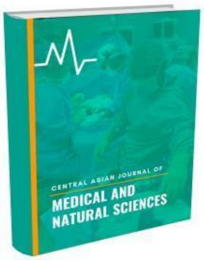

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Article

Study of the Effect of Sintering Temperature on the Physical and Mechanical Properties of MgO–Ni Composite Prepared by Powder Metallurgy

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Abstract: This research addressed the preparation and study of a ceramic-metal composite consisting of 65% MgO + 35% Ni using powder metallurgy technology, focusing on studying the effect of sintering temperature within the range (700–1100°C) on the microstructure and mechanical and physical properties of the composite. The results obtained revealed a number of important conclusions, which can be summarized as follows: Scanning electron microscope (SEM) images showed that the prepared composite has a relatively homogeneous microstructure, characterized by a uniform distribution of grains and a clear absence of cracks or large agglomerates, reflecting the efficiency of the preparation and sintering method used. Measurements derived from SEM images also showed that the average grain size gradually increased with increasing sintering temperature, ranging from 165.4 nm to 179.6 nm. This behavior is attributed to improved atomic diffusion and increased grain boundary mobility at higher temperatures. Despite this grain growth, it remained limited and uniform, indicating balanced sintering without excessive grain growth, which is desirable from an application standpoint. The mechanical properties of the composite showed a marked improvement with increasing sintering temperature. Vickers hardness gradually increased from 301.7 HV at 700°C to 367.8 HV at 1100°C. This improvement is attributed to reduced porosity, increased density, and improved cohesion between grains. The high MgO content also played a key role in increasing hardness due to its hard ceramic nature, while the Ni mineral phase contributed to enhancing structural cohesion and reducing brittle fracture susceptibility. Compressive strength showed a limited gradual increase within the range of 320.8–339.6 MPa, indicating the stability of the composite's mechanical behavior and the stability of the compressive strength mechanism as a result of the stability of the chemical composition and the absence of new phases forming with increasing sintering temperature. The wear test results showed a clear decrease in the wear rate with increasing sintering temperature, from 6.82×10^{-4} to 3.98×10^{-4} mm^3/ N·m. This is attributed to increased hardness, improved microstructural cohesion, and reduced porosity, which limits the separation of surface particles during friction. The balanced interaction between the MgO ceramic phase and the Ni metallic phase also contributed to improved wear resistance by combining high hardness with the ability to absorb part of the stresses generated during the wear process. The physical properties of the composite showed a gradual improvement with increasing sintering temperature, with both true and apparent densities increasing, while porosity decreased to less than 3% at all sintering temperatures, indicating the efficiency of the pressing and sintering processes in producing highly compacted and defect-free samples. The thermal conductivity of the composite also increased from 21.8 to 31.2 W/m·K with increasing sintering temperature, as a result of reduced porosity and the formation of effective thermal paths due to the presence of the Ni metal phase within the MgO matrix, with values remaining within the expected range for ceramic-metal composites. In general, it can be concluded that the sintering degree is a decisive factor in controlling the microstructure and improving the mechanical and physical properties of the MgO–Ni composite without the need to change the chemical composition. The results confirm that the prepared

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compound has good structural stability and mechanical and thermal performance, making it suitable for engineering applications that require materials with high hardness, improved wear resistance, high density, and stability under various loads and thermal conditions.

Keywords: MgO–Ni Composite, Sintering Degree, Powder Metallurgy, Microstructure, Scanning Electron Microscope (SEM)

1. Introduction

This chapter presents and discusses the experimental results obtained from studying the effect of heat treatment (sintering) on the structural, physical, and mechanical properties of a 65% MgO + 35% Ni compound prepared by powder metallurgy. The compacts were sintered at different temperatures ranging from 700 to 1100 °C for two hours, with the aim of studying the role of sintering temperature in improving the internal structure and properties of the material .The compositional tests included X-ray diffraction (XRD) analysis to determine the crystalline phases and study the crystal size, in addition to scanning electron microscopy (SEM) to evaluate the microstructure and determine the grain size[1]. The physical properties were also analyzed by measuring the true density, apparent density, and porosity ratio. while the mechanical properties included measurements of Vickers hardness, compressive strength, and wear rate. The thermal conductivity of the composite was also studied and related to the nature and proportions of the constituent materials. The discussion of the results in this chapter aims to relate the effect of the sintering degree to the changes in the crystalline and microscopic structure, and then the reflection of these changes on the physical and mechanical properties of the compound. The results are also compared to show the correlation between the different properties and to clarify the suitability of the MgO–Ni compound for engineering applications that require materials with structural stability and mechanical and thermal performance [2].

2. The Theoretical aspect

2.1 Physical properties

Apparent density is the ratio of the mass of a material to its total apparent volume, which includes solids as well as all open and closed pores. This property is used to evaluate the degree of internal cohesion of materials and coatings resulting from spraying or sintering processes.[3]

$$\mathrm{P_a} = \frac{\rho_w \times W_d}{W_s - W_{sub}} \dots\dots\dots\dots (1)$$

True density is defined as the mass of solid material alone divided by the true volume of solid material without including any porosity. True density is used as a basic reference for calculating other volumetric properties such as porosity and apparent density.[4]

$$\mathrm{P_t} = \frac{\rho_w \times W_d}{W_d - W_{sub}} \dots\dots\dots\dots (2)$$

Apparent porosity is the ratio between the volume of open pores within a material and the total volume of the sample, and includes only pores that are permeable to liquids, excluding closed pores. This property is essential for evaluating the quality of sintered materials and coatings because it directly affects absorbency, corrosion, and durability.[5]

$$\mathrm{P_a}(\%) = \left[\frac{(\mathrm{Ws} - \mathrm{Wd})}{W_s - W_{sub}}\right] \times 100 \dots\dots\dots\dots (3)$$

True porosity represents the total sum of open and closed pores within a material. It is a more accurate measure of internal microstructure than apparent porosity and is widely used in the description of porous materials and agglomerated structures[6]

$$P_t(\%) = \left[1 - \frac{\rho_a}{\rho_s}\right] \times 100 \ldots\ldots\ldots\ldots (4)$$

Water absorption is the percentage increase in the mass of a sample after it has been saturated with water compared to its dry mass, and reflects the material's ability to absorb liquids through open pores. This property is an important criterion for evaluating the quality of ceramic materials and thermal coatings [7] [8]

$$WA(\%) = \left[\frac{(W_s - W_d)}{W_d}\right] \times 100 \ldots\ldots\ldots\ldots (5)$$

Where ϱ_w is the density of water, Wd is the dry weight of the sample, Ws is its weight after saturation with water, Wsub is its weight when suspended in water, and ϱ_s is the true density of the material.

2.2 Mechanical properties

Vickers hardness can be defined as a measure of a material's resistance to scratching or permanent deformation under the influence of applied force. Vickers hardness is measured by pressing a pyramidal diamond indenter onto the surface of the sample with a specific force, and then measuring the average length of the two diameters resulting from the indentation on the surface. The hardness of materials depends on the type of force binding between molecules or atoms, the type of surface, the high temperature, and the heat treatment. It can be calculated using the following equation:[9]

$$HV = 1.854\, P \,/\, d^2 \ldots\ldots\ldots\ldots (6)$$

Where:

HV- Vickers hardness, p- amount of force applied in units (Kg), d- represents the average diameter of the pyramid impact in units (2mm).

3. Practical aspect

Vickers hardness of the 65%MgO+35%Ni compound

The results of the Vickers hardness test for the 65% MgO + 35% Ni compound prepared and sintered within the temperature range of 700–1100°C showed a gradual and clear improvement in hardness values with increasing sintering temperature, as shown in Figure (1). The lowest hardness value was recorded at a sintering temperature of 700°C, reaching approximately 301.7 HV, then rising to about 314.9 HV at 800°C, and continuing to increase.

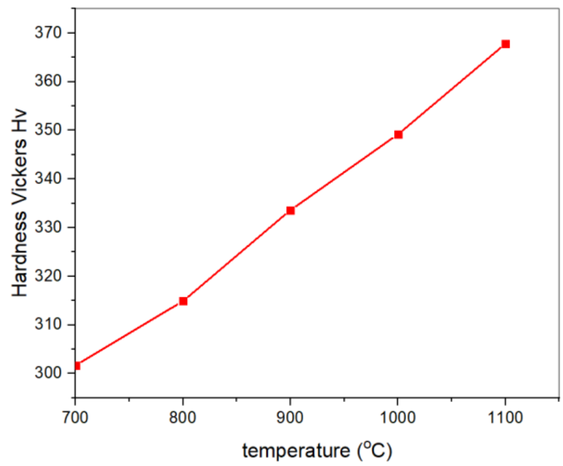

Figure 1. Sintering temperatures versus Vickers hardness of the prepared composite

It increased to 333.6 HV at 900°C and 349.2 HV at 1000°C, reaching its highest value at a sintering temperature of 1100°C at around 367.8 HV. This improvement in hardness is mainly attributed to the effect of the sintering process on the development of the microstructure of the composite, as the increase in sintering temperature leads to increased atomic diffusion and improved interparticle bonding, resulting in a more cohesive structure and higher resistance to indentation under micro load. The high MgO content (65%) also contributes to increased hardness due to its hard ceramic nature, while Ni (35%) acts as a metallic phase that contributes to enhancing structural cohesion and improving interparticle bonding during sintering. With increasing sintering temperature, the residual porosity within the sample decreases and the density increases, which reduces structural weaknesses and increases the surface resistance to penetration, directly reflected in higher Vickers hardness values. The achievement of higher hardness values at higher sintering temperatures indicates that the sintering conditions were effective in improving the packing and fusion between grains within the MgO–Ni composite, making the material more suitable for applications requiring good surface resistance, such as wear and friction resistance, while maintaining the role of nickel in improving cohesion and reducing the brittle fracture susceptibility of the composite[10]

4. Physical properties

4.1 True density

The true density results for the 65% MgO + 35% Ni composite showed a gradual increase with increasing sintering temperature within the range of 700–1100°C, as shown in Figure (2). The true density value reached approximately 4.12 g/cm^3 at a sintering temperature of 700°C, then increased to about 4.18 g/cm^3 at 800°C, and continued to increase to 4.24 g/cm^3 at 900°C and 4.29 g/cm^3 at 1000°C, reaching its highest value at 1100°C at around 4.34 g/cm^3.This behavior indicates a clear improvement in the internal packing of the material and the development of its structural composition as a result of heat treatment. The increase in sintering temperature activates atomic diffusion within the compound, which helps reduce microvoids and crystalline defects within the grains and improves the regularity of the crystal lattice of both MgO and Ni. This contributes to better atomic convergence within the structure, which directly reflects in an increase in the true density of the compound.The nature of the compound's components also plays an important role in this behavior; the Ni metal phase contributes to improving the bonding between particles and enhancing packing, while MgO provides high structural stability due to its ceramic nature. The balanced interaction between these two phases during the sintering process leads to the formation of a more cohesive and stable internal structure.In general, the regular increase in true density with increasing sintering temperature indicates the success of the preparation and sintering processes in improving the internal structure of the MgO–Ni compound. This improvement is also supported by the results obtained from Vickers hardness and wear rate reduction, and enhances the suitability of the material for applications that require materials with stable density and reliable mechanical performance.[11]

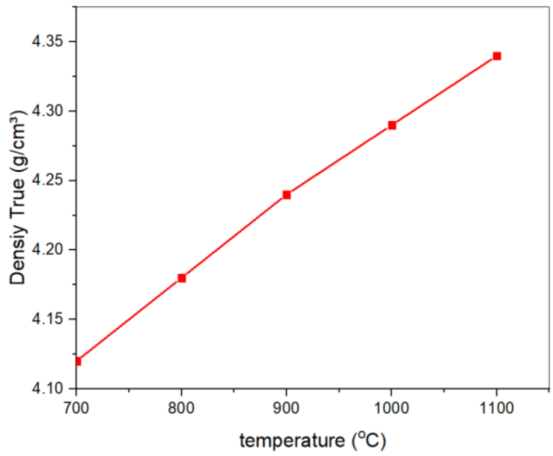

Figure 2. Sintering temperatures versus true density of the prepared composite

4.2 Apparent density

The apparent density results for the 65% MgO + 35% Ni compound showed a clear increase with increasing sintering temperature within the range of 700–1100°C, as shown in Figure (3). The apparent density reached approximately 3.42 g/cm³ at a sintering temperature of 700°C, then increased to about 3.55 g/cm³ at 800°C, and continued to increase to 3.69 g/cm³ at 900°C and 3.82 g/cm³ at 1000°C, reaching its highest value at 1100°C at 3.95 g/cm³. This behavior reflects the gradual improvement in particle packing and the decrease in the size and number of open pores within the sample body. At low sintering temperatures, the particles are close together, but interstitial voids and open pores remain between the grains, resulting in lower apparent density values. As the sintering temperature increases, strong necks form between the particles, and the size and number of pores decrease as a result of grain rearrangement and growth, which contributes to an increase in the measured density of the sample as a whole. The homogeneous distribution of the Ni metal phase within the MgO ceramic matrix also helps to improve the sintering process, as nickel fills some of the interstitial voids and enhances the cohesion of the structure, resulting in a reduction in overall porosity and an increase in apparent density. This improvement is consistent with the microstructure observed in scanning electron microscope (SEM) images, which show a gradual decrease in pores with increasing sintering temperature. In general, the regular increase in apparent density indicates the development of the composite's volumetric structure and improved sintering quality, which positively affects the mechanical properties and enhances the material's efficiency in applications that require cohesive and low-porosity materials.[12]

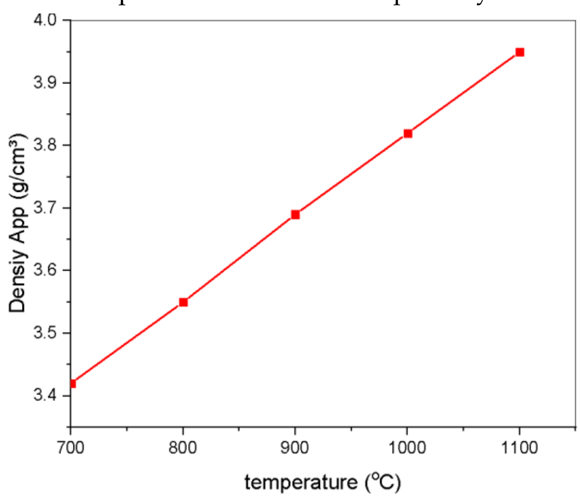

Figure 3. Sintering temperatures versus apparent density of the prepared composite

4.3 Porosity

The porosity results for the 65% MgO + 35% Ni composite compacts show low values at all sintering temperatures within the range of 700–1100°C, as shown in Figure (4), The porosity did not exceed 3%, indicating the efficiency of the pre-pressing process and the success of the sintering process in producing samples with high packing and dense structure. The porosity reached about 2.85% at a sintering temperature of 700°C, then decreased to about 2.42% at 800°C, and continued to decrease to 1.98% at 900°C and 1.55% at 1000°C, reaching its lowest value at a sintering temperature of 1100°C at around 1.12%. This gradual decrease in porosity reflects a clear improvement in the pore closure process as a result of the formation of strong necks between the grains during sintering. As the temperature rises, atomic diffusion increases and grain boundary mobility improves, leading to a reduction in the size and number of pores remaining within the sample body. The presence of the Ni mineral phase also contributes to reducing porosity by improving the bonding between MgO particles and filling some of the interstitial voids, which enhances the cohesion of the structure and limits the survival of open pores. This behavior leads to the formation of a more homogeneous structure, which is consistent with the apparent and true density results obtained. Overall, the reduction in porosity to levels below 3% at all sintering temperatures reflects the success of the preparation and sintering conditions in improving the internal structure of MgO–Ni compacts. This improvement also contributes to enhanced mechanical properties, particularly Vickers hardness and wear resistance, making the material suitable for engineering applications that require high-density, low-porosity materials.[12]

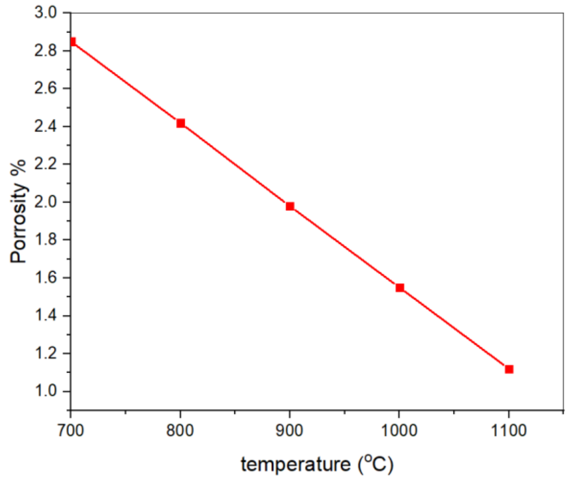

Figure 4. Sintering temperatures versus porosity of the prepared composite.

5. Conclusion

The results of this study show that the 65% MgO + 35% Ni compound was successfully prepared using the powder metallurgy method at different sintering temperatures, with the results showing a homogeneous microstructure and uniform grain distribution without any obvious cracks or agglomerates. The study also showed that increasing the sintering temperature leads to gradual grain growth as a result of improved atomic diffusion without excessive grain growth. The mechanical properties showed a clear improvement with increasing sintering degree, particularly Vickers hardness and wear resistance, as a result of reduced porosity and increased structural cohesion. Compressive strength showed a limited gradual increase, indicating the stability of the composite's mechanical behavior. The physical properties, represented by true and apparent density, also showed a noticeable increase with a decrease in porosity to less than 3% at all sintering temperatures. Thermal conductivity also improved with increasing sintering temperature as a result of the development of the internal structure and the formation of effective thermal paths. Overall, the results confirm that controlling the sintering degree plays a key role in improving the properties of MgO–Ni composite and making it suitable for engineering applications that require structural stability and good mechanical and thermal performance.

REFERENCES

[1] R. M. German, Sintering: From Empirical Observations to Scientific Principles, Elsevier, 2014.

[2] M. F. Ashby and D. R. H. Jones, Engineering Materials 1: An Introduction to Properties, Applications and Design, 4th ed., Butterworth-Heinemann, 2012.

[3] W. D. Callister and D. G. Rethwisch, Materials Science and Engineering: An Introduction, 9th ed., Wiley, 2014.

[4] J. F. Shackelford, Introduction to Materials Science for Engineers, 8th ed., Pearson, 2015.

[5] ASTM C20-00, “Standard Test Methods for Apparent Porosity, Water Absorption, Apparent Specific Gravity, and Bulk Density of Burned Refractory Brick,” ASTM International, 2015.

[6] T. S. Sudarshan and M. Jeandin, “Composite coatings by thermal spray,” Surface Engineering, vol. 18, no. 2, pp. 120–128, 2002.

[7] R. S. Lima and C. C. Berndt, "Thermal spray coatings," Surface & Coatings Technology, vol. 201, no. 8, pp. 4699–4706, 2006.

[8] Dania F. Abbas Aljuboori, Kadhim K. Resan, Ayad M. Takhakh "Investigate the Microstructure and the Mechanical Properties of Ni-Ti-Cu Shape Memory Alloys, Al-Nahrain Journal, Engineering Sciences, Vol. 20, No.1. PP.105-112.2016.

[9] Baatarsuk, Munkhbayar, et al. "Characteristics of Sputter-Deposited Ti-Ni-Cu Shape Memory Alloy Thin Films. Science of Advanced Materials 10.7, PP. 974-978.2018

[10] Zhenghua Deng, Haiqing Yin, et al. "Microstructure and mechanical properties of Cu-12 Al-6 Ni with Ti addition prepared by powder metallurgy. The journal Materials Science and Engineering, Volume 803. 2021.

[11] Kaftaranova, Maria, et al. "Investigation of the effect of copper addition on physical and mechanical properties of TiNi-Cu porous alloy." Metais 12.10. 1696. 2022.

[12] Mustafa Khalid Nasif Latif Al-Ajili, "Study of the Effect of Sintering on the Structural, Physical, and Mechanical Properties of Nickel Compacts Prepared by Powder Technology," Master's thesis. Department of Physics Education, University of Tikrit, 2024.