PRODUCTION OF COPPER MATRIX COMPOSITES

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Abstract

Composites containing two or more distinct components, and having significantly different chemical, physical, and mechanical properties, are important materials for engineering applications. Copper is widely used as a matrix material in aviation, space, transportation, and electrical contact transmission due to its excellent electrical conductivity and its lubrication and friction prevention performance. Copper, which is one of the most basic components of the electrical and electronics sector, also has high thermal conductivity. In addition, copper is preferred in many engineering applications due to its low thermal expansion coefficient, good oxidation resistance, high corrosion resistance, high alloying ability, low cost, and good ductility. However, despite the many excellent properties of copper, its ductility makes it vulnerable to mechanical stresses. In the study, TiB_2 *ceramic particles with properties such as high hardness, wear resistance and good thermal stability were reinforced into the copper matrix as a reinforcement material. The mechanical properties of the obtained composite will be investigated.*

Keywords: *copper,* TiB_2*, powder metallurgy, mechanical properties*

1. INTRODUCTION

Copper is widely used in engineering applications due to its excellent electrical and thermal conductivity. However, its relatively low hardness and limited mechanical strength restrict its application in demanding structural environments [1-2]. One effective approach to enhance the mechanical properties of copper is the incorporation of ceramic reinforcements, leading to the development of copper matrix composites (CMMCs) with improved performance characteristics [3-5].

Among various reinforcement candidates, titanium diboride (TiB_2) has gained significant attention owing to its high hardness, superior elastic modulus, chemical stability, and good compatibility with the copper matrix. TiB_2 also offers relatively better electrical and thermal conductivity compared to many other ceramic materials. The addition of TiB_2 particles not only improves strength and hardness but also refines the grain structure of the matrix through the pinning effect during sintering [6-8].

Long et al. demonstrated that the combined use of TiB_2 microparticles with other reinforcements, such as carbon nanotubes, leads to a synergistic strengthening effect. This improvement is attributed to enhanced interfacial bonding, better dispersion, and stress transfer mechanisms, as well as the mismatch in thermal expansion between the reinforcements and the matrix. In particular, a Cu composite reinforced with 4.8 vol.% TiB_2 showed noticeable gains in ultimate tensile strength, even when used without hybrid reinforcement [9].

Furthermore, Pellizzari and Cipolloni showed that mechanical alloying (MA) followed by spark plasma sintering can achieve nearly full densification (96–99%) in Cu-TiB_2 composites, with tensile strength increasing from 276 MPa (pure Cu) to 489 MPa after prolonged milling. However, these improvements in strength are often accompanied by a reduction in ductility, highlighting the need to optimize both reinforcement content and sintering parameters [10].

Moreover, sintering temperature plays a vital role in determining the densification, grain growth, and mechanical properties of the final composites. Studies have shown that sintering Cu–TiB_2 composites at optimized temperatures can significantly enhance their strength and wear performance due to improved particle bonding and matrix densification [11]

In light of these considerations, the present study aims to fabricate TiB_2-reinforced copper matrix composites using powder metallurgy with varying reinforcement ratios. The composites are sintered at three different temperatures (700 °C, 800 °C, and 900 °C) to systematically evaluate the effect of sintering temperature on densification, microstructure evolution, and mechanical performance. By building upon prior research and exploring these parameters in a unified framework, the results are expected to provide insight into identifying optimal processing conditions for high-performance Cu-TiB_2 composites.

2. MATERIALS AND METHODS

2.1. Materials

Cu powders (average particle size 40 µm, theoretical density 8.96 g/cm3, and purity 99.8%) and TiB_2 (mean particle size ~13µm, theoretical density 4.52g/cm3, and purity 99.95%) were supplied by Alfa Aesar Inc. (United Kingdom) and Nanografi (Turkey), respectively. The Scanning Electron Microscope (SEM) image of pure TiB_2 (Fig. 1a) and pure Cu (Fig. 1b) shows that they have a sharp corner morphologies.

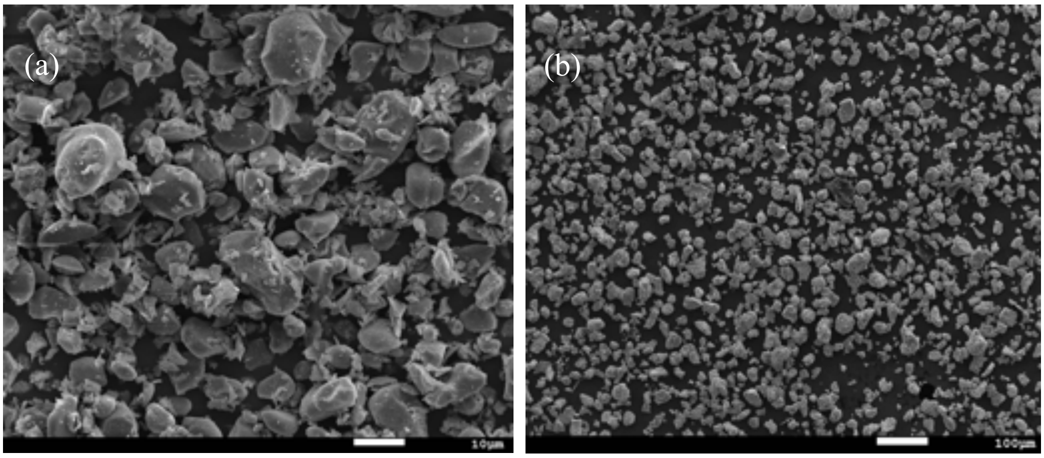

Fig. 1. SEM images of (a) pure TiB_2 (b) pure Cu

2.2. Methods

Cu-TiB_2 composites were produced using the powder metallurgy (PM) method, with the entire procedure illustrated in Fig. 2. In this process, copper powder was blended with varying amounts of TiB2 (1,5, 2,5, and 3,5 wt.%) in an ethanol medium using a planetary ball mill. A steel mold and steel balls were employed for mixing, maintaining a ball-to-powder ratio of 5:1. The milling was carried out at 300 rpm for a total duration of 3 hours, consisting of 30-minute milling sessions followed by 15-minute rest intervals. Following the mixing stage, the slurry was dried in an oven for 24 hours. The resulting powder mixtures were then compacted under pressures of 900 MPa [12]. Finally, the green compacts underwent sintering in an argon (Ar) atmosphere at temperatures of 700, 800, and 900 °C also hours of 1 and 2h to identify the optimal sintering condition.

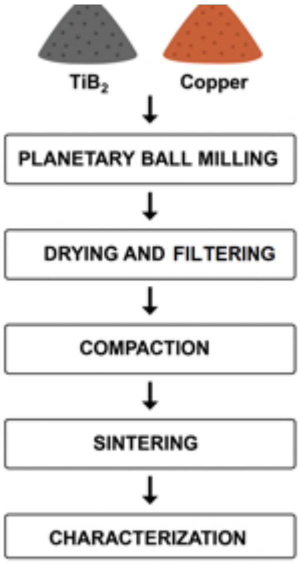

Fig. 2. Schematic diagram of Cu-TiB2 composite production process

The influence of TiB_2 on the density of the developed composites was evaluated both measured using Archimedes' principle and theoretically, through the rule of mixtures. The measured density was calculated using the following mathematical Eqn (1) [13-14].

$$\rho_m = \frac{m_a}{m_a - m_w} x \rho_w \tag{1}$$

Where m_a is the mass of the sample in air, m_w is the mass sample in water, ρ_w is the density of water and ρ_m is the measured density of the small composite sample. The porosity percentage of the composites was calculated using the corresponding formula in Eqn (2) [15].

$$\mathrm{P} = 1 - \frac{\rho_{measured}}{\rho_{theoretical}} x100 \tag{2}$$

The micro Vickers hardness of the composites was measured using microhardness tester under a 0.98 N load with a dwell time of 15 seconds. To determine the final hardness value, a minimum of four measurements were taken from the sample surface and averaged. Compressive strength testing was conducted using an Instron machine with a load capacity of 100 kN. The microstructural and phase analyses of the composites were carried out using SEM-EDX (JEOL JSM–7001F) and XRD techniques. All characterization studies were performed at the Black Sea Advanced Technology Research and Application Center (KITAM) of Ondokuz Mayıs University.

3. RESULTS AND DISCUSSION

Copper matrix composites reinforced with different weight percentages of TiB_2 (1.5%, 2.5%, and 3.5%) were successfully fabricated and sintered at 700 °C, 800 °C, and 900 °C for durations of 1 and 2 hours. The densification behavior of the composites was evaluated using Archimedes' principle, and the results are shown in Fig. 3(a-b). It was observed that the measured density of pure copper increased with sintering temperature and time up to 800 °C but decreased at 900 °C, likely due to grain growth and oxidation. In contrast, TiB_2-reinforced samples showed generally improved densification at higher temperatures, especially at 800 °C 1 h, where the 3.5 wt.% TiB_2 sample reached the highest density (89.1%). This can be attributed to enhanced particle bonding and diffusion at this temperature, which may be optimal for sintering without causing grain coarsening or excessive oxidation. At 700 °C, the relatively lower density values suggest insufficient sintering, while at 900 °C, the decrease in density especially for 2h sintering may be due to grain growth or possible degradation of the matrix-composite interface, which could trap pores and reduce densification. The porosity graphs (Fig.3(c-d)) support these trends. Porosity decreased significantly with increasing TiB_2 content and sintering temperature, with the lowest porosity values occurring at 800 °C for 1h. This confirms that both the reinforcement and thermal energy contribute to reducing voids by promoting better particle rearrangement and densification. However, excessive sintering time or temperature, such as 900 °C-2h, appears to slightly increase porosity in some cases, likely due to abnormal grain growth or trapped gases during sintering.

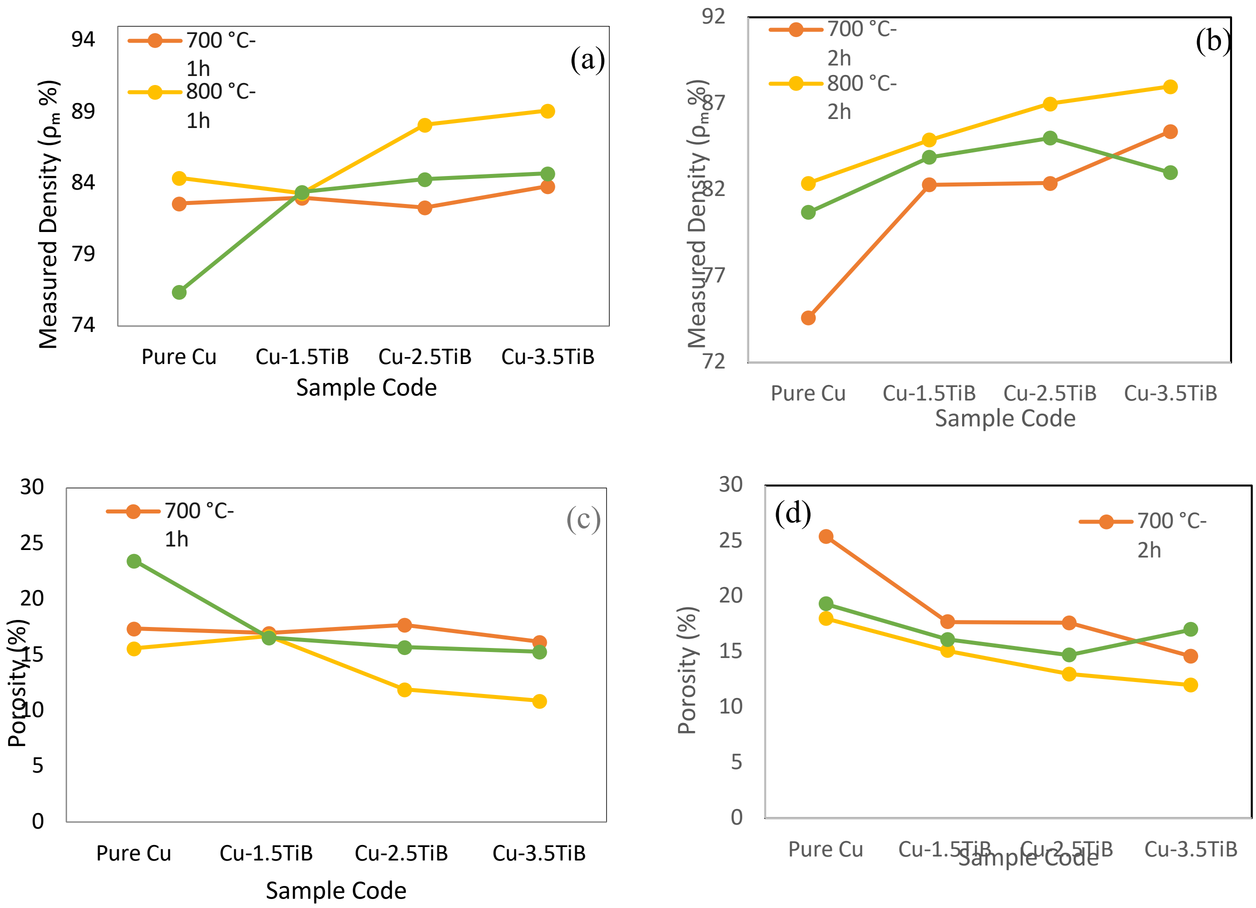

Fig. 3. Measured density and porosities values of Cu- TiB_2 composite sintering at different temperatures and time (a-b) 1 hour (c-d) 2 hours

The hardness of the composites generally increased with the addition of TiB_2, which is expected due to the intrinsic hardness of the ceramic reinforcement. In both 1h and 2h (Fig. 4a-b) sintering conditions, Cu-3.5TiB_2 samples exhibited the highest hardness values. Specifically, the peak hardness was observed for Cu-3.5TiB_2 sintered at 800 °C for 1 hour, reaching ~121HV**,** indicating an optimal combination of particle bonding and matrix-reinforcement interaction at this condition. Conversely, the lowest hardness values were recorded for pure copper**,** particularly when sintered at 900 °C**,** where the values dropped to 37.11 HV (1h) and 37.97 HV (2h)**.** This reduction could be due to grain coarsening of the matrix at high temperatures in the absence of any reinforcing phase. At 700 °C, the hardness values were moderate for both sintering times, reflecting insufficient densification and weak bonding. Interestingly, 800 °C provided consistently better hardness results than both 700 °C and 900 °C across all TiB_2 additions, likely due to its optimal role in promoting densification without inducing excessive grain growth. 800 °C sintering for 1 hour appears to be the most favorable condition for achieving high hardness in Cu-TiB_2 composites, particularly at 3.5 wt% TiB_2**,** while high temperatures or extended sintering durations without reinforcement tend to lower hardness due to matrix degradation.

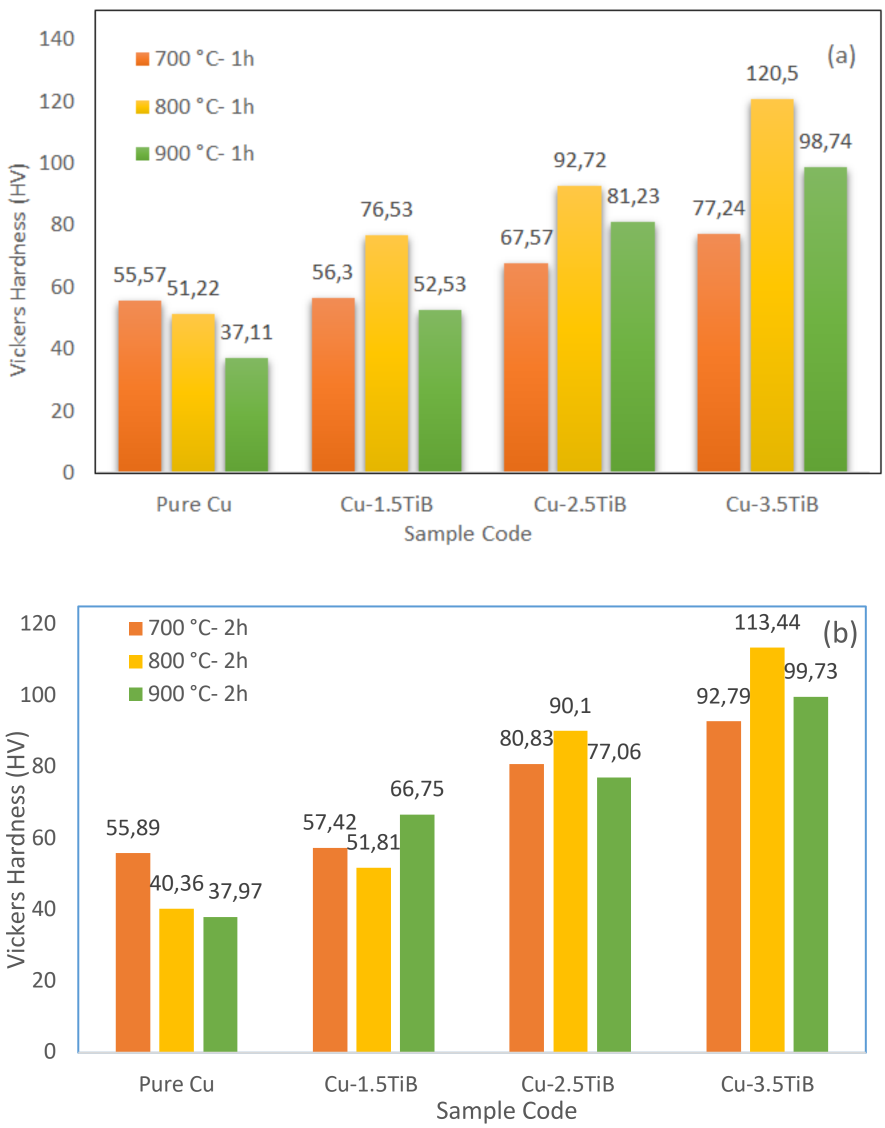

Fig. 4. Micro Vickers hardness test of Cu-TiB_2 composite sintering at different temperatures and time (a) 1 hour (b) 2 hours

Figure 5(a–d) presents optical microscope images of the composite samples sintered at various temperatures and durations. The sample surfaces were etched using a mixture of glycerol, HNO_3, and distilled water. As the sintering temperature increases (Fig. 5a–d), grain growth occurs and becomes more pronounced with longer sintering times. This grain growth negatively impacts the mechanical properties of the composites. Furthermore, as the TiB_2 content increases (Fig. 5c-d), darker regions observed in the images correspond to the TiB_2 particles within the microstructure.

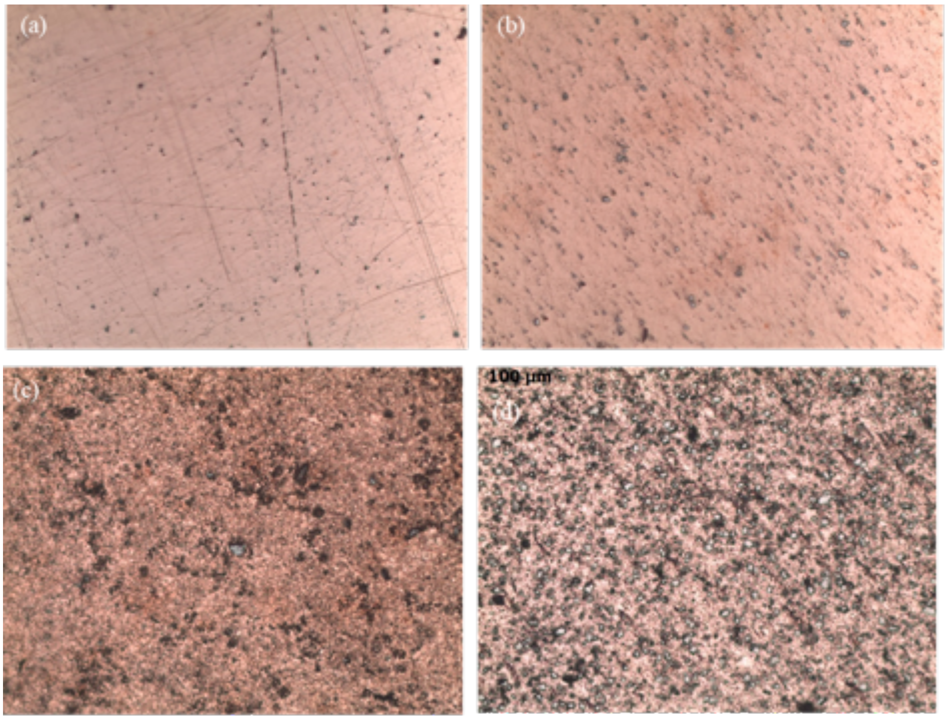

Fig. 5. Optical microscope images of Cu- TiB_2 composites under different sintering conditions (a) pure Cu sintered at 700ºC 1h (b) Cu-1.5TiB_2 composite sample sintered at 800°C1h, (c) Cu-2.5TiB_2 composite sample sintered at 800°C 2h, and (d) Cu -3.5 TiB_2 composite sample sintered at 900 °C for 2 hours

4. CONCLUSIONS

In this study, copper matrix composites reinforced with varying weight percentages (1.5%, 2.5%, and 3.5wt.%) of TiB_2 were successfully fabricated using the powder metallurgy method and sintered at different temperatures (700 °C, 800 °C, and 900 °C) for 1 and 2 hours. The effects of TiB_2 addition and sintering parameters on the density, porosity, microstructure, and mechanical properties of the composites were investigated. The results showed that the incorporation of TiB_2 particles significantly improved the hardness and densification of the copper matrix. Among the tested parameters, sintering at 800 °C for 1 hour produced the most favorable combination of mechanical and physical properties, with the Cu-3.5TiB_2 sample achieving the highest hardness (121 HV) and lowest porosity**.** Conversely, samples sintered at 900 °C exhibited signs of grain coarsening, leading to reduced mechanical performance, especially in pure copper. Optical microscopy revealed that TiB_2 particles were uniformly distributed in the matrix, appearing as darker regions, and that higher sintering temperatures led to visible grain growth. This grain growth, particularly at prolonged sintering times, negatively impacted hardness and densification. Overall, the study demonstrates that both TiB_2 content and sintering parameters must be carefully optimized to enhance the performance of Cu-based composites. A TiB_2 addition of 3.5 wt.% combined with a sintering condition of 800 °C for 1 hour was found to yield the best balance between mechanical strength and microstructural stability.

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