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# Investigation of Electrical and Mechanical Properties of Cu Matrix TiC Reinforced Composites

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**Original Research Article**

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**Abstract:** In this paper, copper matrix composites which reinforced with different content of titanium carbide were produced by powder metallurgy method. Change in mechanical and electrical properties of composites with variation of TiC amount was investigated. Composites were produced at low reinforcement content to prevent reduction of electrical conductivity. Distribution of TiC particles in copper matrix was investigated with optical microscopy technique. Phases in the composites were determined by X-Ray diffraction analysis. The bulk density, hardness and electrical conductivity of composites were measured and the effect of reinforcement ratio on these properties was investigated.
**Keywords:** TiC, Cu, Metal Matrix Composites, Electrical Contact, Mechanical properties.

## INTRODUCTİON

Copper is one of the highest electrical and thermal conductive materials. Due to high electrical and thermal conductivity, copper is common material for electrical and electronical applications such as electrical contacts, electrodes, switches, heat exchangers [1-3]. Further, the hardness and wear resistance are necessary for various applications [3]. But pure copper isn't hard enough and this leads to shorter service life [2, 4]. There are some methods to enhance mechanical properties of Cu. Alloying is one of them. With alloying, mechanical properties can be improved, but electrical conductivity deteriorate even if alloying element content is little [5]. The effect of the alloying elements on electrical conductivity of Cu was investigated by Kaczmar *et al.*, They indicated that addition of 0, 3 vol.% Zn to Cu reduced the electrical conductivity of Cu to 85% IACS, of 1,25% Al to 70% IACS and of 0,1% P to 50% IACS from 100% IACS [6].

The other way to increase of mechanical properties of Cu is precipitation hardening. But precipitation hardened alloys don't keep their high mechanical properties at elevated temperature due to coarsening or dissolution of precipitate phase [7]. On the other hand, precipitation-hardening is expensive method to increase of strength due to need of additional processes [1]. An alternative way to improve mechanical properties of pure copper without decreasing the conductivity is composite approach [8].

Metal matrix composites are very important materials in terms of combined best properties of metal matrix and ceramic reinforcement. Cu matrix composites exhibit excellent electrical and thermal conductivities and high temperature strength [4]. These composites combine toughness of Cu and hardness of ceramics [3]. They are used for many applications where need to high electrical conductivities and good wear resistance at elevated temperature such as torch nozzle, electrical sliding contact, collectors, etc. [9, 10]. Carbides, oxides, borides such as SiC, TiC, $B_4C$, $Al_2O_3$, $TiB_2$ can be used as reinforcement [5, 7, 11]. TiC with high modulus, hardness and melting temperature is desirable reinforcing compound for metallic matrix such as Cu, Fe, Ni, Al [4, 12]. In recent years, TiC reinforced Cu matrix composites have comprehensively been studied [5]. TiC is refractory ceramic and it has high electrical conductivity comparable with metals besides good mechanical properties [13]. Furthermore, TiC has high chemical stability when reacting metals [3].

Arc erosion which causes the degradation of electrical contacts occurs in the contact materials [14]. The electrical arc results in melting, evaporating, sputtering, solidifying at the arc regions on the surface of the contacts. These processes lead to mass transfer between anode and cathode. Therefore, electrical contact materials not only have high electrical conductivity, but also good mechanical properties and chemical stability [15]. Metallic materials can't meet all of these properties and can't prevent mass transfer. Strengthening particles can integrate to metal matrix to reduce mass transfer [16]. Good properties of TiC make it candidate as reinforcement material to reduce of mass transfer on the surface of electrical contacts.

In this study, mechanical and electrical properties of copper matrix TiC reinforced composites were investigated. Composites were produced at low reinforcement amount to prevent reduction of electrical conductivity. TiC was incorporated in copper matrix with ratio of 0,5, 1, 2% by weight. Then, the effect of reinforcement content on hardness and electrical conductivity of copper matrix composites were determined.

## MATERIALS AND METHODS

Copper (%99,5< purity, SENTESBIR, Turkey) powders with particle size less than 100 µm and commercial TiC powders with particle size less than 10 µm were used as starting materials. TiC powders were added into Cu with different content (0,5-1-2 wt%). Powder mixtures were charged to planetary ball mill under air atmosphere. Milling was applied for 10 min under air atmosphere. Milling speed and weight ratio of ball to powders were 300 rpm and 2:1, respectively. After milling, powder mixtures of composites and pure copper were pressed at 250 bar with uniaxial press in cylindrical die with 15 mm diameter. Composites were sintered at 800 °C for 2 h in air. Graphite powder bed was used at sintering in order to prevent oxidation of copper.

Sintered samples were analyzed using X –ray diffraction (XRD, Panalytical-Empyrean) analysis with Cu Kα (λ=1,5406 Å) radiation in the 2θ range of 5-80° at rate of 2°/min. to determine reactions between Cu and TiC or air. Distribution of TiC in Cu matrix was examined with optical microscopy (Nikon Eclipse LV150). True density of samples was measured with His gas pycnometer (Micromeritics Accupyc II 1340) and then relative densities were calculated. Brinell hardness method with 2,5 mm diameter ball and load of 62,5 kg. was used to determine hardness (Digirock-RBOV). The electrical conductivities of samples were measured by eddy currents as %IACS (Fischer, Sigmascope SMP350).

## RESULTS AND DISCUSSIONS

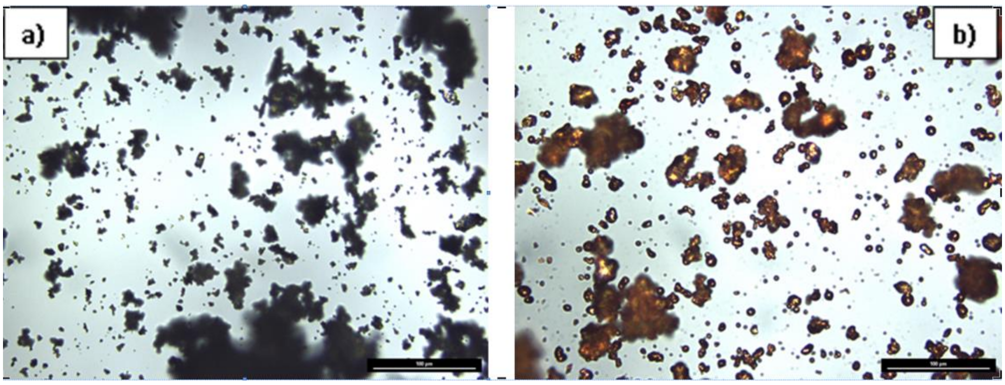

**Fig-1: Optical micrographs of, a)TiC, b)Cu (200X) powders in as-received state**

Fig-1 shows optical microscopy images of Cu and TiC powders. Copper powders were in spherical shape and wide range of particle sizes. TiC powders were in angular shape.

Fig-2 shows the optical microscopy images of composites and pure copper samples. After sintering, TiC particles couldn't dispersed homogeneously in the matrix Cu phase. It can be seen at the optical micrographs some TiC particles pulled-out from matrix. Due to the pull-out of TiC particles, the amount of porosity increased with increasing of reinforcement content. In addition, it was observed that not densified regions on the surface (Fig-2). These types of properties influence mechanical and electrical properties negatively.

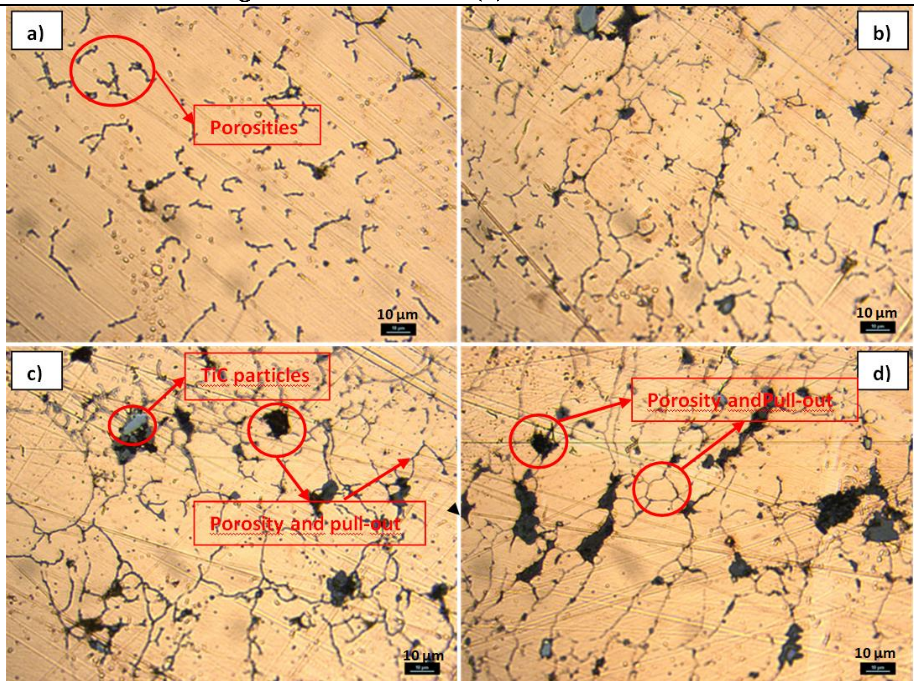


**Fig-2: Optical micrograph images of, a) Cu, b) Cu-TiC (0,5wt%), c) Cu-TiC (1wt%), d) Cu-TiC(2wt%)**

Cu and TiC peaks were observed in XRD patterns (Fig-3 & 4). This indicated that during sintering copper oxide phase didn't form. It can be concluded that use of graphite powder bed is sufficient to prevent oxidation of copper.

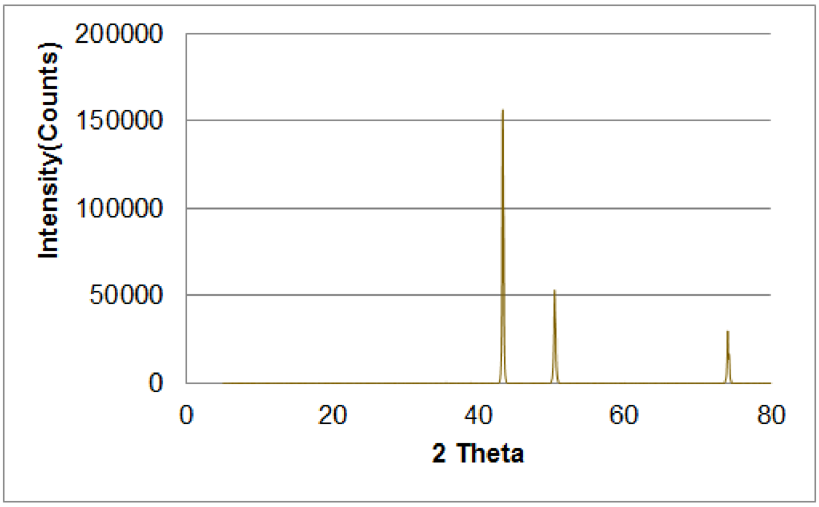


**Fig-3: XRD patterns of unreinforced Cu**

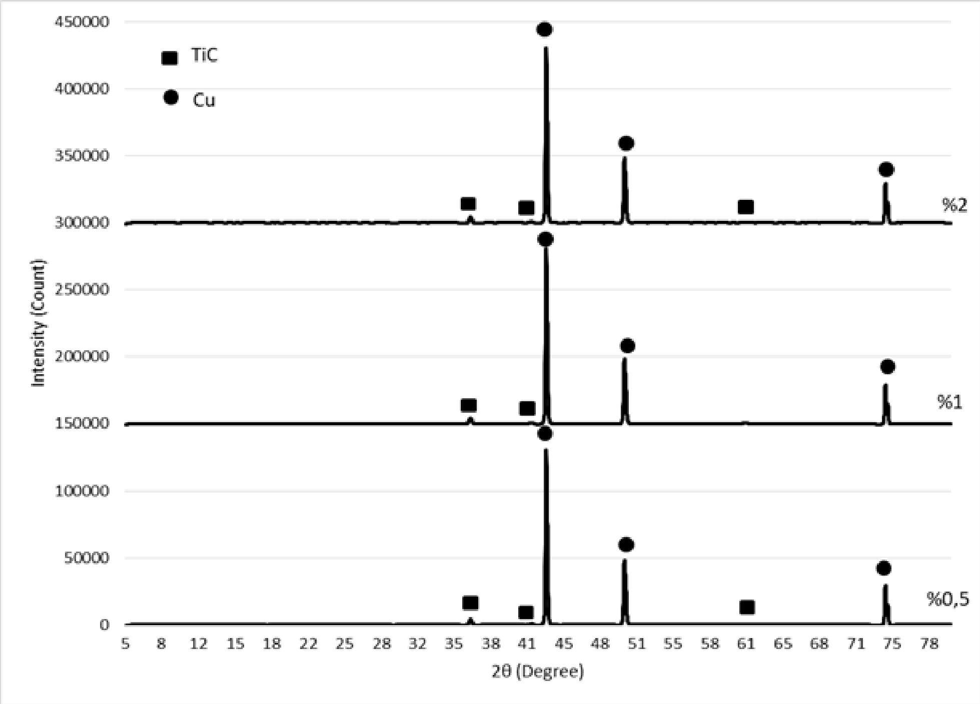


**Fig-4: XRD patterns of Cu/TiC composites**

It was observed that TiC addition reduce the relative densities. Change in the relative densities with reinforced content was illustrated in Fig-5. These results were coincided with the porosity of the specimens. Fig.5 shows that porosity increased with the amount of TiC. As expected increase in porosity results in decrease in relative densities.

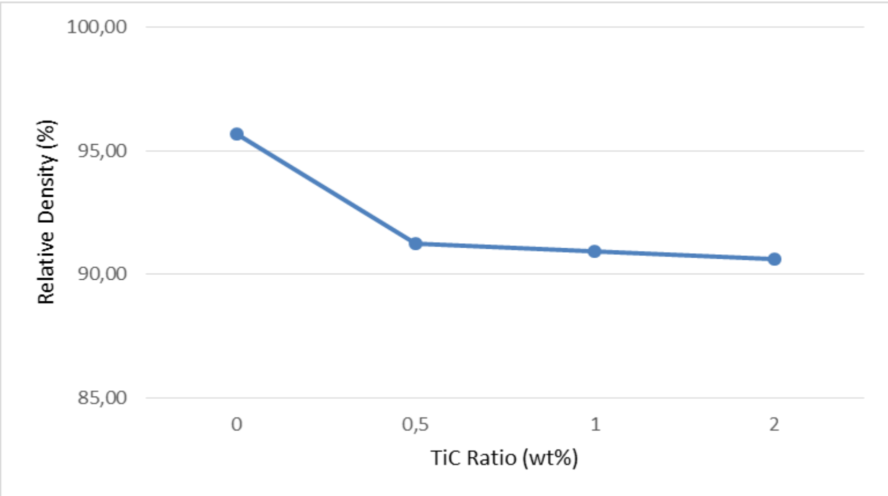


**Fig-5: Change of the relative density of specimens due to TiC content**

Density has crucial effect on the hardness and electrical conductivity. The higher content of porosity leads to decrease of relative density and hence hardness and electrical conductivity impair. Due to the increasing of the porosity, hardness of the composites decreased with increasing content of TiC (see Fig-6). On the other hand, uniform distribution of the reinforcement particles in to the matrix prevents dislocation motions and causes dispersion hardening. Inhomogeneities of the TiC particulates in the copper matrix decreased the effect of the dispersion hardening.

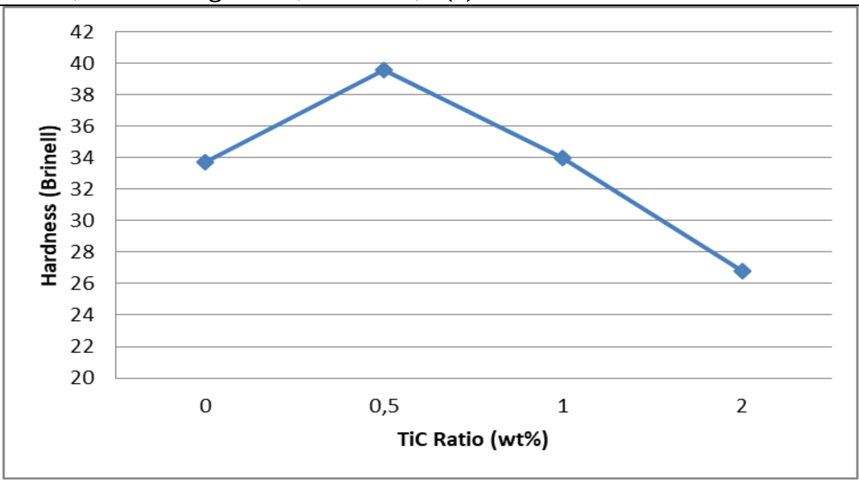


**Fig-6: Change of the hardness with TiC content**

Increase in the amount of the nonconductive particles in the conductive matrix causes decreases of the electrical conductivity of the composites. In our study, electrical conductivities of the composites decreased with increase in TiC content in accordance with the literature. However, reduction in the electrical conductivity was higher than expected. Even if the composites including low amount of reinforcement phase, the decrease in electrical conductivity is too much (see Fig-7). This was resulted from the porosity of the copper matrix. Depend on the porosity, electrical conductivity of the pure copper was also decreased, significantly. This showed that, porosity was dominant effect on the reduction of electrical conductivity. All of the mechanical and electrical results illustrated in Table 1.

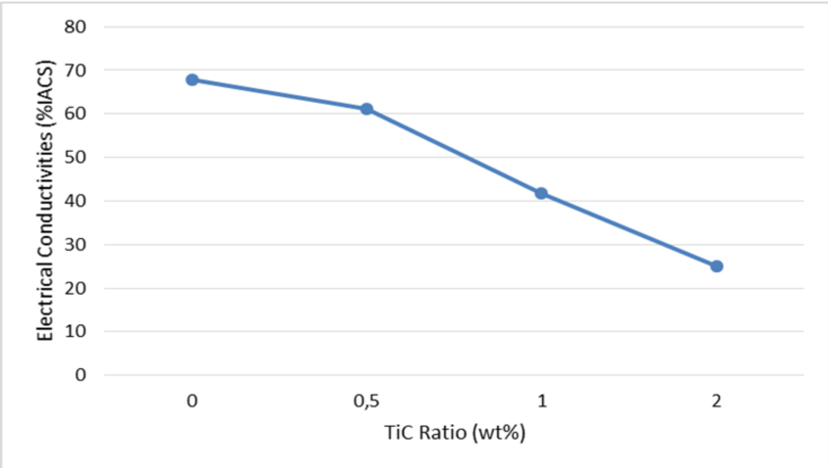


**Fig-7: Change of electrical conductivities with TiC content**

**Table-1: Mechanical and electrical test results**

| | Relative Density (%) | Hardness (Brinell) | Electrical Conductivities (%IACS) |
|---|---|---|---|
| **Cu** | 95,69 | 33,74 | 67,8 |
| **0,5wt%TiC-Cu** | 91,23 | 39,57 | 61 |
| **1wt%TiC-Cu** | 90,95 | 33,99 | 41,6 |
| **2wt%TiC-Cu** | 90,6 | 26,79 | 25,1 |

## CONCLUSIONS

In this study, mechanical and electrical properties of copper matrix TiC reinforced composites were investigated. Following results were obtained:

- TiC grains pulled out from copper matrix. These caused porosity on the surface of the composites.
- Non-uniform distribution of the reinforcement in to the matrix and the higher porosity content impair the hardness and electrical conductivity.
- Use of the graphite powder bed prevented oxidation of the copper.
- Minimum porosity level was obtained at composites that reinforced with 0,5 wt% TiC. Due

to the low porosity the best results was obtained with 0,5wt%TiC containing Cu matrix composites. Hardness of the 0,5wt%TiC-Cu composite increased by 17% from 33,74 to 39,57. And electrical conductivities of 0,5wt%TiC-Cu composite decreased by 10% from 67,8 to 61.

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