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Effect of MgO addition on physico-chemical, mechanical and thermal behaviour of Al/Si_3N_4 composite material developed via hybrid casting technique

Shashi Prakash Dwivedi[a,*], Ashok Kumar Mishra[b] and V. R. Mishra[a]
[a]*G. L. Bajaj Institute of Technology & Management, Greater Noida, Gautam Buddha Nagar, U.P., India*
[b]*Mechanical Engineering Department, SRM University, Sonipat, Haryana, India*

In the present investigation, aluminium based composite material developed by using Si_3N_4 as primary reinforcement material and MgO as secondary reinforcement material by hybrid casting techniques. The microstructure of composite developed by hybrid casting technique showed a uniform distribution of Si_3N_4 and MgO particles in the AA2024 aluminium alloy. Maximum tensile strength and hardness were found to be 214.5 MPa and 78 BHN for heat-treated AA2024/7.5% Si_3N_4/5% MgO composite material. Minimum thermal expansion was also found for AA2024/7.5% Si_3N_4/5% MgO composite material. However, minimum corrosion loss was found for AA2024/10% Si_3N_4/2.5% MgO composite material. Though, toughness and ductility were reduced by adding the Si_3N_4 and MgO particles in AA2024 aluminium alloy. XRD analysis of AA2024/7.5% Si_3N_4/5% MgO composite material was also observed to see the effect of Si_3N_4 and MgO particles addition in AA2024 aluminium alloy.

Keywords: Wettability; XRD; Thermal expansion; Corrosion loss; Si_3N_4, MgO.

1. Introduction

Aluminium based metal matrix composites are used in various industrial application where high specific strength and low corrosion rate materials are required. Its demand in aircraft industries and automobile industries is mainly due to its low cost of processing and a broad range of properties [1]. Aluminium based metal matrix composite (AMC) has been used in the design of specific aerospace and automotive components such as ventral fins, fuel excess door covers, rotating blades sleeves, gear parts, crankshafts, and suspension arms [2]. Among all aluminium alloys, AA2024 alloy is broadly used in aircraft industries in making wing and fuselage structure under simple tension because of its high fatigue, and tensile strength. The major component of AA2024 aluminium alloy is copper. The copper provides substantial increases in strength and facilitates precipitation hardening. The introduction of copper to aluminium also reduces corrosion resistance. The susceptibility to solidification cracking of aluminium-copper alloys is increased [3].

Magnesia or magnesium oxide (MgO) is an alkaline earth metal oxide. It is obtained from the calcination of naturally occurring minerals. Other important sources of magnesium oxide are seawater, underground deposits of brine and deep salt beds where magnesium hydroxide [$Mg(OH)_2$] is processed [4]. Magnesium is the eighth-most abundant element and equals about two per cent of the earth's crust and typically 0.12% of seawater. Both $MgCO_3$ and $Mg(OH)_2$ are converted to MgO by calcinations [5]. It has an empirical formula of MgO and consists of a lattice of Mg^{2+} ions and O^{2-} ions held together by ionic bonding. Magnesium hydroxide forms in the presence of water ($MgO + H_2O \rightarrow Mg(OH)_2$), but it can be reversed by heating it to separate moisture [6]. Silicon nitride (Si_3N_4) is a chemical compound of the elements silicon and nitrogen. It is the most thermodynamically stable of the silicon nitrides. Si_3N_4 is prepared by heating powdered silicon between 1,300 °C and 1,400 °C in a nitrogen environment by chemical reaction ($3Si+2\ N_2 \rightarrow Si_3N_4$). Si_3N_4 contains silicon (Si) [7]. The addition of silicon (present in Si_3N_4) to aluminium during casting reduces melting temperature and improves fluidity. Si_3N_4 alone in aluminium produces a non-heat-treatable aluminium based composite material; however, in combination with MgO enhanced precipitation hardening of aluminium based composite material. The addition of MgO and Si_3N_4 to aluminium produces the compound magnesium-silicide (Mg_2Si) [8]. The formation of this compound enhanced the heat treatable property of aluminium based composite material.

In conventional development of composite material by the mechanical stir casting technique, some porosity developed inside the solidified composite. While, during the development of metal matrix composite via electromagnetic stir casting technique, most of the ceramic particles settled down at the bottom of the solidified

*Corresponding author:
Tel : +91120-3272515
Fax: +91120-2323817
E-mail: spdglb@gmail.com

composite. Resulting, agglomeration of reinforcement particles was observed. However, in the electromagnetic stir casting process, very less amount of porosity developed inside the composite. Keeping these facts in the mind, In the present investigation, an attempt was made to develop the Si_3N_4 and MgO reinforced composite via hybrid casting techniques to avoid agglomeration of reinforcement particles and minimize the porosity. In the hybrid casting process, composite material developed by stir casting process, then in mushy zone transferred to electromagnetic stir casting process to obtain final composite. Wettability of composite materials refers to the interaction between reinforcement particles and matrix material. Good interfacial reaction layer between the matrix material and reinforcement particles indicates proper wettability [9]. Proper wettability between reinforcement and matrix material always play a significant role in enhancing the mechanical properties. It was observed from the literature that by using MgO powder as reinforcement material in aluminium base matrix, mechanical properties such as tensile strength and hardness were much improved [10]. MgO powder also enhanced the wettability of aluminium based composite material with reinforcement particles. Keeping these facts in the mind, in this study, MgO powder is used as a secondary reinforcement material with Si_3N_4 in development of aluminium based composite material [11].

Table 1 shows the summary of composite material developed by MgO and Si_3N_4 reinforcement particles. Some researchers (Table 1) developed aluminium based hybrid composite material by using Si_3N_4 as primary reinforcement material and ceramic particles such as Gr, AlN, ZrB_2, Al_2O_3 etc. as secondary reinforcement material. In the same way, some researchers (Table 1) developed aluminium based hybrid composite material by using MgO as primary reinforcement material and ceramic particles such as Al_2O_3 as secondary reinforcement material. But, from archival literature, it was observed that no researcher used MgO powder and Si_3N_4 particles together in the development of aluminium-based hybrid composite material by hybrid casting technique. Keeping these facts in the mind; in the present investigation, MgO powder was added as a supplementary reinforcement in Al/Si_3N_4 composite to enhance wettability property. Properties such as tensile strength, hardness, toughness, ductility, thermal expansion and corrosion test were carried out to observe the MgO addition effect in Al/Si_3N_4 composite material. Heat treatment of composite material was carried out to enhance further mechanical properties of the composite.

Materials and Methods

Experimental procedure

In this study, AA2024 is considered as a matrix material. Measured mechanical properties of AA2024 alloy are shown in Table 2. Silicon Nitride (Si_3N_4) is considered as a primary reinforcement material. Silicon nitride (Si_3N_4) attributes an excellent combination of various properties. It is almost light as silicon carbide (SiC), but it gives excellent thermal shock resistance to material [12]. Fracture toughness of traditional ceramic particles such as SiC, Al_2O_3 and B_4C is very low. Fracture toughness of silicon nitride (Si_3N_4) is high as compared to SiC, Al_2O_3 and B_4C. Magnesium oxide

Table 1. Composite material developed by MgO and Si_3N_4 reinforcement particles.

Ref. No.	Authors (Year)	Developed Composite	Investigated properties
12	N. Mathan Kumar et al. (2016)	Al 2618/Si3N4/AlN/ZrB_2 Composite	The tribological and mechanical properties
13	R. Ambigai et al. (2017)	Al-Gr-Si_3N_4 hybrid composite	Tribological behaviour
14	Qingfei Xu et al. (2018)	(AlN + Si_3N_4)/Al composite	Mechanical properties
15	R.Ambigai et al. (2019)	Al-Gr-Si_3N_4 hybrid composite	Tribological behaviour
16	Chenxu Zhang et al. (2019)	Al/β-Si_3N_4 whiskers	Microstructure and mechanical properties
17	Chenxu Zhang et al. (2019)	Al/β-Si_3N_4 whiskers	Mechanical properties and tribological behaviours
18	Qingfei Xu et al. (2018)	AlN + Si_3N_4/Al composite	The tensile properties at room temperature and high temperature (350 °C)
19	Peng Jiang et al. (2017)	Al-Si_3N_4-Al_2O_3 composite	Thermal dynamic analysis
20	Chenxu Zhang (2017)	Al/β-Si_3N_4 whiskers	Densification and tensile behaviour of composites
21	A. Lotfy et al. (2018)	Al-5%Cu / BN and Si_3N_4 composites	Microstructure, thermal and mechanical properties
22	Ehsan Ghasali et al. (2019)	Mg/Al_2O_3 and Mg/Si_3N_4 metal matrix composites	Corrosion behaviour and in-vitro bioactivity
23	Yang Sun et al. (2018)	Al-Si-MgO composites	XRD, SEM and EDS
24	Mingwei Yan et al. (2018)	Al-Al_2O_3-MgO composite	XRD, SEM and EDS, evolution mechanism of MgAlON
25	Muharrem Pul et al. (2014)	Al-MgO metal matrix composites	Mechanical and wear behaviour
26	K.V. Rao et al. (2017)	Al-7075/MgO composite	Sliding wear Behavior
27	H. Abdizadeh et al. (2014)	A356/MgO nanoparticles composite	Microstructure and mechanical properties
28	S.M.Latifi et al. (2017)	Mg-Al spinel ($MgAl_2O_4$) and MgO/Al_2O_3 nanocomposites	Structural properties

Table 2. Measured properties of AA2024 alloy.

Melting point	580 °C
Density (g/cm^3)	2.78
Tensile Strength (MPa)	180
Hardness (BHN)	48
Toughness (Joule)	11
Ductility (percentage elongation)	12

(MgO) particles were considered as a secondary reinforcement material to enhance further mechanical properties of composites.

Fig. 1(a) shows a schematic diagram of the stir casting technique. Matrix material was heated in muffle furnace up to 750 °C. Preheated reinforcement particles (Si_3N_4 and MgO) were added in matrix material at the temperature 700 °C. Stir casting process involves stirring of melt composite material, in which the melt matrix material with reinforcement particles is stirred which exposes the melt composite material surface to the atmosphere which tends to continuous oxidation of aluminium melt. Resulting, the wettability of the reinforcement particles with aluminium reduces and the reinforcement particles remain unmixed. Therefore adding wetting agents such as TiK_2F_6, borax and magnesium in the melt is an alternate solution of this problem and widely used for the fabrication of aluminium based composite material. In this study, MgO was added in Al/Si_3N_4 composite material. Fig. 1(a) shows the microstructure of composite material obtained from stir casting technique. Non-uniform distribution of reinforcement particles in matrix material was observed by using stir casting technique.

Fig. 1(b) shows a schematic diagram of the electromagnetic stir casting technique. AA2024 aluminium alloy was heated in muffle furnace above its liquidus temperature (650 °C). Si_3N_4 and MgO reinforcement particles were also preheated before mixing to avoid wettability problem. Melt AA2024 matrix material was poured into a graphite crucible for stirring by the electromagnetic field of the motor. The traditional EMS (electromagnetic stirring) process mainly works in the mushy zone of the alloy, i.e., supercooled + EMS. There are two hypotheses to explain the formation mechanism

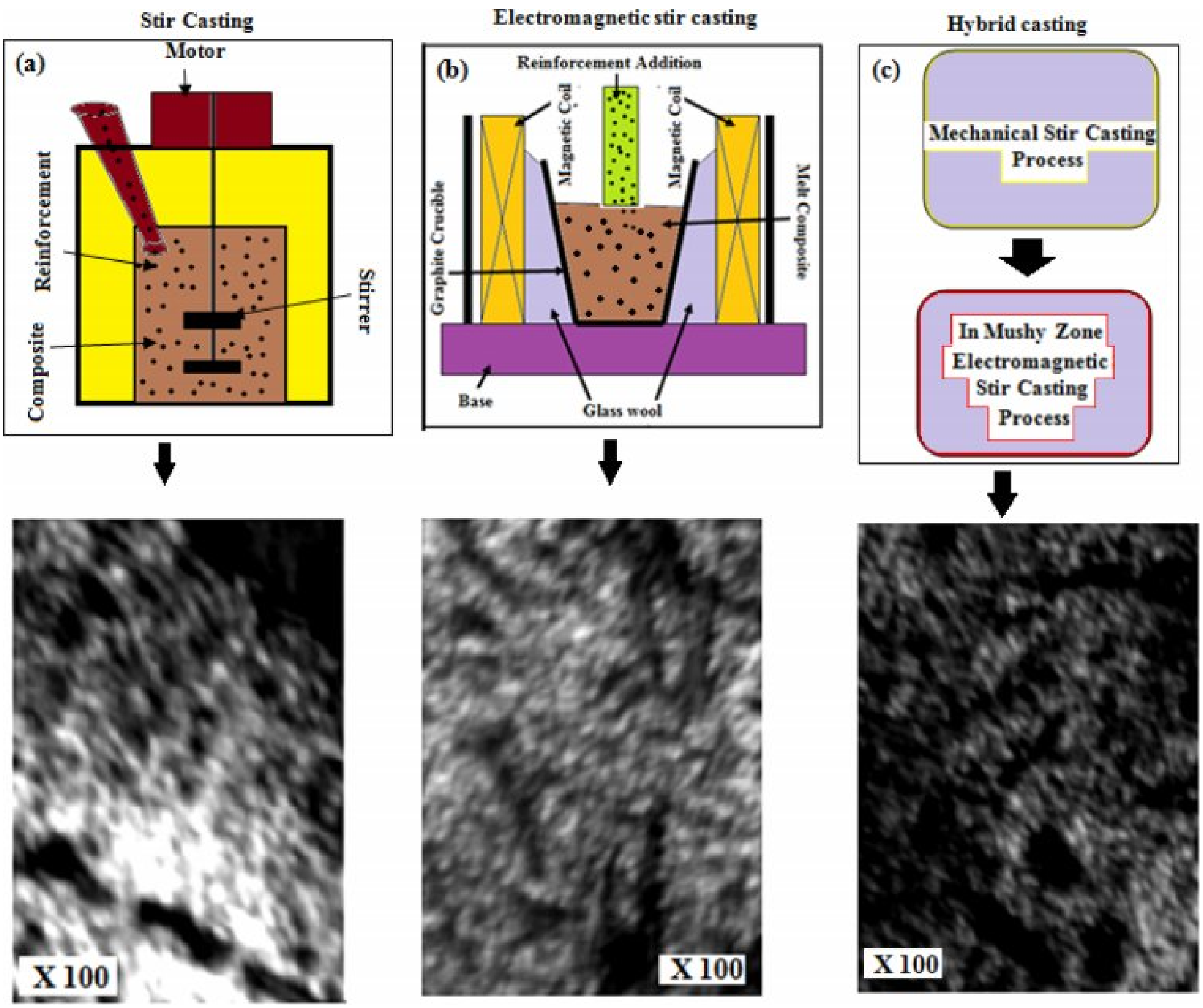


Fig. 1. Development of composite by; (a) Stir casting technique, (b) Electromagnetic stir casting technique, (c) Hybrid casting technique.

Table 3. Stir casting parameters for the development of composite.

Casting Parameters	Parameter setting
Stirring Temperature	700 °C
Blades speed (rotational speed of shaft in RPM)/ stirring speed	240
Time to hold/ stirring time	600 seconds
Blade angle	45°

Table 4. Electromagnetic stir casting process parameters [33].

S.No	Parameters	Values set as
1	Voltage supply	180 V
2	Current	18 Ampere
3	Stirring speed	215 rpm
4	Stirring time	3 minutes
5	Stirring temperature	700 °C

of non-dendrites, that is, mechanical fragmentation and the root remelting of the dendrite arms [29]. The homogenization of the temperature and constituents caused by the forced convection during stirring can prompt the nucleation of the primary α-Al phase and restrain the growth of dendrites. The argon gas was used during the mixing of reinforcement particles in the melt of AA2024 alloy. Fig. 1(b) shows the microstructure of composite developed by electromagnetic stir casting technique. Less amount of porosity was observed. However, some agglomeration of reinforcement particles was also identified [30].

Fig. 1(c) shows the hybrid casting technique. Firstly, preheated reinforcement particles were mixed in the stir casting process at parameters shown in Table 3. After mixing the reinforcement particles in mechanical stir casting, composite in the mushy zone was transferred to electromagnetic stir casting route. Here, a mixed composite material in the mushy zone was stirred by the electromagnetic field [31]. Table 4 shows the parameters at which hybrid composite material was prepared. Uniform microstructure with less porosity was obtained by the development of hybrid casting technique process. Hence, the entire composite for this study was prepared by the hybrid casting technique as shown in Table 5.

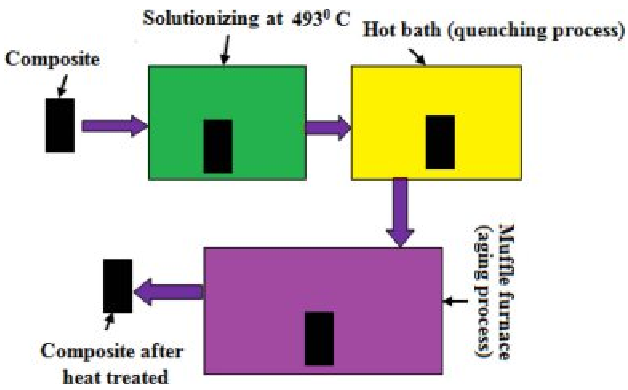


Fig. 2. Heat treatment process of composites [32].

Precipitations hardening process

The precipitations hardening process is used to improve the yield strength of composite as well as other properties such as hardness and fatigue strength. Schematic diagram of the precipitation-hardening process is shown in Fig. 4. Precipitation hardening process was carried out in three different phases. Firstly, the solutionizing process was done at a temperature of 530 °C for 4.5 hours and then quenched in a hot bath at temperature 70 °C. In muffle furnace ageing process was carried out for 13.5 hours [32].

Mechanical characterizations and sample preparation

The developed composites were characterized in terms of microstructure, tensile strength, hardness (10 mm × 10 mm × 25 mm), toughness (10 mm × 10 mm × 55 mm with 45° V notch at center of 2 mm depth according to ASTM A370 standard), thermal expansion and corrosion loss and XRD of composite. The tensile sample was prepared on a lathe machine. The tensile samples were tested at room temperature. Tensile samples were prepared according to ASTM B557 standard (Test methods for tension testing wrought and cast aluminium and magnesium-alloy products). The

Table 5. Composite developed by the hybrid casting technique.

S. No.	Sample Designation	Composition	Wt.% of Si$_3$N$_4$ Particles	Wt.% of MgO Powder
1	G_1	Al + 0% Si$_3$N$_4$ + 12.5% MgO	0	12.5%
2	G_2	Al + 2.5% Si$_3$N$_4$ + 10% MgO	2.5%	10%
3	G_3	Al + 5% Si$_3$N$_4$ + 7.5% MgO	5%	7.5%
4	G_4	Al + 7.5% Si$_3$N$_4$ + 5% MgO	7.5%	5%
5	G_5	Al + 10% Si$_3$N$_4$ + 2.5% MgO	10%	2.5%
6	G_6	Al + 12.5% Si$_3$N$_4$ + 0% MgO	12.5%	0%
7	G_7	Al + 2.5% Si$_3$N$_4$ + 2.5% MgO	2.5%	2.5%
8	G_8	Al + 5% Si$_3$N$_4$ + 5% MgO	5%	5%
9	G_9	Al + 7.5% Si$_3$N$_4$ + 7.5% MgO	7.5%	7.5%
10	G_{10}	Al + 10% Si$_3$N$_4$ + 10% MgO	10%	10%
11	G_{11}	Al + 12.5% Si$_3$N$_4$ + 12.5% MgO	12.5%	12.5%

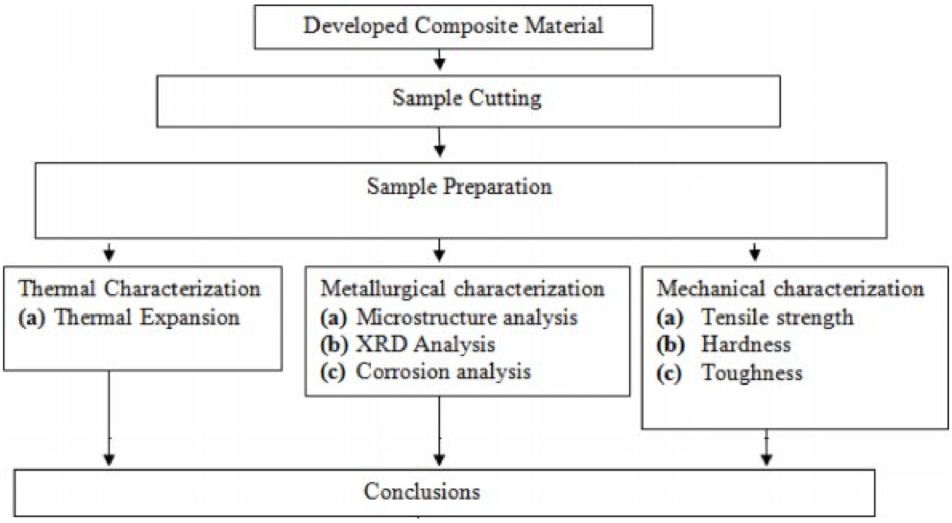


Fig. 3. Flow chart of experimental techniques followed.

diameter of the sample prepared was 6 mm and the gauge length was 36 mm. Flow chart of experimental techniques followed for the present study is shown in Fig. 3.

Results and Discussion

Microstructure analysis

Microstructure analysis was carried out to identify the distribution of reinforcement particles in the matrix material. MgO powder was used to enhance wettability property of aluminium based composite with Si_3N_4 reinforcement particles. However, MgO was also responsible to improve tensile strength and hardness of composites. Scanning electron microscopy (SEM) is used to observe the distribution of reinforcement particles. Fig. 4(a) shows the microstructure of composite (upper layer) developed by stir casting technique. It can be observed that most of the reinforcement particles are settled down at the bottom. Porosity and cracks can be seen inside the composite developed through mechanical stir casting technique. Fig. 4(b) shows the microstructure of the composite developed by the electromagnetic stir casting process. However, less amount of porosity and cracks were observed in composites developed via electromagnetic stir casting process. But, in this process also most of the ceramic particles were settled down at the bottom. Fig. 4(c) shows the microstructure of composite developed through hybrid casting technique. In this technique; firstly, reinforcement materials were mixed in melt matrix material by mechanical stir casting technique. When reinforcement particles were mixed properly by a stirrer, then composite with crucible in the mushy zone was transferred to the electromagnetic stir casting process. Composite material began to rotate in the mushy zone by the electromagnetic force produced developed from magnetic flux. The obtained composite material showed the proper distribution of reinforcement because in mushy zone reinforcement materials were not able to settle down at the bottom. Further, the grain structure of composite material was also improved as shown in Fig. 4(c). In this study, MgO powder was used as a secondary reinforcement material. MgO powder is also responsible in minimization of porosity and inclusion inside the composite. Fig. 4(d) shows that the grain structure of the composite more refined after the heat-treatment process. Microstructure image showed that the hybrid casting technique showed better results as compared to other technique. Hence, for further study, the hybrid casting technique is used to develop aluminium based composite material reinforced with MgO powder Si_3N_4 ceramic particles.

Tensile strength analysis

Fig. 5 shows the tensile strength of Si_3N_4 and MgO reinforced AA2024 aluminium-based hybrid metal matrix composite developed through hybrid casting technique. It was observed that by increasing the percentage of Si_3N_4 in AA2024/MgO composite tensile strength is continuously increases. The addition of magnesium oxide (MgO) to AA2024/Si_3N_4 composite increases strength through solid solution strengthening and improves their strain hardening ability. But, much higher content of MgO is not the dominant mechanism for densification. It is likely that the extra MgO is located in the grain boundaries and acts as a grain growth inhibitor [13]. Hence, beyond the 5% of MgO addition in AA2024/Si_3N_4 composite, tensile strength began to decreases. Maximum tensile strength was found to be 204 MPa for AA2024/7.5 wt% Si_3N_4/5 wt% MgO hybrid metal matrix composite. AA2024 is a good heat treatable material. Keeping this fact in the mind, heat treatment of composite material was also carried out in this study. It was observed that the tensile strength of composite significantly improved after the heat treatment process. Tensile strength was further

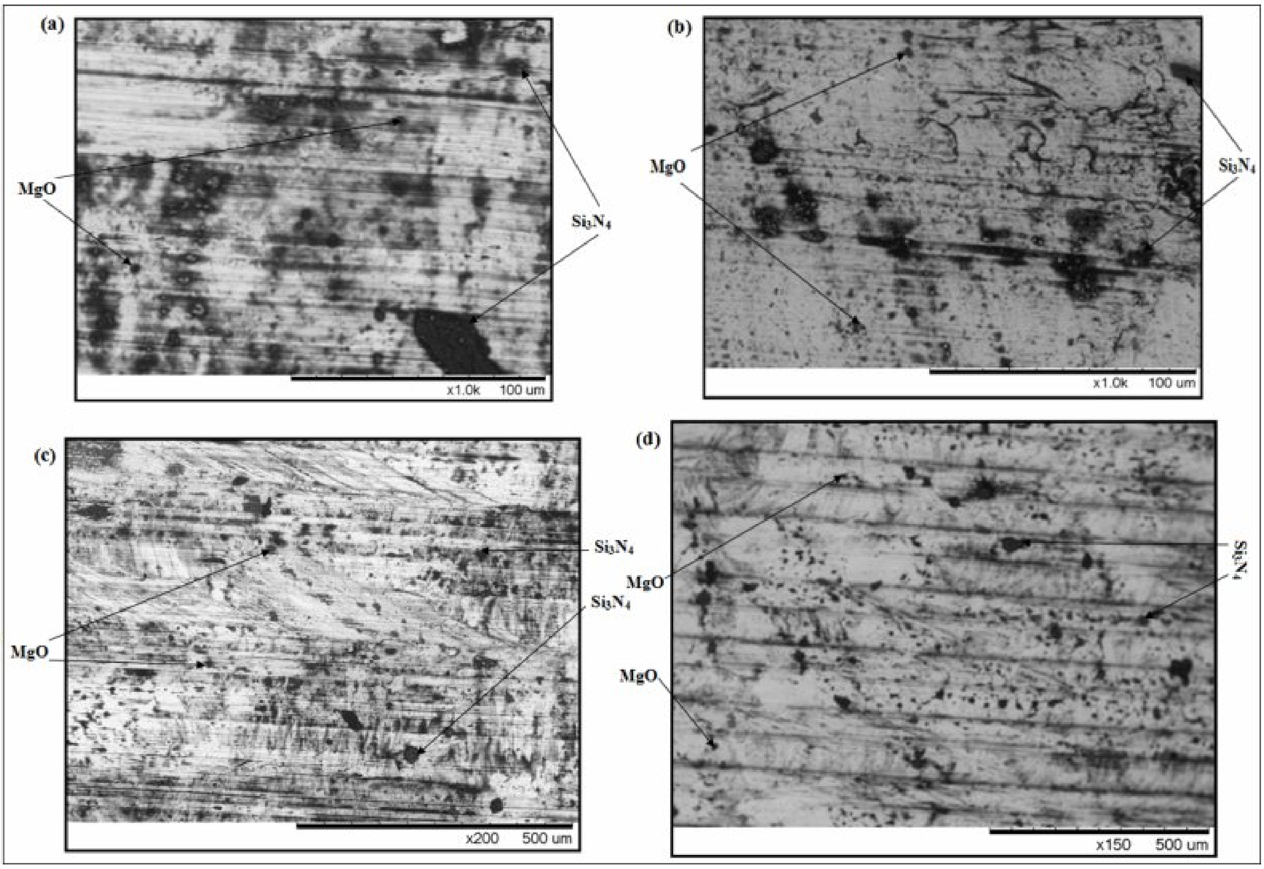
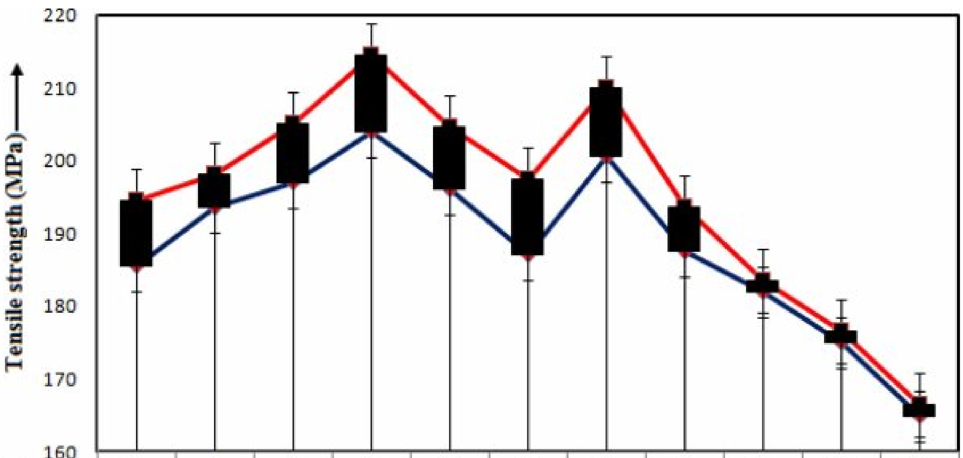


Fig. 4. SEM image of upper surface composite developed by; (a) mechanical stir casting technique, (b) electromagnetic stir casting technique, (c) hybrid stir casting technique, (d) hybrid stir casting technique after heat treatment.



Sample No.	1	2	3	4	5	6	7	8	9	10	11
As cast	185.5	193.5	197	204	196	187	200.5	187.5	182	175	165
As heat treated	194.5	198	205	214.5	204.5	197.5	210	193.5	183.5	176.5	166.5

Fig. 5. Tensile strength of composite materials.

improved after the heat treatment process of AA2024/ 7.5 wt% Si_3N_4/5 wt% MgO composite material. In this study, MgO powder was used to enhance the wettability of Si_3N_4 with AA2014 aluminium alloy.

N. Mathan Kumar et al. [12] mixed Si_3N_4 (Silicon Nitride), AlN (Aluminium Nitride) & Zrb_2 (Zirconium Boride) with wt.% of (0,2,4,6,8) in Al 2618 aluminium alloy. Ultimate tensile strength of Al 2618 was 440 MPa. Ultimate tensile strength of Al 2618 with 8 wt.% reinforcement was 493 MPa. Results showed that

12.045% tensile strength improved. While in the present study, after the addition of 7.5% Si_3N_4 and 5% MgO in AA2024 aluminium alloy, about 13.33% tensile strength was improved with respect to the base metal. It was also notified that after the heat treatment of AA2024/ 7.5% Si_3N_4/5% MgO, about 19.16% tensile strength was improved. MgO has adequate atmospheric resistance and moderate strength. Magnesium (Mg) also enhanced the castability of the composite. MgO powder addition in aluminium has also improved the wettability of reinforcement particles with the aluminium matrix material.

Hardness analysis

Fig. 6 shows the hardness of AA2024/Si_3N_4/MgO hybrid metal matrix composite before and after heat treatment developed by hybrid casting technique. Hardness is increased by increasing the weight percent of MgO powder up to 5% in AA2024/7.5% Si_3N_4 composite. XRD results (Fig. 11) shows the presence of hard phases such as Si_3N_4, Fe_2O_3 and MgO in AA2024/7.5% Si_3N_4/5% MgO composite material. Presence of these phases was responsible for enhancing the hardness of the composite. Proper wettability and uniform distribution of reinforcement particles in a matrix material were also played a significant role in enhancing the hardness of the composite. When Si_3N_4 and MgO particles increase beyond 7.5% and 5% respectively in AA2024 alloy, hardness began to decreases. Air is interrupted inside the composite material with reinforcement particles when weight percent of reinforcement increases (beyond 7.5% for Si_3N_4 and 5% for MgO). Maximum hardness was found to be 73 BHN of AA2024/7.5% Si_3N_4/5% MgO hybrid metal matrix composite.

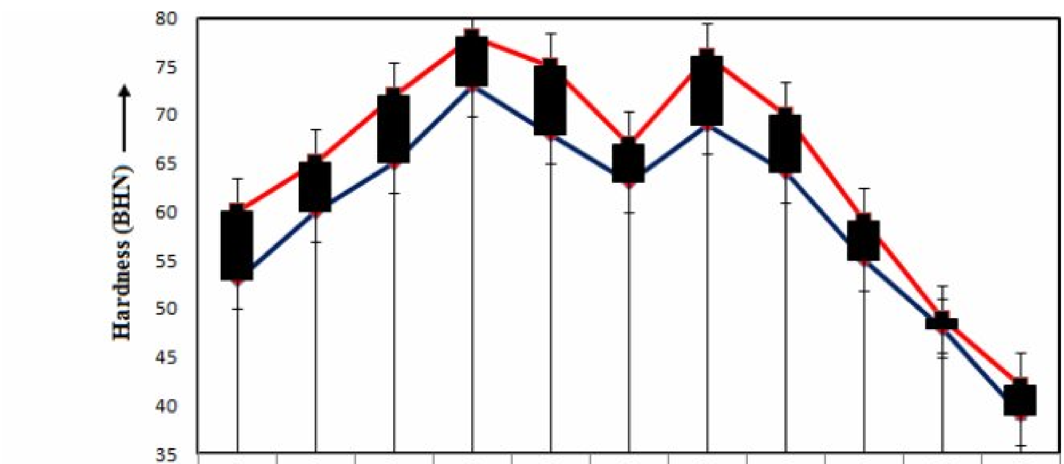
N. Mathan Kumar et al. [12] showed that by using Si_3N_4 with AlN and Zrb_2 as reinforcement in Al 2618 aluminium alloy, about 48.33% hardness increased. The present study showed that about 37.73% hardness enhanced by using 7.5% Si_3N_4 and 5% MgO in AA2024 alloy. The hardness of the composite was further improved after the heat treatment process. After the heat treatment process, about 62.5% hardness was improved with respect to the base metal.

Toughness

Results show that MgO addition in AA2024/Si_3N_4 composite enhanced the tensile strength and hardness of composite hybrid casting technique. So, samples developed by the hybrid casting technique were considered for further study. Fig. 7 shows the impact strength of AA2024/Si_3N_4/MgO hybrid metal matrix composite. Silicon nitride (Si_3N_4) is a material with high fracture toughness and excellent thermal shock resistance. MgO powder addition in AA2024/ /Si_3N_4 composite influence the grain boundary mobility, surface diffusivity along with higher pore mobility of grains and grain boundary anisotropy of composite material. However, It can be observed from the analysis that toughness is continuously decreased by increasing the percentage of Si_3N_4 in AA2024/MgO composite [13]. The toughness of all the compositions was improved after the heat treatment process.

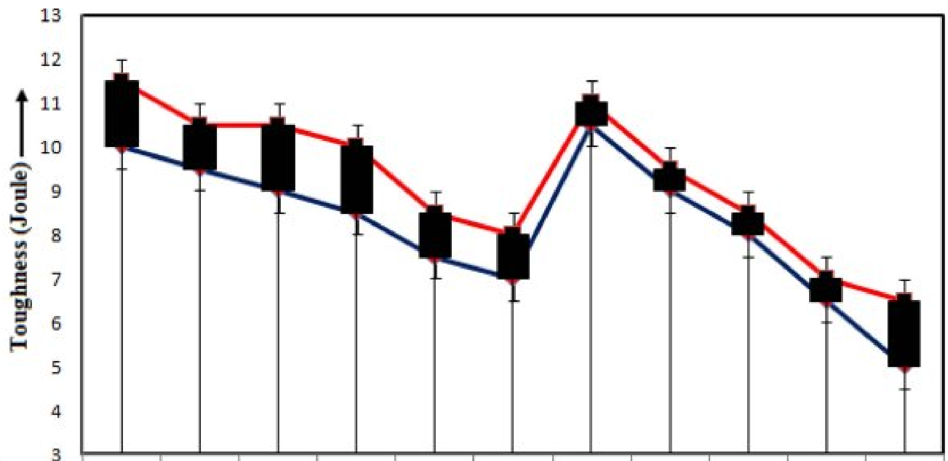
Ductility

Ductility of hybrid metal matrix composite was also observed to the find out the percentage elongation of the composite. Percentage elongation was calculated on extensometer during tensile testing. ASTM B557 standard was used to prepare the tensile samples. Magnesium oxide (MgO) has low ductility. It also shows unusual behaviour, such as a regime of increasing strength with



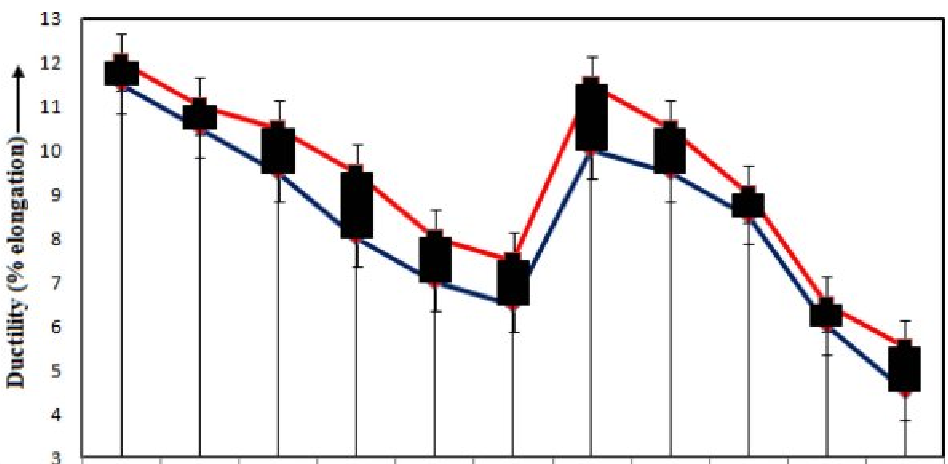
Sample No.	1	2	3	4	5	6	7	8	9	10	11
As cast	53	60	65	73	68	63	69	64	55	48	39
As heat treated	60	65	72	78	75	67	76	70	59	49	42

Fig. 6. Hardness of composite materials.



Sample No.	1	2	3	4	5	6	7	8	9	10	11
As cast	10	9.5	9	8.5	7.5	7	10.5	9	8	6.5	5
As heat treated	11.5	10.5	10.5	10	8.5	8	11	9.5	8.5	7	6.5

Fig. 7. Toughness of hybrid composite**.**



Sample No.	1	2	3	4	5	6	7	8	9	10	11
As cast	11.5	10.5	9.5	8	7	6.5	10	9.5	8.5	6	4.5
As heat treated	12	11	10.5	9.5	8	7.5	11.5	10.5	9	6.5	5.5

Fig. 8. Ductility of hybrid composite.

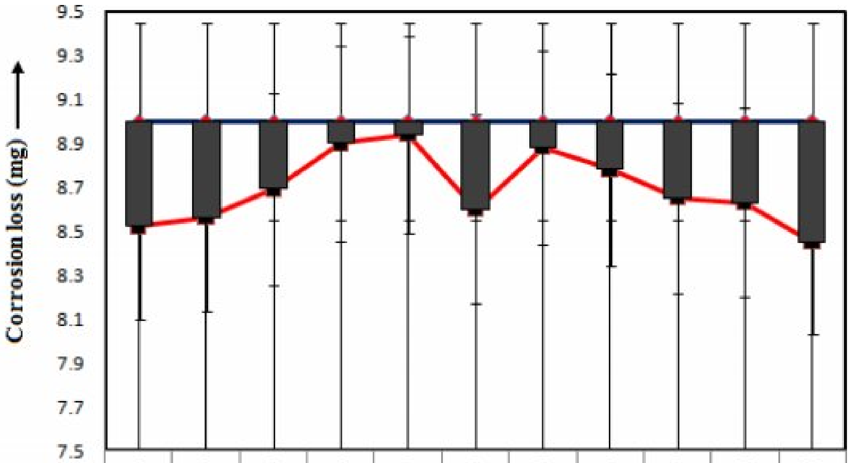
increasing temperature, which is the opposite of most metals. Fig. 8 shows the ductility of AA2024/Si_3N_4/MgO hybrid metal matrix composite. Results showed that the ductility of the hybrid composite was also decreased by increasing the percentage of Si_3N_4 in AA2024/MgO composite material. The heat treatment effect was also observed in the ductility samples. Purple deviation bars show the enhancement of ductility after the heat treatment process.

Corrosion behaviour

Tensile strength and hardness results showed that MgO addition in AA2024/Si_3N_4 composite provides better results as compared to without addition of MgO in AA2024/Si_3N_4 composite. Hence, in this study, the corrosion behaviour of AA2024/Si_3N_4/MgO hybrid composite was observed. Corrosion test of all the samples was carried out in 3.5 wt.% NaCl for 120 hours. Weight of each sample was taken 9 mg to make uniformity for the corrosion test. Fig. 9 shows the corrosion weight loss of hybrid metal matrix composite. Minimum corrosion loss was found to be 0.06 mg for AA2024/10% Si_3N_4/2.5% MgO composite material.

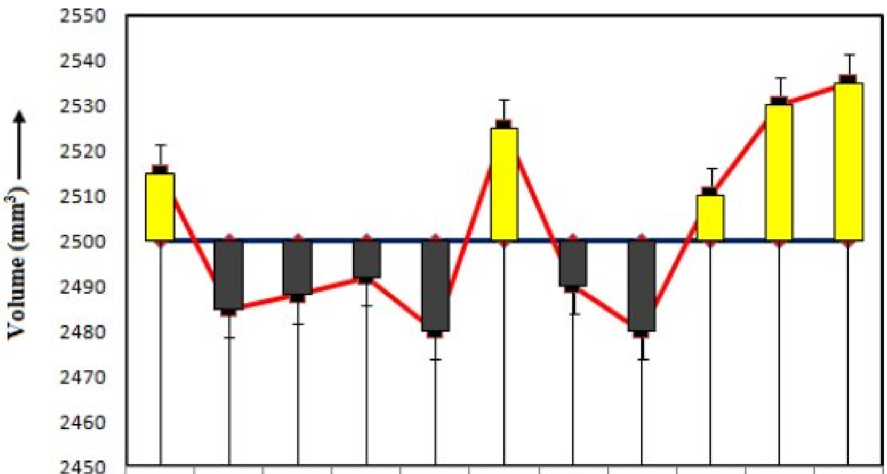
Thermal expansion behaviour

Thermal expansion property of each green composite material was identified to observe the appropriateness of material in a high-temperature environment. Dimension (Volume: 2,500 mm^3 (25 × 10 × 10)) of each sample was kept constant. Thermal expansion test was carried out



Sample No.	1	2	3	4	5	6	7	8	9	10	11
Weight of sample before test	9	9	9	9	9	9	9	9	9	9	9
Weight of sample after test	8.52	8.56	8.69	8.9	8.94	8.6	8.88	8.78	8.65	8.63	8.45

Fig. 9. Corrosion weight loss of hybrid composite**.**



Sample No.	1	2	3	4	5	6	7	8	9	10	11
Volume of sample before test	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500
Volume of sample after test	2515	2485	2488	2492	2480	2525	2490	2480	2510	2530	2535

Fig. 10. Thermal expansion of hybrid composite.

for 72 hours at 450 ºC in a muffle furnace. Thermal expansion behaviour of AA2024/Si_3N_4/MgO hybrid composite was observed. Fig. 10 shows the thermal expansion result of hybrid metal matrix composite. Minimum volume difference was found to be 8 mm^3 for AA2024/7.5% Si_3N_4/5% MgO hybrid composite material. Si_3N_4 exhibits an unusually low coefficient of thermal expansion, which is a useful property for designers working with high-temperature applications.

XRD Analysis

XRD of AA2024/7.5% Si_3N_4/5% MgO hybrid metal matrix composite was observed to identify the various phases form during the development of composite material. Phases such as Al, Si_3N_4, Fe_2O_3 and MgO were found at angles (2Θ degree) 44º, 50º, 75º and 90º respectively as shown in Fig. 11. Formation of these phases may be responsible for increasing the tensile strength and hardness of AA2024/7.5% Si_3N_4/5% MgO hybrid metal matrix composite material.

Conclusions

Following conclusions can be drawn from the analysis.

1. AA2024 aluminium base composite material successfully developed by using Si_3N_4 as primary reinforcement material and MgO as a secondary reinforcement material by hybrid casting technique.
2. Microstructure results showed the uniform distribution

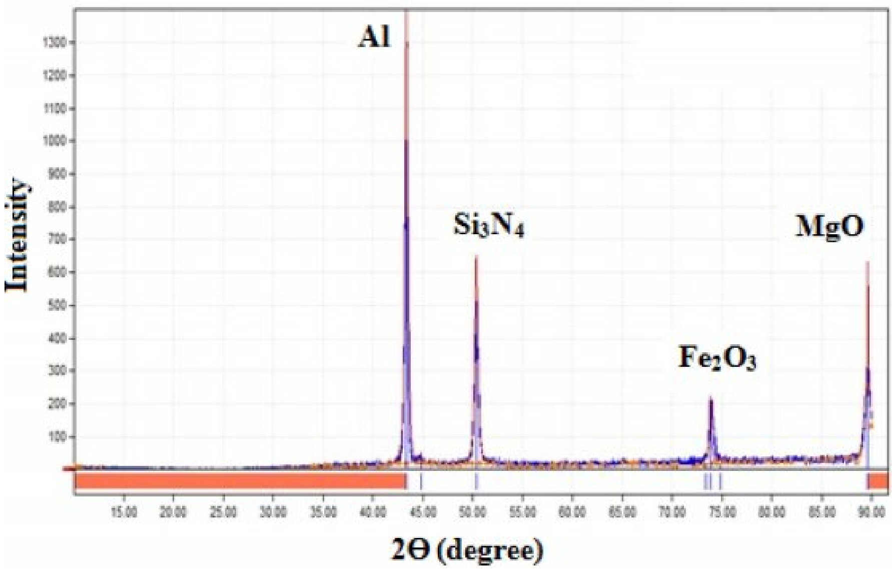


Fig. 11. XRD Analysis of AA2024/7.5% Si_3N_4/5% MgO hybrid metal matrix composite.

and proper wettability of Si_3N_4 ceramic particles in AA2024 aluminium alloy by adding MgO particles in composite material.

3. Maximum tensile strength and hardness were found to be 204.5 MPa and 72 BHN for AA2024/7.5% Si_3N_4/5% MgO composite material. Results showed that tensile strength and hardness increased about 19.16% and 62.5% with respect to base metal AA2024 aluminium alloy after the heat-treatment process.
4. Toughness and Ductility were continuously decreased by adding the Si_3N_4 and MgO particles in AA2024 aluminium alloy.
5. Minimum corrosion loss was found to be 0.06 mg for AA2024/10% Si_3N_4/2.5% MgO composite material. Similarly, Minimum volume difference was found to be 8 mm^3 for AA2024/7.5% Si_3N_4/5% MgO hybrid composite material.
6. XRD of AA2024/7.5% Si_3N_4/5% MgO hybrid metal matrix composite showed the formation of Al, Si_3N_4, Fe_2O_3 and MgO phases at angles (2Θ degree) 44°, 50°, 75° and 90° respectively.

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