

# Effects of TiC content on transverse rupture strength (TRS) of Cu-TiC composites produced using powder metallurgy (PM) technique

S. ISLAK<sup>a\*</sup>, S. BUYTOZ<sup>b</sup>, Ö. ESKI<sup>c</sup>

<sup>a</sup>*Kastamonu University, Faculty of Engineering and Architecture, Department of Materials Science and Nanotechnology Engineering, 37000 Kastamonu, Turkey*

<sup>b</sup>*Firat University, Faculty of Technology, Department of Metallurgy and Materials Engineering, 23100 Elazig, Turkey*

<sup>c</sup>*Kastamonu University, Faculty of Engineering and Architecture, Department of Mechanical Engineering, 37000 Kastamonu, Turkey*

Cu-TiC composites have been produced by powder metallurgy technique. Mixtures of Cu-TiC powders corresponding to weight fractions of 1, 3, 5, 10 and 15 wt.% TiC were hot-pressed for 4 min at 700 °C under an applied pressure of 50 MPa. The transverse rupture strength (TRS) of the composites was evaluated by a three-point bending test. SEM were used to analyze the resulting fracture surfaces from the bending test. The TRS decreased rapidly in the 0-5 wt.% TiC contents, while it decreased slowly in the 5-15 wt.% TiC contents. SEM results showed that with the increase in the addition of titanium carbide to copper matrix, pores and gaps were present in the structure.

(Received July 17, 2014; accepted January 21, 2015)

*Keywords:* Metal matrix composites, Cu-TiC, transverse rupture strength

## 1. Introduction

Metal matrix composites (MMCs) reinforced hard particulates have been the subject of extensive research due to their excellent electrical and thermal conductivities, enhanced hardness, good wear resistance, and frictional properties [1]. The selection of a compatible reinforcement is very important for MMCs. During the last decade, composites reinforced with one kind of particle have been extensively studied and TiC, Al<sub>2</sub>O<sub>3</sub>, TiB<sub>2</sub>, SiC and BN are known as excellent reinforcements used in the MMCs [2-5]. TiC has been receiving much attention lately for its high melting temperature (3160 °C), low thermal coefficient of expansion, extraordinary hardness, excellent wear and abrasion resistance [6,7].

MMCs can be synthesized by such methods as standard ingot metallurgy (IM), powder metallurgy (PM), disintegrated melt deposition (DMD) technique, spray atomization and co-deposition approach. The PM processing route is generally preferred since it shows a number of product advantages. The uniform distribution of ceramic particle reinforcements is readily realized. On the other hand, the solid-state process minimizes the reactions between the metal matrix and the ceramic reinforcement, and thus enhances the bonding between the reinforcement and the matrix [8-10].

The application of copper is restricted in industry by its low hardness, low tensile yield strength and poor creep resistance property, although it has high electrical and thermal conductivities, fabrication and good corrosion resistance [11,12]. In order to overcome this problem, the copper matrix composites are manufactured by addition of carbide, oxide and ceramic particles into copper [13,14].

In the present investigation, our main aim is to investigate the transverse rupture strength (TRS) of the Cu matrix composite reinforced by TiC particulates produced by conventional powder metallurgy route using hot pressing techniques.

## 2. Experimental studies

The materials used in this work were copper and titanium carbide powders. Cu powder was of 99.9 wt% purity with particle size 20 µm; and TiC powder was of 99.9 wt% purity with particle size 10 µm. Cu powders were mixed with TiC to prepare composite powder mixture of 1, 3, 5, 10 and 15 vol.% of TiC. The acquired powder mixture were sintered in a graphite mold by using a hot press (HP). As illustrated in Fig. 1, sintering was performed as follows: The acquired powder mixture were first heated to 480 °C and held for 3 min (for dewaxing).

They were then heated to 700 °C and held for 4 min under sintering pressure of 50 MPa.

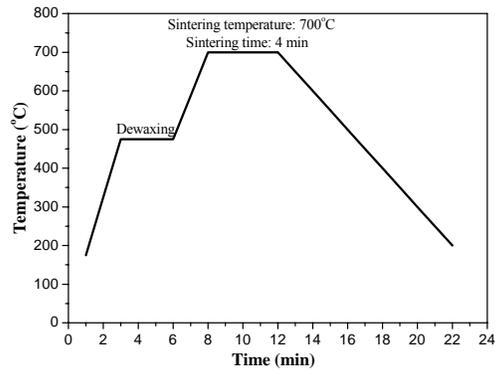


Fig. 1. Sintering graph.

Relative densities of samples were measured according to Archimedes' principle. Micro-hardness measurements of pure copper and Cu-TiC composites were performed using a Vickers hardness instrument under a load of 100 gf. In order to determine the transverse rupture strength (TRS) of the alloys, three-point bending tests were performed using a Schimatzu universal testing machine at a loading rate of 1 mm/min at room temperature (Fig. 2). The size of the hot-pressed samples for the three-point bending test was 40 x 10 x 10 mm. An optical microscopy (OM) and scanning electron microscope (SEM) were used to investigate microstructure and fractured surfaces of composites.

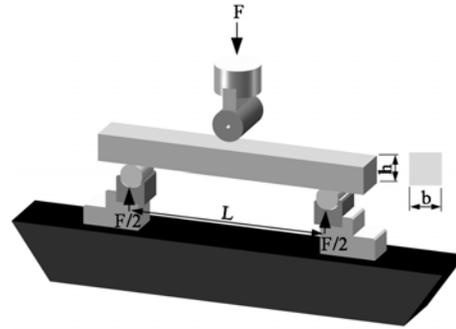


Fig. 2. Three-point bending test setup.

### 3 Results and discussion

#### 3.1. Microstructure

According to Fig. 3, the TiC reinforcing particles were homogeneously distributed in Cu matrix. The dark, angular particles in the micrograph represent the TiC reinforcement phase. The micrographs show the presence of small amount of pores. Since Cu cannot melt at such low temperature of 700 °C, the grain growth might proceed by means of solid state atomic diffusion. In order to avoid the negative effects of copper-ceramic reaction during sintering at high temperatures, sintering temperature was selected as 700 °C. The limit of sintering temperature of 750 °C is recommended in the literature [15].

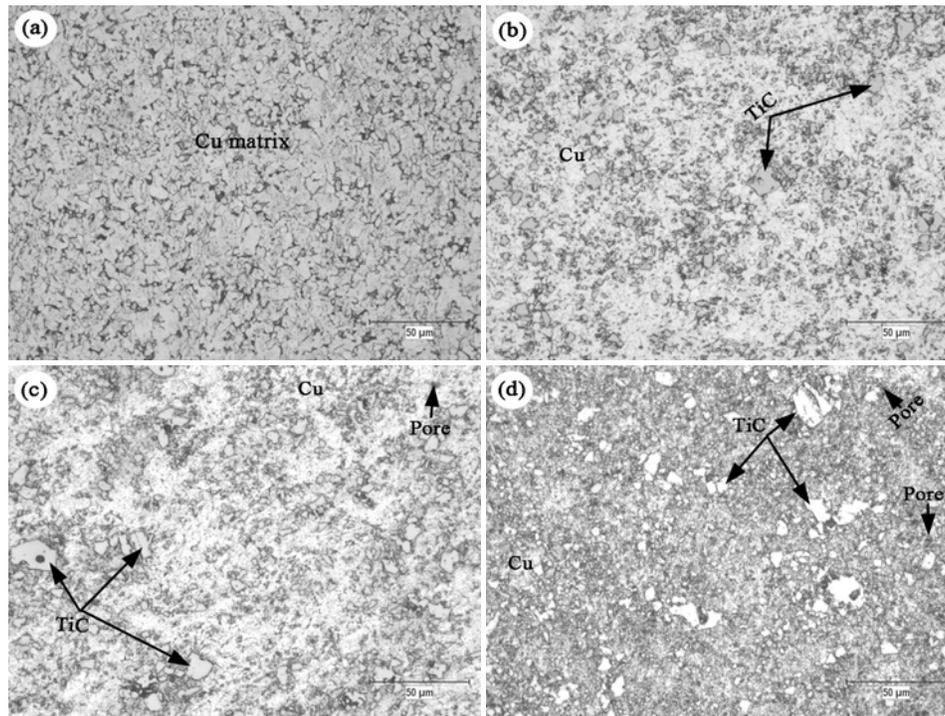


Fig. 3. Optical micrographs of (a) Cu, (b) Cu-5 wt.% TiC, (c) Cu-10 wt.% TiC and (d) Cu-15 wt.% TiC.

### 3.2. Relative densities and hardness

Table 1 illustrates the effect of TiC addition on relative density and hardness of Cu-TiC composites produced via hot pressing. Relative densities of the composites were determined according to Archimedes' principle. With increasing TiC addition, relative densities decreased. This decrease in the relative densities could be associated with the fact that increasing rate of TiC affected the sintering adversely [16]. Another reason is that huge difference between melting points of matrix and reinforcing member, namely Cu and TiC was an inhibiting factor in the rearrangement of particles during sintering. Moreover, the fact that density of TiC is lower than density of copper is another reason for the decrease in the relative densities. Hardness of Cu-TiC composites produced with addition of TiC significantly increased. This hardness increase was caused by dispersion strengthening effect of titanium carbide. Additionally, the increase in addition of TiC caused an increase in dislocation density in the Cu matrix and consequently it is thought that hardness of composites increased.

Table 1. Relative densities and hardness of Cu-TiC composites.

TiC content (wt %)	Relative density (%)	Hardness (HV <sub>0.1</sub> )
0	98.6	47.5
1	98.1	58.6
3	96.1	74.2
5	93.3	76.3
10	84.3	83.4
15	78.8	87.8

### 3.3. Transverse Rupture Strength (TRS)

The transverse rupture strength for each composite was determined by using a three-point bending test. The three-point bending test was repeated five times for every sample. Transverse rupture strength graph of Cu with 0, 1, 3, 5, 10 and 15 wt.% of TiC composite fabricated by hot pressing method is given in Fig. 4. It can be seen that TRS decreases with increasing TiC content. While the TRS value of PM Cu with no addition was measured as 307 MPa, the TRS values of Cu-TiC composites with 1, 3, 5, 10 and 15 % TiC addition were measured as 289 MPa, 235 MPa, 195 MPa, 188 MPa and 168 MPa, respectively. The reason for this decrease can be explained as the increase of TiC particles lead to the

increase of the total area of the weakly bonded interface, which results in the decrease of the TRS [17,18]. In addition to, Dwan [19] explained that the level of porosity influences the fracture toughness of the PM material. The TRS decreased rapidly in the 0-5 wt.% TiC contents, while it decreased slowly in the 5-15 wt.% TiC contents. As the reason for this, it is thought that TiC particles in Cu matrix were clustered at high rates of less than 5 wt.% TiC. SEM images in Fig. 5 are evidence of that. Arik [20] reported that the most important factors affecting the TRS of the particle-reinforced composites are dispersion of reinforcement materials in the matrix structure.

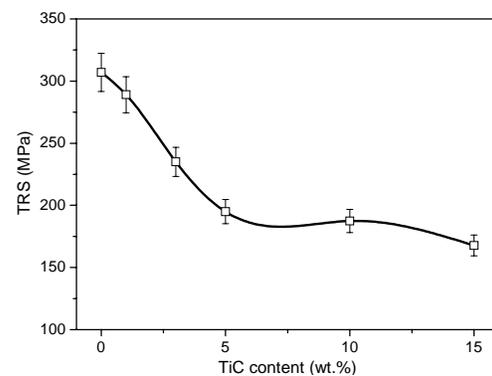


Fig. 4. The influence of TiC content on TRS.

The SEM images taken from the fracture surfaces of the Cu-TiC composites are shown in Fig. 5. As it can be seen, the increase in titanium carbide content was attributed to the changing microstructure of fracture surface. Fracture surface of Cu revealed dimple patterns showing ductile behavior (Fig. 5a). With the increase in the addition of titanium carbide to copper matrix, pores and gaps were present in the structure (Fig. 5(b-f)). The pores and gaps resulted in a decrease in the transverse rupture strength (TRS). The increase in the amount of TiC has led to an increase in size and amount of pores and gaps. According to the SEM images in Fig. 5(b-f), the weak bonding between TiC and Cu matrix was due to insufficient sintering conditions. The quality of bonding between TiC and Cu matrix can be improved by changing sintering parameters. When the sintering temperature is too low, the powder particles that make up the matrix may remain unreacted. An example of a sintering mistake is shown in Fig. 5(c and e). The Cu powder particle has not reacted because of the insufficient sintering parameters [21].

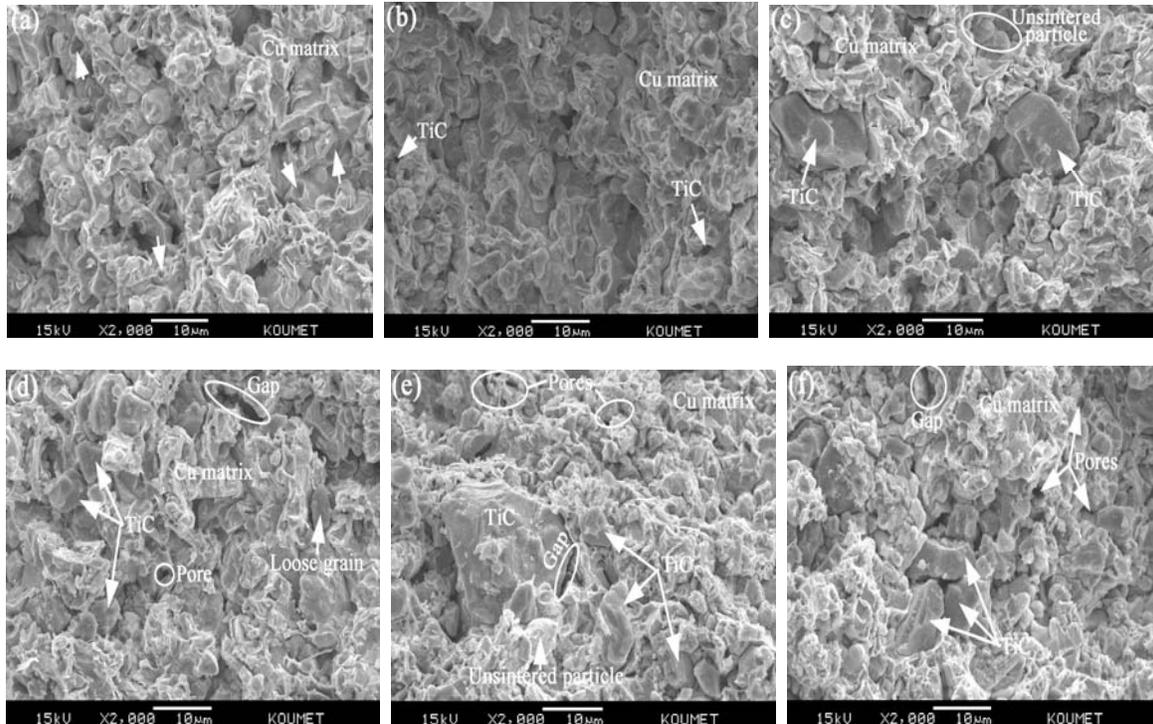


Fig. 5. The SEM images of the fracture surfaces of (a) Cu un-reinforced, (b) Cu-1 wt% TiC, (c) Cu-3 wt% TiC, (d) Cu-5 wt% TiC, (e) Cu-10 wt% TiC and (f) Cu-15 wt% TiC

#### 4. Conclusions

Cu-TiC composites were successfully produced using a hot pressing method. Despite hardness of Cu-TiC composites was increased with increasing the amount of TiC particle, relative density decreased. The TRS decreased rapidly in the 0-5 wt.% TiC contents, while it decreased slowly in the 5-15 wt.% TiC contents. As the reason for this, it is thought that TiC particles in Cu matrix were clustered at high rates of less than 5 wt.% TiC.

#### Acknowledgements

The authors acknowledge financial support by Kastamonu University Scientific Research Projects Coordination Unit (No: KUBAP-01/2012-15).

#### References

- [1] M.R. Akbarpour, E. Salahi, F. Alikhani Hesari, A. Simchi, H.S. Kim, *Ceramics International* **40**, 951 (2014).
- [2] M. Roy, B. Venkataraman, V.V. Bhanuprasad, Y.R. Mahajan, G. Sundararajan, *Metallurgical Transactions A* **23**, 2833 (1992).
- [3] H. Kaftelen, N. Ünlü, G. Göller, M. L. Öveçoğlu, H. Henein, *Composites Part A, Applied Science and Manufacturing* **42**, 812 (2011).
- [4] I.Y. Kim, B.J. Choi, Y.J. Kim, Y.Z. Lee, *Wear* **271**, 1962 (2011).
- [5] M. Taskin, U. Caligulu, A.K. Gur, *International Journal of Advanced Manufacturing Technology* **37**, 715 (2008).
- [6] Y. Wang, W.M. Rainforth, H. Jones, M. Lieblich, *Wear* **251**, 1421 (2001).
- [7] N. Nemati, R. Khosroshahi, M. Emyam, A. Zolriasatein, *Materials & Design* **32**, 3718 (2011).
- [8] J. Zhu, L. Liu, H. Zhao, B. Shen, W. Hu, *Materials & Design* **28**, 1958 (2007).
- [9] E. Çelik, S. Islak, D. Kır, C. İlkılıç, *Optoelectron. Adv. Mater. – Rapid Comm.* **7**, 406 (2013).
- [10] H. Wang, R. Zhang, X. Hu, C.A. Wang, Y. Huang, *Journal of Materials Processing Technology* **197**, 43 (2008).
- [11] ASM Handbook, Vol. 6, Properties and Selection: Nonferrous Alloys and Special-Purpose Materials, 10<sup>th</sup> ed., Metals Park, ASM International, Ohio 1990.
- [12] H. Chen, C. Jia, S. Li, *International Journal of Minerals, Metallurgy and Materials* **20**, 180 (2013).
- [13] A.T. Alpas, H. Hu, J. Zhang, *Wear* **162–164**, 188 (1993).

- [14] A.K. Shukla, S.V.S. Narayana Murty, R. Suresh Kumar, K. Mondal, *Journal of Alloys and Compounds* **580**, 427 (2013).
- [15] K.M. Shu, G.C. Tu, *Materials and Manufacturing Processes* **16**, 483 (2001).
- [16] M. Rahimian, N. Ehsani, N. Parvin, H.R. Baharvandi, *Journal of Materials Processing Technology* **209**, 5387 (2009).
- [17] X. Jin, L. Wu, Y. Sun, L. Guo, *Mater. Sci. Eng. A.* **509**, 63 (2009).
- [18] S. Islak, D. Kır, E. Çelik, H. Çelik, *Scientific Research and Essays* **7**, 2095 (2012).
- [19] J. Dwan, *Ind. Diamond Rev.* **1**, 33 (2007).
- [20] H. Arik, *Materials & Design* **29**, 1856 (2008).
- [21] M. Zeren, Ş. Karagöz, *Materials Characterization* **57**, 111 (2006).

---

\*Corresponding author: serkan@kastamonu.edu.tr