Mechanical and Metallurgical properties of AZ31D/SiC Composite Fabricated through Powder Metallurgy

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Abstract

Metal Matrix Composites (MMC) are highly advantageous materials which are utilized in the automotive industry to enhance fuel efficiency and decrease overall weight. Among lightweight materials, magnesium alloys rank second only to aluminum. By combining a magnesium alloy with hard ceramic particles, superior mechanical strength can be achieved. This study focuses on AZ31D magnesium alloy reinforced with SiC particles, fabricated using powder metallurgy. The SiC particle content ranged from 0 to 4 wt.% with a uniform particle size of 5.35µm. Green compact specimens were prepared using an isostatic compacting press and subsequently sintered at 600℃ in an argon environment using a tubular furnace. Physical and mechanical testing methods were employed to examine the specimens. The density of the composites increased compared to the base material as the weight percentage of reinforcement increased. Microstructural analysis revealed a defect-free composite with a fine-grained structure. The Micro Vickers hardness and compression strength of the composites with 4 wt.% SiC particles exhibited an improvement compared to the base matrix, owing to the presence of hard SiC particles and the sintering process, which enhanced workability and work hardening properties.

Keywords: *AZ31D/SiC, Powder Metallurgy; Mechanical and Metallurgical properties*

1.0 Introduction

Composite materials are specially made materials that include two or more different materials with unique properties [1]. Even though these materials have distinct identities in the final product, combining them creates special characteristics not found in the individual components. Composite materials are often used in industries like automotive and construction, where the demand for strong and lightweight materials is high [2]. In this research work, a Metal Matrix Composite (MMC) is being developed using AZ31 Magnesium Alloy as the main material and SiC (Silicon

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Carbide) as the reinforcing material.

The focus is on how these materials are put together and understanding their mechanical and metallurgical properties.

A manufacturing technique called powder metallurgy (PM) is being used in this Research. PM technique involves mixing powders, compressing them into a mold, and then heating the compressed mixture in a furnace. This method allows for precise shaping of parts with minimal waste while maintaining desired properties [3]. Research on the AZ31 magnesium alloy spans various processing techniques, surface treatments, and potential applications. Studies have explored improving the mechanical properties of aircraft brackets through forging [4] and enhancing strength and ductility using severe plastic deformation[5]. Fabrication of Mg-SiC composites with promising properties for automotive applications has also been investigated [6]. Surface treatments like conversion coatings show potential for improved corrosion resistance, with factors like surface finish and native oxide film playing a role [7]. Development efforts using powder metallurgy have explored microstructure, mechanical properties, and workability limits of AZ31B Mg alloy [8] and even designed a Mg-based matrix model with enhanced corrosion resistance and biodegradability for orthopaedic applications [9]. Biocompatibility and degradation behaviour of AZ31D alloy for artificial bone implants have also been studied [10]. Additionally, research has ventured into recycling Al-Si-Zn-Mg alloy milling chips through powder metallurgy [11]. This overview demonstrates the diverse and ongoing research efforts surrounding the AZ31 magnesium alloy and its potential in various fields. The objective of this research is to understand their mechanical and metallurgical properties. FSP involves creating grooves in magnesium alloy plates, filling them with TiC particles, and using specific parameters for effective processing.

2.0 Magnesium alloys and Silicon Carbide

These composites were fabricated using magnesium ally AZ31D and silicon carbide to enhance the metallurgical properties. Powder Metallurgy (PM) is a widely used technique to address formability challenges associated with magnesium (Mg) while providing the advantage of near-net-shape processing. Advanced gas atomizing techniques are typically employed to produce metal powders, including Mg, by melting the bulk metal and then atomizing it to achieve the desired particle size [3]. To ensure uniform mixture and prevent segregation, the powder is carefully blended with alloying elements before compaction. However, excessive blending can alter the powder characteristics, generating additional fine particles or modifying the particle surface. The compacted powder is then sintered in a controlled atmosphere at a lower temperature than the melting point but sufficiently high to enable large diffusion between the powder particles.

2.1 Magnesium alloys

Magnesium alloys are well-known for their lightweight nature, making them the lightest structural alloys available. These alloys primarily consist of magnesium, combined with other metallic elements like manganese, aluminium, zinc, silicon, copper, zirconium, and rare-earth metals to enhance their physical properties as detailed in Table 1. Incorporating these elements improves various characteristics of the alloy. Notably, magnesium alloys possess a low specific gravity and exhibit a high strength-to-weight ratio, making them highly desirable for numerous applications in aerospace, automotive, industrial, electronic, and biomedical fields.

Table 1. Matrix material composition

Element	Composition (%)
Magnesium	97 .00
Aluminium	2.500 - 3.500
Zinc	0.600 - 1.400
Manganese	0.20
Silicon	0.10
Copper	0.05
Calcium	0.04
Iron	0.005
Nickel	0.05

2.2 Silicon Carbide (SiC)

Silicon carbide (SiC) is a semiconductor composed of silicon and carbon. It is an incredibly rare mineral called moissanite when found naturally. Since 1893, synthetic SiC powder has been manufactured on a large scale due to its abrasive properties as shown in Fig. 1. Through the process of sintering, silicon carbide grains can be fused together to create highly durable ceramics that are extensively used in applications requiring exceptional durability.

Silicon carbide has played a significant role in the field of electronics. As early as 1907, it was utilized in electronic applications such as light-emitting diodes (LEDs). SiC is particularly valuable for high temperature semiconductor electronic devices, high voltages, or both. The Lely method allows for the growth of large crystals of silicon carbide, which can then be used to produce synthetic moissanite gems.

Fig. 1. Silicon Carbide Powder

3.0 Methods

3.1 Ball Milling

Ball milling is a grinding technique used to pulverize nanotubes into exceptionally fine powders. This process involves the collision of small, rigid balls inside a closed container, resulting in the generation of localized high pressure.

3.2 Compacting

The powder, which had been preheated, was subjected to cold compaction using a hydraulic press with a uniaxial pressure of 800 MPa. A cylindrical die as shown in Fig. 2 was utilized to form pellets with a diameter of 15 mm and height of 12 mm as shown in Fig. 3. The resulting green compacts were then sintered using either a muffle furnace or a microwave furnace.

Fig. 2. Compacting Process

Fig. 3. Material after Compacting

3.3 Sintering Process

Sintering, also known as frittage, is a manufacturing process that involves compacting and shaping a solid material without melting it completely. Tubular Furnace as shown in Fig. 4 used to sintering process, and processed samples are shown in Fig. 5. This process utilizes heat or pressure to achieve the desired result. Sintering occurs naturally in mineral deposits and is also employed in various manufacturing processes for materials such as metals, ceramics, plastics, and other substances.

Fig.4. Tubular furnace

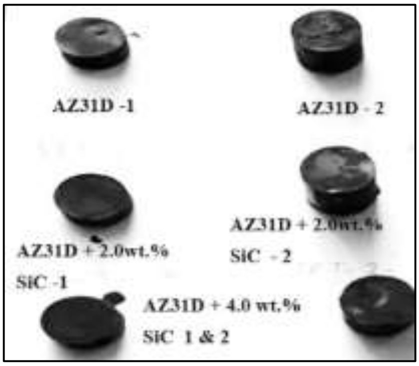

Fig. 5 Material after tubular furnace

4.0 Results and Discussion

4.1 Density analysis

The physical characteristics, including sintered density, green density, and porosity, were assessed. The porosity of the sintered composites was calculated following the guidelines of ASTM C-1309-85 as detailed in Table 3. The sintered density was determined using the Archimedes principle. The density of the samples was calculated based on the rule of mixtures and detailed graph shown in Fig. 6.

Table 3. Density Analysis

SL. No.	Composition	Theoretical Density (g/cm^3)	Density After Compacting (g/cm^3)	Density After Sintering (g/cm^3)
1.	AZ31D	1.81	1.78	1.75
2.	AZ31D + 2.0wt.% SiC	1.851	2.013	1.802
3.	AZ31D + 4.0 wt.% SiC	1.871	2.124	1.811

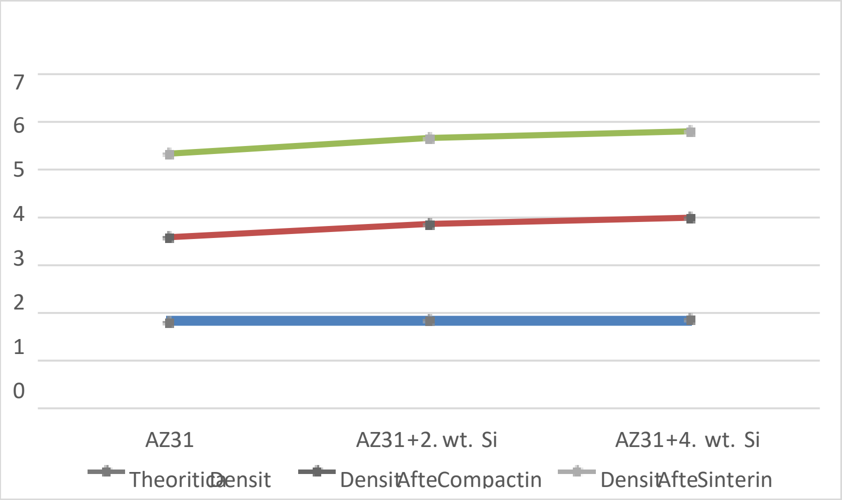

Fig. 6. Density Analysis Chart

4.2 Micro Vickers Hardness Test

The Vickers method employs an optical measuring system to determine hardness. The Micro hardness test, as specified by ASTM E-384, involves applying with a light range of loads using a diamond indenter to create an indentation, which is then measured and converted into a hardness value. This method is highly versatile and suitable for testing various materials, but it requires the test samples to be meticulously polished for accurate measurement of the indentations. The hardness ranges for the fabricated samples are shown in Fig. 7.

Optical Microscopy

In order to validate the characteristics of the composites, the surfaces of the sintered composite specimens were sequentially cleaned and polished using SiC abrasive papers of fine grit sizes 600, 800, and 1000 in a disc polishing-machine to achieve a reflective surface finish. Subsequently, the polished composite specimens were etched according to the metallographic study and analysed for their characterization. The examination from Fig. 8 to 10 revealed the presence of primary magnesium dendrites (α phase) coexisting with dark interdimeric precipitates of intermetallic β phase.

The composite structure exhibited a combination of flake and polygonal shapes of varying sizes, resulting from the clustering of SiC reinforcement particles with the Mg matrix. The addition of SiC particles had an effect on grain refinement in the composite samples. Compared to AZ31, the composite specimens displayed a finer grain size. The presence of SiC particles contributed to grain refinement during the blending and ball-milling processes and hindered grain growth during heating. As the SiC content increased, the amount and distribution of the SiC particles became more homogeneous.

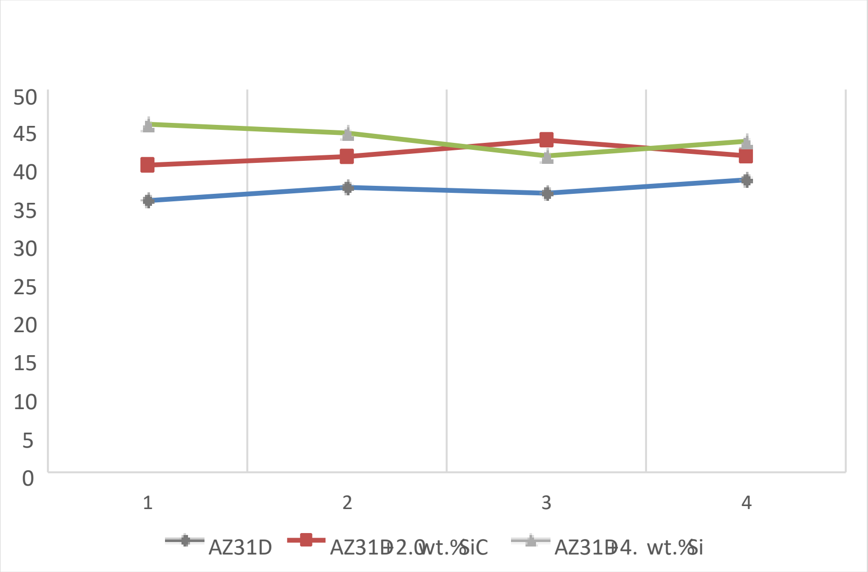

Fig. 7. Micro Vickers's Hardness Test Chart

Table 4. Micro Vickers's Hardness Test

Location/ Composite	**1**	**2**	**3**	**4**
AZ31D	35.5	37.2	36.45	38.2
AZ31D + 2.0wt.% SiC	40.12	41.23	43.4	41.33
AZ31D + 4.0 wt.% SiC	45.45	44.32	41.35	43.24

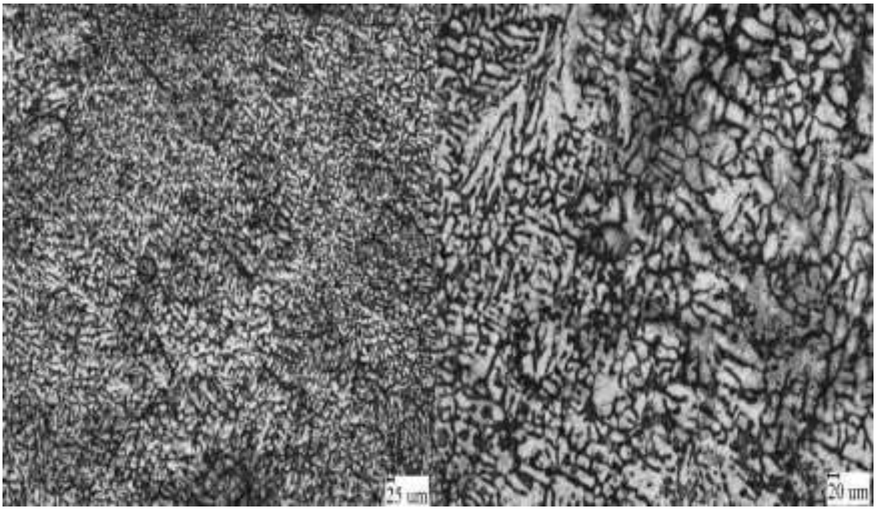

Fig. 8 Optical Microscopy of AZ31D

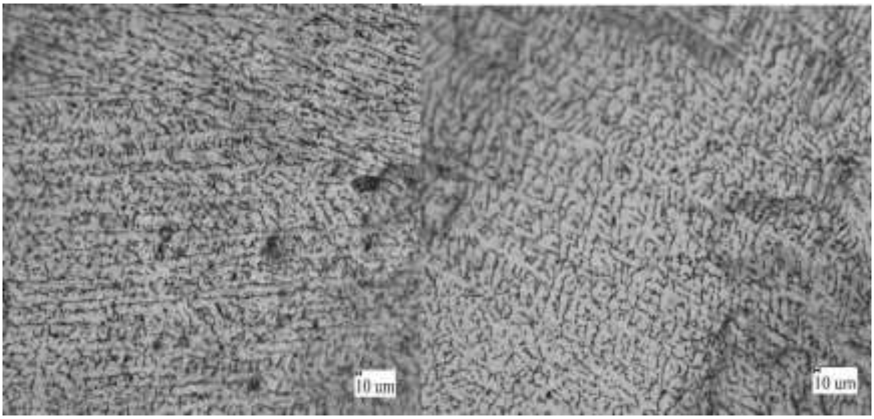

Fig. 9. Optical Microscopy of AZ31D/2wt. % SiC

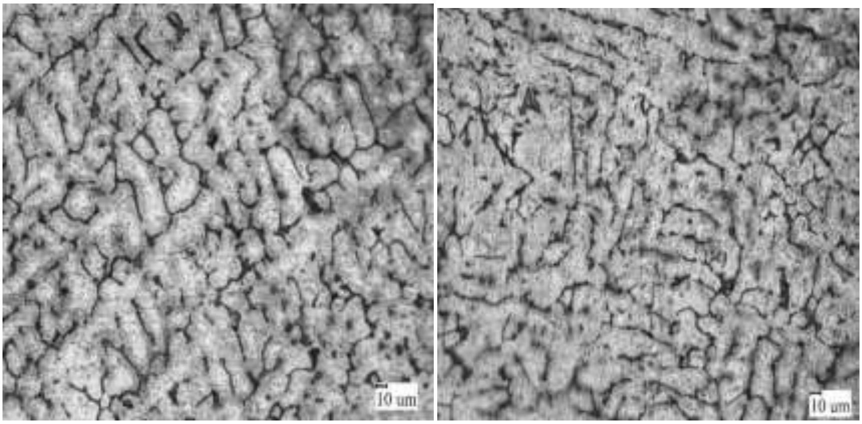

Fig. 10 Optical Microscope image for AZ31D/ 4 wt. % SiC

4.3 Compression Test

The mechanical characterization of the samples was assessed through a compressive test in accordance with the ASTM E9-89 by computerized servo-controlled UTM F-100. The test was conducted at a feed rate of 1mm/min. Among the different aspect ratios studied, the better load-bearing capacity was observed for the 0.8 aspect ratio.

AZ31D: max compressive strength: 5.345 KN (break load)

AZ31D + 2 wt. % SiC: max compressive strength: 9.160 KN (break load)

AZ31D + 4 wt. % SiC: max compressive strength:10.635 KN (break load)

For each composition, compression tests were performed on samples with dimensions of length l =12 mm and diameter d=15 mm (L/D = 0.8). The end surfaces of the samples were positioned perpendicular to the fixture surface.

5.0 Conclusion

In the present investigation, Mg and Mg-SiC composites are fabricated through powder metallurgy with different SiC content, the characterization was done with optical microscope, density with Archimedes' principle, hardness on micro- Vickers hardness tester and compression behaviour using UTM. Based on the experiments carried out, the following conclusions can be derived.

The tubular sintering process demonstrated a more effective response in terms of densification due to its uniform volumetric heating. The density of the composite increased with the addition of SiC, resulting in improved densification compared to the base matrix. The optical microscopy revealed the presence of SiC particles with uniform distribution on base matrix with defect free composites. The hardness of 4 wt.% SiC composite shows higher hardness than another fabricated samples, the hard SiC resist the deformation during indentation.

The AZ31D+4 wt.% SiC composite exhibited a maximum compressive strength of 10.635 KN, indicating its ability to resist plastic deformation and exhibit higher strain hardening. The disparity in density between the magnesium (Mg) and SiC particles contributes to increased internal stress and a higher density of dislocations within the composite, further enhancing its mechanical properties.

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