Characterization And Fabrication Of Az91/Sic/Graphite Reinforced Metal Matrix Hybrid Composites By Stir Casting Method

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Magnesium alloys are increasingly common in automotive applications owing to their low mass density and mechanical characteristics. The current study seeks to create AZ91 Mg-Alloy-based composites reinforced with Silicon carbide (SiC) and graphite particles at various volume percentages. Composites were fabricated utilizing the stir casting process with reinforcing particles of 53 µm and fractions of 2, and 4 percentages. The variation in grain structure, particle size, and volume percentage of SiC and graphite particles was thoroughly examined. The regular distribution of reinforced particles enhances the dendritic structure. SEM and EDAX were used to analyse the microstructures of both basic alloys and composites. The mechanical parameters of reinforced and unreinforced composites, including hardness, density, young's modulus, and tensile strength, were assessed and reported. Fractography of tensile specimens was also addressed.

Keywords: Magnesium composites, stir casting, Mechanical properties and characterization.

INTRODUCTION:

Currently, the majority of research efforts in the automotive business are directed on product development with the aim of enhancing vehicle performance. Using alternative materials is the most efficient and economical approach. The choice of materials is crucial in determining the product's usefulness, cost, and environmental impact. The study on magnesium materials serves as an alternative to cast iron, polymers, aluminium alloy, and composites [1-4]. Due to its unfavorable mechanical qualities, such as low density, pure magnesium is seldom utilised [5]. The addition of aluminium and zinc as alloying components enhances the mechanical qualities of magnesium material. AZ91 is a commercially used magnesium alloy known for its excellent castability and mechanical qualities [6]. The development of composites using magnesium alloys is a favourable option for achieving thermal stability.

The choice of material depends on the size, kind, and volume fraction of the reinforcements. It is crucial to consider how these reinforcements interact with the matrix in order to achieve desirable qualities. Ceramic particles are used as reinforcements to enhance the melting point, thermal stability, high hardness, and strength. The magnesium matrix was reinforced with silicon carbide powder, resulting in composites with enhanced thermal stability, high hardness, and strength. There were seven researchers that researched on SiC in MMC's. The composites exhibited brittleness due to the presence of SiC particles [8, 9].

Various methods, including as powder metallurgy, powder sintering, spray deposition, and stir casting, were used to produce composites reinforced with particles [10, 11]. The stir casting technology is preferred due to its cost-effectiveness and rapid rate of production. The stirring method significantly influences the dispersion of reinforced particles inside the liquid matrix. This approach ensures the consistent distribution of reinforcement inside the matrix, effectively addressing porosity and enhancing grain refinement. Over the last several decades, significant efforts have been made to develop and conduct research on magnesium and its alloys. The availability of work on the creation and characterization of magnesium-based composites using the stir casting process is quite limited. The current study involves the fabrication of composites reinforced with SiC and graphite using the stir casting process. The addition of SiC particles increases the strength qualities, while the inclusion of graphite particles enhances wear resistance. The samples that were casted underwent homogenization, and their mechanical characteristics were characterized.

2. METHODOLOGY AND MATERIALS

2.1 Materials

The AZ91D Mg alloy, in ingot form, was obtained commercially from Venuka Engineering Pvt Ltd. The elemental chemical composition of the AZ91D alloy is shown in Table 1. This study suggests using SiC particles as reinforcement into the AZ91 Mg alloy matrix. The composites were produced using the stir casting process, including reinforced SiC and graphite particles with an average size of 53µm. The reinforced particles were provided by Krish Met Tech Limited in Chennai. Figures 1 and 2 show the microstructural images of SiC and graphite reinforcements. Figure 3 displays the Energy Dispersive Spectroscopy (EDS) graph indicating the elemental composition of the SiC particles.

Table 1 displays the elemental chemical makeup of the AZ91D magnesium alloy

Elements	Al	Zn	Mn	Cu	Fe	Ni	Si	Mg
Wt%	3	0.98	0.20	0.002	0.002	<0.001	<0.01	Rest

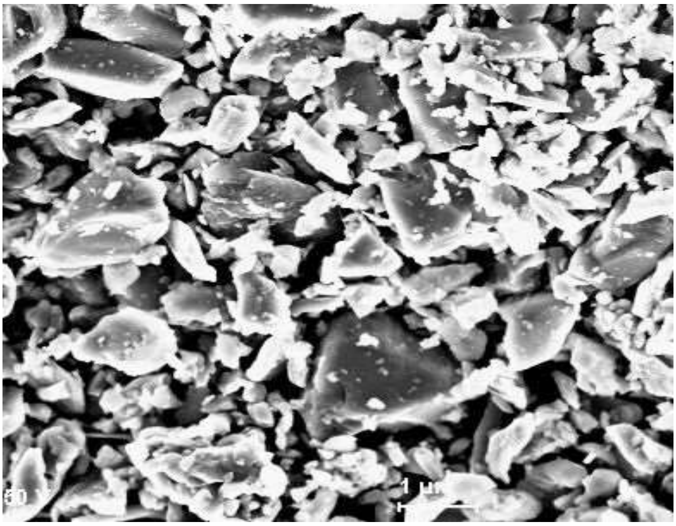


Figure 2 Microstructural image of SiC particulate reinforcement

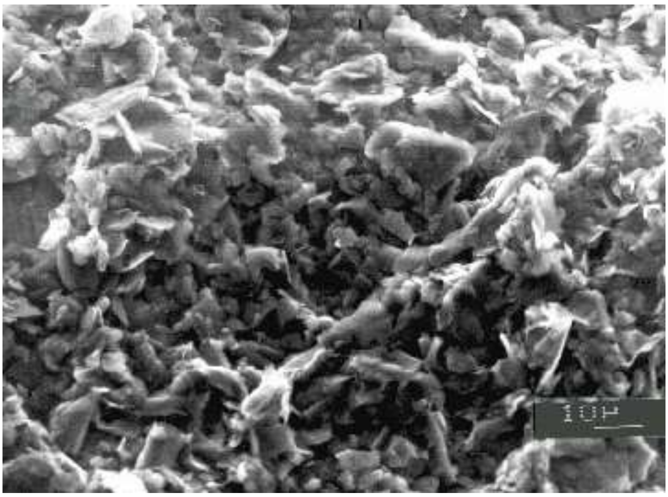
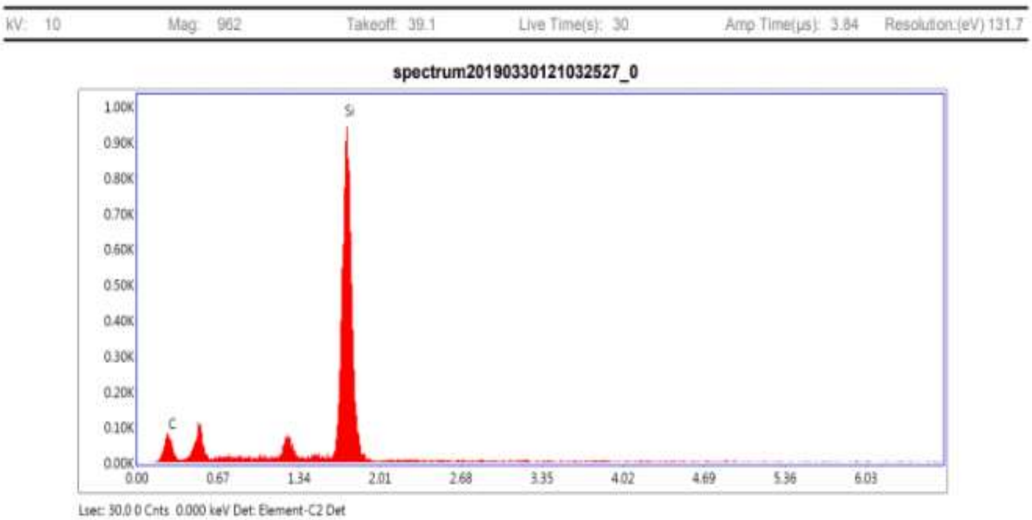


Figure 3 Microstructural image of graphite powder



Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	20.08	37.00	14.97	18.36					
SiK	79.92	63.00	280.18	3.32					

Fig 4 EDS of SiC particulates

2.2 Composites fabrication

The fabrication of composites was carried out making use of the stir casting process. The ingot-shaped material was divided into smaller pieces and placed within a graphite crucible, as shown in figure 5. This was done to prevent any chemical reactions from occurring while the matrix material is in its liquid condition. The crucible and raw material are preheated to eliminate the presence of external gases and minimise casting faults. The crucible is first heated to 400°C in the muffle furnace and then filled with the material. Subsequently, the temperature is raised to 650°C. The boiler was filled with high quality argon gas (99.9%) to produce a vacuum atmosphere. The flux, consisting of 1wt% of a matrix composed of 15wt% CaF2, 15wt% MgO, 20wt% KCl, and 50wt% $MgCl_2$, is used to eliminate the presence of foreign gases in the molten metal. A 10wt% surplus of alloy material was selected to compensate for losses due to oxidation and the removal of slag. The vortex is generated using a standard stirrer equipped with a graphite impeller rotating at a speed of 700 rpm, which is controlled by an electrical variac. The preheated SiC and graphite reinforcement powders, at a temperature of 200°C, were introduced into the vortex to ensure a homogeneous distribution inside the molten metal. Once reinforcement was added, the molten metal was poured into a warmed cylindrical mould made of grey cast iron. The composite samples were rapidly cooled in cold water at room temperature to enhance their strength and hardness. The process of homogenisation was conducted for a duration of 24 hours in order to eliminate any internal tensions.

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. Figure 5 Composite preparation

2.3 Porosity measurements

The porosity and density of both reinforced and non-reinforced composites were assessed according to both theoretical and experimental methods [8, 9]. Theoretical measurements were conducted using the Rule of Mixtures technique. The experimental measurements were conducted using Archimedes' principle.

% of Porosity= 1-(measured density/ theoretical density) x 100

2.4 Microstructure evaluation

The microstructure of both reinforced and non-reinforced composites was evaluated to analyse the process of grain refinement and creation. The produced samples underwent polishing using polishing sheets to achieve a mirror-like finish. The samples were treated with an etchant solution consisting of 10ml distilled water, 70ml of 95% ethanol, 4.2g picric acid, and 10ml acetic acid. This solution was used to eliminate undesired substances on the surface and display the microstructural pictures. The Scanned Electron Microscopy was used to analyse the grain refinement and uniform distribution of reinforcement particles.

2.5 Mechanical characterization

Magnesium composites of various volume percentages of reinforcement have been examined. Micro hardness studies were carried out to study the effect of reinforcement in the MMC. Micro hardness was evaluated at a load of 100 gm and a dwell period of 10s. Tensile tests were conducted on Instron 8801 UTM with a ram speed of 3mm/min at room temperature to find out the tensile strength and young's modulus. The specimens used for tensile test those are prepared as per the ASTM E8-3 standard.

3.Results and discussion

3.1Microstructure characterization

The microstructure characterization was done on both reinforced and unreinforced composites shown in figure no 6. Figure 6(a) exhibits the SEM micrograph of primary α-Mg dendritic structure with secondary phases on grain boundaries [12]. Figure 1(b), 1(c) are the SEM micrographs of composites containing 4% and 2% volume percentages of 53 μm size of SiC and graphite particles in equal ratio. By clearly examine and noticed that there was uniform distribution of SiC particles and grain refinement. This refinement may enhance the mechanical properties. In figure 1(a) the inter dendrite regions (IDR's) was identified. The IDR's along with SiC reinforced particles were acknowledged in the composites with uniform distribution. Sic particles were uniformly distributed in the matrix, therefore there was no agglomerations occurred in the reinforced composites. By increasing the volume fraction of the reinforcement which will increases the properties of the composites. Figure 1(d) was the interface between the matrixes to the reinforcement. This interface shows the grain refinement leads to improve the properties of the composite with respect to the product development. Figure 7 gives the EDS analysis of reinforced composites. There were no oxygen peaks noticed in the alloy and composites because of continuously impinge the argon gas during the casting procedure.

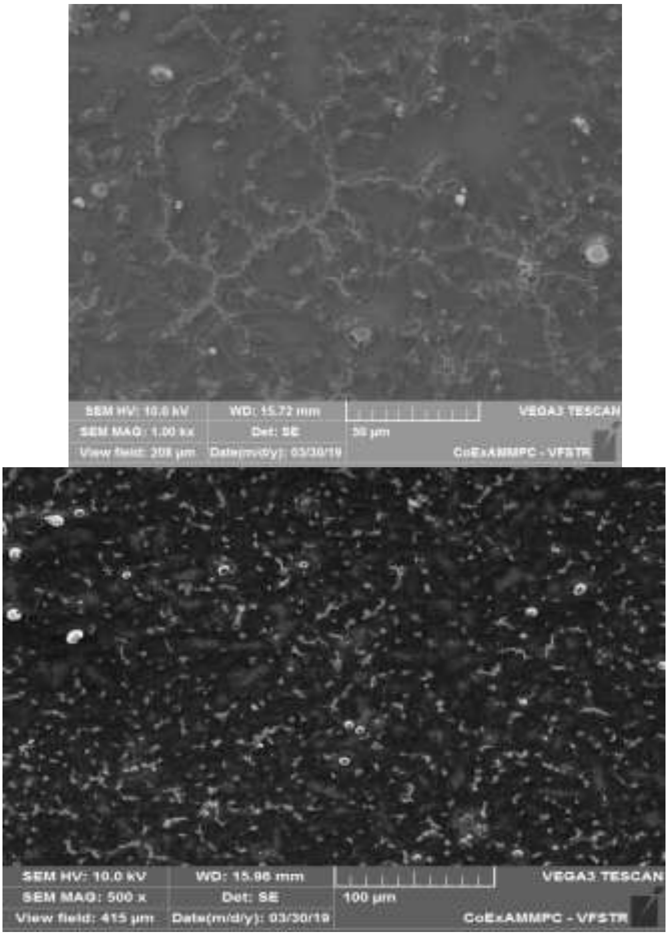
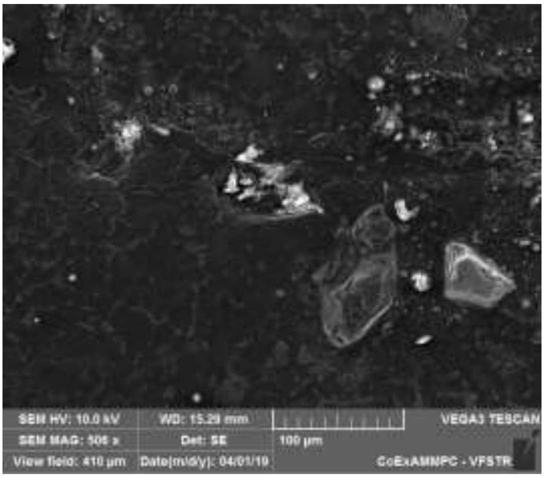
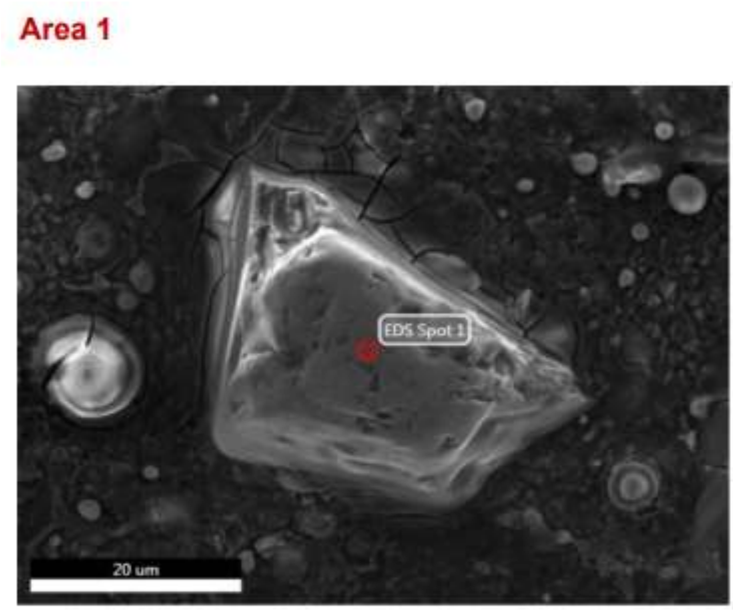
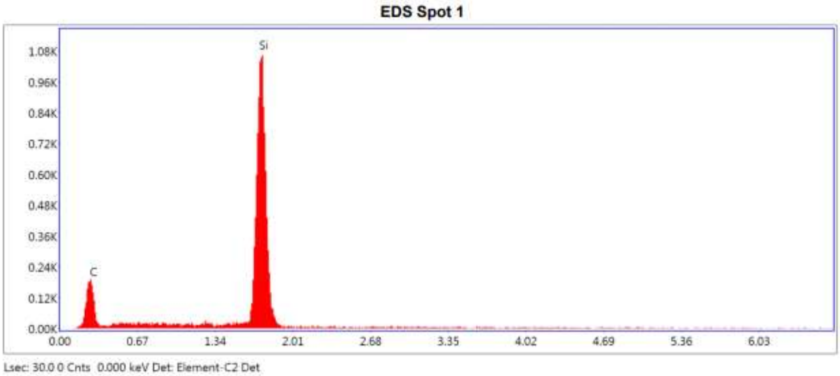


Fig 6(a) SEM image for AZ91 Mg alloy (b) SEM image of AZ91+4%SiC/Graphite composite



c)SEM image of AZ91+2%SiC/Gr composite





eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	34.16	54.82	43.28	13.93	0.0668	1.1153	0.9545	0.1753	1.0000
SiK	65.84	45.18	325.32	3.26	0.6152	0.9369	1.0182	0.9955	1.0020

Figure 7 EDS on SiC particle for as cast AZ91D Mg alloy and composites

3.2 Mechanical properties

3.2.1 Density

Table 2 gives the comparison of theoretical density, measured density and porosity of the alloy and composites. The low porosity exhibits successful castings. However, the measured density values are lesser than the theoretical density the addition of reinforcements may be the reason for enhancement of the porosity and also due to the occurrence of agglomerations, interstatial voids and non-continuity during stirring and pouring into moulds by gasses entrapment [13]. The theoretical and measured densities have been depicted in Figures 8 and 6.

Table 2. Density and porosity of alloy and composites.

Material	Density(g/cc) theoretical	Density(g/cc) Measured	% porosity
AZ91 Mg Alloy	1.8	1.799	±0.6
AZ91+2% SiC	1.82	1.812	±0.5
AZ91+4% SiC	1.84	1.83	±0.6

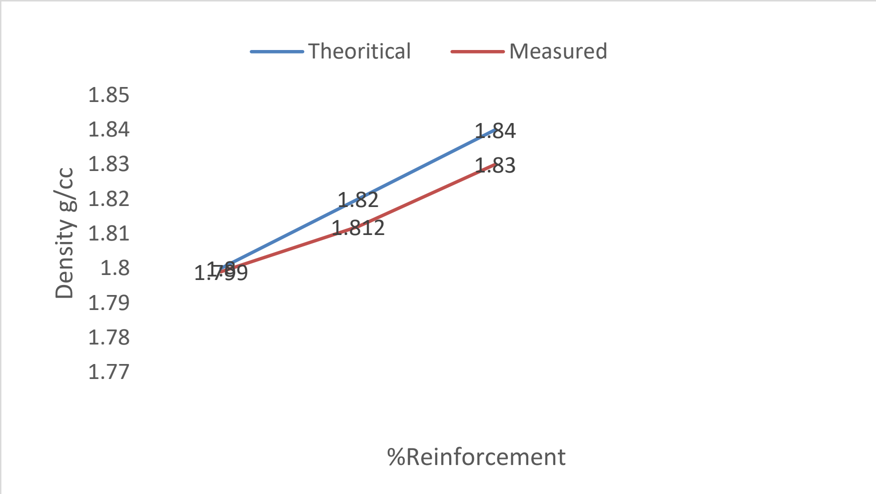


Figure 8 Density differences in composites

3.2.2 Compressive strength

The compressive and yield strengths of the composites were enhanced as a result of the higher volume % of SiC particles in the magnesium alloy composite. The strength of the composite material is influenced by the size of the particles that make up the reinforcement and the quality of the bonding between the reinforcement and the matrix material [14]. Enhanced strength may be attained due to the decrease in the size of reinforcing particles. The interfacial connection between the reinforcement and the matrix is sufficient, allowing the applied stress to be transferred to the magnesium alloy matrix via the reinforced particles. The alloy exhibits a compressive strength of 173.42 MPa, but a higher compressive strength of 380 MPa was recorded when the composite had a weight percentage of 4%. The inclusion of ceramic particles in the matrix may lead to a reduction in ductility and an increase in compressive strength. The compression characteristics were provided in table 3.

Table 3. Compressive strength and yield strength.

Material	Compressive strength(MPa)	Compressive strain mm/mm	Modulus of Elasticity (GPa)
AZ91D	173.42	0.324	2.4
AZ91D+2% SiC/Gr	913.35	0.281	2.7
AZ91D+4% SiC/Gr	380.20	0.132	2.6

3.2.3 Hardness

Table 4 provides comprehensive micro and macro hardness measurements for Alloy, as well as various weight percentages of reinforcement. It is evident that both the micro and macro hardness values rise proportionally with the amount of reinforcement, in comparison to the base alloy. The pure AZ91D alloy had a Hardness value of 99.2 VHN. However, when reinforcement particles were added at a concentration of 2%, the hardness value increased to 100.5 VHN. This measurement was obtained using a digital micro hardness tester, with a load of 100g, and an average of 5 tests were conducted on a sample. The inclusion of reinforcing particles at a concentration of 4% results in the lowest hardness value when compared to other compositions and the base alloy. Figure 9 depicts a graphical depiction of the fluctuations in hardness for both the alloy and the composite. The increase in hardness is a result of the strengthening effect caused by the distribution of particles inside the alloy matrix. These particles act as reinforcements and transfer the load to the particles at the bonding interface in the composites.

Table 4. Hardness value (VHN)

Material	Micro Hardness VHN
AZ91 Mg Alloy	90.08
AZ91+2% SiC	80.97
AZ91+4% SiC	71.89

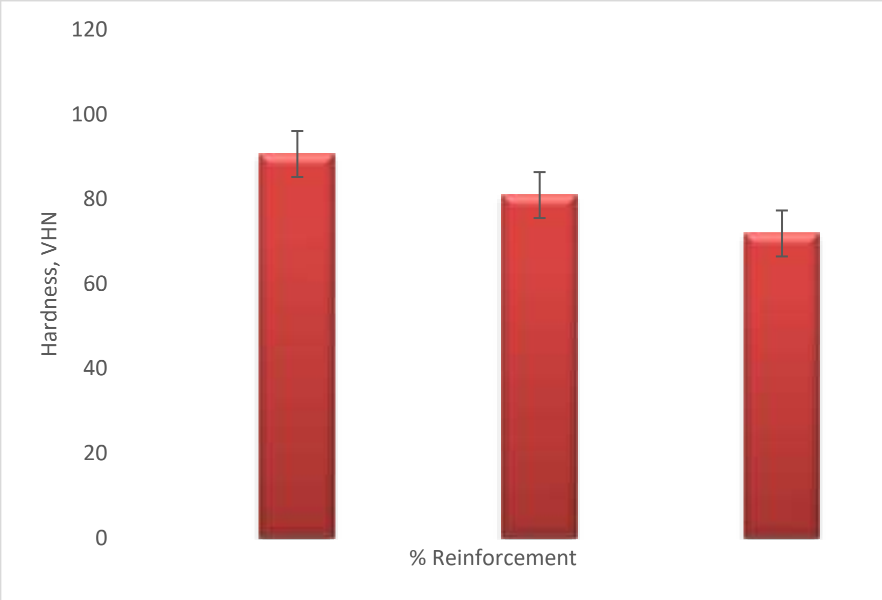


Figure 9 Micro hardness variations of composites

Conclusions:

1. Composites were produced utilising the stir casting technique. The reinforcement was evenly dispersed throughout the matrix and securely linked together to enhance the characteristics of the composites.
2. The inclusion of SiC particles in the matrix enhances the young's modulus and ultimate tensile strength.
3.The composites achieved a notable improvement in grain refinement as a result of the impact of SiC particles.

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