Bull. Chem. Soc. Ethiop. **2024**, 38(2), 305-312. ISSN 1011-3924
Printed in Ethiopia
DOI: https://dx.doi.org/10.4314/bcse.v38i2.3 Online ISSN 1726-801X


# INVESTIGATION AND CHARACTERISTICS OF AZ91 MAGNESIUM METAL MATRIX COMPOSITE USING THE POWDER METALLURGY PROCESS

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(Received August 31, 2023; Revised November 24, 2023; Accepted November 28, 2023)

**ABSTRACT**. This paper aims to investigate the mechanical and metallurgical properties of magnesium AZ91 composite. Zinc and Aluminium were selected as reinforcement particles in the Magnesium metal matrix composite. The composites 88.5%Mg-9%Al-1.5%Mn-1%Zn, 87.5%Mg-9%Al-2.5%Mn-1%Zn, 86.5%Mg-9%Al-3.5%Mn-1%Zn, 85.5Mg-9%Al-4.5%Mn-1%Zn, 84.5%Mg-9%Al-5.5%Mn-1%Zn and 83.5%Mg-9%Al-6.5%Mn-1%Zn are prepared through powder metallurgy. The hardness and compressive tests are used to investigate the mechanical properties of the magnesium composite. The results of the mechanical properties indicate that manganese plays a vital role in improving the hardness of the AZ91 composite. The thermogravimetric analysis investigated the weight ratio % at the 400OC. The scanning electron. microscopic analysis was used to investigate the reinforcement particle's bonding level and the defects on the composite. Based on the results, the manganese plays a vital role in improving the mechanical properties of the AZ91 composite.

**KEY WORDS**: Magnesium, Composite, Mechanical properties, Hardness, Compressive, Corrosive behaviour

## INTRODUCTION

Magnesium (Mg) is considered a highly promising material in the aerospace and automotive industries due to its advantageous characteristics, such as its low density and high specific strength. However, the subpar mechanical, wear, and corrosion properties pose significant challenges for utilizing it in industrial applications [1, 2]. To address the drawbacks associated with magnesium, various alloys have been employed for an extended period of time [3]. Among the numerous magnesium alloys available, AZ91 stands out as a widely used alloy due to its favourable characteristics, such as excellent castability, machinability, and corrosion resistance [4]. While magnesium alloys are generally not considered suitable for use as bearing and gear materials, there is still a possibility that their surfaces may come into contact with various other materials [5]. Wear is a highly significant and crucial factor contributing to reduced service life. Hence, conducting a comprehensive analysis of the tribological characteristics of magnesium alloys holds significant significance [6]. This study aimed to analyze the behaviour of SiC particles in a magnesium matrix (AZ92) and evaluate their resistance to corrosion in neutral salt fog and in a solution containing 3.5-weight percent NaCl. According to the findings of numerous studies, Mg-SiC exhibited a high susceptibility to corrosion in a neutral fog solution, which led to the production of a wide variety of corrosion by-products. On the other hand, its corrosion resistance was significantly improved when subjected to circumstances of high humidity [7]. In order to explore the behaviour of corrosion in the AZ91 alloy, a series of experiments were carried out after alumina particles were dispersed throughout the material. The research also included

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electrochemical impedance spectroscopy (EIS), a potentiodynamic polarisation test, and immersion tests in an alkaline solution [8].

Both pure magnesium and magnesium alloys exhibit limitations, such as limited ductility, suboptimal tribological properties, low heat stability, and inadequate corrosion resistance. To mitigate these limiting variables, it is common practice to intentionally incorporate reinforcements of varying sorts, amounts, forms, and length scales (ranging from micron to nano size) into magnesium alloys. The demand profile of reinforcing phases exhibits various characteristics and is influenced by multiple elements, including the matrix system, production processes, and fabrication procedures [9]. The production of the Mg-6wt%Zn alloy resulted in mechanical qualities such as tensile strength and elongation attained of 279.5 MPa and 18.8%, respectively, and the rate of deterioration in simulated bodily fluid was lower than that of pure magnesium. The in vivo tests and the cytotoxicity grade of 0-1 both demonstrated that it has good biocompatibility in bone [10]. The rates of corrosion experienced by several magnesium alloys, wherein the degradation rates were altered by alloying the magnesium with various other elements to produce new alloys. Another method for slowing the pace of deterioration is to select a magnesium alloy that is readily available on the market and then apply surface coatings to slow the rate at which it corrodes [11]. The tests were conducted with the L18 orthogonal array (OA) design. Single-objective optimization was carried out employing the Taguchi method, while multi-objective optimization was conducted. A comparative analysis was conducted to assess the performance of the technique for order of preference by similarity to ideal solution (TOPSIS) and artificial neural network (ANN) methodologies, with a focus on their respective outcomes. The type of electrolyte supply was taken into consideration. The evaluation focused on one specific element and its impact on MRR (mean reciprocal rank) and OC (overall correlation) [12]. Because of its superior mechanical qualities, biocompatibility, and bioactivity, functional-graded magnesium matrix composites (FGMMCs) are widely used in biomedical, aeronautical, and thermal barrier applications [13]. Based on the existing research, most researchers prefer the alumina and SiC particles to be used to reinforce with AZ91 alloy. Manganese is preferred as the reinforcement particle in this work due to its hard and brittle nature.

## EXPERIMENTAL

The manufacturing sector is the economy's engine since raw resources are transformed from one form into another and where additional value is created. The fabrication of metallic biomaterial composites can be broken down into three distinct categories depending on the temperature of the metallic biomaterials. There is the process of fabricating in a liquid state, the method of fabricating in a solid state, and the process of fabricating in two phases. The solid-state fabrication of powder metallurgy creates this investigation's biodegradable magnesium AZ91 alloy, shown in Figure 1. Matrix and reinforced materials were purchased from Parshwamai Metals Mumbai. Powder metallurgy refers to the production and processing of metal powders, which is accomplished by compacting the powders in appropriate dies and then sintering (heating without melting) them. Items such as gears, cams, bushings, cutting tools, porous items such as filters and oil-impregnated bearings, and automotive components such as piston rings, valve guides, connecting rods, and hydraulic pistons are typical examples of the types of products that can be manufactured using powder metallurgy techniques.

Powder metallurgy allows for the use of either metals in their purest form, alloys, or combinations of metallic and non-metallic components. Iron, copper, aluminium, tin, nickel, titanium, and refractory metals are the metals that are utilized most frequently in modern society. Pre-alloyed powders are utilized to produce brass, bronze, steel, and stainless steel components. These powders contain individual particles that are themselves alloys. Powder manufacturing, blending, compacting, sintering, and finishing are the processes that make up the powder metallurgy process. The finishing process follows these operations shown in Figure 2.

Figure 1. AZ91 magnesium powder.

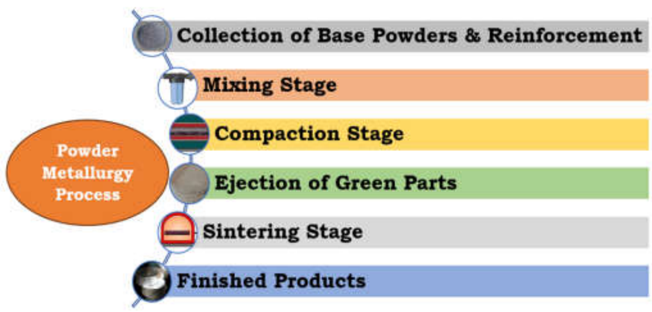


Figure. 2. Powder metallurgy process.

The compaction process involves the application of pressure to the mixture of powders, resulting in the formation of desired shapes within dies. This pressure is often applied through either hydraulic or mechanical presses. The element composition of the AZ91 alloy is shown in Table 1.

Table 1. Elements of AZ91 alloy.

| Element | Content (%) |
|---|---|
| Aluminum (Al) | 8.3-9.7 |
| Manganese (Mn) | 0.15-0.50 |
| Zinc (Zn) | 0.35-1 |
| Silicon (Si) | 0.1 |
| Copper (Cu) | 0.03 |
| Iron (Fe) | 0.005 |
| Nickel (Ni) | 0.002 |
| Magnesium, Mg | Remainder |

The primary objective of compaction is to provide the desired form, density, and inter-particle contact, enhancing the component's structural integrity for subsequent processing. The compact form of pressed powder is called "green compact." For the powder to be effectively introduced into the cavity, it must exhibit high fluidity. The process of pressing is often conducted under ambient conditions. The schematic design illustrating the die for compaction is presented, which has been fabricated using oil hardening non-shrinking steel (OHNS). Sintering refers to the controlled heating of crushed metal powder in a specific environment to a temperature below its melting point yet sufficiently elevated to facilitate the fusing and bonding of the individual particles. Various supplementary procedures can be conducted after the sintering process to enhance the attributes of sintered powder metallurgy (P/M) products or imbue them with distinctive features. Coining and sizing are supplementary compaction procedures carried out using high-pressure presses. The primary objective of these processes is to enhance the dimensional correctness of the sintered component while augmenting its strength and surface quality through further densification. Manganese is in a powder state, with a melting point of 1246 °C. The metallic grey Mn has a good density in the 7.26 g/cm$^3$ range. The selected alloy elements with bio-absorbable magnesium AZ91 biomaterials are evaluated, and their percentage levels are measured using a digital weighing balance. These proportions are used in manufacturing this alloy by using the stir casting process, which is one of the most economical methods of processing the biomaterials of composite materials. The detailed proportions for this alloy are described below in Table 2.

Table 2. Compositional values for various alloys.

| Composition | Zn (%) | Al (%) | Mn (%) | Mg (%) |
|---|---|---|---|---|
| 1 | 1.0 | 9.0 | 1.5 | 88.5 |
| 2 | 1.0 | 9.0 | 2.5 | 87.5 |
| 3 | 1.0 | 9.0 | 3.5 | 86.5 |
| 4 | 1.0 | 9.0 | 4.5 | 85.5 |
| 5 | 1.0 | 9.0 | 5.5 | 84.5 |
| 6 | 1.0 | 9.0 | 6.5 | 83.5 |

Surface coatings are used to protect magnesium alloys against the corrosive effects of salt spray or maritime exposure, industrial atmospheres, etc. Most of these alloys have small levels of aluminium and other impurities, making magnesium less corrosion-resistant, whereas manganese makes it more corrosion-resistant.

## RESULTS AND DISCUSSION

### *Compression test*

The compression strength, made through compression testing machines and their factors, is evaluated in Table 3.

Table 3. Compression test evaluations.

| Composition % | Fluidity Stress N/mm$^2$ | Strain mm | Ultimate Stress N/mm$^2$ | Strain mm |
|---|---|---|---|---|
| 1 | 220 | 0.245 | 250 | 0.14 |
| 2 | 240 | 0.14 | 280 | 0.154 |
| 3 | 260 | 0.14 | 290 | 0.155 |
| 4 | 280 | 0.145 | 310 | 0.155 |
| 5 | 320 | 0.16 | 325 | 0.16 |
| 6 | 316 | 0.27 | 380 | 0.18 |

The data provided indicates that considering fluidity stress is pertinent to assessing compression strength, whereas evaluating ultimate stress is relevant to the analysis of tensile strength. Consequently, the fifth composition demonstrates superior fluidity stress and can withstand compressive forces in demanding load-bearing scenarios. Compared to alternative alloying compositions, the magnesium AZ91 alloy, containing 5wt% manganese, demonstrates favourable properties.

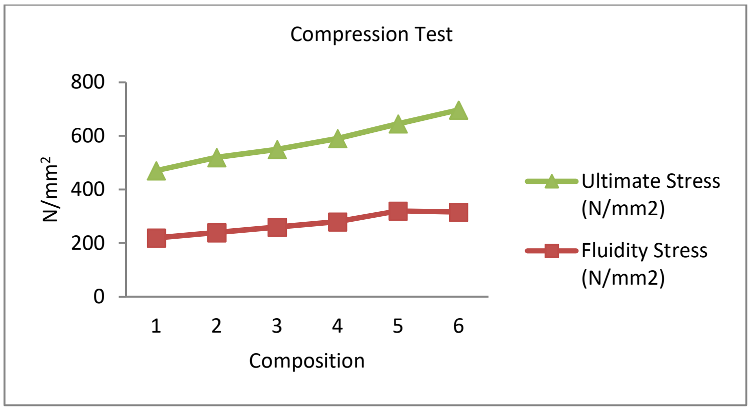


Figure 3. Compression test analysis.

The compression testing machine (CTM) was utilized to investigate the mechanical properties of magnesium alloy specimens containing different levels of manganese, as shown in Figure 3. Based on the research outcomes, it has been shown that a magnesium alloy containing 5% manganese has robust mechanical characteristics, favourable intermetallic bonding, and demonstrates stability as an alloy.

*Thermogravimetric analysis of AZ91 composites*

According to research, micro-alloying the magnesium composite AZ91 with beryllium can boost oxidation resistance at elevated temperatures. Because the beryllium diffuses and vaporizes the Mg ions. For weight reduction and increasing oxidation resistance, microalloying with beryllium may enable more extensive uses of these light alloys in implantation, aerospace and automotive sectors. The experimental composites were undergone thermogravimetric analysis for five hours in air at 400 °C. In order to understand the effects of TGA, property predictions are shown below in Figure 4.

*Hardness test*

All samples were loaded with 25 kg and then subjected to the Brinell hardness test. The force was applied for a period of 30 s to induce plastic deformation in the material. It had a diameter of 2.5 mm and was spherical in shape. The levels of hardness of the various produced samples are displayed in Figure 5. The growing volume fraction of manganese in magnesium composites resulted in a rise in the material's initial hardness, but after reaching a volume percentage of manganese of more than 6%, the hardness of the composite began to decline. The hardest material, measured at 120 BHN, was a magnesium composite with a 6% volume of manganese added to it for reinforcement.

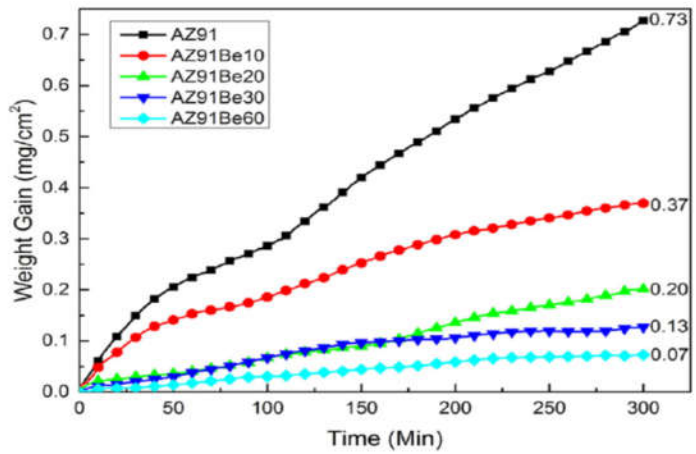


Figure 4. TGA findings for AZ91 composite oxidized in air for 5 hours at 400 °C.

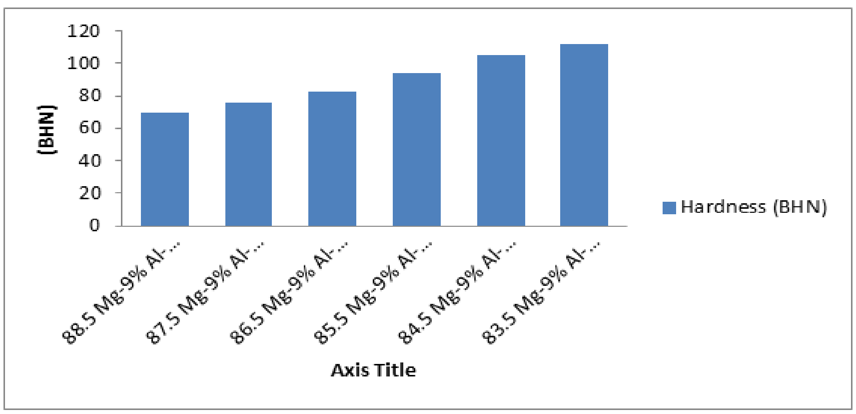


Figure 5. Hardness values of AZ91 composite

*Microstructure analysis*

Figure 8 displays the microstructures of each sample taken from the experiment. The fact that the sample of pure magnesium has a high porosity can be seen from the data. The samples that were strengthened with Mn have a lower overall porosity. Additionally, it can be shown that the AZ91 composite that has been strengthened with 8% manganese exhibits strong agglomeration and burn phases, as shown in Figure 6.

The SEM analysis shows bonding between the matrix and reinforced particles. Figure 8d shows the position of manganese and aluminium particles in 83.5 Mg-9% Al-6.5%Mn-1%Zn composite.

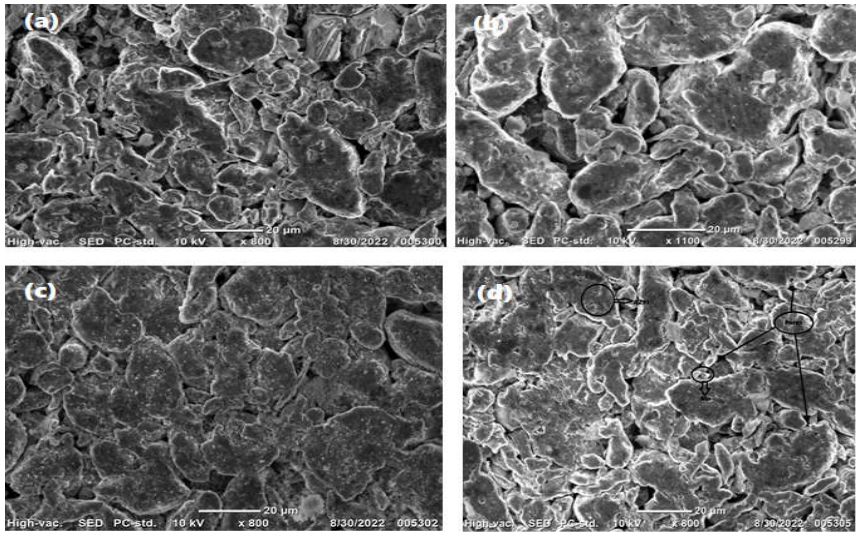


Figure 6. Microstructure images of (a) 88.5 Mg-9% Al-1.5%Mn-1%Zn, (b) 87.5 Mg-9% Al-2.5%Mn-1%Zn composite, (c) 86.5 Mg-9% Al-3.5%Mn-1%Zn and (d) 83.5 Mg-9% Al-6.5%Mn-1%Zn composite.

## CONCLUSION

This study involves the production of a magnesium alloy with different weight percentages of manganese using powder metallurgy. This investigation aims to examine the mechanical and microstructural properties of magnesium AZ91. The alloy was synthesized using meticulous and secure protocols and underwent a series of comprehensive examinations after that. The following results are observed in AZ91 composite: (i) In compression test analysis, fluid stress and ultimate stress increase the maganese particle. Higher fluidity stress 316 Mpa attained in the 83.5 Mg-9% Al-6.5%Mn-1%Zn composite. (ii) The Brinell hardness test clearly shows the manganese particle is used to improve the hardness value of the AZ91 composite. The maximum hardness value of 112 BHN was attained in 83.5 Mg-9% Al-6.5%Mn-1%Zn composite. (iii) SEM analysis shows the pores presented in AZ91 composite while adding the manganese, zinc, and aluminum. The agglomeration also clearly shows in 83.5 Mg-9% Al-6.5%Mn-1%Zn composite.

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