1.923 $\mu A\ cm^{-2}$ for different Mg-MMCs.
- In Mg-MMCs the amount of wear and friction depends upon its process parameters like; applied load (10-80 N), sliding distance (100-2000 m), sliding velocity (1-3 m/s), sliding time (5-30 minutes) and various weight/volume percentage reinforcement (0-25%). The material loss during wear measurement and coefficient of friction (COF) of Mg-MMCs ranges from 0.0174-0.09 g and 0.90-0.0234, respectively.

References

1. Singh S, Angra S. Experimental evaluation of hygrothermal degradation of stainless steel fibre metal laminate. *Eng Sci Technol an Int J.* 2018;21(1): 170-179.
2. Kumar A, Vichare O, Debnath K, Paswan M. Fabrication methods of metal matrix composites (MMCs). *Mater Today Proc*. 2020;46: 6840-6846.
3. Sahu V, Gayathri V. Strength Studies of Dadri Fly Ash Modified with Lime Sludge – A Composite Material. *Int J Eng Technol Innov.* 2014;4(3): 161-169.
4. Charan NRKS. Experimental Analysis on Three Body Abrasive Wear Behaviour of Stir Cast Al LM 25 / TiC Metal Matrix Composite. *Trans Indian Inst Met.* 2017;70(9): 2233-2240.
5. Shoba C, Ramanaiah N, Nageswara Rao D. Effect of reinforcement on the cutting forces while machining metal matrix composites–An experimental approach. *Eng Sci Technol an Int J.* 2015;18(4): 658-663.
6. Fatile OB, AkinruliI J fedayo, Amori AA. Microstructure and Mechanical Behaviour of Stir-Cast Al-Mg-Sl Alloy Matrix Hybrid Composite Reinforced with Corn Cob Ash and Silicon Carbide. *Int J Eng Technol Innov.* 2014;4(4): 251-259.
7. Sahu V, Srivastava A, Gayathri V. Effect of lime and gypsum on engineering properties of badarpur fly ash. *Int J Eng Technol Innov*. 2016;6(4): 294–304.
8. Kumar D, Angra S, Singh S. Mechanical Properties and Wear Behaviour of Stir Cast Aluminum Metal Matrix Composite: A Review. *Int J Eng Trans A Basics*. 2022;35(4): 794–801.
9. Ramanathan A, Krishnan PK, Muraliraja R. A review on the production of metal matrix composites through stir casting – Furnace design, properties, challenges, and research opportunities. *J Manuf Process*. 2019;42(May): 213–245.
10. Anand N, Senthil Kumaran S. Development and influence of tribomechanical properties on magnesium based hybrid metal matrix composites-a review. *Mater Res Express*. 2020;7(3): 036520.
11. Gope PC. Maximum tangential stress coupled with probabilistic aspect of fracture toughness of hybrid bio-composite. *Eng Sci Technol an Int J.* 2018;21(2): 201–214.
12. Sinmazçelik T, Avcu E, Özgür M, Çoban O. A review : Fibre metal laminates, background, bonding types and applied test methods. *Materials & Design.* 2011;32(7): 3671–85.
13. Tan J, Ramakrishna S. Applications of magnesium and its alloys: A review. *Appl. Sci.* 2021;11(15): 6861.
14. Srivastava A, Bhatnagar N. Production and characterisation of new bioresorbable radiopaque Mg–Zn–Y alloy to improve X-ray visibility of polymeric scaffolds. *J. Magnes.*

Alloy. 2021;10(6): 1694-1703.
15. Yang Y, Lu C, Peng S, Shen L, Wang D, Qi F, et al. Laser additive manufacturing of Mg-based composite with improved degradation behaviour. *Virtual Phys. Prototyp.* 2020;15(3):278–93.
16. Marakini V, Pai S, Bhat A, Bangera S. Surface integrity optimization in high speed milling of AZ91 magnesium alloy using TOPSIS considering vibration signals. *Mater. Today Proc.* 2022;52: 802–809.
17. Joseph EJ, Panneerselvam K. Manufacturing and Characterization of Tungsten Particulate-Reinforced AW106 Epoxy Resin Composites. *Trans Indian Inst Met.* 2021;74(4): 817–825.
18. Surya MS, Prasanthi G. Manufacturing, microstructural and mechanical characterization of powder metallurgy processed Al7075/SiC metal matrix composite. *Mater Today Proc*. 2021; 39: 1175-1179.
19. Rotella G, Candamano S. Fabrication and characterization of zeolite coatings on aluminum and magnesium alloys. *Eng. Sci Technol. an Int. J*. 2020;23(5): 1273–1278.
20. Rohatgi P. Cast aluminum-matrix composites for automotive applications. *JOM*. 1991;43(4): 10–15.
21. Tun KS, Gupta M. Effect of extrusion ratio on microstructure and mechanical properties of microwave-sintered magnesium and Mg/Y2O3 nanocomposite. *Journal of Materials Science.* 2008;43: 4503–4511.
22. Prasad DS, Shoba C, Varma KR. Damping behavior of commonly used reinforcement powders – An experimental approach. *Eng. Sci. Technol. an Int. J.* 2015;18(4): 674–679.
23. Dash D, Samanta S, Rai RN. Study on Fabrication of Magnesium based Metal Matrix Composites and its improvement in Mechanical and Tribological Properties- A Review. *IOP Conf. Ser.: Mater. Sci. Eng*. 2018;377: 012133.
24. Hossain S, Rahman M, Chawla D, Kumar A, Prakash P, Gupta P, Kumar D, Agrawal R, Jamwal A. Materials Today : Proceedings Fabrication , microstructural and mechanical behavior of Al-Al2O3-SiC hybrid metal matrix composites. *Mater. Today Proc*. 2020;21: 3–6.
25. Alaneme KK, Bodunrin MO, Casting S. Mechanical behaviour of alumina reinforced AA 6063 metal matrix composites developed by two step-stir casting process. *Acta Technica Corviniensis – Bulletin of Engineering.* 2013;6: 105-110.
26. Meher A, Mahapatra MM, Samal P, Vundavilli PR. Study on effect of TiB2 reinforcement on the microstructural and mechanical properties of magnesium RZ5 alloy based metal matrix composites. *J. Magnes. Alloy.* 2020;8(3): 780–792.
27. Kumar NS, Sozhamannan GG. Investigating the effect of mechanical properties of magnesium alloy (AZ91D) reinforced with graphene metal matrix composite by stir casting method [preprint]. To be piblished in *Mater Today Proc*. 2022.
28. Arab MS, El Mahallawy N, Shehata F, Agwa MA. Refining SiCp in reinforced Al-SiC composites using equal-channel angular pressing. *Mater Des.* 2014;64: 280–286.
29. Singh GR, Singh SCE, Sivapragash M, Anselm L, Kumar RS, Lenin AH. Tensile and compression behaviour, microstructural characterization on Mg-3Zn-3Sn-0.7Mn alloy reinforced with SiCp prepared through powder metallurgy method. *Mater. Res. Express*. 2020;7(10): 106512.
30. Ghasali E, Alizadeh M, Niazmand M, Ebadzadeh T. Fabrication of magnesium-boron carbide metal matrix composite by powder metallurgy route: Comparison between microwave and spark plasma sintering. *J. Alloys Compd*. 2017;697: 200-207.
31. Prakash P, Om S, Devendra P. Studies on the Effect of Processing Parameters on Microstructure and Properties of Magnesium Compacts Prepared via Powder Metallurgy. *Trans Indian Inst Met.* 2020;73(11): 2715–2726.

32. Alem SAA, Latifi R, Angizi S, Hassanaghaei F, Aghaahmadi M, Ghasali E, Rajabi M. Microwave sintering of ceramic reinforced metal matrix composites and their properties: a review. *Mater Manuf Process.* 2020;35(3): 303–327.
33. Gibson BT, Lammlein DH, Prater TJ, Longhurst WR, Cox CD, Ballun MC, Dharmaraj KJ, Cook GE, Strauss AM. Friction stir welding: Process, automation, and control. *J. Manuf. Process.* 2014;16(1): 56-73.
34. Awasthi S, Gupta P, Pachuri P, Tyagi M, Aniruddha. Optimization of magnesium ZK60A/SiC/B4C hybrid composite fabricated by friction stir processing. *Mater. Today Proc*. 2022;62: 191-197.
35. Du Z, Tan MJ, Guo JF, Bi G, Wei J. Fabrication of a new Al-Al2O3-CNTs composite using friction stir processing (FSP). *Mater. Sci Eng. A.* 2016;667: 125–131.
36. Dinaharan I, Zhang S, Chen G, Shi Q. Assessment of Ti-6Al-4V particles as a reinforcement for AZ31 magnesium alloy-based composites to boost ductility incorporated through friction stir processing. *J. Magnes. Alloy*. 2022;10(4): 979-992.
37. Deepan M, Pandey C, Saini N, Mahapatra MM, Mulik RS. Estimation of strength and wear properties of Mg/SiC nanocomposite fabricated through FSP route. *J. Brazilian Soc. Mech. Sci Eng.* 2017;39(11): 4613–4622.
38. Sharma S, Handa A, Singh SS, Verma D. Influence of tool rotation speeds on mechanical and morphological properties of friction stir processed nano hybrid composite of MWCNT-Graphene-AZ31 magnesium. *J. Magnes. Alloy*. 2019;7(3): 487–500.
39. Mehra D, Mahapatra MM, Harsha SP. Processing of RZ5-10wt%TiC in-situ magnesium matrix composite. *J. Magnes. Alloy*. 2018;6(1): 100–105.
40. Sundaraselvan S, Senthilkumar N, Tamizharasan T, Sait AN. Materials Today : Proceedings Surface modification of AZ61 Magnesium Alloy with Nano TiO2/Al2O3 using Laser Cladding Technique. *Mater. Today Proc*. 2020; 21: 717-721.
41. Jayabharathy S, Mathiazhagan P. Investigation of mechanical and wear behaviour of AZ91 magnesium matrix hybrid composite with TiO2/graphene. *Materials Today: Proceedings.* 2019;27: 2394–2397.
42. Vasu C, Durga KJAN, Srinivas I, Dariyavali S. ScienceDirect Developing composite of ZE41 magnesium alloy- calcium by friction stir processing for biodegradable implant applications. *Mater. Today Proc*. 2019;18: 270–277.
43. Ram B, Deepak D, Bala N. Microstructural Refinement and Enhancement in Mechanical Properties of Magnesium/SiC as-Cast Composites via Friction Stir Processing Route. Trans Indian Inst Met. 2019;72: 1313–1321.
44. Karthick E, Mathai J, J MT, Marikkannan SK. Processing, Microstructure and Mechanical Properties of Al2O3 and SiC Reinforced Magnesium Metal Matrix Hybrid Composites. *Mater Today Proc.* 2017;4(6): 6750–6756.
45. Bala N. Evaluation Of Microstructural And Mechanical Behavior Of Some Magnesium Metal Matrix Composites. *Int. J. Adv. Mater. Manuf. Charact.* 2017;7(2): 38–43.
46. Seetharaman S, Subramanian J, Tun KS, Hamouda AS, Gupta M. Synthesis and Characterization of Nano Boron Nitride Reinforced Magnesium Composites Produced by the Microwave Sintering Method. *Materials.* 2013;6(5): 1940-1955.
47. Yang WZ, Huang WM, Wang ZF, Shang FJ, Huang W, Zhang BY. Thermal and mechanical properties of graphene-titanium composites synthesized by microwave sintering. *Acta Metall Sin English Lett*. 2016;29(8): 707–713.
48. Sundaraselvan S, Senthilkumar N, Tamizharasan T, Naveen Sait A. Surface modification of AZ61 Magnesium Alloy with Nano TiO2/Al2O3 using Laser Cladding Technique. *Mater Today Proc*. 2020;21: 717–721.
49. Gangil N, Nagar H, Kumar R, Singh D. Shape memory alloy reinforced magnesium matrix composite fabricated via friction stir processing. *Mater Today Proc*. 2020;33: 378–

381.
50. Satish J, Satish KG. Preparation of magnesium metal matrix composites by powder metallurgy process. *IOP Conf. Ser. Mater. Sci Eng*. 2018;310(1): 012130.
51. Vaira Vignesh R, Padmanaban R, Govindaraju M, Suganya Priyadharshini G. Investigations on the corrosion behaviour and biocompatibility of magnesium alloy surface composites AZ91D-ZrO2 fabricated by friction stir processing. *Trans Inst Met Finish.* 2019;97(5): 261–270.
52. Fatile BO, Adewuyi BO, Owoyemi HT. Synthesis and characterization of ZA-27 alloy matrix composites reinforced with zinc oxide nanoparticles. *Eng Sci Technol an Int J.* 2017;20(3): 1147–1154.
53. Wong WLE, Karthik S, Gupta M. Development of hybrid Mg/Al2O3 composites with improved properties using microwave assisted rapid sintering route. *Journal of Materials Science*. 2005;40: 3395–3402.
54. Wong WLE. Development of High Performance Mg/SiC Composites Containing Nano-Size SiC Using Microwave Assisted Rapid Sintering. In: *Proc. ASME 2005 International Mechanical Engineering Congress and Exposition*. ASME; 2016. pp.511-515.
55. Wong WLE, Gupta M. Development of high performance Mg/SiC composites containing nano-size SiC using microwave assisted rapid sintering. *Am. Soc. Mech. Eng. Aerosp. Div. AD*. 2005;70AD: 511–515.
56. Hassan SF, Nasirudeen OO, Al-Aqeeli N, Saheb N, Patel F, Baig MMA. Processing, microstructure and mechanical properties of a TiO2 nanoparticles reinforced magnesium for biocompatible application. Metall Res Technol. 2017;114(2): 1-8.
57. Hassan SF, Tun KS, Patel F, Gupta M. Effect of Copper Nano Particles on High Temperature Tensile Behavior. *Metals and Materials International.* 2015;21(3): 588–592.
58. Thakur SK, Kwee GT, Gupta M. Development and characterization of magnesium composites containing nano-sized silicon carbide and carbon nanotubes as hybrid reinforcements. *J. Mater. Sci*. 2007;42: 10040–10046.
60. Pradeep Raja C, Ramesh T. Influence of size effects and its key issues during microforming and its associated processes – A review. *Eng. Sci. Technol. an Int. J.* 2021;24(2): 556–570.
61. Nunes PCR, Ramanathan L V. Corrosion behavior of alumina-aluminum and silicon carbide-aluminum metal-matrix composites. *Corrosion*. 1995;51(8): 610–617.
62. Liu B, Wang H, Zhang Y, Yang Y, Ren X. Journal of Physics and Chemistry of Solids The influence of adding samarium on the microstructure , mechanical performance and corrosion behavior of as-extruded AZ41 alloys. *J. Phys. Chem. Solids.* 2021;150: 109851.
63. Liu L, Yu S, Zhu G, Li Q, Liu E, Xiong W, Wang B, Yang X. Corrosion and wear resistance of micro-arc oxidation coating on glass microsphere reinforced Mg alloy composite. *J. Mater Sci*. 2021;56(27): 15379–15396.
64. Lei T, Tang W, Cai SH, Feng FF, Li NF. On the corrosion behaviour of newly developed biodegradable Mg-based metal matrix composites produced by in situ reaction. *Corros Sci.* 2012;54(1): 270–277.
65. Khatkar SK, Verma R, Kharb SS, Thakur A, Sharma R. Optimization and Effect of Reinforcements on the Sliding Wear Behavior of Self-Lubricating AZ91D-SiC-Gr Hybrid Composites. *Silicon*. 2021;13: 1461-1473.
66. Liu T, Rui S, Li S. Layer-by-layer self-assembly composite coatings for improved corrosion and wear resistance of mg alloy for biomedical applications. *Coatings*. 2021;11(5): 515.
67. Rahmani K, Majzoobi GH, Ebrahim-Zadeh G, Kashfi M. Comprehensive study on quasi-static and dynamic mechanical properties and wear behavior of Mg—B4C composite compacted at several loading rates through powder metallurgy. 2021;31(2): 371-381.

68. Moustaf EB, Khalil AM, Ahmed HM, Hefni M, Mosleh AO. Microstructure, Hardness, and Wear Behavior Investigation of the Surface Nanocomposite Metal Matrix Reinforced by Silicon Carbide and Alumina Nanoparticles. *J. Miner. Met. Mater. Eng.* 2021;7: 57–62.
69. Olalekan ON, Abdul Samad M, Hassan SF, Elhady MMI. Tribological evaluations of spark plasma sintered Mg–Ni composite. *Tribol - Mater Surfaces Interfaces*. 2022;16(2): 110-118.
70. Ra'ayatpour M, Emamy M, Rassizadehghani J. Influence of Hot Extrusion on the Microstructure, Tensile and Wear Properties of Mg–5Sb–xSiC Hybrid Composites. *Metals and Materials International*. 2022;28: 679–694.
71. Sadooghi A, Rahmani K. Experimental study on mechanical and tribology behaviors of Mg-SiC nano / micro composite produced by friction stir process. *Journal of Mechanical Science and Technology*. 2021;35: 1121–1127.
72. Patle H, Ratna Sunil B, Anand Kumar S, Dumpala R. Effects of inert gas environment on the sliding wear behavior of AZ91/B4C surface composites. Proc Inst Mech Eng Part J J Eng Tribol. 2022;236(9): 1880-1888.
73. Meher A, Mahapatra MM, Samal P, Vundavilli PR. Abrasive Wear Behaviour of TiB2 Reinforced In-Situ Synthesized Magnesium RZ5 Alloy based Metal Matrix Composites. *Met Mater Int.* 2021;27(9): 3652–3665.
74. Kailasanathan C, Rajkumar PR, Rajini N, Sivakumar GD, Ramesh T, Ismail SO, et al. Characterization and optimization of influence of MoS2 hybridization on tribological behaviours of Mg–B4C composites. *Bull Mater Sci*. 2021;44: 192.
75. Jojith R, Sam M, Radhika N. Recent advances in tribological behavior of functionally graded composites: A review. *Eng Sci Technol an Int J.* 2022;25: 100999.
76. Sharma VK, Kumar V, Joshi RS. Experimental investigation on effect of RE oxides addition on tribological and mechanical properties of Al-6063 based hybrid composites. *Mater Res Express*. 2019;6(8): 0865d7.
77. Aktar Zahid Sohag M, Gupta P, Kondal N, Kumar D, Singh N, Jamwal A. Effect of ceramic reinforcement on the microstructural, mechanical and tribological behavior of Al-Cu alloy metal matrix composite. *Mater Today Proc.* 2020;21:1407–1411.
78. Nirala A, Soren S, Kumar N, Garg R, Kumar Sharma S, Shrivastava AK. Comprehensive study of magnesium based metal matrix composite. *Mater Today Proc*. 2020;46: 6587–6591.
79. Królczyk G, Feldshtein E, Dyachkova L, Michalski M, Baranowski T, Chudy R. On the microstructure, strength, fracture, and tribological properties of iron-based MMCs with addition of mixed carbide nanoparticulates. Materials. 2020;13(13): 2892.
80. Kumaar RK, Vinoth KS, Kavitha M. Dry sliding wear performance of AA7075/MoS2 composite materials. *J. Eng. Res*. 2021;9: 1–24.
81. Srinivas V, Jayaraj A, Venkataramana VSN, Avinash T, Dhanyakanth P. Effect of Ultrasonic Stir Casting Technique on Mechanical and Tribological Properties of Aluminium–Multi-walled Carbon Nanotube Nanocomposites. *J. Bio- Tribo-Corrosion*. 2020;6(2): 1–10.
82. Alaneme KK, Adewale TM, Olubambi PA. Corrosion and wear behaviour of Al-Mg-Si alloy matrix hybrid composites reinforced with rice husk ash and silicon carbide. *J. Mater. Res. Technol.* 2014;3(1): 9–16.
83. Danappa GT, Raghavendra CR, Swamy RP, Naik K. Dry sliding wear behaviour of Al7075/Gr/nano TiO2MMC using RSM. *Mater Today Proc.* 2020;38: 2797-2802.
84. Kumar P, Skotnicova K, Mallick A, Gupta M, Cegan T, Jurica J. Mechanical characterization of graphene nanoplateletsreinforced mg-3sn alloy synthesized by powder metallurgy. *Metals.* 2021;11(1): 1–14.
85. Natarajan N, Vijayarangan S, Rajendran I. Wear behaviour of A356/25SiCp

aluminium matrix composites sliding against automobile friction material. *Wear*. 2006;261(7–8): 812–822.

86. Kailasanathan C, Rajkumar PR, Rajini N, Sivakumar GD, Ramesh T. Characterization and optimization of influence of MoS 2 hybridization on tribological behaviours of Mg – B 4 C composites. *Bull Mater Sci*. 2021;44; 192.

87. Arunbharathi R, Rathish R, Vignesh RS, Seelan PS, Prasanth RV. Mechanical and Tribological Characteristics of Particulates Embedded Aluminium Based Composites - A Review. *PAIDEUMA JOURNAL*. 2021;XIV(3): 12–16.

88. Radhika N, Reghunath R, Sam M. Improvement of mechanical and tribological properties of centrifugally cast functionally graded copper for bearing applications. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*. 2019;233(9): 3208–3219.

89. Manu KMS, Sreeraj K, Rajan TPD, Shereema RM, Pai BC, Arun B. Structure and properties of modi fi ed compocast microsilica reinforced aluminum matrix composite. *JMADE*. 2015;88: 294–301.

90. Tang W, Kang S, Liu Z. Dynamic Compression Deformation and Constitutive Model of Extruded Mg–1Zn–2Y Bar. *Trans Indian Inst Met.* 2021;74(12): 2967–2975.

91. Mao G, Liu S, Gao W, Wang J, Liu D. Effect of Zn or Zn + Cu Addition on the Precipitation in Al–Mg–Si Alloys: A Review. *Trans Indian Inst Met.* 2021;74(12): 2925–2938.

92. Dey A, Pandey KM. Wear behaviour of Mg alloys and their composites-a review. *Int J Mater Res.* 2018;109(11): 1050–1070.

93. Anbu selvan S, Ramanathan S. Dry sliding wear behavior of as-cast ZE41A magnesium alloy. *Mater Des*. 2010;31(4): 1930–1936.

94. Gupta M, Wong WLE. Magnesium-based nanocomposites: Lightweight materials of the future. *Mater Charact.* 2015;105: 30–46.

95. Jiang S, Li W, Liu J, Jiang J, Zhang Z, Shang W, et al. ZnO@ZIF-8 core-shell structure nanorods superhydrophobic coating on magnesium alloy with corrosion resistance and self-cleaning [preprint]. To be published in: *J Magnes Alloy*. 2022.

96. Banerjee S, Poria S, Sutradhar G, Sahoo P. Corrosion behavior of AZ31-WC nano-composites. *J Magnes Alloy*. 2019;7(4): 681–695.

97. Johari NA, Alias J, Zanurin A, Mohamed NS, Alang NA, Zain MZM. Anti-corrosive coatings of magnesium: A review. *Mater Today Proc*. 2021;48: 1842–1848.

98. Moharana GB, Senapati AK. Tribological analysis of Al-Si alloy based MMCs at elevated temperature. *Mater Today Proc.* 2021;49: 1749–1755.

99. Ozerov MS, Klimova MV, Stepanov ND, Zherebtsov SV. Microstructure evolution of a Ti/TiB metal-matrix composite during high-temperature deformation. *Materials Physics and Mechanics.* 2018;38(1): 54–63.

100. Behnamian Y, Serate D, Aghaie E, Zahiri R, Tolentino Z, Niazi H. Tribology International Tribological behavior of ZK60 magnesium matrix composite reinforced by hybrid MWCNTs / B 4 C prepared by stir casting method. *Tribol Int.* 2022;165:107299.

101. Mansoor P, Dasharath SM. A review paper on magnesium alloy fabricated by severe plastic deformation technology and its effects over microstructural and mechanical properties. *Mater Today Proc.* 2021;45: 356–364.

102. Yousefpour F, Jamaati R, Aval HJ. Investigation of microstructure, crystallographic texture, and mechanical behavior of magnesium-based nanocomposite fabricated via multi-pass FSP for biomedical applications. *J Mech Behav Biomed Mater*. 2022;125: 104894.

103. Flores JF, Neville A, Kapur N, Gnanavelu A. Corrosion and erosion-corrosion processes of metal-matrix composites in slurry conditions. *J Mater Eng Perform*. 2012;21(3): 395–405.

104. Irfan OM, Alaboodİ AS. On the compression properties and erosion- corrosion behavior of Al 6061/15% Sic p composite On the Compression Properties and Erosion-Corrosion Behaviour of Al 6061 / 15 % Sic p Composite. *Journal of Polytechnic.* 2020;23(2): 415-425
105. Althahban S, Jazaa Y, Bafakeeh O, Alomari AS, Sallam HEDM, Atta M. The Effect of Reinforcement Preheating Temperatures on Tribological Behavior of Advanced Quranic Metal-Matrix Composites (QMMC). *Materials.* 2022:15(2): 659.
106. Dobkowska A, Cie BA, Koralnik M, Chromi W. Corrosion behavior of fine-grained Mg-7.5Li-3Al-1Zn fabricated by extrusion with a forward-backward rotating die (KoBo). *Journal of Magnesium and Alloys.* 2022;10(3): 811–820.

THE AUTHORS

Kumar Dinesh
e-mail: dinesh_61900120@nitkkr.ac.in
ORCID: 0000-0003-1885-2431

Singh Satnam
e-mail: satnamsingh@nitkkr.ac.in

Angra Surjit
e-mail: surjit.angra@yahoo.com