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RESEARCH

Synthesis of Al/Mg Hybrid Nanocomposite by Electromagnetic Stir Cast: Characteristics Study

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Abstract

The ¾ of pure aluminium and ¼ of magnesium metal particles are fixed as a matrix and developed with different weight percentages of alumina (Al_2O_3) and silicon carbide nanoparticles through liquid state electromagnetic stir cast process found good interfacial bonding was proved by scanning electron microscope (SEM) and X-ray diffraction (XRD) technique. Influences of electromagnetic stir action for Al_2O_3 and SiC presence on hardness, tensile, and impact strength of developed composites are studied. Similarly, the composite's thermal adsorption behaviour was estimated using Differential-Thermo-Analysis (DTA) with a temperature span of 23ºC to 600ºC at a 24ºC/min heat rate. The composite consists of 9wt% Al_2O_3 and 5wt% SiC and facilitates superior mechanical properties such as Vickers hardness, tensile and impact strength was 143.91 ± 0.92HV, 230.91 ± 1.10 MPa, and 11.98 ± 0.25 J respectively. The material loss of composite during thermal analysis was found to be negligible.

Keywords Electromagnetic stir cast · Hybrid nanocomposite · Microstructure, Mechanical and Thermal properties

1 Introduction

Hybrid composite materials contain more than two constitutions of material phase in a single matrix chemically bonded with a conventional casting process to attain superior mechanical, tribological, and thermal properties compared to conventional materials. Advanced hybrid composite materials are finding various automotive, airspace, marine, structural, and electronic applications due to their enhanced characteristics [1]. The properties of the composite are decided or varied by the effective interfacial behaviour between the matrix and reinforcements. Two phases make it: solid (physical) and liquid (chemical). In the physical phase interactions, find the wettability of material via nonreactive liquids like organic and water. At the same time, the chemical phase interactions find wettability via reactive domains like inorganic substances [2]. The solid interfacial action between matrix and reinforcements authorizes indentation to high load distribution from matrix to reinforcement, increasing advanced composite strength and elastic modulus [3, 4].

However, the selection of the matrix material, reinforcement (organic/inorganic), and process techniques (solid, liquid, and vapour) to ensure wetting condition, adhesion properties, and chemical reaction rate during the mixing of matrix and reinforcements at desired temperature reached above recrystallization stage [5–7]. Aluminium and magnesium materials are widely utilized as a matrix with major constitutions due to their low density, good thermal stability, better mechanical properties, easy-to-form desired shape, and economy [8, 9]. The aluminium-based alloy matrix materials can bond with inorganic substances like silicon carbide, alumina, whiskers, and graphite fiber [10]. The various weight percentages of silicon carbide reinforced aluminium alloy (Al7075) composite developed by squeeze die casting process. The results were that the sample containing

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higher silicon carbide showed a good hardness value [11]. Aluminium alloy (Al7075) hybrid composite was prepared with different weight percentages of Si_3N_4, TiB_2, and B_4C ceramic powder via the powder metallurgy route. The result revealed that the composite with 5wt% of Si_3N_4, TiB_2, and B_4C ceramic powder found zero porosity with increased mechanical strength. Further additions of ceramic showed decreased plastic deformation [12]. The various volume percentages of silicon carbide (SiC) reinforced aluminium alloy (AA7075) were synthesized by stir casting. It was found that the incorporation of SiC in AA7075 alloy showed higher calorimetric heat capacity [13]. The liquid stir cast process produced the Al_2O_3 particle-reinforced aluminium alloy (Al7075) composite. 140VHN increased microhardness of composite at 425ºC temperature [14]. SEM and XRD analysis evaluated the stir cast developed AA7075/SiC composite microstructure.

The results showed that the uniform distribution of SiC particles in the AA7075 matrix enhances the characteristics of the composite [15]. Aluminium alloy (AA6061/glass fiber/Al_2O_3/SiC/B_4C) hybrid composite was prepared by stir casting technique. 5% of glass fiber with SiC/B_4C found superior mechanical strength compared to unreinforced alloy [16]. The various weight fractions of SiC reinforced Al alloy composite fabricated by the stir casting. The results proved that the hardness and impact strength of the composite increased with increased SiC content [17]. The stir cast developed boron carbide (B_4C) and rice husk ash reinforced aluminium alloy (AA7075) hybrid composite was studied its microstructure and mechanical characteristics. It was found that the composite containing 5wt% of boron and 5wt% of RHA showed the highest hardness, tensile, and compressive strength of 121Hv, 260 MPa, and 563 MPa, respectively. However, the hybrid composite contains multi-reinforcement results in higher mechanical, wear, and thermal properties than the conventional alloy materials [18]. Recently, Al/Mg/Si/T6 SiC hybrid nanocomposite was developed by stir casting for high-strength applications. The applied uniform stir speed enhances particle distribution with the limited void. It offered the excellent mechanical properties of composites compared to unreinforced Al/Mg/Si alloy [19]. Chandla et al. [20] developed an aluminium alloy (Al6061) hybrid composite bonded with Al_2O_3 and bagasse ash via vacuum stir casting. They revealed that the composites' hardness increased with the bagasse ash content of 6%. Similarly, the tensile strength of the composite was improved, but the ductility and impact strength of the composite was decreased because of microvoids and dislocations of the particle during high-impact load.

Moreover, the hardness of the composite is influenced by the additions of Al_2O_3 nanoparticles in the soft matrix [21, 22]. The mechanical properties of the composite are significant by the additions of carbide particles [23], and a higher quantity of carbide damages the composite under static load [24]. The optimized stir-casting parameters are reported by Krishnan et al. [25]. Among the various reinforcements, the ceramic-based (boron, nitrides, carbide, and oxide) particles performed enhanced mechanical and wear characteristics [26]. The aluminium hybrid nanocomposite was recently synthesized by alumina and graphene oxide through spark plasma sintering technique to find good compression strength with low thermal coefficiency [27]. The wear performance of silicon carbide and hexagonal boron nitride reinforced aluminium alloy hybrid nanocomposite was studied by different loading conditions, and it reported that the composite contained 1.5wt% SiC and h-BN offered excellent wear resistance [28]. The thermal characteristics were analyzed using a computational fluid dynamics platform [29]. Moreover, metal coating gathers significance in engineering material application [30, 31]. The effect of SiC and Al_2O_3 on the mechanical and microstructural properties of aluminium alloy hybrid nanocomposite was investigated by ASTM standards. They reported that the additions of reinforcements improved compressive strength and hardness [32]. Moreover, the magnesium combination was found to have superior machining performance [33]. The Al/Mg hybrid nanocomposite was developed with SiC and Al_2O_3 via vacuum die-cast and studied the effect of stir speed on SEM and mechanical behaviour of aluminium alloy hybrid nanocomposites. They reported that 700 rpm facilitates good mechanical properties compared to others. [34]. Conventional stir cast technique developed aluminium alloy composite found good mechanical and thermal properties [35].

The novelty of the present Investigation is to enhance the mechanical and thermal behaviour of Al/Mg alloy composite by incorporating Al_2O_3 and SiC nanoparticles through an electromagnetic stir cast process. The presence of a ceramic particle in the Al/Mg matrix is proven with surface morphology studies, and its peak points were found with the help of XRD. The mechanical properties like Vickers hardness, tensile and impact strength of the developed composite were estimated by ASTM test standards. The quality of interfacial action of hybrid nanocomposite on thermal adsorption properties was studied via differential-thermo-analysis under the heat rate of 24ºC/min with a temperature span of 23ºC to 600ºC.

2 Materials and Methods

2.1 Matrix and Reinforcements Details

Pure aluminium and magnesium metal particles with 3 to 5 mm are chosen as matrix material ratios of 75:25. Both materials are widely used in various engineering

Table 1 Characteristics of matrix and reinforcements

Descriptions	Materials/Properties	Density	Hardness	Modulus of Elasticity	Melting point	Thermal conductivity	Size of particles
		g/cc	VHN	GPa	ºC	W/mK	-
Matrix	Pure Al	2.6989	15	68	660	210	3–5 mm
	Pure Mg	1.74	30	44	650	159	
Reinforcements	Al_2O_3	3.96	1365	370	2054	30	50 nm
	SiC	3.1	1440	410	2797	77.5	50 nm

Table 2 Interfacial phase formation on constitutions ratio

Samples / Materials	Constitutions ratio in Wt%		
	Al/Mg	Al_2O_3	SiC
H1	100	0	0
H2	94	5	1
H3	90	7	3
H4	86	9	5

applications due to their enhanced mechanical properties, low density, distinct solidification, and recycling ease [8, 9].

The ceramic-based alumina (Al_2O_3) and silicon carbide (SiC) nanoparticles (50 nm) were utilized as reinforcement. Both ceramic particles are good thermal stability, high hardness, and low thermal coefficient [9]. It has been extensively applied in recent research [21–23]. Table 1 represents the characteristics of matrix /reinforcements and their compositions for the fabrication of composite is shown in Table 2

2.2 Preparation of Hybrid Nanocomposite

The actual metal (aluminium/magnesium) melting furnace equipped with an electromagnetic stirrer is shown in Fig. 1(a). According to Table 2, the compositions of Al/Mg (matrix) metal particles were kept in a graphite-made crucible and preheated via an electrical resistance muffle furnace at 300ºC. Meantime, externally preheated (300ºC) Al_2O_3 and SiC nanoparticles (Fig. 1b) followed the constitution ratio (Table 2). The preheated reinforcement's moisture content and gasses desorption were minimized and increased wettability [25].

Based on the past literature reported by Chandradass et al. [9] and Chandla et al. [20], the stir casting parameters were followed to obtain a good composite casting. Table 3 shows liquid-state electromagnetic stir cast process parameters.

The temperature of matrix material was increased to 800ºC for 15 min under an inert (Sulphur hexafluoride SF6) atmosphere. Next stage, the temperature of the molten metal was reduced to 750ºC and added the preheated

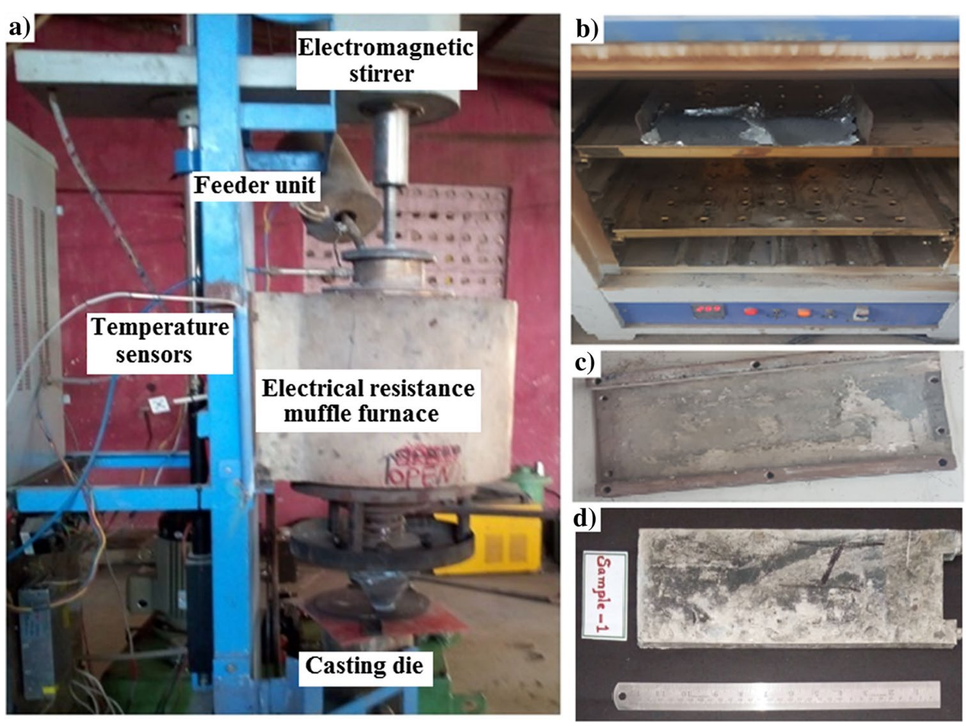

Fig. 1 Hybrid nanocomposite fabrication **a**) Actual experimental setup **b**) Muffle furnace **c**) rectangular casting die and **d**) hybrid nanocomposite samples

Table 3 Liquid state-electromagnetic stir cast process parameters [9, 20, 34]

Process parameter	Stir speed	Stirrer temperature	Stirrer time	Stage of Impeller	No. of blade	Blade angle	Feed
Unit	700 rpm	750ºC	10 min	1	2	29º	0.8 g/sec

reinforcement via a feeder unit. The inert atmosphere helps reduce oxidation during stirrer action. The molten Al/Mg alloy and reinforcements were stirred at 700 rpm for 10 min via an electromagnetic stirrer rotor. The electromagnetic stirrer reduced porous and increased wettability and interfacial bonding strength. After solidification of the matrix/reinforcement phase, transferred into preheated die size of 300mmX100mmX20mm is shown in Fig. 1(c). The cast samples were cooled at elevated temperatures. The developed hybrid nanocomposites are shown in Fig. 1(d).

2.3 Characterization Study of Developed Composites

The developed composite specimen for each sample is shaped as 10mmX10mmX10mm cubic through wire cut electrical discharge machining technique. Different grade emery sheets polish the cubic test samples continued that fine polish via a rotating disc configured with velvet cloth. After polishing, test specimens are cleaned with a chemical solvent containing 1.5% hydrofluoric acid, 2.6% nitric acid, and distilled water as balance. The cleaned test specimen is placed on the ZESIS SEM apparatus [8]. The Vickers hardness of the developed composite is evaluated by ASTM E92 standard via S.E. make V3 model Vickers hardness tester configured with diamond tip indenter followed an applied load of 500 g at 30-s duration [9, 33]. The impact toughness of the composite was tested by an S.E. model IT 30 mode impact tester configured with 300 J capacity. Each composite tested three test samples, and an average value was noted. Based on the ASTM E23 standard [22], the impact strength of composites was noted in Table 4. ASTM E8 examines the tensile strength of composite via a P.C. 2000 model tensiometer configured with an electronic plotter [9, 20]. The thermal adsorption of composite is studied via Differential-Thermo-Analysis (DTA-404) [13] with a temperature span of 23ºC to 600ºC at a 24ºC/min heat rate.

3 Results and Discussions

3.1 Surface Morphology of Developed Composite Samples

Figure 2(a-d) illustrates the surface morphology of cast Al/Mg alloy and its hybrid nanocomposites. Figure 2(a) represented the SEM image of cast Al/Mg alloy and showed the porosity-free structure with few slag. The interfacial bonding peaks were represented in XRD. It is located on the right side of Fig. 2(a). It showed the peak point of aluminium, having more than 30,000 counts. The constitutions of Al/Mg alloy are proved in an XRD pattern graph. Based on the processing parameters, it was varied [14, 34].

Figure 2(b) shows the SEM image/XRD pattern of an Al/Mg hybrid nanocomposite containing 5wt% Al_2O_3 and 1wt%SiC. It was observed from Fig. 2(b) that the Al_2O_3 and SiC were distributed uniformly in Al/Mg matrix. During solidification, the parent material temperature was improved above the slag formation's melting temperature. High stir speed was one of the reasons for slag formation [25].

The XRD peak proved the matrix and reinforcement phase, and one minor wave in the XRD pattern image found a magnesium oxide layer due to the chemical reaction with Al_2O_3 particles. It may have resulted in the microporosity of the composite, which reduces the mechanical strength.

Figure 2(c, d) illustrates a micrograph of the various weight percentages of Al_2O_3 and SiC nanoparticle-reinforced Al/Mg alloy hybrid nanocomposite. It reveals that the matrix shows a uniform distribution of nano Al_2O_3 and SiC particles. The white and dark field dot image in Fig. 2(c, d) indicates the nano-size Al_2O_3 and SiC particles. The average interface span between each reinforcement was represented in the XRD pattern, and its particle was shown in the SEM image. However, the electromagnetic stirrer developed hybrid nanocomposite found good interfacial bonding with appropriate interface span effect between matrix, and reinforcement can withstand the maximum load.

Table 4 Mechanical characteristics of developed hybrid nanocomposites

Samples / Properties	Vickers Hardness VHN	Impact strength J	Tensile strength MPa	Elongation rate %
H1	121.23	25.3	146.7	9.81
H2	134.21	22.13	187.8	8.78
H3	139.5	19.76	210.92	6.71
H4	143.91	11.98	230.91	5.81

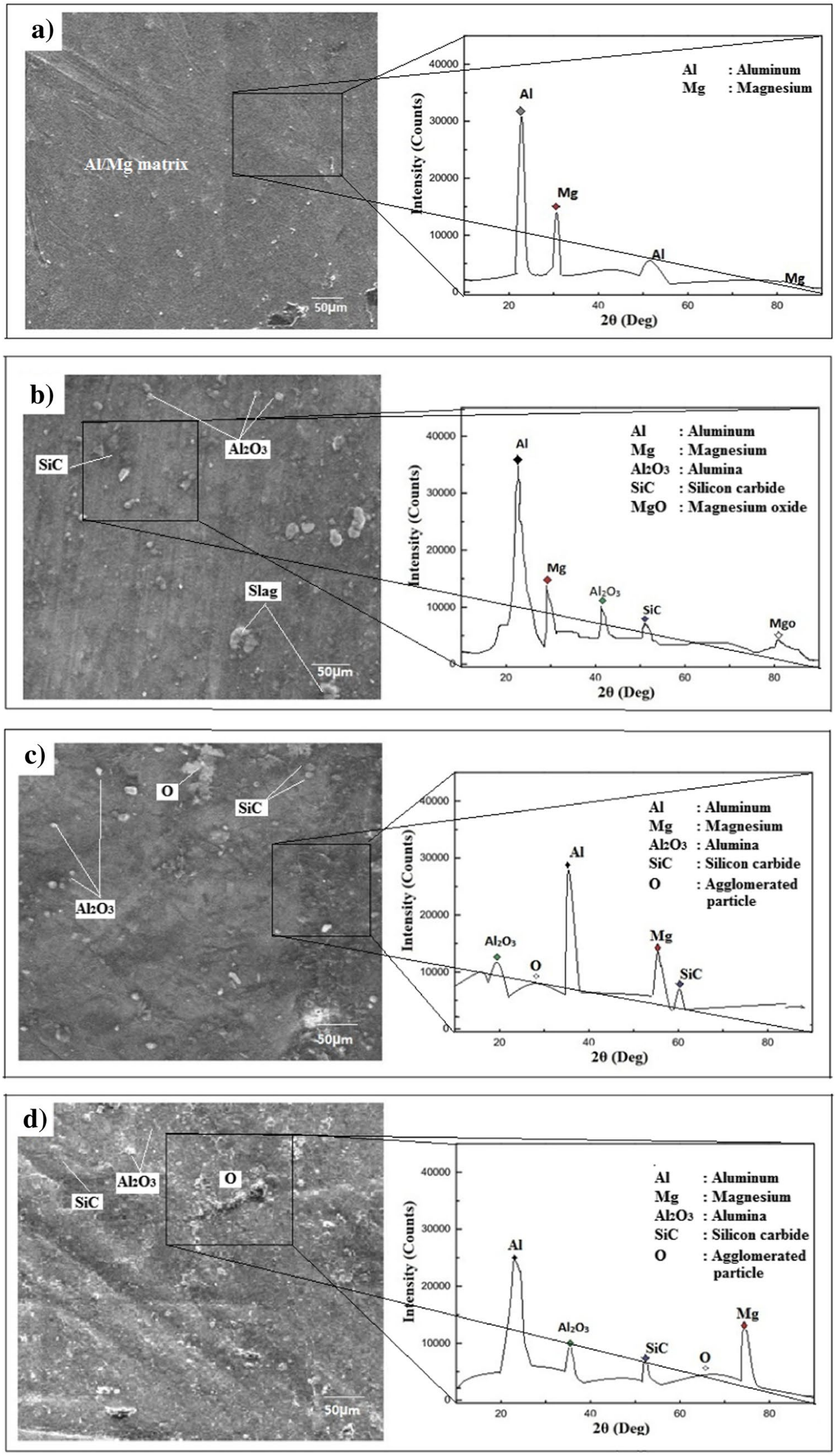

Fig. 2 **a**) SEM /XRD pattern illustrations of cast Al/Mg alloy. **b**) SEM /XRD pattern illustrations of Al/Mg /5wt% Al_2O_3 /1wt%SiC composite. **c**) SEM/XRD pattern illustrations of Al/Mg/ 7wt% Al_2O_3/3wt% SiC composite. **d**) SEM /XRD pattern illustrations of d) Al/ Mg/ 9wt% Al_2O_3/5wt%SiC composite

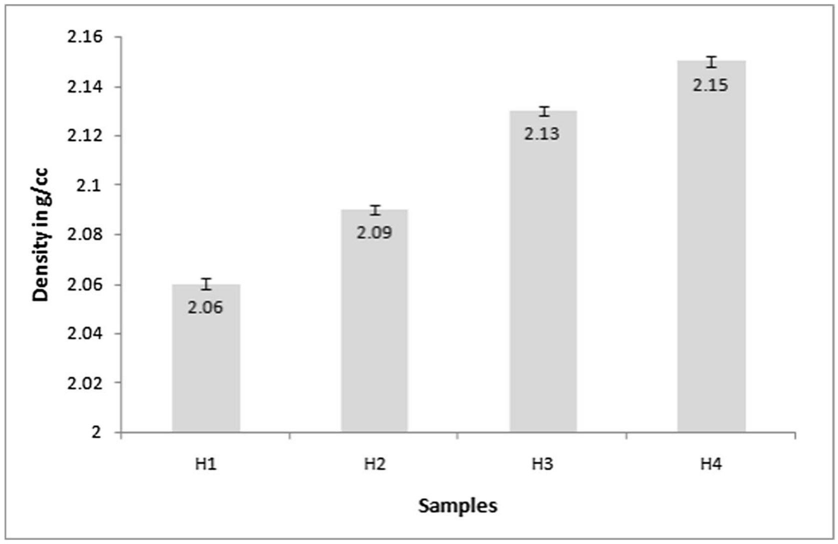

Fig. 3 Density of cast Al/Mg alloy and its hybrid nanocomposites

3.2 The density of Developed Composite Samples

Figure 3 illustrates the density of cast Al/Mg alloy and its hybrid nanocomposite containing different weight percentages of nano-sized Al_2O_3 and SiC particles. The density of the composite is increased with an increase in the content of hard ceramic particles. Based on density and percentage, adding in matrix offered increased density [14].

The density of cast Al/Mg alloy is 2.06 ± 0.34 g/cc, while adding the 5:1 wt% of alumina: SiC showed 2.09 ± 0.45 g/cc. The maximum density of 2.15 ± 0.12 g/cc is found on the composite containing 9:5 wt% of Al_2O_3 and SiC nanoparticle. The increased density is due to the incorporation of hard ceramic nanoparticles in Al/Mg is the prime reason. However, it was proven the matrix and reinforcement presence.

3.3 Mechanical Performance of Developed Composite Samples

The experimental test results of Al/Mg alloy and its hybrid nanocomposite are mentioned in Table 4. It shows the Vickers hardness, impact strength, tensile strength, and elongation rate of tested composites.

3.3.1 Vickers Hardness

Figure 4 represents the Vickers hardness of unreinforced and reinforced Al/Mg alloy hybrid nanocomposite. It significantly improved hardness compared to cast Al/Mg alloy.

The actual experimental test results of the Vickers hardness number are mentioned in Table 4. It was revealed from Fig. 4 that the hardness of the composite was increased with an increase in the content of reinforcements. The unreinforced

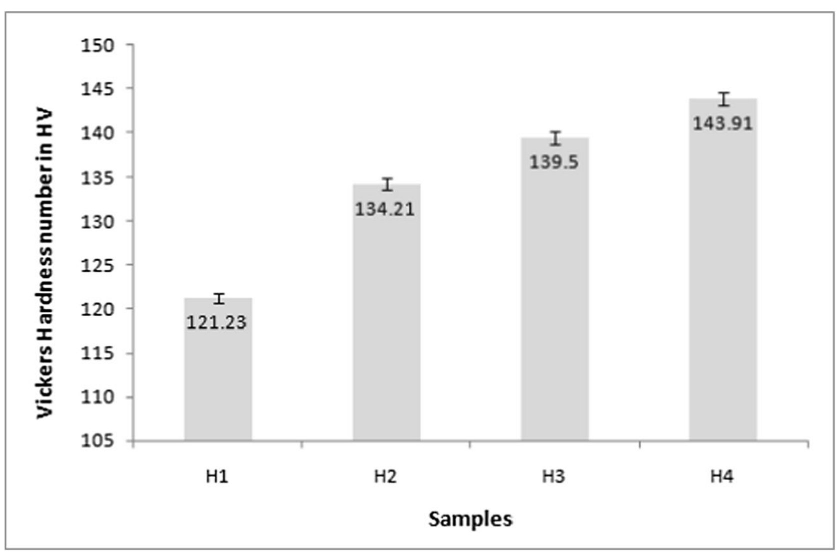

Fig. 4 Vickers hardness of cast Al/Mg alloy and its hybrid nanocomposites

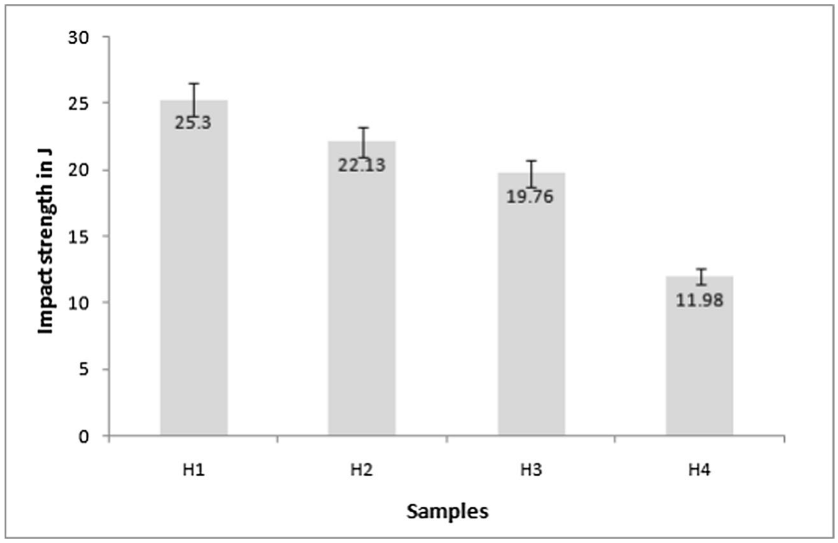

Fig. 5 Impact strength of cast Al/Mg alloy and its hybrid nanocomposites

Al/Mg alloy was found to be 121.1 ± 0.87Hv; 134.21 ± 1.09Hv was 5wt% Al_2O_3/1wt% of the SiC nanoparticle reinforced Al/Mg hybrid nanocomposite. The composite enclosed with 9wt% of Al_2O_3/5wt% SiC showed a maximum hardness value of 143.91 ± 0.92Hv. It increased by 16% compared to unreinforced cast Al/Mg alloy. The hardness improvement was due to hard ceramic particles in the Al/Mg matrix forming an adequate interfacial bonding with fine grain structure (Fig. 2d) facilities with good resistance against indentation. A similar trend was reported by Velavan et al. [32]

3.3.2 Impact Strength

Figure 5 indicates the impact toughness of cast Al/Mg alloy and its hybrid nanocomposite synthesized using various weight percentages of Al_2O_3 and SiC nanoparticles. It showed a progressive decrement in impact toughness value with increased reinforcement percentages. It was due to hard ceramic particles leading to brittle fractures.

The unreinforced Al/Mg alloy was found to be 25.3 ± 1.23 J. In contrast, an increase in Al_2O_3 content from 5wt% to 9wt% and 1wt% to 5wt% of SiC reduced impact strength by 12.5%, 21.8% and 52.6%, respectively. It was due to the increased content of hard ceramic particles in the Al/Mg matrix found brittle. Some particles were de-bonded during high-impact load is the prime reason for decreased impact toughness. However, the impact of the composite was varied due to the selection of matrix and reinforcements and processing technique [23].

3.3.3 Tensile Strength

It was observed from Fig. 6 that the tensile strength of the composite was progressively increased with an increased content ratio of Al_2O_3 and SiC nanoparticles. The tensile strength

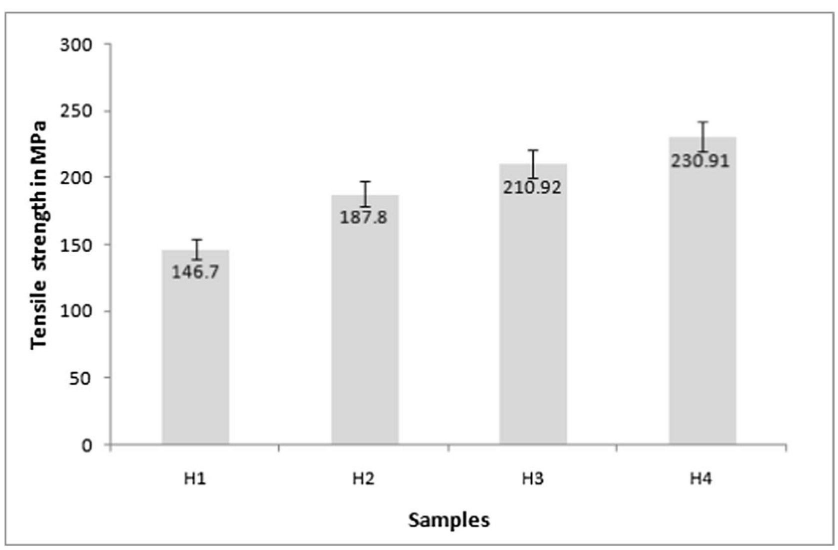

Fig. 6 Tensile strength of cast Al/Mg alloy and its hybrid nanocomposites

of cast Al/Mg alloy was found to be 146.7 ± 2.11 MPa. The 1wt% SiC reinforced Al/Mg/5wt%Al_2O_3 hybrid nanocomposite showed 187.8 ± 1.72 MPa. It was increased by 22% compared to cast Al/Mg alloy.

The hybrid nanocomposite (Al/Mg/5wt%Al_2O_3) containing 5wt% of SiC observed a 36.46% improvement compared to cast Al/Mg alloy. Further increases in SiC content (3wt%, 5wt %) in Al/Mg matrix showed high tensile strength with a reduced elongation rate of 6.71% and 5.81%, respectively. The composite's tensile strength was improved due to the adequate interfacial bonding leading to resisting particle dislocation and providing good tensile strength. The adequate bonding strength with uniform distribution of nanoparticles in the Al/Mg matrix is shown in Fig. 2(b-d).

However, the homogenous particle distribution along the matrix phase must increase the composite's tensile strength [25]. The effect of the electromagnetic stirrer action on the casted sample showed an even dispersion of reinforcement [26]. According to a) Orowan Strengthening mechanism, the strength composite increases with decreased grain size. Orowan stresses equation.

$$\Delta\tau_P = \left\{ \frac{Gb}{2\pi(1-\gamma)} \right\} In\left(\frac{D}{r^{\circ}} \right) \quad (1)$$

where the subscript p refers to 'particles', G is the shear modulus, b is the magnitude of the Burgers vector, γ is Poisson's ratio, l is the spacing between the particles (i.e. particle centre spacing L less the particle diameter d) and the inner cut-off radius, r^0, is set equal to b.

3.4 Thermal Adsorption of Developed Composite Samples

The effect of interfacial bonding quality on thermal adsorption behaviour on cast Al/Mg alloy and its hybrid nanocomposites was tested by Differential-Thermal-Analysis with the temperature span of 23ºC to 600ºC at 24ºC/min heat rate as shown in Fig. 7(a-d). Figure 7(a) represents the mass loss of Al/Mg alloy, and its hybrid nanocomposite showed a downtrend pattern on the increased temperature range. The steady-state heat flow rate (24ºC/min) on cast Al/Mg alloy showed a gradual mass loss from 26 to 7 mg at an increased

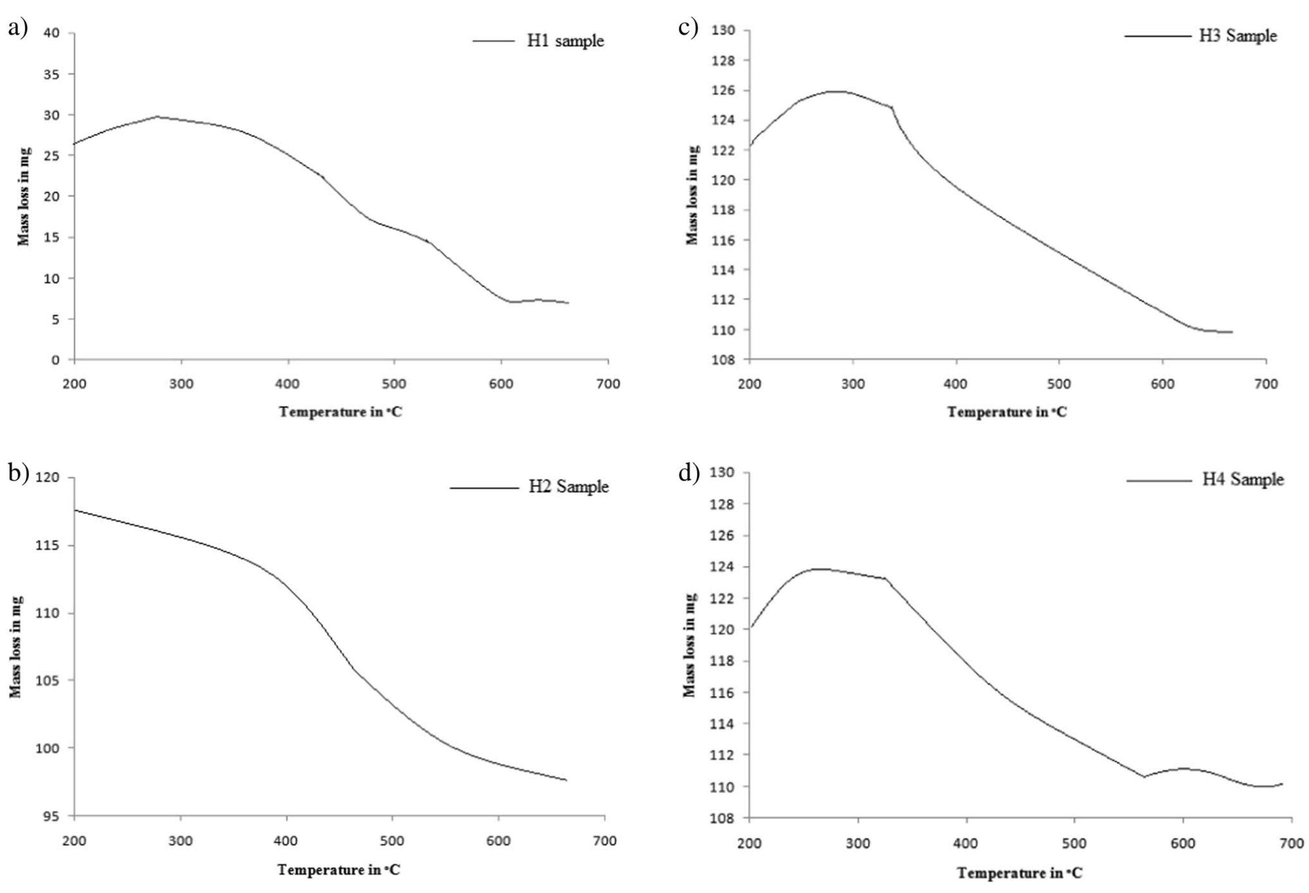

Fig. 7 **a**) Differential-Thermal-Analysis pattern of cast Al/Mg alloy. **b**) Differential-Thermal-Analysis pattern for Al/Mg/5wt% Al_2O_3/1wt% SiC hybrid nanocomposite. **c**) Differential-Thermal-Analysis pattern for Al/Mg/7wt% Al_2O_3/3wt% SiC hybrid nanocomposite. **d**) Differential-Thermal-Analysis pattern for Al/Mg/9wt% Al_2O_3/5wt% SiC hybrid nanocomposite

temperature of 600ºC. Further, the rise in temperature 600ºC trend showed a stable line. It was due to the reaction between matrix materials like dissociation.

It was noted from Fig. 7(b-d) that the weight loss on thermal adsorption and behaviour of hybrid nanocomposite was heated at 24ºC/min with 250 ml/min airflow. The variations of temperature in the matrix showed dehydration or decomposition of layers. It was observed from Fig. 7(c) that the weight loss of composite increased from 120 to 124 mg on the temperature rise of 200ºC to 300ºC. It was due to their higher adsorption capability of base matrix dilution.

However, the presence of hard ceramists limits the mass loss at a higher temperature of 600ºC. The weight loss of the curve illustrates a downtrend with minor increases in weight loss, shown in Fig. 7(d). It was due to the effect of liquid dehydration on the matrix interlayer. Initially, the mass loss of composite was maintained at 122 mg on the temperature of 350ºC to 417ºC, and then the decomposition rate was decreased with increased temperature. However, hard ceramic particles can withstand higher temperatures. Al_2O_3 and SiC nanoparticles have good thermal stability and high melting point compared to matrix materials [22, 23]. Moreover, the effective interfacial bonded structure is also the prime reason for decreased mass loss of composite. The hybrid nanocomposite contained 9wt% Al_2O_3 and 5wt% SiC nanoparticle showed a limited weight loss and high thermal stability compared to another hybrid nanocomposite. So the weight loss of hybrid nanocomposite was limited by good interfacial bonding of reinforcement in the matrix.

4 Conclusions

The Al/Mg alloy hybrid nanocomposite was successfully synthesized with and without Al_2O_3 and SiC nanoparticles through the liquid state electromagnetic stir cast process. SEM and X-ray techniques observed its particle distribution. It revealed fine grains with few slags and agglomerated particles due to oxidation. Homogenous particle distribution with void-free structure facilitates good mechanical and thermal behaviour. In XRD, patterns for developed composites were shown all the constitution's presence. The various peaks on the pattern found that matrix, reinforcement, and reactive phases. Some XRD patterns illustrate reactive patterns like MgO and other oxides formed due to the reaction against hard ceramics. The H4 composite contained 9wt% Al_2O_3/5wt% of SiC and offered maximum hardness and tensile strength. While compared to cast Al/Mg alloy, It was improved by 16% and 36.46%, respectively, and the impact strength of hybrid nanocomposite is limited by 52.6% compared to unreinforced Al/Mg alloy. The effect of interfacial bonding quality on thermal adsorption characteristics of Al/Mg alloy and its hybrid nanocomposite was studied effectively by differential-thermo-analysis with a temperature span of 23ºC to 600ºC at 24ºC/min heat rate. The results showed limited mass loss at a higher temperature. Both Al_2O_3 and SiC nanoparticles were stable at high temperatures.

Author Contributions All authors contributed to the study's conception and design. The first draft of the manuscript was written by R. Venkatesh, and the individual contributions of ALL authors are given below.

K.R. Padmavathi – Formal analysis, Investigation, Melvin Victor De Poures—Methodology, Writing, Review & Editing, G. Selvakumar– Investigation, Writing & Language help, R. Venkatesh -Original draft preparation, Supervision, and Validation. All authors read and approved the final manuscript.

Data Availability All the data required are available within the manuscript.

Declarations

Ethics Approval This is an observational study. Synthesis of Al/Mg hybrid nanocomposite by electromagnetic stir cast: Characteristics study, Research Ethics Committee has confirmed that no ethical approval is required.

Consent to Participate Informed consent was obtained from all individual authors included in the study.

Consent for Publication We give our consent for the publication of Synthesis of Al/Mg hybrid nanocomposite by electromagnetic stir cast: Characteristics study to be published in the Silicon Journal.

Competing & Financial Interests The authors have no relevant financial or non-financial interests to disclose.

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All authors certify that they have no affiliations with or involvement in any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript.
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Competing Interests The authors declare no competing interests.

References

1. Menachery N et al (2023) Processing of nano reinforced aluminium hybrid metal matrix composites and the effect of post-heat treatment: a review. Appl Nanosci 13:4075–4099
2. Khelge S et al (2022) Effect of reinforcement particles on the mechanical and wear properties of aluminium alloy composites: Review. Mater Today Proc 52(3):571–576
3. Saravanakumar M et al (2023) Investigation on mechanical behaviour of Al–Mg–Si alloy hybridized with calcined eggshell and TiO2 particulates. Biomass Convers Biorefinery. https://doi.org/10.1007/s13399-023-04215-8
4. Seetharaman S et al (2022) Mechanical Properties of Sustainable Metal Matrix Composites: A Review on the Role of Green Reinforcements and Processing Methods. Technol 10:32

5. Kim So Yeon, Li Ju (2022) 'Machine learning of metal-ceramic wettability. J Meteriomics 8(1):195–203
6. Mortensen A, Jin I (1997) Solidification processing of metal matrix composites. Int Mater Rev 37:101–123
7. Eustathopouls N (1998) Dynamic of wetting in reactive metal/ceramic systems'. Acta Mater 46(1998):2319–2327
8. Ramesh Kannan C et al (2022) Synthesis and Characterization of Mechanical Properties of AA8014 + Si_3N4/ ZrO_2 Hybrid Composites by Stir Casting Process'. J Adv Mater Sci Eng 9150442:11
9. Chandradass J et al (2021) Effect of silicon carbide and silicon carbide/alumina reinforced aluminium alloy (AA6061) metal matrix composite. Material Today Proc 45:7147–7150
10. Zhang XX et al (2007) Mechanical properties of ABOw+MWNTs/Al hybrid composites made by squeeze cast technique. Mater Lett 61:3504–3506
11. Kalkanli K et al (2008) Synthesis and characterization of aluminium alloy 7075 reinforced with silicon carbide particulates. Mater Des 29:775–780
12. Cambronero LEG et al (2003) Mechanical characterization of AA7015 aluminium alloy reinforced with ceramics. J Mater Process Technol 143–144(1):378–383
13. Karthikeyan B et al (2010) A calorimetric study of 7075 Al/SiCp composites. Mater Des 31:S92–S95
14. Karthik R et al (2022) Influence of stir casting parameters in mechanical strength analysis of Aluminium Metal Matrix Composites (AMMCs). Mater Today Proc 62(4):1965–1968
15 Kumar BR, Kumar Sudhir (2013) Fabrication and characterization of 7075 Al alloy reinforced with SiC particulates. Int J Adv Manuf Technol 65:611–624
16. Nanjan S et al (2019) Characteristics of A6061/ (Glass fiber+Al_2O_3+SiC+B_4C) reinforced hybrid composite prepared through STIR casting. Adv Mater Sci Eng 6104049:12. https://doi.org/10.1155/2019/6104049
17. Singla M et al (2009) Development of aluminium based silicon carbide particulate metal matrix composite. J Miner Mater Charact Eng 8(6):455–467
18. Wua C et al (2014) Effect of plasma activated sintering parameters on microstructure and mechanical properties of Al-7075/B_4C composites. J Alloy Compd 615:276–282
19. Sharma S et al (2021) 'Investigation on mechanical, tribological and microstructural properties of Al/Mg/Si/T6/SiC/ muscovite-hybrid metal-matrix composites for high strength applications. J Mater Res Technol 12:1564–1581
20. Chandla NK et al (2020) Experimental analysis and mechanical characterization of Al6061/alumina/bagasse ash hybrid reinforced metal matrix composite using vacuum-assisted stir casting method. J Compos Mater 54(27):4283–4297
21 Venkatesh R et al (2022) Synthesis and Experimental Investigations of Tribological and Corrosion Performance of AZ61 Magnesium Alloy Hybrid Composites. J Nanomater 2022:12 (**Article ID 6012518**)
22. Thirugnanasambandham T et al (2018) Fabrication and Mechanical Properties of Alumina Nanoparticle Reinforced Magnesium Metal Matrix Composite by Stir Casting Method. SAE Technical Paper 28:0098. https://doi.org/10.4271/2018-28-0098
23. Sijo MT, Jayadevan KR (2016) Analysis of stir cast aluminium silicon carbide metal matrix composite: a comprehensive review. Procedia Technol 24:379–385
24. Kumar prakash, Singh NK (2022) Sensitivity of Al/Mg/Ti/Cu/SiC Hybrid Composite to Static Loads. Adv Mech Mater Technol https://doi.org/10.1007/978-981-16-2794-1_102
25 Mohana Krishnan A et al (2022) Evaluation of mechanical strength of the stir casted aluminium Metal matrix composites (AMMCs) using Taguchi method. Mater Today Proc 62(4):1943–1946
26. Zhou C et al (2017) Ceramic material. Ceramic international. https://doi.org/10.1016/j.ceramint.2017.12.212
27. Mohammed AS et al (2021) Mechanical and Thermal Evaluation of Aluminum Hybrid Nanocomposite Reinforced with Alumina and Graphene Oxide. Nanomaterials 11:1225. https://doi.org/10.3390/nano11051225
28. Paulraj P, Harichandran R (2020) The tribological behaviour of hybrid aluminium alloy nanocomposites at High temperature: Role of nanoparticles. J Mater Res Technol 9(5):11517–11530. https://doi.org/10.1016/j.jmrt.2020.08.044
29 Vijayan V et al (2021) CFD modeling and analysis of a two-phase vapour separator. J Thermal Anal Calorim 145:2719–2726
30. Afkhm Y et al (2018) Incorporation of Silicon Carbide and Alumina Particles into the Melt of A356via Electroless Metallic Coating Followed by Stir Casting. Silicon 10:2353–2359. https://doi.org/10.1007/s12633-018-9771-x
31. Venkatesh R et al (2022) The Investigation on Newly Developed of Hydrophobic Coating on Cast AZ91D Magnesium Alloy Under 3.5 wt% NaCl Solutions. J Inorg Organomet Polym Mater 32:1246–1258
32 Velavan K et al (2021) Implications of SiC/Al_2O_3 Reinforced Al-Mg-Zn Alloy Hybrid Nano Composites Using Vacuum Sintering Method. Silicon 13:3639–3647. https://doi.org/10.1007/s12633-020-00928-x
33. R Venkatesh, Siva Chandran S (2022) Magnesium Alloy Machining and its Methodology: A Systematic Review and Analyses, AIP Conf Proc, 2473 (1). https://doi.org/10.1063/5.0096398
34. Raja Sekaran P et al (2023) Mechanical and Physical Characterization Studies of Nano Ceramic Reinforced Al–Mg Hybrid Nanocomposites. Silicon. https://doi.org/10.1007/s12633-023-02473-9.
35. Periasamy K et al (2022) Appraisal on Thermo-Mechanical Performance of Aluminum Metal Matrix Composites using Stir Casting Technique, Adv Mater Sci Eng, 2381425. https://doi.org/10.1155/2022/2381425