Study of Fabrication and Mechanical Characterization of Magnesium Metal Matrix Composites

A Nirala1,2*, S Soren1, Navneet Kumar2, Raj Kumar2, AK Shrivastava2, H Prasad2, Sanjeev Kumar Sharma3 and J K Yadav2

1Department of Fuel, Minerals and Metallurgical Engineering, Indian Institute of Technology (ISM) Dhanbad, India
2Galgotias College of Engineering and Technology, Greater Noida 201310, India
3Department of Mechanical Engineering, Amity University Uttar Pradesh, Noida, India

* niralaiitk@gmail.com

Abstract. Magnesium matrix composites are used widely because of light weight, higher mechanical, and physical properties and due to that, it is used potentially in numerous applications of aviation and defense organizations. Improving specific strength, stiffness, dampening behavior, wear behavior, shrinkages, and fatigue properties, in comparison with traditional engineering materials, is greatly affected by the integration of reinforcement into the magnesium metal matrix. The present research paper describes the results and merits of various reinforcements in magnesium and its alloy and it addresses important processes, such as interfacial transformation, agglomeration, fiber-matrix interaction, and the difficulties with the distribution of reinforcement particles. The effect of strengthening on the microstructural and mechanical properties was often discussed in detail, such as Tensile properties, hardness and wear properties of the composites. Furthermore, the development and invention of new magnesium metal matrix composites are challenges for future study. The study of nanocomposites of magnesium matrix is a future research aim for the automotive/aviation sector.

1. Introduction
In particular, scientific research as well as commercial use, magnesium and its alloys have gained widespread interest as energy conservation and efficiency demands and it is increased because of lighter in weight. In automotive and aerospace applications, these properties play an important role in lowering fuel consumption and greenhouse emissions [1-3]. However, instead of their reduced creep properties low strength, and low wearing resistance at high temperatures inhibited use of magnesium alloys[5]. Reinforcements are then necessary to enhance the characteristics of the base metal (Magnesium) or alloys. Magnesium metal matrix composite may be a suitable option for aluminum metal matrix composite. The lightest materials (Mg matrix Composite), along with advantages at high temperature is high modules of elasticity, high resiliency, high creep tolerance and wear resistance. Consequently, their ductility was diminished and their general use was restricted[6,7]. A well judged choice of the reinforcement (Morphology and composition) will accomplish the desired properties. The reinforcement materials should be unwavering and non-reactive at the specified working temperature as well.

Verities of techniques have been practiced to produce magnesium matrix composite such as stir casting[8-16], squeeze stir casting[17-20], and powder metallurgy technique[21-22]. Stir casting was considered an easy to adjust and most used process. among these techniques. The near-net shaping of composites by traditional foundry processes is also an advantage of this process. The stir casting method for the mixing of reinforcing particles with the melt has taken place under the safety atmosphere of CO2/SF6 or Ar inert for preventing the burning of molten magnesium. These
protective gases can be immersed in a stir casting in the melt due to the vortices, resulting in increased porosity of the composite obtained. However, because of the oxidation environment above the melt surface, the procedure would not remove the oxide formation of elevated magnesium. The present scenario of research and manufacturing of magnesium matrix composites is also minimal relative to aluminum matrix composites. One of the major factors may be that Mg matrix composites are difficult to extract due to their high chemical activity.

It's not large enough to achieve those special properties in its purest form, on the whole, a high strength-to-weight ratio is allocated with various elements. In different nonferrous metals, magnesium is used widely as an alloying element. Magnesium alloys are also used where lightweight is of prime significance in structural and non-structural applications. Several researchers have been studied and their findings were carried out on composites with Mg metal matrix.

2. Literature Survey

2.1. Reinforcement of SiC in Mg Matrix

The wear behavior of composites (MMC), which were strengthened by carbide particulate silicon particles (SiCp) during dry sliding, and was investigated by Lim et al. [4]. The composites have marginally superior resistance to wear at minimum load, but the effect on the wear of the SiC partial reinforcement is not as conclusive at higher loads. Wear became the dominant and allowed the magnesium matrix to become distorted at the interface. Wang et al. [23] performed an ultrasonographical analysis on the novel stir casting of hardened magnesium matrix composites by micro-SiC particles. In contrast to conventional casting, the ultrasonic operation increased the mechanical behaviors of composites manufactured in various parameters substantially. Adding SiC particles means grain size is refined. Grain composite sizes declined as particle contents were increased. As the particle content grew, the modulus of elasticity and ultimate tensile strength was significantly strengthened. Kandil et al. [24] have fabricated and investigated SiC reinforced Mg alloy (AZ91) matrix composites, and found that morphological and mechanical properties are enhanced as expected. The reinforcements of SiC had been preheated for 2 hours at 1100°C to deter oxidation. Graphite crucible is used to melt matrix materials in an inert atmosphere at 725°C. The preheated SiC reinforcements have been mixed to the vortex of the molten matrix and stirred for one minute at a temperature of 700°C. Homogeneity or dispersion of the reinforcement in the matrix phase is examined through SEM (Scanning Electron Microscopy) and energy dispersion X-ray analysis. With the rise in SiC particles, the hardness is increased but the % deformation is minimized. A two-step stir casting technique was used by Lianxi et al. to fabricate SiCw/ZK51A magnesium matrix composite. The two-step stir casting technique is the latest fabrication technique and it showed improved strength and modulus of the composite than unreinforced alloy. The SiC reinforcement is a stable reinforcement of ZK51A alloy and it is confirmed by the absence of interfacial reaction between matrix and reinforcement [25].

Rzychoń et al. [26], produced magnesium alloy matrix composites reinforced with SiC particles and studied their mechanical properties. They have reinforced 45µm sized SiC in 0.3, 2, 5, and 10% volume fractions. To eliminating the oxide layer of the matrix it is preheated in an inert atmosphere in the furnace at 450°C and temperature raised to 720°C to melt the matrix phase and hold for 20 minutes and obtained a homogeneous temperature to entire molten metal. Preheated reinforcements have been added to the molten matrix as predetermined content of the reinforcements. Agitation of the slurry has been done for 10 minutes by stainless steel stirrer (stirrer speed 150 rpm) to get a homogeneous mixture. Now at the end of the process, a uniformly distributed slurry of composites is poured in cylindrical graphite mold of 4 cm diameter at 720°C. The microstructural examination has been performed by Scanning electron microscopy (SEM) and optical microscopy to demonstrate a consistent reinforcement distribution in the
matrix. The composite hardness is improved but the final strength and strain are decreased by increasing SiC content.

2.2 Al₂O₃ Reinforced Mg-MMC

The magnesium alloy matrix (AM100) of alumina (Al₂O₃) reinforced composites had been made by Jayalakshmi et al. using squeeze-casting methodologies. There were reinforcements of 15%, 20%, and 25% Al₂O₃ volume fraction added to the matrix. They studied the highest hardness (165 BHN) for 25% reinforced and it about twice as much as a base alloy. Tensile properties have been investigated at room temperature, 100, 150, and 200°C. The unreinforced base alloy's overall tensile strength is highly susceptible to temperature and simultaneously raising temperature reduces the strength of the composites. Temperature influences the strength of the composites, and it has been found that strength at test temperature is 1/3rd of room temperature strength. Present research findings also explained % elongation was enhanced by raising the temperature [27].

The authors explored the tensile behavior and microstructure of the fibers-ceramic particles in the squeeze casting of the Magnesium AM60 hybrid-composite. Composite AM60 based hybrid incorporating alumina fibers enhancing microstructure and tensile behavior. Microscopy of the optical and scanning electron consistently demonstrates strengthening without agglomeration in an alloy matrix. The composite reinforced with alumina has examined their mechanical properties and found improved modulus of elasticity, tensile strength, and hardness [28].

Al₂O₃ reinforced Mg alloy (AZ31B) composites produced by the disintegrated melt deposition technique, subsequently machined followed by hot extruded by authors and they have investigated tribological properties of Mg alloy (AZ31B) composites. The wear properties have been studied at 10 m/s speed and 10 N and 30 N load. At low speeds, composite wear values are greater than Mg alloy and it is increased by increasing the nano-alumina reinforcement. The lower output strengths of the composites are largely responsible [29].

2.3 TiC Reinforced Mg-MMC

The wear behavior of TiC reinforced Mg MMC’s are manufactured using the powder metallurgical (P/M) process, and studied by Narayanasamy et al. They did mix 0, 5, 10, 15, and 20 wt. % of reinforcement in magnesium matrix. In order to explain the distribution of TiC particles in the magnesium matrix, microstructural analysis of as-sintered specimens is carried out. Furthermore, the impact of TiC is to be examined on the hardness and wear properties. Inhomogeneous and agglomerated TiC particles were found on the surface of Mg–20TiC composites when the TiC content was greater than 15%. When the TiC content is increased, the density of sintered composites increases and the hardness increases up to 15% volume fraction of TiC. When the TiC content is increased from 15% to 20%, there is a slight improvement in hardness, and the wear loss of composites is nearly equal. As compared to pure Mg, Mg composites made with TiC with a different volume fraction have better microhardness, less wear, and a higher friction coefficient[30].

| S.No. | Reinforcement | Finding | Reference |
|-------|---------------|---------|-----------|
| 1     | SiCp          | Wear properties enhanced | C. Y. H. Lim et al. [4] |
Micro-SiC reinforcements improved the ultimate tensile strength, yield strength, and elastic modulus. X. J. Wang et al. [23]

The strain decreases by increasing the SiC particles' volume fraction. A. Kandil et al. [24]

In comparison to the unreinforced matrix alloy, modulus and mechanical strength increase considerably. Improved hardness value, ultimate tensile strength but decreases % elongation with the increase of SiC. H Lianxi et al. [25]

SiC

Tensile strength decreases and strain improved at test temperature compared to room temperature. Jayalakshmi et al. [27]

Al$_2$O$_3$

In contrast to matrix alloy, the mechanical properties such as elastic module, tensile strength, and hardness increased. Zhang et al. [28]

Al$_2$O$_3$

With the rise in nano-alumina, wear resistance has improved. Nguyen et al. [29]

TiC

Density and wear properties enhanced by TiC. P. Narayanasamy et al. [30]

B$_4$C

Enhanced wear properties by addition of B$_4$C. Q.C. Jiang et al. [31]

Graphite particle

By increasing the reinforcements strain value increases dramatically, but when it reaches 15%, it decreases. Aatthisugan et al. [32]

2.4 Mg-MMC’s Reinforced with B$_4$C
The research analyzed B$_4$C particulates made of powder metallurgy (P/M) process, which have been reinforced with different fractions of 10, 15% and 20%. The authors studied precipitation phenomena in magnesium matrix composites of B$_4$C reinforcement. They inferred that the ceramic reinforcement promotes Mg$_{17}$Al$_{12}$ nucleation at the reinforcement-matrix interface by favoring the heterogeneous precipitation process. The inclusion of B$_4$C particulates increases the composites' hardness greatly. When compared to a 10% B$_4$C/Mg composite, the wear rate of a 20% B$_4$C/Mg composite is smaller. The P/M process was used to successfully fabricate magnesium matrix composites that were reinforced with 10, 15, and 20% B$_4$C particulates. The hardness and wear resistance of the composite increased after B$_4$C particulate was incorporated into the matrix[31].

2.5 Graphite Particulate Reinforced Mg-MMC
Aatthisugan et al. [32] stated that Mg matrix composites reinforced by graphite particles (particle size of 50 μm reinforced 5-20%) and stir casting methods have been employed to fabricate the composites. A dynamic mechanical analyzer has been used to calculate the damping capacities of the composites. The findings show that graphite particles have a significant impact on the damping capacities of the
graphite reinforced composites. The strain of the composites increases initially up to 15 volume % graphite reinforcement but decreases when graphite is more than 15 volume %.

2.6 Fe$_2$O$_3$ Reinforced Hybrid Mg-MMC

According to Rodríguez, C. Gómez et al., nano-alumina or nano-iron oxide was applied to the Magnesia matrix up to 5% by weight. X-ray diffraction (XRD) and scanning electron microscopy (SEM) was used to investigate the crystalline phases and microstructure properties of specimens sintered at 1600 °C for 4 hours in an electric furnace. Density and porosity are used to describe the physical properties. A cold crushing strength (CCS) test was used to investigate the mechanical properties. Also, the chemical activity of slag attacks was investigated. The presence of nano-iron oxide in the formation of magnesioferrite spinel induced by the magnesium matrix was thus found which enhanced the sintering operation. The bonding structure was also affected by nano-iron oxide due to a direct bonding enhancement. The inclusion of nano-alumina in the magnesia matrix, on the other hand, caused magnesium-aluminate spinel formation, resulting in lower properties than those obtained by adding nano-iron oxide[33].

3. Conclusion

Many conflicts must be overcome to enhance the engineering use of magnesium matrix composites, such as manufacturing methods, reinforcement effects, and mechanical properties reinforcement effect on microstructure and mechanical properties. From the previous works, the key results were drawn between Magnesium metal matrix and reinforcements as shown in Table.1 and it showed the effects of reinforcements by addition of reinforcements. The current study emphasized that reinforcements such as SiC, B$_4$C, and Al$_2$O$_3$ improved mechanical properties such as tensile strength, yield strength, strain, and hardness. However, the addition of TiC, nano, and micro-sized graphite particles improved the wear properties. The application of nanoparticles and their impact on mechanical/physical/chemical properties may be affected unexpectedly, and future research will be required to predict such possibilities.

References

[1] S. Nimityongskul, M. Jones, H. Choi, R. Lakes, S. Kou and X. Li // Mater. Sci. Eng. A 527 (2010) 2104.

[2] B.L. Mordike and T. Ebert // Mater. Sci. Eng. A 302 (2004) 37.

[3] M. Habibnejad-Korayem, R. Mahmudi and W.J. Poole // Mater. Sci. Eng. A 519 (2009)198

[4] C.Y.H Lim, S.C Lim, M Gupta//Wear, Volume 255, Issues 1–6,2003,Pages 629-637,ISSN 0043-1648, https://doi.org/10.1016/S0043-1648(03)00121-2

[5] P. Poddar, V.C. Srivastava, P.K. De and K.L. Sahoo // Mater. Sci. Eng. A (2007) 357.

[6] M.Y. Zheng, W.C. Zhang, K. Wu and C.K. Yao // J. Mater. Sci. 38 (2003) 2647.

[7] V. Viswanathan, T. Laha, K. Balani, A. Agarwal and S. Seal // Mater. Sci. Eng. R 54(2006)121

[8] V. Laurent, P. Jarry, G. Regazzoni, and D. Apelian: //J. Mater. Sci., 1992, 27, pp. 4447-59.

[9] A. Martin and J. Llorca: //Mater. Sci. Eng., 1995, A201, pp. 77-87.

[10] R.A. Saravanan and M.K. Surappa://Mater. Sci. Eng., 2000, A276, pp. 108-16.

[11] S.C. Sharma, B. Anand, and M. Krishna: // Wear, 2000, 241, pp. 33-40.

[12] A. Bochenek and K.N. Braszczyńska: //Mater. Sci. Eng., 2000, 290A, pp. 122-27.

[13] Y. Cai, M.J. Tan, G.J. Shen, and H.Q. Su: // Mater. Sci. Eng., 2000, 282A, pp. 232-39.

[14] H. Hu: // Scripta Mater., 1998, 39, pp. 1015-22.
[15] T. Imai, S.W. Lim, D. Jiang, Y. Nishida, and T. Imura: //Mater. Sci. Forum, 1999, 304/306, pp. 315-20.
[16] A. Luo//Metall. Mater. Trans., 1995, 26A, pp. 2445-55.
[17] C. Mayencourt and R. Schaller//Mater. Sci. Eng.., 2002, A325, pp. 286-91.
[18] M. Yoshida, S. Takeuchi, J. Pan, G. Sasaki, N. Fuyama, T. Fujii, and H. Fukunaga//Adv. Compos. Mater., 1999, 8, pp. 258-68.
[19] L. Hu and E. Wang: // Mater. Sci. Eng., 2000, 278A, pp. 267-71.
[20] M.Y. Zheng, K. Wu, and C.K. Yao//Mater. Sci. Eng., 2001, 318A, pp. 50-56.
[21] H. Ferkel and B.L. Mordike: // Mater. Sci. Eng., 2001, 298, pp. 193-99.
[22] B.W. Chua, L. Lu, and M.O. Lai//Compos. Struct., 1999, 47, pp. 595-601.
[23] X.J. Wang, N.Z. Wang, L.Y. Wang, X.S. Hu, K. Wu, Y.Q. Wang, Y.D. Huang//Materials & Design, Volume 57,2014, Pages 638-645, ISSN 0261-3069, https://doi.org/10.1016/j.matdes.2014.01.022
[24] Kandil, A// Journal of Engineering Sciences, 40, 1, 255–270, 2012. https://journals.ekb.eg/article_112726.html
[25] Lianxi, H. and Erde, W.//Materials Science and Engineering, A, 267–278, 2000. https://www.mdpi.com/2075-4701/8/6/431/pdf
[26] Rzychoń, T., Dybowskii, B., Gryc, A., Dudek, M.//Archives of Foundry Engineering, 15, 1, 99–102, 2015.
[27] S. Jayalakshmi, S.V. Kailas, S. Seshan//Composites: Part A 33 (2002) 1135–1140. http://library.nmlindia.org/FullText/CA330281135.pdf
[28] Zhang, Xuezhi & Zhang, Qiang & Hu, Henry//Materials Science and Engineering: A. 607. (2014) 269–276. 10.1016/j.msea.2014.03.069..
[29] Nguyen, Q. B., Sim, Y. H. M., Gupta, M., & Lim, C. Y. H.//Tribology International, 82(Part B), (2015) 464-471. https://doi.org/10.1016/j.triboint.2014.02.024
[30] P. Narayanasamy, N. Selvakumar, P. Balasundar//Materials Today: Proceedings, Volume 5, Issue 2, Part 2,2018, Pages 6570-6578, ISSN 2214-7853
[31] Q.C. Jiang, H.Y. Wang, B.X. Ma, Y. Wang, F. Zhao,//Journal of Alloys and Compounds,Volume 386, Issues 1–2,2005, Pages 177-181, ISSN 0925-8388 http://doi.org/10.22214/ijraset.2017.1004
[32] Aatthisugan, I., Rose, A. R., & Jebadurai, D. S// Journal of magnesium and alloys, 5(1), (2017) 20-25 https://doi.org/10.1016/j.jma.2016.12.004
[33] Rodriguez, C. G., Roy, T. D., Shahi, S., Rodriguez, G. C., Quiñonez, L. G., Rodríguez, E., ... & Aguilar-Martínez, J. A. //Ceramics International, 41(6), (2015) 7751-7758.