Fabrication, Microstructure, and Mechanical Properties of AZ31/Silicon Carbide/Graphite Reinforced Hybrid Composites

Itha Veeranjaneyulu[1*], Chittaranjan das Vemulapalli[2], M. Gopi Krishna[1]

[1] Department of Mechanical Engineering, Acharya Nagarjuna University, Guntur, India

[2] RVR & JC College of Engineering, Guntur, India

* Corresponding author's e-mail: anjimech@gmail.com

ABSTRACT

Magnesium matrix composites (MMCs) exhibit excellent strength, low mass, and density. In the current study, silicon carbide (SiC) and graphite (Gr) particles are used as reinforcement, using AZ31 alloy as the matrix material. Using the stir casting method, AZ31-SiC-Gr hybrid composites were developed with different compositions of SiC and Gr (0, 2, 4, and 6 wt.%). The microstructure of developed hybrid composites and AZ31 alloy was analyzed using SEM and EDS. The densities, hardness, tensile and compressive properties of the fabricated hybrid composites were examined. The experimental results show that adding reinforcements improved the developed hybrid composites' mechanical characteristics. The micro hardness was raised by 27% with the addition of 6% SiC and Gr to the base alloy. The AZ31 hybrid composite with 4% SiC and Gr particles exhibited a maximum compressive strength of 365.56 MPa and UTS of 158.4 MPa. Overall, the results of the AZ31-SiC-Gr hybrid MMCs are promising for automobile applications because of their low mass, high strength and good wear resistance.

Keywords: AZ31, hybrid composites, stir casting, SEM, EDS.

INTRODUCTION

Nowadays, many research outcomes were concentrating on the advancement of a product to enhance vehicle performance in the automotive industry by applying lightweight materials with high strengths. Magnesium and its alloys appealed to modern businesses because of their low mass when compared to older metals like aluminium and steel. The inclusion of tougher ceramic reinforcement particles in metal matrix composites can overcome a few restrictions [1–3]. The ideal composite materials have exhibited better mechanical properties due to the addition of reinforcements (titanium [4], SiC [5], ZrB_2 [6], TiO_2 [7], and Graphite [8]). A popular and economical technique that has been commercially adopted among all approaches is stir casting. Its advantages include mass production, affordable processing, and simplicity of customization. Reinforcing particles incorporate at semi solid state. Many researchers

are studied SiC with Al-Zn and Aluminium matrix composites and few of them studied magnesium matrix composites. Among AZ31 magnesium alloy with SiC particles is shown the better mechanical properties. According to research by Subramani et al. [9], SiC particles successfully improved the base alloy's functionality in the low temperature range and decreased the mobility of dislocations. Huang et al [10], examined the effect of micro SiC_p on AZ61 magnesium alloy and reported that the AZ61 1 wt.% SiCp exhibited superior mechanical and fatigue capabilities to base alloy and 2 wt.% SiCp composite. Zang et al. [11], investigated the AZ31/GNP composites produced by FSP, and found that the three multi-pass FSPs were necessary to produce defect-free composites with uniform GNP dispersion. The mechanical properties of the AZ31/silicon carbide composite have improved in comparison to the basic alloy, according to Kumar et al. [12]. Kumar et al. [13] discovered that the addition of SiC particles

causes a considerable change in microstructure, lowers grain refinement, and improves mechanical properties. Subramani et al [14], examined the impact of SiC nanoparticles on the AZ31 magnesium alloy, they discovered that the increase in SiC nanoparticle concentration improved hardness, yield strength, and wear resistance. Images taken with SEM demonstrated the development of SiC clusters and $Mg_{17}Al_{12}$ lamellar intermetallic structures in the nanocomposites. Rao et al. [15] studied the microstructure and mechanical behavior of MMCs under the cast and heat-treated circumstances, and reported that the heat-treated hybrid MMCs performed better than the as-cast specimens. Kumar et al. [16], concluded that the homogenous distribution of reinforcement particles within the matrix alloy has improved the mechanical properties of the hybrid composite in contrast to the base alloy. Al-Maamari et al. [17], reported that the hybrid MMCs outperformed in terms of mechanical properties as compared with the composites.

The investigations into the fabrication and mechanical properties of composite materials have yielded no definitive results, and more research is needed to determine the optimal matrix and reinforcing material composition. As a result, fabrication, microstructural assessment, and mechanical characteristics of AZ31/SiC/Gr reinforced hybrid composites have been attempted. The fabrication, microstructure analysis, and mechanical characteristics of stir-cast AZ31/SiC/Gr reinforced hybrid composites are the key areas of attention in the current work. The SiC particles enhance the strength properties, whereas the graphite particles improve the resistance to wear. These functional properties of the material were more important, for its victorious applications in the automotive and aerospace industries.

MATERIALS AND METHODS

Materials and composites fabrication

Table 1 shows AZ31's elemental composition. The reinforcement materials are Silicon Carbide and graphite particles of sizes 220 mesh and 60 mesh, respectively. AZ31 was selected as the matrix alloy. The manufacturing process of hybrid composites is carried out in Figure 1 depicts the experimental setup, and Figure 2 is a schematic design of the casting furnace. The AZ31 alloy was loaded in a graphite crucible and fed into the furnace to withstand the chemical reactions occurring while the matrix material is still liquid. To remove various gases and fix casting flaws, raw materials and crucibles are heated. The muffle furnace's crucible is preheated to 400 °C and loaded with the material by increasing the temperature up to 650 °C. Argon gas was utilized to establish a vacuum inside the furnace to stop air oxidation. The pre-warmed (200 °C) reinforcements were included in the centre of the pool created by the stirring process [18, 19]. The traditional stirrer was rotated at 700 rpm and poured into a heated mould immediately.

Microstructure

SEM was used to examine the S1, S2, S3, and S4 samples' microstructure. The sample was prepared by using several grades of polishing paper and a disc polishing machine. Etchant was applied to remove unwanted elements from the sample's surface.

Mechanical properties

The theoretical and measured density of the S1, S2, S3, and S4 samples were calculated using the rule of mixture and Archimedes principle respectively. The porosity of the samples was calculated using Eq. 1.

$$\% \, Porosity = \left(1 - \frac{Measured\,density}{Theoretical\,density}\right) \times 100 \quad (1)$$

Vickers hardness testers were used to conduct hardness tests on magnesium base alloy and composite specimens. The applied load is 100 grams, and the dwell time is 20 seconds. Each hardness value was averaged over three readings. Tensile and compressive tests were performed using UTM (INSTRON-E1025) on cylindrical specimens of S1, S2, S3, and S4 with a ram speed of 3 mm/min. The experiment was conducted for three samples of each specimen and the value was averaged over three readings.

Table 1. Elemental composition of AZ31

Elements	Al	Zn	Mn	Cu	Fe	Si	Mg
Wt%	3	0.98	0.01	0.02	0.001	0.01	Rest

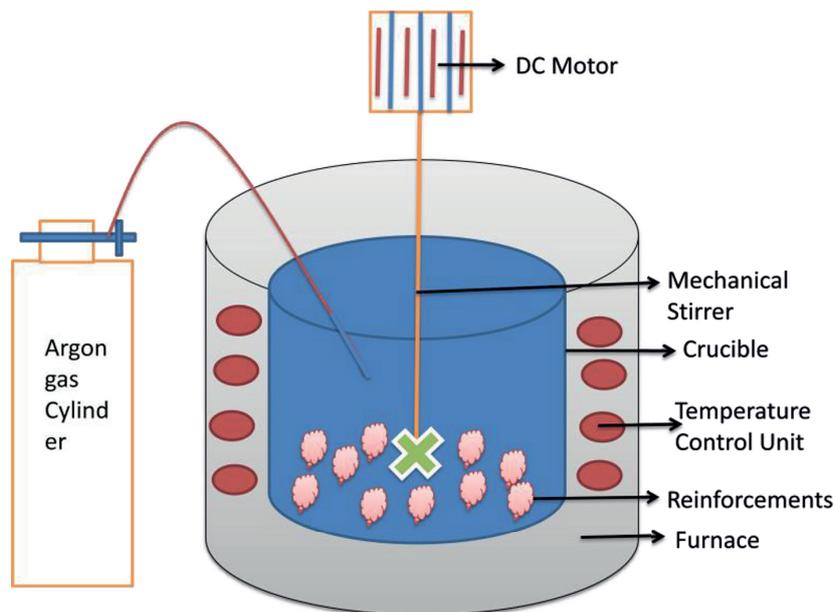**Fig. 1.** Experimental setup

Fig. 2. Schematic diagram of casting furnace

RESULTS AND DISCUSSION

Micro structural analysis

The SEM images of monolithic alloy and hybrid composites are depicted in Figure 3. Figure 3a exhibits the SEM image of AZ31 alloy. Figures 3b, c, d showing the SEM images of hybrid composites. During the experiment, noticed that there was a regular dispersal of SiC and Gr particles which enhanced the mechanical properties [20]. SiC and Gr were uniformly distributed along with the matrix, therefore there is no agglomerations occurred in the reinforced composites. By adding the wt.% of reinforcement, few cracks are identified in the composite. Due to this reason, the strength of the hybrid composite was a little reduced.
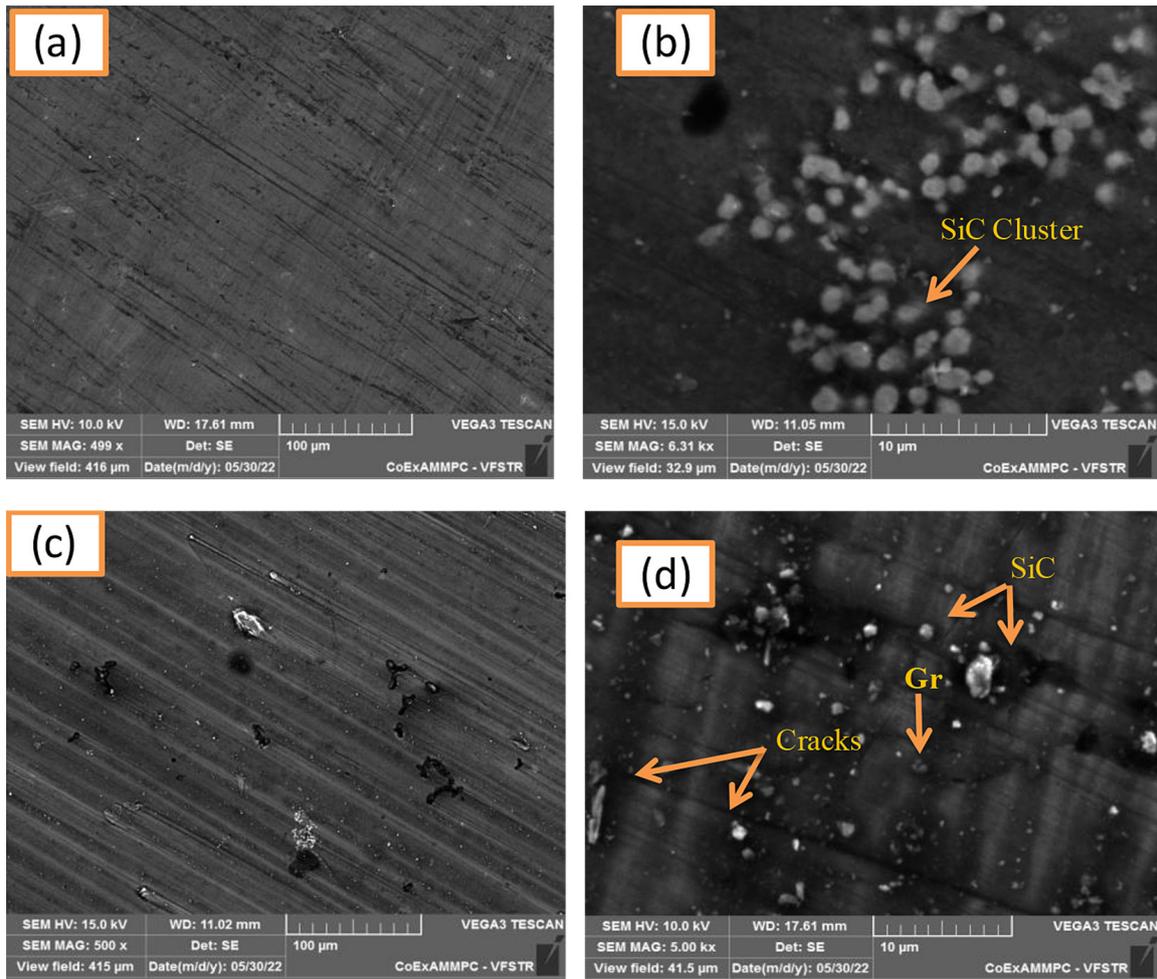
Fig. 3. SEM images: a) AZ31, b) A31+2%SiC+2% Gr, c) AZ31+4%SiC+4% Gr and d) AZ31 +6%SiC+6% Gr
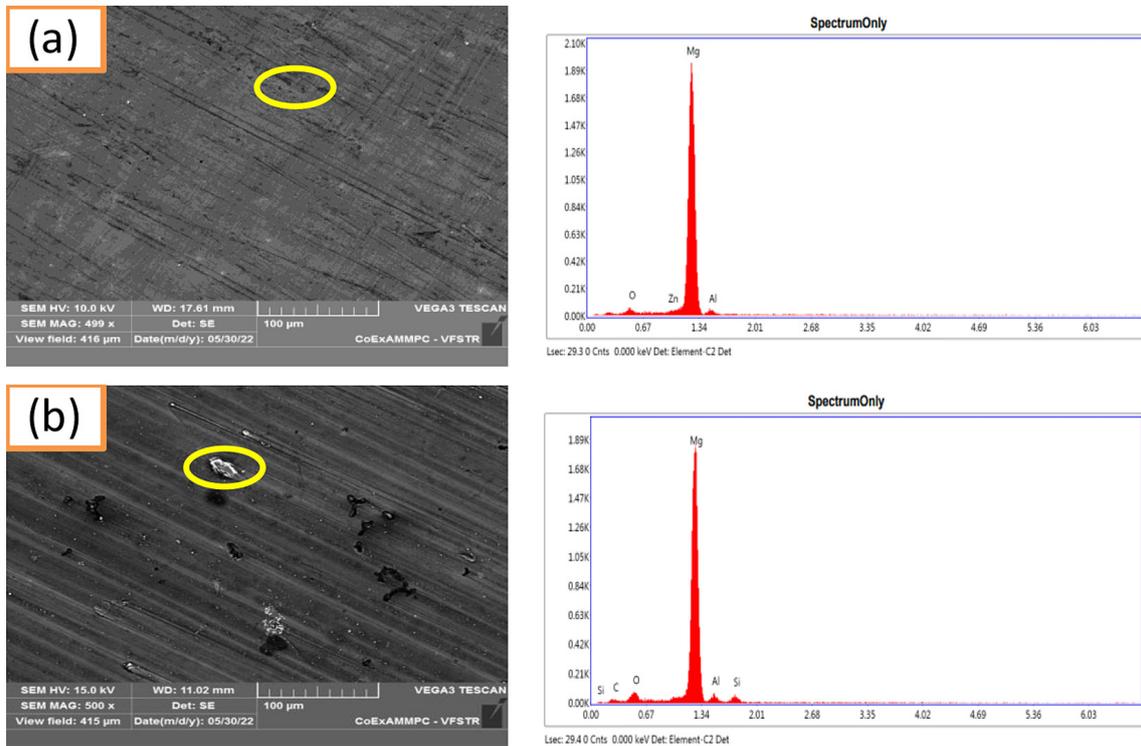

Fig. 4. EDS spectrum: a) AZ31 and b) AZ31/SiC/Gr

Energy dispersive spectroscopy (EDS) analysis

EDS was carried out for monolithic alloy and hybrid composites. Figure 4 represents the elements of Aluminium (Al), Zinc (Zn), Silicon (Si), Carbon (C), and Magnesium (Mg) in the material. By the continuous impingement of the argon gas into the furnace, the oxygen heights were not significant in either the alloy or the composite [21].

Mechanical properties

Density and micro hardness

The incorporation of reinforcements in the semi-solid condition as the contract to the monolithic alloy, which is illustrated in Table 2, is responsible for the rise in the density of hybrid composites. Comparing the measured density to the theoretical density, lower values were found. The SiC and Gr particles improve the density and porosity of the hybrid composite, which helps to raise the hardness of the material. Figure 5 depicts the micro hardness of hybrid composites. The hybrid composite of AZ31-6%SiC-6%Gr was 27% stronger than the monolithic alloy [22].

Tensile properties

The UTS and YS of hybrid composites are increased by changing the weight percent ratio of SiC and Gr reinforcements. In micro particle reinforced metal matrix composites, the strengthening process is absent. Figure 6 shows that the 6% hybrid composite decreased in strength compared with 4%, probably because the reinforcement was overstretched, the alloys lattice and leftover strain energy prevented them from gaining ductility. The strength of the composite may be impacted by the grain size of the reinforcements and the bonding between the reinforcements and the matrix [23]. The addition of SiC and Gr can lead to a significant increase in the tensile strength of the composites around 54% compared with monolithic alloy [24].

Compressive properties

Due to the addition of reinforcements, the compression properties of the hybrid composites are improved. The composite's strength varies depending on the reinforcement's grain size and how they have been bonded to the matrix. The alloy has a compressive strength of 173.42 MPa, although the S3 composite showed enhanced

Table 2. Density and porosity

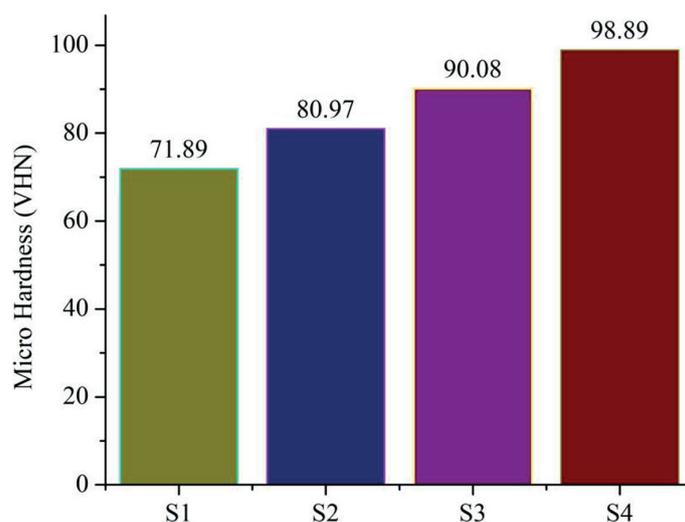| Sample	Alloy and composites	Theoretical density (g/cc)	Measured density (g/cc)	% porosity
S1	AZ31	1.8	1.799	0.06
S2	AZ31+2%SiC+2%Gr	1.84	1.834	0.33
S3	AZ31+4% SiC+4%Gr	1.86	1.855	0.27
S4	AZ31+6% SiC+6%Gr	1.87	1.862	0.43

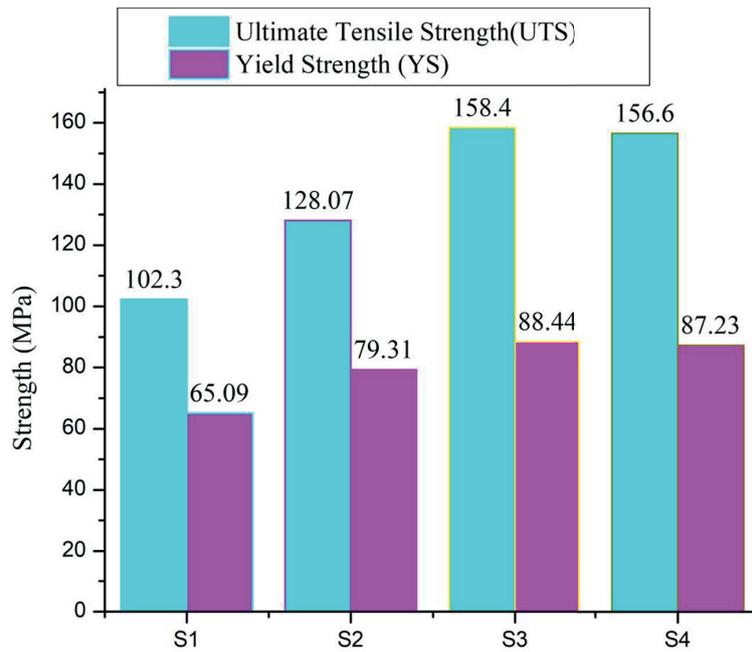**Fig. 5.** Variation of micro hardness of hybrid composites

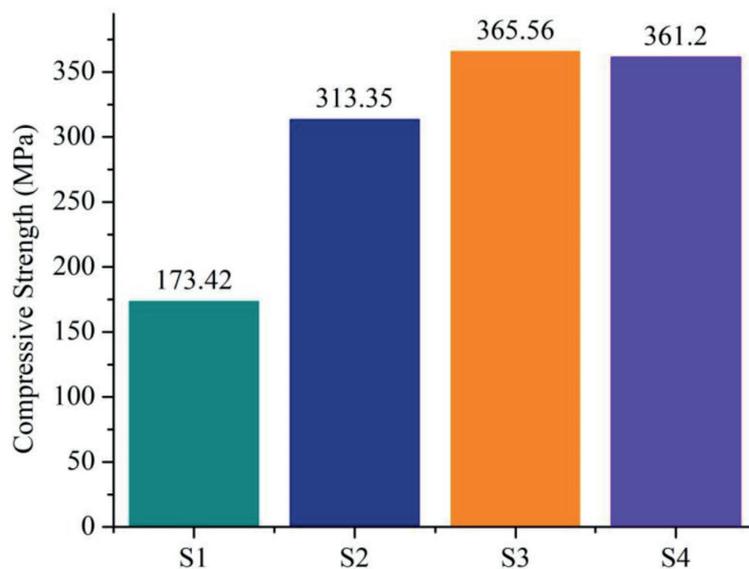**Fig. 6.** Variation of YS and UTS of hybrid composites

Fig. 7. Variation of compressive strength of hybrid composites

compressive strength (365.56 MPa) due to refined grain. Figure 7 illustrates how the inclusion of ceramic particles may reduce flexibility and increase compressive strength [25].

CONCLUSIONS

Effective fabrication of the base alloy and AZ31-SiC-Gr hybrid composite has been accomplished using the stir casting technique. The SEM and EDS analysis were performed on AZ31 base alloy and hybrid composites. SEM images revealed the distribution of the particles, SiC cluster, and cracks. The elements which are presented in the hybrid composite. In the EDS analysis, Al, Zn, C, Si, and Mg elemental peaks were observed in the selected region. The combination of AZ31-6%SiC-6%Gr yielded the greatest density of 1.87 g/cc and hardness of 98.89 Vickers hardness number. This was caused by the presence of SiC, and it demonstrates the improvement in density and hardness when compared to the AZ31 alloy.

In comparison to other composites, the AZ31-4%SiC-4%Gr hybrid composite displayed the highest ultimate tensile strength (158.4 MPa) and compressive strength (365.56 MPa). This was due to the uniform distribution of reinforcements in the matrix. The mechanical properties were improved significantly as compared with base alloy. Overall, the S3 hybrid composite showed better results. The properties, however, started to degrade above 4% SiC/Gr, eventually; this was due to the agglomeration and clustering of reinforcing particles.

REFERENCES

1. Dutta S., Gupta S., Mangal R. Recent Developments in Magnesium Metal–Matrix Composites for Biomedical Applications: A Review. ACS Biomaterial Science & Engineering. 2020; 9: 4748–4773.

2. Aghion E., Bronfin B., Friedrich H., Rubinovich Z. Magnesium Technology. 2004; 167–172.

3. Mordike B.L., Ebert T. Magnesium: properties-applications-potential. Materials Science and Engineering: A. 2001; 320: 37–45.

4. Dinaharan I., Zhang S., Chen G., Shi Q. Development of titanium particulate reinforced AZ31 magnesium matrix composites via friction stir processing. Journal of Alloys and Compounds. 2020; 820: 153071.

5. Moustafa E.B., Mikhaylovskaya A.V., Taha M.A., Mosleh A.O. Improvement of the microstructure and mechanical properties by hybridizing the surface of AA7075 by hexagonal boron nitride with carbide particles using the FSP process. Journal of Materials Research and Technology. 2022; 17: 1986–1999.

6. Durga Vithal N., Bala Krishna B., Gopi Krishna M. Microstructure, mechanical properties and fracture mechanisms of ZrB_2 ceramic reinforced A7075 composites fabricated by stir casting. Materials Today Communications. 2020; 25: 101289.

7. Yoganandam K., Raja K., Lingadurai K. Mechanical and Micro Structural Characterization of Al6082-TiO2 Metal Matrix Composites produced via Compo Casting Method. Indian Journal of Science and Technology. 2016; 9: 14.

8. Al-maamari A.E.A., Asif Iqbal A.K.M., Nuruzzaman D.M. Wear and mechanical characterization of Mg-Gr self-lubricating composite fabricated by mechanical alloying. Journal of Magnesium and Alloys. 2019; 7: 283–290.

9. Subramani M., Tzeng Y.C., Tseng L.W., Tsai Y.K., Chen G.S., Chung C.Y., Hot deformation behaviour and processing map of AZ61/SiC composites. Materials today Communications. 2021; 29: 102861.

10. Huang, S.J., Subramani M., Ali A.N., Alemayehu D.B., Aoh, J.N., Lin, P.C. The effect of micro-SiC_p content on the tensile and fatigue behaviour of AZ61 magnesium alloy matrix composites. International Journal of Metal casting. 2021; 15: 780–793.

11. Zang Q., Chen H., Zhang J., Wang L., Chen S., Jin Y. Microstructure mechanical properties and corrosion resistance of AZ31/GNPs composites prepared by friction stir processing. Journal of Materials Research and Technology. 2021; 14: 195–201.

12. Kumar A., Ravindra S.R., Rajesh P. Microstructure evolution, mechanical properties, and fractography of AA7068/ Si_3N_4 nanocomposite fabricated thorough ultrasonic assisted stir casting advanced with bottom pouring technique. Materials Research Express. 2022; 9: 015009.

13. Kumar K.C.K., Kumar B.R., Rao N.M. Microstructural, Mechanical Characterization and Fractography of AZ31/SiC Reinforced Composites by Stir Casting Method. Silicon. 2022; 14: 5017–5027.

14. Subramani M., Huang S.J., Borodianskiy K. Effect of SiC Nanoparticles on AZ31 Magnesium Alloy. Material. 2022; 15: 1004.

15. Rao G., Vundavilli P.R., Meera Saheb K. Microstructural and Mechanical Behaviour of Al6061/ Gr/WC Hybrid Metal Matrix Composite. Advances in Materials and Manufacturing Engineering. 2020; 525–531.

16. Siva Kumar N. Mechanical and Wear Behavior of ZA-27/Sic/Gr Hybrid Metal Matrix Composites. Materials Today Proceedings. 2018; 5: 19969–19975.

17. Al-maamari A.E.A., Iqbal A.A., Nuruzzaman D.M. Mechanical and tribological characterization of self-lubricating Mg-SiC-Gr hybrid metal matrix composite (MMC) fabricated via mechanical alloying. Journal of Science: Advanced Materials and Devices. 2020.

18. Rama Kanth U., Srinivasa Rao P., Gopi Krishna M. Mechanical behaviour of fly ash/SiC particles reinforced Al-Zn alloy-based metal matrix composites fabricated by stir casting method. Journal of Materials Research and Technology. 2019; 8: 737–744.

19. Abhijit B., Dipankar Dey, Ajay B. Microstructure mechanical and wear behaviour of Al7075/SiC aluminium matrix composite fabricated by stir casting. Indian Journal of Engineering & Materials Sciences. 2021; 28: 46–54.

20. Huang S.J., Subramani M., Chiang C.C. Effect of hybrid reinforcement on microstructure and mechanical properties of AZ61 magnesium alloy processed by stir casting method. Composites communications. 2021; 25: 100772.

21. Furjan M.S.H., Hajmohammad M.H., Shen X., Dipen Kumar Rajak. Evaluation of tensile strength and elastic modulus of 7075-T6 aluminum alloy by

adding SiC reinforcing particles using vortex casting method. Journal of Alloys and Compounds. 2019; 886: 161261.

22. Aravindan S., Rao P.V., Ponappa K. Evaluation of physical and mechanical properties of AZ91D/SiC composites by two step stir casting process. Journal of Magnesium and Alloys. 2015; 3: 52–62.

23. Nourbakhsh S.H., Shahrokhian M.A., Hassanzadeh M., Atrian A. Investigation of mechanical and microstructural properties of AZ31/SiC nanocomposite fabricated by squeeze stir casting. Materials Research Express. 2018; 108380.

24. Effect of Nanofillers on the Mechanical Properties of Vinyl Ester Resin Used as a Carbon Fiber Reinforced Polymer Matrix. Advances in Science and Technology Research Journal. 2022; 16(4): 10–21.

25. Narayanasamy P., Selvakumar N. Tensile, compressive and wear behaviour of self-lubricating sintered magnesium based composites. Transactions of Nonferrous Metals Society of China. 2017; 27: 312–323.