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Research Article

The Microstructure, Hardness and Density Investigation of Mg Composites Reinforced with Nanoclay

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ABSTRACT

Magnesium (Mg) stands out as a prevalent material in engineering, finding essential utility as a biomaterial due to its unique combination of low density, stiffness, high damping capacity, superior bending resistance, and impressive specific strength. Despite its high reactivity and somewhat inadequate mechanical properties for rigorous engineering applications, the incorporation of reinforcing nanoparticles has shown significant potential in enhancing the performance of magnesium-based composites. This study investigates the microstructure evaluation, hardness, and density of magnesium composites reinforced with nanoclay using a powder metallurgy approach. Nanoclay was preferred as a reinforcement element at weight percentages of 1%, 3%, 5%, and 7%. The densities of the composites were measured using the Archimedean principle, revealing that the addition of nanoclay generally increases the density of the composites due to the higher density of nanoclay compared to pure magnesium. However, the composite with 5% nanoclay exhibited a lower density than the one with 3% nanoclay, likely due to agglomerations leading to increased internal voids. Surface preparation for Vickers hardness testing involved sanding with 600, 1000, and 2000 mesh sanders, followed by polishing with 6µ and 3µ diamond suspensions. Hardness measurements, conducted using an AOB Vickers microhardness tester, indicated that the highest hardness value was observed in the composite with a 7% weight percentage of nanoclay, demonstrating that nanoclay addition enhances hardness. However, the composite with 3% nanoclay showed lower hardness compared to other reinforced composites. Optical images of the structures revealed metallographic spots indicative of contamination. These findings contribute to the understanding of the structural and mechanical behavior of nanoclay-reinforced magnesium composites, highlighting the potential for optimizing such materials for various applications in automotive, aerospace, and medical fields.

Keywords: *Nanoclay, Mg composites, Hardness, Microstructure and density measurement*

Nanokil ile Takviye Edilmiş Mg Kompozitlerin Mikroyapılarının Sertliklerinin ve Yoğunluklarının Araştırılması

ÖZ

Magnezyum (Mg), mühendislikte yaygın bir malzeme olarak öne çıkmakta ve düşük yoğunluk, sertlik, yüksek sönüm kapasitesi, üstün eğilme direnci ve etkileyici spesifik mukavemet gibi benzersiz kombinasyonu nedeniyle biyomalzeme olarak hayati bir işlev görmektedir. Yüksek reaktivitesine ve zorlu mühendislik uygulamaları için mekanik özelliklerinin yetersiz olmasına rağmen, güçlendirici nanoparçacıkların eklenmesi, magnezyum bazlı kompozitlerin performansını artırma potansiyeli göstermiştir. Bu çalışma, toz metalurjisi yaklaşımı kullanılarak nanokil ile güçlendirilmiş magnezyum kompozitlerinin mikro yapı değerlendirmesi, sertlik ve yoğunluğunu araştırmaktadır. Nanokil, ağırlık yüzdeleri olarak %1, %3, %5 ve %7 oranlarında bir güçlendirme elemanı olarak tercih edilmiştir. Kompozitlerin yoğunlukları, Archimedes prensibi kullanılarak ölçülmüştür ve nanokilin

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eklenmesinin genellikle kompozitlerin yoğunluğunu artırdığı, çünkü nanokilin saf magnezyumdan daha yüksek bir yoğunluğa sahip olduğu görülmüştür. Ancak, %5 nanokil içeren kompozit, %3 nanokil içeren kompozitten daha düşük yoğunluk göstermiştir, bu durum aglomerasyonların iç boşlukları artırması ile ilişkilendirilebilir. Vickers sertlik testi için, numune 600, 1000 ve 2000 mesh zımpara ile zımparalandı ve ardından 6µ ve 3µ elmas süspansiyonları ile parlatıldı. AOB Vickers Mikrosertlik testi kullanılarak yapılan sertlik ölçümleri, en yüksek sertlik değerinin %7 ağırlık yüzdesine sahip nanokil içeren kompozitte gözlemlendiğini ve nanokil eklemenin sertliği artırdığını göstermiştir. Ancak, %3 nanokil içeren kompozit diğer güçlendirilmiş kompozitlere göre daha düşük sertlik göstermiştir. Yapıların optik görüntüleri, kontaminasyonu belirten metalografik noktaları ortaya çıkarmıştır. Bu bulgular, nanokil ile güçlendirilmiş magnezyum kompozitlerinin yapısal ve mekanik davranışlarının anlaşılmasına katkıda bulunur ve bu tür malzemelerin otomotiv, havacılık ve tıp alanlarındaki çeşitli uygulamalar için optimize edilme potansiyelini gösterir.

Anahtar Kelimeler: *Nanokil, Mg kompozit, Sertlik, Mikroyapı ve yoğunluk*

I. INTRODUCTION

Metal matrix composites (MMCs) have garnered significant attention for their promising reinforcement properties[1]. Especially, magnesium (Mg) composite stands out as a prevalent material in engineering and finds essential utility as a biomaterial [2]. The potential of Mg-based metal matrix composites extends across diverse sectors, including automotive, aerospace, and medical fields [3]. MMC Mg systems, at their core, exhibit remarkable high strain rate capabilities [4]. This makes them pivotal in the pursuit of weight reduction and the attainment of optimal mechanical properties crucial for aerospace and automotive components [5].

Recently, there has been a remarkable surge in the application of Mg as a structural material. Mg boasts dimensional stability and excellent machinability [6]. As the 8th most abundant element on Earth, Mg also exhibits high thermal conductivity. The allure of Mg lies in its unique combination of attributes: low density, stiffness, high damping capacity, superior bending resistance, and impressive specific strength [7].

The high reactivity of pure magnesium and its somewhat inadequate mechanical properties for rigorous engineering applications have led to the prevalent use of magnesium with reinforcing nanoparticles in such contexts[8-10]. Researchers have focused their efforts on developing magnesium matrix composites with diverse reinforcements [11-20]. In these studies, various particles are used to enhance mechanical properties of the Mg composites. Nie et al.[21] studied SiC nanoparticle reinforced Mg matrix composite fabricated by ultrasonic vibration squeeze casting method. At the interface, composites featuring 10 µm SiC particles exhibit notably high dislocation density, whereas those with 60 nm SiC particles show fewer dislocations near the interface between the particles and the matrix. Additionally, a significant number of dislocations are generated due to thermal mismatch, constituting thermodynamically unstable crystal defects that render materials with high energy levels unstable. Another study conducted by Reddy et al. [22] is related to the titanium oxide reinforced magnesium composites. The findings unveil that the incorporation of nano reinforcement particles results in a reduction in the density of the dendritic pattern, along with a uniform dispersion of nano reinforcement particles within the magnesium phase. Various properties including hardness (18.24%), tensile strength (22.12%), compressive strength (24.32%), and wear resistance (26.52%) were improved. Lastly, Kumar et al.[23] examine nanoclay reinforced aleminium metal matrix composite produced by semi-solid state casting method. Results indicates that nanoclay led to increase from 74 BHN to 82 BHN .

In this study, the microstructure evaluation, hardness, and density of magnesium composites reinforced with nanoclay were investigated using a powder metallurgy approach. The impact of varying nanoclay ratios on the resulting magnesium metal matrix composites was also explored.

II. MATERIALS AND METHODS

In the production of the nanoclay-reinforced magnesium composites, both magnesium and nanoclay were procured from Nanografi and Grafene Chemical Industries, respectively. Raw form of SEM of nanoclay particles is given in Figure 1.

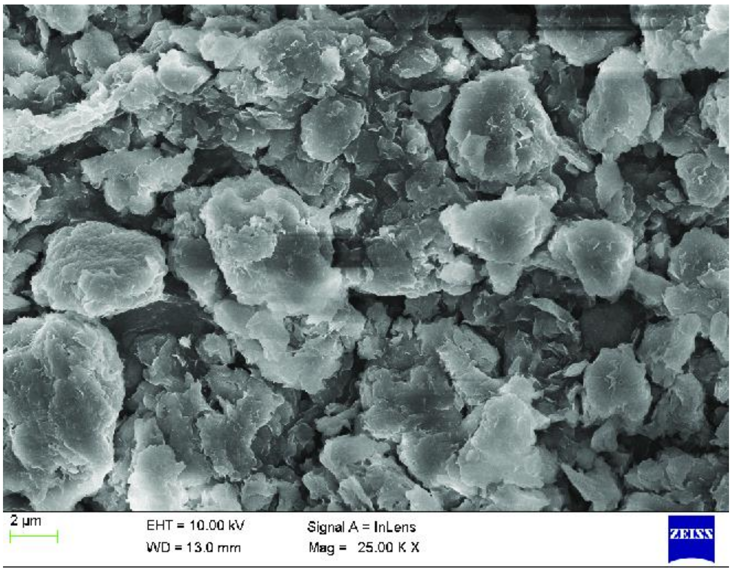


Figure 1. *The SEM of nanoclay particles*

Samples weighing 10 g each were carefully measured. Four different weight percentages of nanoclay (1%, 3%, 5%, and 7%) were selected. Subsequently, the materials were blended in a beaker and thoroughly mixed using a magnetic stirrer operating at 800 rpm for thirty minutes to achieve homogeneity. After the powder attained a uniform distribution, it was cold-pressed in a steel die at 200 MPa to yield bulk samples. The procedure of producing nanoclay reinforced Mg composites is given in Figure 2.

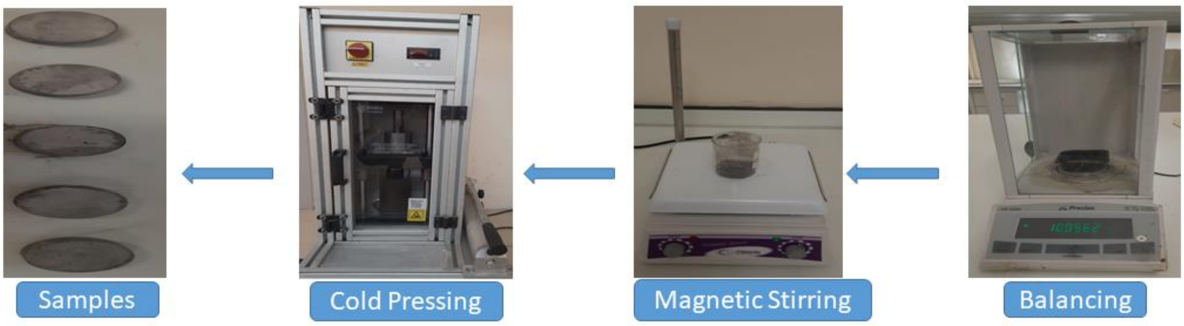


Figure 2. *The procedure of fabricating of the given composites*

III. RESULTS AND DISCUSSION

Nanoclay was preferred as reinforcement elements at weight percentages of 1%, 3%, 5%, and 7%. The densities of the studied materials were measured via the Archimedean principle. Figure 3 indicates the measured densities of the composites at various nanoclay ratios. Except for the sample with 1% nanoclay, nanoclay addition leads to increase in density values. This is consistent because the density of nanoclay is higher than the density of pure magnesium. However, the density of the sample having with 5% nanoclay is lower density than the sample having 3% nanoclay. Agglomerations in this composite lead to increased internal voids, reducing the composite's density since the presence of these agglomerates can lead to the formation of internal voids or gaps within the composite. These voids arise because the clustered nanoparticles occupy a larger volume than if they were uniformly distributed. The existence of voids reduces the overall packing density of the composite material. Since density is defined as mass per unit volume, the presence of internal voids decreases the mass that contributes to the composite's total volume, leading to a lower overall density.

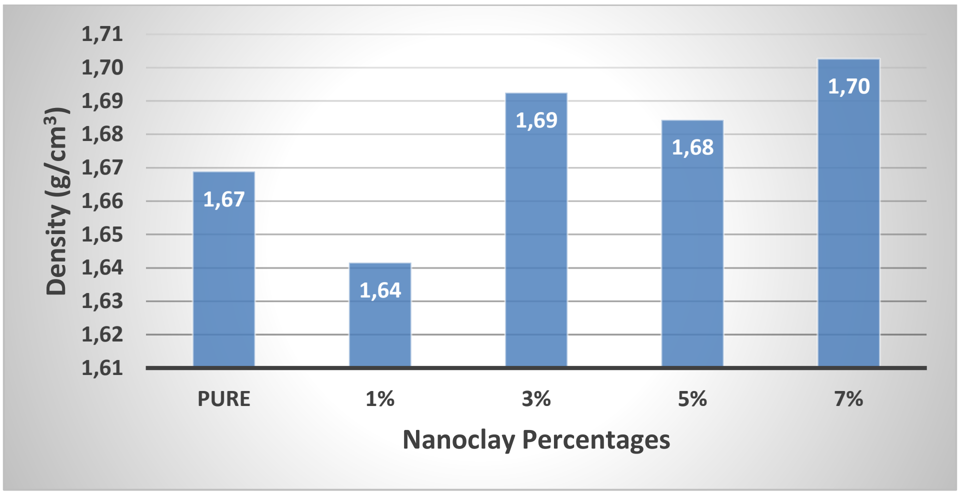


Figure 3. *Density measurements of the given composites*

Sanding and polishing were implemented to prepare the surface for the vickers hardness. 600, 1000 and 2000 mesh sanders were used for metallographic sanding process. Then, for polished better quality surfaces, the samples were polished with 6µ and 3µ diamond suspensions respectively. Hardnesss measurements were conducted using an AOB Vickers Microhardness tester with a load of 0.1 kgf and a dwell time of 5 seconds. 10 measurements were taken for each measurements and then the average values were calculated. Figure 4 illustrates the Vickers hardness values of the given samples. The highest hardness value was seen in the composite with a 7% weight percentage of nanoclay. This indicated that the addition of the nanoclay led to increase in the hardness values. However, the composite having 3% weight percentage of nanoclay is lower value than the other reinforced composites. It may be related to the slightly higher number of spots on the surface in this sample, which reduces the hardness values. The standard errors for the samples with 0%, 1%, 3%, 5%, and 7% reinforcements are 1.61, 2.30, 1.59, 1.57, and 2.18, respectively. The minimal standard variations in the hardness values indicate that the nanoclay particles were homogeneously distributed within the Mg matrix to an acceptable degree. Notably, the highest standard error was recorded in the 1% sample, which corresponds with the density values.

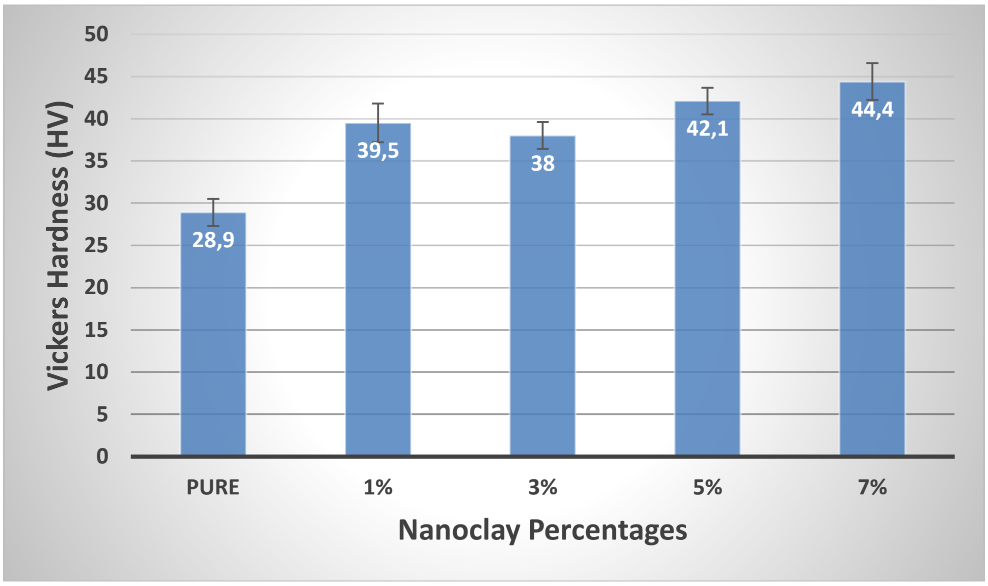
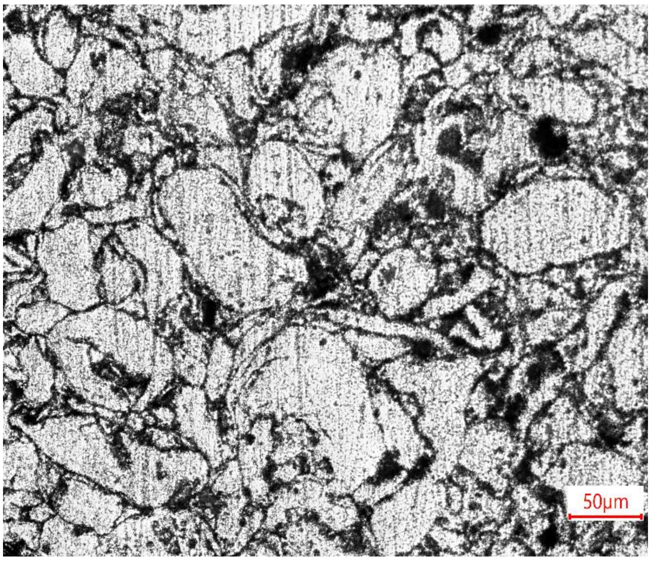
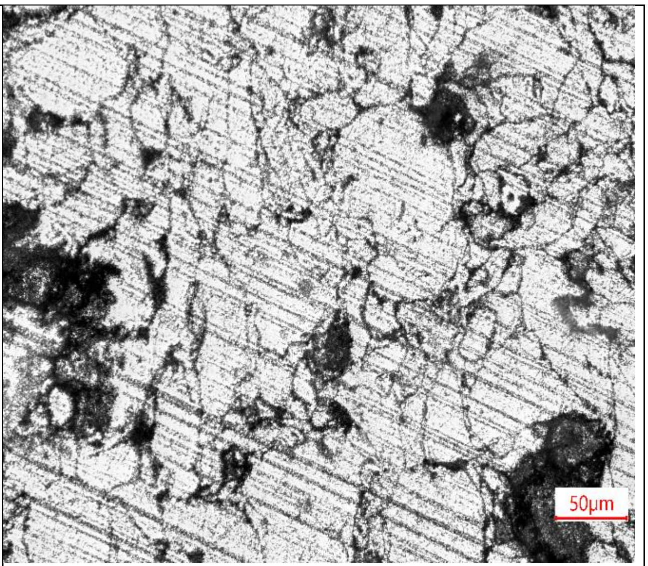


__Figure 4.__ Vickers hardness of the given composites.

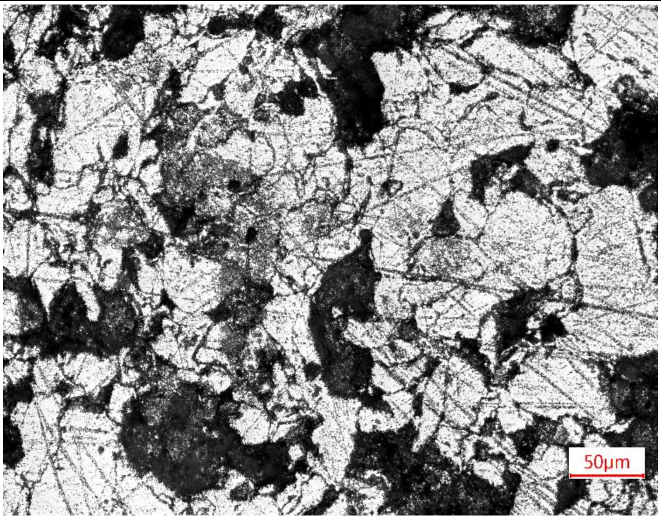
Figure 5 displays optical microscope images of the given structures, within which metallographic spots are visible, indicative of contamination. Grain boundaries are visible in all structures, but there is no clear evidence to suggest that the addition of nanoclay alters grain size of the composites.



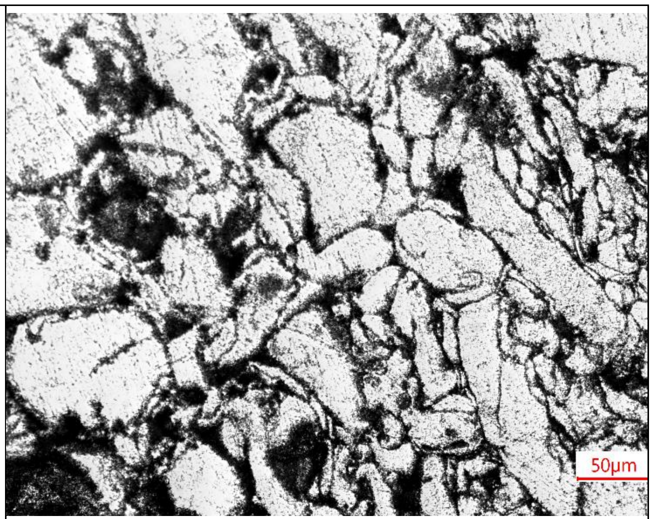
Pure Magnesium



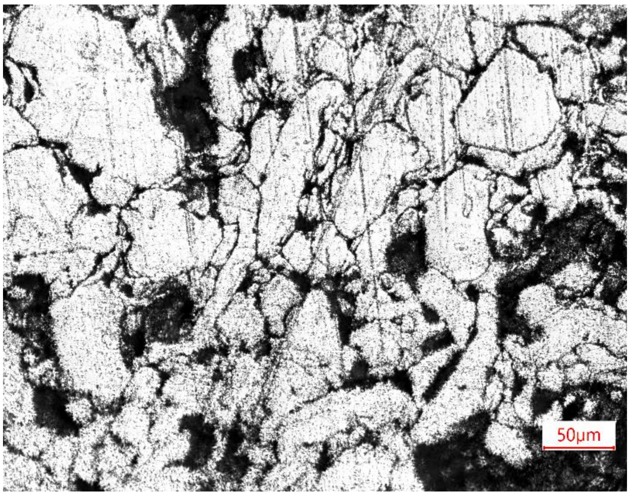
%1 Nanoclay



%3 Nanoclay



%5 Nanoclay



%7 Nanoclay

Figure 5. *Optical microscope image of the given composites.*

IV. CONCLUSION

This study successfully investigated the microstructure, hardness, and density of magnesium composites reinforced with varying percentages of nanoclay using a powder metallurgy approach. Key findings include:

1. **Density Measurements**: The addition of nanoclay generally increased the density of the composites, consistent with the higher density of nanoclay compared to pure magnesium. However, the composite with 5% nanoclay exhibited a lower density than the one with 3% nanoclay, likely due to agglomerations that increased internal voids.

2. **Hardness Testing**: Vickers hardness measurements revealed that the composite with a 7% weight percentage of nanoclay had the highest hardness value, indicating that nanoclay addition enhances hardness. Conversely, the composite with 3% nanoclay showed lower hardness than the other reinforced composites.

3. **Microstructure Analysis**: Optical images showed metallographic spots indicative of contamination across all samples. Grain boundaries were visible in all structures, but there was no clear evidence suggesting that nanoclay addition alters the grain size of the composites.

Overall, the incorporation of nanoclay into magnesium composites can significantly enhance their density and hardness, although care must be taken to manage agglomerations that can affect these properties negatively. These insights are valuable for optimizing magnesium-based composites for applications in automotive, aerospace, and medical fields, where mechanical strength and material stability are critical. Future research should focus on refining the dispersion techniques to minimize agglomeration and further enhance the composite properties. Additionally, future research could explore the use of various nanoparticles or hybrid nanoparticles to enhance mechanical properties of magnesium composites for applications in automotive, aerospace, and medical fields.

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