Review of Magnesium Metal Matrix Composites

Ravikumar. Saranu¹, Ratnam. Chanamala², SrinivasaRao. Putti³

¹Assistant Professor, Department of Mechanical Engineering, Bapatla Engineering College, GBC Road, Mahatmajipuram, Bapatla, Guntur District, Andhra Pradesh-522102, India.
²Professor, Department of Mechanical Engineering, Andhra University, Waltair Junction, AU North Campus, Visakhapatnam, Andhra Pradesh-530003, India.
³Professor, Department of Mechanical Engineering, Andhra University, Waltair Junction, AU North Campus, Visakhapatnam, Andhra Pradesh-530003, India.

E-mail: ravikumar.saranu@gmail.com

Abstract. In recent years, Magnesium Metal Matrix Composites (Mg-MMC) plays a significant part in an extensive application such as chemical, automotive and aerospace application as because of its lightweight structural and low density properties. In this present investigation, the literature review of Mg-MMCs study includes, reinforcing substantial, processing techniques, Characterization, tribological and mechanical behavior of Mg-MMCs. Furthermore, the CNT, Carbonaceous, Fullerene, SiC, Al₂O₃, TiC, B₄C, Graphene reinforced Mg-MMC articulates are explained in this study. Consequently, the mechanical behavior of tensile strength, hardness, compressive strength and tribological properties of wear rate and corrosion performance was analyzed for various state of the art methods. From the observation, it shows that the ceramic reinforcing increases the hardness and strength of the material. Nevertheless, the ductility was diminished, yet, the ductility and strength of Mg-MMCs can enhance by the titanium based metallic reinforcement.

1. Introduction
In topical centuries, the usage of mg based material is increased due to the aspects of environmental and economic, because mg is a lightweight material contrasted with other iron and aluminum based material [1-2]. Moreover, the mg has 1.74 gr per cm³ of low density, high rigidity, finest machinability and specific toughness [3]. For this reason, the mg alloys are extensively utilized in electronic industries, aerospace and automotive applications [4]. Nevertheless, the lightweight and more specific toughness materials are require to enhancing the efficiency because the structure of mg is a hexagonal sealed filled construction and less ductility [5-6]. Moreover, the mg has poor wear resistance, average corrosion resistance, and underprivileged mechanical properties [7]. Therefore, mg based alloys are not utilized in profitable utilization compared with the iron and aluminum [8]. In the application of aerospace and automotive, the weightless, finest mechanical characteristics and good wear resistant material characteristics are essential [9-10]. Hence, the tribological behavior of mg and its compounds are ought to be enhanced to satisfy the applications demand [11]. As a result, the researchers have interested to propose tribological behavior of mg alloys by means of mg with composite categorization [12]. The new MMCs material is formed by the combination of matrix along
with reinforcement’s process [13]. The new MMCs have various merits such as, under high temperature provides finest properties, more specific toughness and less constant of thermal increases [14]. As because of these advantages, the MMCs are the advance composites [15]. While MMCs are designed by the casting technique has less standardized separation of matrix material compared with Powder Metallurgy (PM) method [16]. Nevertheless, the PM process can provide equivalent microstructure without dendritic segments; these may affect the mechanical properties [17]. Besides, the tribological and mechanical properties of Mg-MMCs are improved by the combination of reinforcement particles namely, \(Al_2O_3\), graphene, fiber, SiC, Fullerene, \(B_4C\) and etc., [18]. The below sections described the recent techniques of Mg-MMC enhancement and its properties analysis.

2. Reinforcement processing material for synthesis of Mg-MMCs

2.1. \(SiC\) Reinforced Mg-MMC

Huang, Song-Jenget et al [19] investigated a \(SiCp/\)AZ61 strengthened Mg-MMCs are fabricated using stir casting technique and enhanced the micro plastic distortion by the heat behavior process. Furthermore, the five weight percentage of \(SiCp/\)AZ61Mg-MMC fabrications significantly lessen the ductile and shear strength. S. Seshanet et al [20] studied discontinuously \(SiC\), reinforced AZ91 and \(Mg−6Al\) alloy for the fracture behavior and tensile strength, having the size \(20\mu m\). JanuszLelitoet al [21] proposed \(SiC\) strengthened materials are embedded on the grain thickness in an AZ91 alloy MMC. The simulation done on this method observed the quantitatively outcomes of cooling turn, the AZ91/SiC fabrication matrix grain thickness in heat separation, SiC material diameter and mass segment. Lim et al [22] studied AZ91 Mg-MMCs reinforced with SiC for wear performance. Juanjuanet al [23] fabricated WS\(_2\) (5 wt%) and SiC (15 wt% to 20 wt%) reinforced Mg-MMCs using PM technique for enhancing the wear and friction (0.1 to 0.2) behavior. S. Dinesh Kumar et al [24] investigated Mg-MMCs reinforced with SiC using PM technique for the improvement of mechanical properties. Enrique et al [25] proposed co-continuous ceramic reinforced MMCs based on the combination of metal part and ceramic. The formation of this reinforcement process is done by solid state method. Jianghua Shenet et al [26] studied the 5 to 15 wt% \(\beta\) phase SiC reinforced Mg-MMCs, this method is referred to as MM Nano Composites (MMNC). When the reinforced nanoparticles are in the weight of 10%, then the ultimate strength and yield was enhanced. Paridhi Malhotraet al [27] fabricated a new hybrid MMCs by the combination of 7075 Aluminum strengthened with 10 wt% ofSiC and Mg alloy of nanoparticles, which is represented as \(Al7075/10%−SiC/Mg\). Moreover, in the course of EDM rotary working Electrode Wear Rate (EWR) and Material Removal Rate (MRR) are estimated. Kavimanjet et al [28] developed a hybrid composites by different weight percentage of SiC incorporated with reduced Graphene Oxide(r-GO) is strengthened the AZ31 of Mg alloy. The performance is tested under sliding distance, velocity and provided load. R. Arrabalet et al [29] proposed Plasma electrolytic oxidation on \(ZC71/12%(SiCp)−T6\) reinforced MMCs for outstanding performance of specific toughness and low density. From the findings, the 3.4 GPa of hardness attained at process time 100 min and more strength. Karthicket et al [30] proposed a hybrid form AZ31 Mg-MMCs reinforced with SiC and \(Al_2O_3\) for enhancing the hardness up to 75.16HV.

2.2. \(Al_2O_3\) Reinforced Mg-MMC

Huang and Lin [31] developed a \(AM\,60/\)\(Al_2O_3\) reinforced Mg-MMCs for an improvement of mechanical properties using Equal Channel Angular Extrusion (ECAE). Moreover, the stir-casting technique is utilized to fabricate the lightweight of \(Al_2O_3\) of 1 wt%, 2 wt% and 5 wt% nano sized particulates aimed at ECAE. Thirugnanasambandhamnet et al [32] proposed Mg-MMCs reinforced with
Al₂O₃ particles in 50 nm size using stir casting method for the wear properties. The test case is applied at 10 N and 20N of load with various sliding speed. Song-Jeng Huang et al. [33] investigated the AM 60/Al₂O₃ MMCs using ECAE. Moreover, by means of stir casting technique, the current 1wt% of AM 60/Al₂O₃ particles reinforced Mg-MMCs are explored for ECAE. Tarasanka et al. [34] studied the AZ91E mg alloy reinforced with Al₂O₃ for optimizing the wear characteristics of MMCs. The analysis are carried out under 1wt % reinforcement, 10N applied load and 500m of sliding distance. Moreover, Niranjan et al. [35] proposed various weight percentage of Al₂O₃ reinforced AZ91-MMCs for surface integrity. Sameer Kumar et al. [36] fabricated a nanocomposites of AZ91E with Al₂O₃ for enriching the hardness, ductility and wear resistance using stir casting approach. Amandeep Singh and Niraj Bala [37] introduced Mg Al₂O₃ MMCs for the synthesis of wear and hardness performance using dissimilar weight percentages.

2.3. CNT Reinforced Mg-MMC
The tribological behavior of mg alloy with the reinforcements of Carbonaceous (C) based accumulation is require to enhance the properties. Therefore, Muhammet Emre Turan et al. [38] proposed Multi-Walled Carbon Nanotubes (MWCNT) reinforcement and a hybrid compound of MWCNT based Graphenenanoplatelets (GNPs) strengthened material for enhancing the wear behavior of AZ91 mg alloy. Moreover, the proposed composites were produced by the process of burning insistent through semi power metallurgy. Muhammad Rashad et al. [39] proposed a new MW-CNTs and GNPs of hybrid combination model, named as CNTs+GNPs for mitigating the demerits of solo GNPs reinforcing. Yunpeng Ding et al. [40] proposed a new CNT strengthened Mg nanocomposites by means of PM method. From this method, the Yield Strength (YS) is 454 MPa and strength of compression obtained as 504MPa.

2.4. Fiber Reinforced Mg-MMC
The strength of the light weight material nanocomposites estimation is essential. Hany S. Abdo et al. [41] fabricated a combination of particles such as TiO₂ as the nanofiber ceramic material and Carbon Nanofibers (CNF) for investigating the MMCs mechanical characterizations. This work mainly focuses on the MMCs and reinforcement relationship in terms of weight fraction, arrangement and shape. Feng Wu et al. [42] studied the combination of graphene and carbon fiber material for reinforced Mg-MMCs. Moreover, a huge amount of Mg₁₇𝑀₂₈₁₂ particles impulsive in the border sheet in an intermittent manner. Lehua, et al. [43] proposed carbon fiber reinforced MMCs for strengthening the parameters. Furthermore, Bakkar and Neubert [44] introduced the AS4/1/ Mg-MMCs with Carbon fiber reinforcement for the minimization of corrosion. The SEM and EDX tests were achieved for the corrosion analysis.

2.5. TiC reinforced Mg-MMC
X.Y. Gu et al. [45] fabricated TiC reinforced MMCs (TiC / AZ91D) with Transient Liquid Phase (TLP) using aluminum interlayer based up on the connection of temperature and time. When the connection temperature is 460°C at the time increase from 1 minute to 1 hour, then concentration of Al in the junction diminishes. Therefore, the microstructure of (Al₁₂Mg₁₇) and TiC is varied, then the quantity of (Al₁₂Mg₁₇) is diminished inclination. Anbuchezhiyan et al. [46] introduced AZ91D Mg nanocomposites with TiC reinforcement under different weight percentage using PM technique, size of 40 μm. Dash et al. [47] studied AZ91D of mg –MMCs with TiC strengthening for mechanical and tribological performance.
2.6. Fullerene Reinforced Mg-MMC
MuhammetEmreTuran [48] is Fabricated a C60 based AZ91 MMCs along with the identical 0.50 wt% fraction of weight through SPM and warm pressing method. Moreover, MWCNT, GNPs and C60 reinforcement method is utilized in this approach. MuhammetEmreTuranet al [49] investigated fullerene reinforced MMCs, which is prepared using Semi Powder Metallurgy (SPM) using aeration, warm pressing, ultrasonication and sintering. Moreover, from the observation of microstructural the fullerene reinforced MMC is consistently connected. MuhammetEmreTuranet al [50] proposed a C60 reinforced Mg-MMC using SPM technique with warm pressing method beneath pure argon environmental condition.

2.7. B4C particulate reinforced Mg-MMC
Q.C. Jiang et al [51] fabricated by the dissimilar divisions of 10 wt% to 20 wt% B4C material reinforced with Mg-MMCs using PM approach. From the results show that the new MMC attained superior wear resistance for 35N at 20 wt % is 5.7039 and hardness 133.3 HB at 20 wt % and 44.0HB at 10 wt%. Therefore, this developed feasible product is more significant and economical for MMCs development. Aydinnet al [52] studied AZ91 Mg-MCCs reinforced with B4C under different weight fraction such as 10 to 30 wt% by means of PM technique. Furthermore, wear behavior is validated by various load condition. Therefore, the hardness, YS and UTS are increased.

2.8. Graphene reinforced Mg-MMC
The GNPs reinforced Mg-MMCs using semi PM technique introduced by Saberi, et al [53]. This method proved as a higher corrosion resistance than ordinary Mg. The antibacterial method increased the concentration of GNPs. Kavimanie t al [54] proposed AZ31 alloy is consistently strengthened with 0.2 wt % to 0.5 wt% of diminished graphene oxide (r-GO). Furthermore, four sequential processes have to be done in this fabrication process namely, solvent treating, automated alloying, cold persistent and sintering below argon condition at 560°C. LinglongMeng et al [55] fabricated GNPs reinforced Mg-MMCs for enhancing the toughness and tensile strength. Muhammad Rashad, et al [56] developed carbon nanotubes along with graphenenanoplatelets strengthened AZ31 Mg alloy by means of PM approach. Therefore, the tensile and compression strength was enhanced due to the reinforcement of carbon nanotubes. The AZ31 with carbon nanotubes composite was expressively diminished the compressive fracture strain up to negative of 14%. Muhammad Rashadet al [57] studied graphenenanoplatelets strengthened AZ61 Mg alloy using fragmented thaw deposition technique. Besides, the temperature from 75 – 225°C and basic strain value 2×10⁻³ s⁻¹ are executed for the study of proposed material tensile strength. Munir et al [58] investigated the reinforcement technique of mg-MMCs with different wt % of GNPs developed by PM method for expands the corrosion and mechanical performance. The fabricated composites microstructure and its properties are examined by the various characterization methods.

3. Processing of Metal-Matrix Nanocomposites
The Mg-MMCs developed by the numerous methods of processing technologies.

3.1. Powder metallurgy processing
In PM process has four steps have to be done. Primarily, the Mg and the reinforcement materials are crushed in to the powder, and then it is combined, forced and sintered at under the regulated atmospheric temperature [59-61]. Moreover, this method has large possible wt% of elements taken yet this method of process has more. By means of PM method various MMCs such as C60/AZ91, B4C, GNPs/ AZ31, CNT/Mg nanocomposites and Mg-SiC have been fabricated [62]. The schematic illustration of PM steps is illustrated in Fig.1.
3.2. Stir casting method

Stir casting method of composite element is a most general technique for fabrication [63]. The graphic illustration of this system setup is illustrated in Fig. 2. The reinforcement material such as AM 60/Al2O3p, SiCp/AZ61 are mixed with MMCs by the assist of stirrer. The MMCs liquid are heated under certain temperature and the reinforcement material is produced. Then, the wettability of reinforcement and matrix stage problems are overcome by scattered in to the molten of matrix using mechanical stirrer [65]. The Molten mixture element is case by conventional casting technique. Nevertheless, the scattering of strengthened composites in to medium is not totally same. Due to the dissimilar densities some groups are formed. In advanced casting method, the MCs are superheated beyond its melting point. Then, the complete melted metal is starts to stirrer [66-67]. In this process, the ultimate solid material is obtained from the melt liquid under the room temperature cooling progress. This method allows 30 wt% of strengthening the matrix stage. Therefore, in MMCs fabrication stir casting has low cost and simple to use. Besides, most of the industries are utilized this technique due to its advantages.

![Figure 1. Flow of PM technique process [62].](image)

![Figure 2. Graphic illustration of Stir casting system [64].](image)

4. Microstructural Characterization

The characterization of the Mg-MMCs is tested using the devices of X-ray Diffraction (XRD) [68], Energy-Dispersive X-Ray Spectroscopy (EDX), Scanning Electron Microscope (SEM) [69] and Field Emission SEM. Moreover, during the analysis of SEM was executed with the accelerating voltage 20
KV, gap 60 μm and 9 mm of processing distance. The composites wear appliances and surface morphology is examined using SEM images [70]. Due to the electron beam the rough interface surface developed, which was examined by SEM and EDX. Consequently, the SEM and EDX are equally distributing the reinforced composite material in MMCs and boost up the relationship of reinforcement and matrix particles.

5. Mechanical Properties
The composites mechanical performance is estimated by the hardness, tensile strength and compressive strength analysis.

5.1. Hardness
The hardness of reinforced composites of SiC, CNF, Al₂O₃, TiC, fullerene and B₄C are elaborated in table1. The addition of 0.5wt % of fullerene improved the hardness performance of strengthened Mg-MMC. The C based reinforcement has been enriched the performance of AZ91 alloy in terms of its corrosion rate and hardness [71]. Consequently, the final consecutive strength is improved to 281 MPaat TiO₂ of 5 percentage weight and enhanced the hardness up to 64% by this ceramic based reinforcement. The micro hardness of AZ61 Mg alloy for 2wt% of SiCp/AZ61 is 76.9HV and 5wt% of SiCp/AZ61 is 78.64 HV at the ageing time of thirty six hours [19]. In hard material, the increase of weight portion augmented the MMCs hardness. Consequently, after four passes the 5wt% of AM 60/Al₂O₃ strengthened MMCs finest hardness is improved to 103.7HV [31]. Moreover, 20 wt% SiC/(r-GO) is strengthened AZ31 of Mg alloy hardness is enriched approximately 66 HV. The proposed 0.5 wt% of r-GO fabrication enhanced hardness 64.6HV and at corrosion condition the inhibition of yield efficiency is up to 84% [54]. The AZ91/30wt% B₄C is significantly increased the hardness as 124 HV.

| S.N0 | Ref | Composites               | YS (Mpa) | UTS (MPa) | Hardness (HV) | Ductility (%) | CS (Mpa) |
|------|-----|--------------------------|----------|-----------|---------------|---------------|----------|
| 1    | [24]| Mg-4wt% SiC             |          |           | 40            | -             | 474      |
|      |     | Mg-8wt% SiC             |          |           | 60            | 524           |          |
|      |     | Mg-12wt% SiC            |          |           | 70            |               | 548      |
| 2    | [35]| AZ91E+1wt% Al₂O₃        | 120      | 160       | 89            | 3.08          | -        |
|      |     | AZ91E+1wt% Al₂O₃        | 140      | 200       | 99            | 2.5           |          |
|      |     | AZ91E+1wt% Al₂O₃        | 150      | 190       | 82            | 1.94          |          |
| 3    | [40]| Mg/Ni-CNT               | 454      | 504       | -             | 10.5          | 504      |
| 4    | [41]| Mg-1wt%/CNF             | 100      | -         | 46.7          | -             | 221      |
|      |     | Mg-3wt%/CNF             | 114      |           | 44.8          |               | 201      |
|      |     | Mg-5wt%/CNF             | 97       |           | 43.9          |               | 174      |
|      |     | Mg-10wt%CNF             | 91       |           | 42.5          |               | 178      |
| 5    | [46]| AZ91 1D+3wt%TiC         | -        | -         | 55.7          | -             | 35       |
|      |     | AZ91 1D+6wt%TiC         |          |           | 62            |               | 34       |
|      |     | AZ91 1D+9wt%TiC         |          |           | 91            |               | 45       |
5.2. Tensile strength

The tensile and yield strength of reinforced composites of SiC, CNF, Al₂O₃, TiC, fullerene and B₄C are elaborated in Table 1. The CNTs added GNPs reinforced Mg-1Al-0.6wt% of MMC obtained the performance enhancement in terms of its failure strain, yield strength, ultimate tensile strength and elastic modules [72-73]. The developed AM 60/Al₂O₃p MMCs improves the mechanical properties after four permits of ECAE namely ductility (+125%), YS (+135%) and UTS (+107%) [31]. The shear strength of (TiCₚ/AZ91D) method attained 58 MPa at the bonding temperature 460°C and time 20 min [45]. Consequently, the GNPs composites attained 160 MPa of tensile strength at 0.25 wt% and 170 MPa of tensile strength at 0.75 wt%. Nevertheless, the pure Mg has attained 136 MPa of tensile strength [56].

5.3. Compressive strength

The compressive of reinforced composites of SiC, CNF, Al₂O₃, TiC, fullerene and B₄C are elaborated in Table 1. As per the standard of ASTM B783, the solid Mg composites Compressive Strength (CS) were estimated using universal test equipment [74]. By means of Mg-MMCs with 4 wt%, 8wt% and 12 wt% of SiC attained improved compressive strength. The highest CS 548MPa is obtained at the 12wt% of SiC in Mg alloy [24]. The CS of various composites under different weight fractions is examined. Besides, the Mg-4wt% SiC are significantly increased the CS as 474MPa.

6. Tribological behavior

6.1. Wear performance

In MMCs modeling, mainly three methods have been utilized for the estimation of wear behavior such as tilling, crossing point and removal of entire materials [75, 76]. Moreover, the wear rate is impacted by the reinforcing material dimension and distribution. However, the tilling process goes to dominant, if the saturation depth using rough pin is higher than the dimension of reinforcement [77-79]. The wear rate of various composites under applied load condition is shown in Fig.3.

![Figure 3. Wear rate under applied load of Mg-MCCs fabrication [38], [32], [48], [52].](image-url)
The equivalent carbon atom distribution is attained on both 0.15 wt% of AZ91 in MWCNT and GNPs composites, thus it provided finest performance of wear resistant. The addition of 0.5 wt% of fullerene improved the wear and hardness performance of strengthened Mg-MMC. The wear rate is diminished up to 64% using the ceramic reinforced MMCs. The proposed 0.5 wt% of r-GO fabrication attained decreased wear rate in the range of $2.6 \text{mm}^3 \text{Nm}^{-1}$. The wear rate of different composites under sliding speed is illustrated in Fig.4. The addition of $\text{Al}_2\text{O}_3$ in MMCs decreased the wear rate $183 \mu \text{m}$ under typical 10 N load states with 800rpm sliding speed [32]. The Coefficient of Friction (CoF) for different composites is illustrated in Fig.5.

6.2. Corrosion rate

The corrosion rate of Mg-MMCs [80] was validated as per the standard of ASTM B-117 in a shower of salt at forty eight hours [81, 82]. From the observations, the AZ91D Mg alloy corrosion value is mainly based on the primary Mg composition, subsequently, it attained higher corrosion value than the secondary Mg state [83]. The C based reinforcement has been enriched the performance of AZ91 alloy in terms of its hardness. The $\text{ZC71}/12\% (\text{SiCp}) - T6$ reinforced MMCs has the 3.5 wt% of NaCl is utilized in corrosion resistance rate reduction and hardness of coatings are evaluated. Due to the current density of corrosion increase, the electron flow was also increases [84], hence the corrosion rate was increased.

7. Application
The vehicle usage is increased in recent year; therefore the lightweight Mg based alloys are utilized in automotive application. Initially, the wheels of the vehicles are alternated by Mg alloy [85-86]. The interior, engine and transmission sections, body of tools, and chassis are developed by the lightweight fabricated Mg alloys [87]. The emission of CO$_2$ is diminished and reduced the weight due to the increase of Mg alloys in automotive industries [88]. In medical application, the bone infection injuries treatment is replaced by the Mg-GNP composites. Pedersen and Ramuluet al [89] introduced the carbide cutting tools for industries. The binder jet additive are designed effectively by the new CNT reinforced Mg-MMCs composites [90]. Thus the Mg-MMCs play an essential role in aerospace, glass, wheel and automotive industries.

8. Conclusion
In this study, the various reinforcement materials, tribological and mechanical performance of MMCs are examined. In order to improve the engineering application of Mg alloy, various kinds of MMCs are developed by dissimilar dimensions, configuration and reinforcement elements category. The proper fabrication and reinforcement of MMCs are the main factor for the composition of microstructure and mechanical performance based on the necessities. From this investigation of review was observed follows, The GNP reinforcement method is a new one, because it has attractive mechanical properties. Nevertheless, the unique attractive characterization of GNP mechanical properties is transfer to combine. This is restricting the GNP effectiveness the application of MMCs. The $Al_2O_3$ and $SiC$ reinforced Mg alloy based MMT provides finest relationship to the fiber matrix contrast to CNTs. Thus the reinforced MMCs attained more influence stress, more tensile strength, less thermal growth and more hardness. Besides, the CNTs reinforced MMCs attained high strength and low mass density due to the friction coefficient reduction. While compare to the $Al_2O_3$ and $SiC$, the CNT fabrication provides light weigh MMCs. The corrosion resistance properties are reduced using $SiC$, yet the properties are enhanced by other reinforced particles. Besides, the mechanical and tribological features are enhanced using new organic material such as fly ash etc., based hybrid composites.

References
[1] Kim W J, An C W, Kim Y S and Hong S I 2002 Mechanical properties and microstructures of an AZ61 Mg Alloy produced by equal channel angular pressing Scriptamaterialia 47(1) 39-44
[2] Park S H C, Sato Y S and Kokawa H 2003 Effect of micro-texture on fracture location in friction stir weld of Mg alloy AZ61 during tensile test ScriptaMaterialia 49(2) 161-166
[3] Pradhan M K 2020 TribologicalBehavior, Machinability, and Optimization of EDM of AA-2014 Hybrid Composite Reinforced With SiC and Glass Particulates Handbook of Research on Developments and Trends in Industrial and Materials Engineering (IGI Global) pp228-269
[4] Romanowski C 2019 Magnesium Alloy Sheet for Transportation Applications Magnesium Technology 2019 (Springer: Cham) pp3-12
[5] Kumar D SandSasanka C T 2017 Magnesium and Its Alloys Lightweight and Sustainable Materials for Automotive Applications (CRC Press) pp329-368
[6] Friedrich H EandMordike B L 2006 Engineering requirements, strategies and examples Magnesium Technology: Metallurgy, Design Data, Applications 499-632
[7] Majumdar J D, Galun R, Mordike B Land Manna I 2003 Effect of laser surface melting on corrosion and wear resistance of a commercial magnesium alloy Materials Science and Engineering: A 361(1-2) 119-129
[8] Wallace F J 1963 The determination of magnesium in aluminium alloys by atomic-absorption spectroscopy Analyst 88(1045) 259-265
[9] Vlasblom M 2018 The manufacture, properties, and applications of high-strength, high-modulus
polyethylene fibers. Handbook of Properties of Textile and Technical Fibres (Woodhead Publishing) pp699-755

[10] Mohanavel V 2019 Synthesis and evaluation on mechanical properties of LM4/AlN alloy based composites Energy Sources, Part A: Recovery, Utilization, and Environmental Effects 1-10

[11] Chan C H, Tang S W, Mohd N Kand Lim W H 2018 Tribological behavior of biolubricant base stocks and additives Renewable and Sustainable Energy Reviews 93 145-157

[12] Gulzar M, Masjuki H H, Kalam M AandVarman M 2016 Tribological performance of nanoparticles as lubricating oil additives Journal of Nanoparticle Research 18(8) 223

[13] Singh S, Singh landDvivedi A 2017 Design and development of novel cost effective casting route for production of metal matrix composites (MMCs) International Journal of Cast Metals Research 30(6) 356-364

[14] Miracle D B 2005 Metal matrix composites–from science to technological significance Composites science and technology 65(15-16) 2526-2540

[15] Allison J Eand Cole G S 1993 Metal-matrix composites in the automotive industry: opportunities and challenges JOM 45(1) 19-24

[16] Ibrahim M A, Sahin Y, Gidado A Yand Said M T 2019 Mechanical Properties of Aluminium Matrix Composite Including SiC/Al2O3 by Powder Metallurgy-A Review GSJ 7(3) 23-38

[17] Vogiatzis C AandSkofianos S M 2016 On the sintering mechanisms and microstructure of aluminium–ceramic cenospheres syntactic foams produced by powder metallurgy route Composites Part A: Applied Science and Manufacturing 82 8-19

[18] Malaki M, Xu W, Kasar A K, Menezes P LandDieringa H 2019 Advanced metal matrix nanocomposites Metals 9(3) 330

[19] Huang S Jand Ali A N 2018 Effects of heat treatment on the microstructure and microplastic deformation behavior of SiC particles reinforced AZ61 magnesium metal matrix composite Materials Science and Engineering: A 711 670-682

[20] Seshan S, Jayamathy Mand Kailas S V 2003 The tensile behavior of two magnesium alloys reinforced with silicon carbide particulates Materials science and engineering: A 363(1-2) 345-351

[21] Lelito J, Zak P L, Shirzadi A A, Greer A LandKrajewski W K 2012 Effect of SiC reinforcement particles on the grain density in a magnesium-based metal–matrix composite: Modelling and experiment ActaMaterialia 60(6-7) 2950-2958

[22] Lim C Y H, Lim S Cand Gupta M 2003 Wear behaviour of SiCp-reinforced magnesium matrix composites Wear 255(1-6) 629-637

[23] Zhu J, Qi J, Guan D, Ma LandDwyer-Joyce R 2020 Tribological behaviour of self-lubricating Mg matrix composites reinforced with silicon carbide and tungsten disulfide Tribology International 146106253

[24] Kumar S D, Ravichandran MandSakthivelu S 2020 Mechanical properties of magnesium-silicon carbide composite fabricated through powder metallurgy route Materials Today: Proceedings

[25] Enrique P D, Marzbanrad EandMahmoodkhani Y 2020 Design of binder jet additive manufactured co-continuous ceramic-reinforced metal matrix composites Journal of Materials Science & Technology

[26] Shen J, Yin W, Wei Q, Li Y, Liu Jand An L 2013 Effect of ceramic nanoparticle reinforcements on the quasistatic and dynamic mechanical properties of magnesium-based metal matrix composites Journal of Materials Research 28(13) 1835-1852
[27] Malhotra P, Tyagi R K, Singh N K and Sikarwar B S 2020 Experimental investigation and effects of process parameters on EDM of Al7075/SiC composite reinforced with magnesium particles Materials Today: Proceedings 21 1496-1501
[28] Kavimani V, Prakash K S, Starvin M S and Skeldon P 2020 Tribo-surface characteristics and wear behaviour of SiC@r-GO/Mg composite worn under varying control factor Silicon 12(1) 29-39
[29] Arrabal R, Matykina E, Skeldon P and Thompson G E 2009 Coating formation by plasma electrolytic oxidation on ZC71/SiC/12p-T6 magnesium metal matrix composite Applied surface science 255(9) 5071-5078
[30] Karthick E, Mathai J and Tony J M 2017 Processing, Microstructure and Mechanical Properties of Al2O3 and SiC Reinforced Magnesium Metal Matrix Hybrid Composites Materials Today: Proceedings 4(6) 6750-6756
[31] Huang S J and Lin P C 2013 Grain refinement of AM60/Al2O3p magnesium metal-matrix composites processed by ECAE Kovove Mater 51(6) 357-366
[32] Thirugnanasambandham T and Chandradass J 2019 Experimental study of wear characteristics of Al2O3 reinforced magnesium based metal matrix composites Materials Today: Proceedings 14 211-218
[33] Huang S J, Lin P and Aoh J N 2015 Mechanical behavior enhancement of AM60/Al2O3p magnesium metal–matrix nanocomposites by ECAE Materials and Manufacturing Processes 30(10) 1272-1277
[34] Tarasasanka C, Snehita K and Ravindra K 2019 Optimization of dry sliding wear properties of AZ91E/nano Al2O3 reinforced metal matrix composite with grey relational analysis International Journal of Engineering, Science and Technology 11(4) 41-48
[35] Niranjan C A, Srinivas S and Ramachandra M 2020 Experimental investigations on depth of penetration and surface integrity in AZ91/Al2O3 nano-composites cut by abrasive water jet The International Journal of Advanced Manufacturing Technology 107(1) 747-762
[36] Kumar S, Suman K N S, Ravindra K and Poddar P 2017 Microstructure, mechanical response and fractography of AZ91E/Al2O3 (p) nano composite fabricated by semi solid stir casting method Journal of magnesium and alloys 5(1) 48-55
[37] Singh A and Bala N 2019 Synthesis and comparative sliding wear behavior of stir cast Mg and Mg/Al2O3 metal matrix composites Materials Research Express 6(7) 076512
[38] Turan M E, Zengin Hand Sun Y 2019 Dry sliding wear behavior of (MWCNT+ GNPs) reinforced AZ91 magnesium matrix hybrid composites Metals and Materials International 1-10
[39] Rashad M, Pan F, Tang A, Asif MandAamir M 2014 Synergetic effect of graphenenanoplatelets (GNPs) and multi-walled carbon nanotube (MW-CNTs) on mechanical properties of pure magnesium Journal of Alloys and Compounds 603 111-118
[40] Ding Y, Xu J, Hu J, Gao Q and Zeng X and Zhang R 2020. High performance carbon nanotube-reinforced magnesium nanocomposite Materials Science and Engineering: A 771 138575
[41] Abdo H S, Khalil K A, El-Rayes M and MansMarzouk W W 2019 Ceramic nanofibers versus carbon nanofibers as a reinforcement for magnesium metal matrix to improve the mechanical properties Journal of King Saud University-Engineering Sciences
[42] Wu F and Zhu J 1997 Morphology of second-phase precipitates in carbon-fiber and graphite-fiber-reinforced magnesium-based metal-matrix composites Composites science and technology 57(6) 661-667
[43] Qi L, Li S, Zhang T, Zhou J and Li H 2019 An analysis of the factors affecting strengthening in
carbon fiber reinforced magnesium composites *Composite Structures* 209 328-336

[44] Bakkar A and Neubert V 2009 Corrosion behaviour of carbon fibres/magnesium metal matrix composite and electrochemical response of its constituents *Electrochimica Acta* 54(5) 1597-1606

[45] Gu X Y, Sun D Q and Liu L 2008 Transient liquid phase bonding of TiC reinforced magnesium metal matrix composites (TiCP/AZ91D) using aluminum interlayer *Materials Science and Engineering: A* 487(1-2) 86-92

[46] Anbugezhiyan G, Mohan Band Kathiresan S 2020 Influence of microstructure and mechanical properties of TiC reinforced magnesium nano composites *Materials Today: Proceedings*

[47] Dash D, Singh R, Samanta Sand Rai R N 2020 Influence of TiC on Microstructure, Mechanical and Wear Properties of Magnesium alloy (AZ91D) Matrix Composites.

[48] Turan M E, Sun Y, Aydin F, Zengin Hand Türen Y 2018 Effects of carbonaceous reinforcements on microstructure and corrosion properties of magnesium matrix composites *Materials Chemistry and Physics* 218 182-188

[49] Turan M E, Sun Yand Akgul Y 2018 Mechanical, tribological and corrosion properties of fullerene reinforced magnesium matrix composites fabricated by semi powder metallurgy *Journal of Alloys and Compounds* 740 1149-1158

[50] Turan M E, Sun Yand Akgul Y 2018 Improved wear properties of magnesium matrix composite with the addition of fullerene using semi powder metallurgy *Fullerenes, Nanotubes and Carbon Nanostructures* 26(2) 130-136

[51] Jiang Q C, Wang H Y, Ma B X, Wang Yand Zhao F 2005 Fabrication of B4C particulate reinforced magnesium matrix composite by powder metallurgy *Journal of Alloys and Compounds* 386(1-2) 177-181

[52] Aydin F, Sun Yand Turan M E 2019 Investigation of microstructure, mechanical and wear behaviour of B4C particulate reinforced AZ91 matrix composites by powder metallurgy

[53] Saberi A, Bakhsheshi-Rad H and Karamian E 2020 Magnesium-graphenenano-platelet composites: Corrosion behavior, mechanical and biological properties *Journal of Alloys and Compounds* 821 153379

[54] Kavimani V, Prakash K Sand Thankachan T 2019 Investigation of graphene-reinforced magnesium metal matrix composites processed through a solvent-based powder metallurgy route *Bulletin of Materials Science* 42(1) 39

[55] Meng L, Hu X, Wang X, Zhang C, Shi Hand Xiang Y 2018 Graphenenanoplatelets reinforced Mg matrix composite with enhanced mechanical properties by structure construction *Materials Science and Engineering: A* 733414-418

[56] Rashad M, Pan F, Zhang Jand Asif M 2015 Use of high energy ball milling to study the role of graphenenanoplatelets and carbon nanotubes reinforced magnesium alloy *Journal of Alloys and Compounds* 646223-232

[57] Rashad M, Pan F, Lin Jand Asif M 2016 High temperature mechanical behavior of AZ61 magnesium alloy reinforced with graphenenanoplatelets *Materials & Design* 891242-1250

[58] Munir K, Wen Cand Li Y2020 Graphenenanoplatelets-reinforced magnesium metal matrix nanocomposites with superior mechanical and corrosion performance for biomedical applications *Journal of Magnesium and Alloys*

[59] Lloyd DJ1994 Particle reinforced aluminium and magnesium matrix composites *International materials reviews* 39(1) 1-23

[60] Tun K Sand Gupta M 2007 Improving mechanical properties of magnesium using nano-yttria
reinforcement and microwave assisted powder metallurgy method Composites Science and Technology 67(13)2657-2664

[61] Kumar N, Bharti Aand Saxena KK 2020 A re-analysis of effect of various process parameters on the mechanical properties of Mg based MMCs fabricated by powder metallurgy technique Materials Today: Proceedings

[62] Manige ST, Gowd GH and Chandra Mohan Reddy B 2019 Processing of magnesium metal matrix composite reinforced with grapheneno platelets through vacuum stir casting and investigating its mechanical behaviour Journal of Thin Films, Coating Science Technology and Application 5(3)21-29

[63] Venkatesh B, Sandeep Pand Ramakrishna MVA 2019 Synthesis and mechanical characterization of magnesium reinforced with SiC composites Materials Today: Proceedings 19792-797

[64] Ceschini L, Dahle A, Gupta Mand Jarfors AEW 2017 Ex Situ Production Routes for Metal Matrix Nanocomposites Aluminum and Magnesium Metal Matrix Nanocomposites (Springer: Singapore) pp 19-40

[65] Hashim J, Looney Land Hashmi MSJ 1999 Metal matrix composites: production by the stir casting method Journal of Materials processing technology 921-7

[66] Lan J, Yang Y and Li X 2004 Microstructure and microhardness of SiC nanoparticles reinforced magnesium composites fabricated by ultrasonic method Materials Science and Engineering: A 386(1-2)284-290

[67] Parthiban GT, Malarkodi D and Palaniswamy N 2010 Corrosion protection by acrylamide treatment for magnesium alloy metal matrix composite (MMC) reinforced with titanium boride Surface engineering 26(5)378-384

[68] Yong MS and Clegg AJ 2005 Process optimisation for a squeeze cast magnesium alloy metal matrix composite Journal of Materials Processing Technology 168(2)262-269

[69] Vinoth R, Asharudeen A, Balachandar E and Kumar D 2019 Enhancement of Mechanical properties of Magnesium metal matrix composites

[70] Zhang J, Wei Q and Joshi SP 2016 Effects of reinforcement morphology on the mechanical behavior of magnesium metal matrix composites based on crystal plasticity modeling Mechanics of Materials 951-14

[71] Luo A 1995 Processing, microstructure, and mechanical behavior of cast magnesium metal matrix composites Metallurgical and Materials Transactions A 26(9)2445-2455

[72] Purazrang K, Kainer KU and Mordike BL 1991 Fracture toughness behaviour of a magnesium alloy metal-matrix composite produced by the infiltration technique Composites 22(6)456-462

[73] Wang HY, Jiang QC, Wang Y, Ma BX and Zhao F 2004 Fabrication of TiB2 particulate reinforced magnesium matrix composites by powder metallurgy Materials letters 58(27-28)3509-3513

[74] Ferguson JB, Sheyk-Jaberi F and Kim CS 2012 On the strength and strain to failure in particle-reinforced magnesium metal-matrix nanocomposites (Mg MMNCs) Materials Science and Engineering: A 558193-204

[75] Kavimani V, Prakash K and Thankachan T 2019 Experimental investigations on wear and friction behaviour of SiC@r-GO reinforced Mg matrix composites produced through solvent-based powder metallurgy Composites Part B: Engineering 162508-521

[76] Wang N, Wang Z and Weatherly GC 1992 Formation of magnesium aluminate (spinel) in cast SiC particulate-reinforced Al (A356) metal matrix composites Metallurgical Transactions A 23(5)1423-1430
[77] Hartmann O, Kemnitzer MannBiermann H2002 Influence of reinforcement morphology and matrix strength of metal–matrix composites on the cyclic deformation and fatigue behaviour International journal of fatigue 24(2-4)215-221
[78] Kavimani V, Prakash KS, Thankachan TandNagaraja S2019 WEDM Parameter Optimization for Silicon@ r-GO/Magnesium Composite Using Taguchi Based GRA Coupled PCA Silicon 1-15
[79] Bakkar AandNeubert V2007 Corrosion characterisation of alumina–magnesium metal matrix composites Corrosion science 49(3)1110-1130
[80] Fathi MH, Meratian MandRazavi M2011 Novel magnesium-nanofluorapatite metal matrix nanocomposite with improved biodegradation behavior Journal of biomedical nanotechnology 7(3)441-445
[81] Hihara LHHandKondepudi PK1993 The galvanic corrosion of SiC monofilament/ZE41 Mg metal-matrix composite in 0.5 M NaNO3 Corrosion science 34(11)1761-1772
[82] Merino MC, Pardo A, Arrabal R, Merino SandCasajús P2010 Influence of chloride ion concentration and temperature on the corrosion of Mg–Al alloys in salt fog Corrosion science 52(5)1696-1704
[83] Martin HJ, Horstemeyer MFand Wang PT2010 Comparison of corrosion pitting under immersion and salt-spray environments on an as-cast AE44 magnesium alloy Corrosion science 52(11)3624-3638
[84] Skar Jand Albright D2016 Emerging trends in corrosion protection of magnesium die-castings Essential Readings in Magnesium Technology(Springer: Cham)pp 585-591
[85] Witte F, Hort N, Vogt C, Cohen SandKainer KU2007 Biodegradable magnesium–hydroxyapatite metal matrix composites Biomaterials 28(13)2163-2174
[86] Luo AA2013 Magnesium casting technology for structural applications Journal of Magnesium and Alloys 1(1)2-22
[87] Merlo AM2003 The contribution of surface engineering to the product performance in the automotive industry Surface and Coatings Technology 174 21-26
[88] Watarai H2006 Trend of Research and Development for Magnesium Alloys-Reducing the Weight of Structural Materials in Motor Vehicles NISTEP Science & Technology Foresight Center
[89] Pedersen WandRamulu M2006 Facing SiCp/Mg metal matrix composites with carbide tools Journal of materials processing technology 172(3)417-423
[90] Rajak DK, Wagh PHandMenezes PL2020 Critical Overview of Coatings Technology for Metal Matrix Composites Journal of Bio-and Tribo-Corrosion 6(1)12

Acknowledgments
None