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POWDER METALLURGY
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Characterization of Hot Pressed CuAl–TiC Composites with Different TiC Grain Sizes[1]

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Abstract—In this study, the CuAl–TiC composite materials were produced using hot pressing process. Effect of TiC grain size (0.2, 4 and 20 μm) on some properties of these materials was investigated experimentally. Production of CuAl–TiC composites was carried out under pressure of 35 MPa, at 700°C, and for a sintering time of 5 minutes. SEM-MAP studies showed that the TiC grains were relatively homogeneously distributed in the CuAl matrix. Microstructure analysis revealed that the composite materials consist of Cu, Al, Cu_9Al_4, $CuAl_2$ and TiC phases. With the decreasing of TiC grain size, the hardness, transverse rupture strength, relative density and sintered density of composites increased.

Keywords: CuAl–TiC composites, microstructure, hardness, TRS, sintering, grain size

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1. INTRODUCTION

Nowadays, there is an increasing need worldwide for the advanced materials in order to obtain the desired properties. This is because a single material generally cannot meet the requirements of harsh engineering environments. That is why the need for composites with unique properties is growing every day. Metal matrix composites (MMCs) are widely used in different industries because of their high mechanical properties and wear resistance [1, 2]. MMCs are attractive and viable alternatives to the traditional engineering alloys, with majority of them having metallic matrices reinforced with high strength, high modulus, and brittle ceramic phases. Reinforcements for the composites can be fibers, fabrics, particles or whiskers [3].

The particle reinforced metal matrix composites can be synthesized by such methods as standard ingot metallurgy, powder metallurgy, disintegrated melt deposition technique, spray atomization and co-deposition approach. Different method results in different properties. The powder metallurgy (PM) processing route is generally preferred since it shows a number of product advantages. The uniform distribution of ceramic particle reinforcements is readily realized [4, 5]. PM method consists of the steps of pressing metal powders inside a mould, bonding powder particles with each other, and sintering. This method is also a large process which several materials are manufactured by pressing-sintering or hot pressing. Not only simple cylindrical shafts, bearings but also complex shaped parts such as filters, gears can be conveniently manufactured through powder metallurgy method [6].

Systems based on Cu and Al is typically considered as candidate materials for electric devices, i.e., transition piece in high direct-current bus systems [7]. Development of high conductivity and high strength Cu–Al alloys can be achieved by uniformly dispersing fine ceramic particles such as oxides, borides, carbides and nitrides in the Cu matrix. Dispersion strengthened Cu–Al composites are also known to have better mechanical properties than precipitation hardened Cu–Al materials at elevated temperatures because of the thermal stability of these dispersoids [8]. TiC is a proper reinforcement candidate for composite materials because of its high melting point, high modulus and grain refining effect, high chemical stability and good electrical conductivity [9–11]. There are no studies available in literature that addresses the characterization and production of TiC having different grain size reinforced Cu–Al matrix composites. Therefore, aim of this work investigates effect of TiC grain size (0.2, 4 and 20 μm) on some properties of hot pressed CuAl–TiC composites. For this purpose microstructure and phase compositions of these composite materials were examined through scanned electron microscope (SEM), energy distribution spectrometer (EDX) and X-ray diffractogram (XRD).

[1] The article is published in the original.

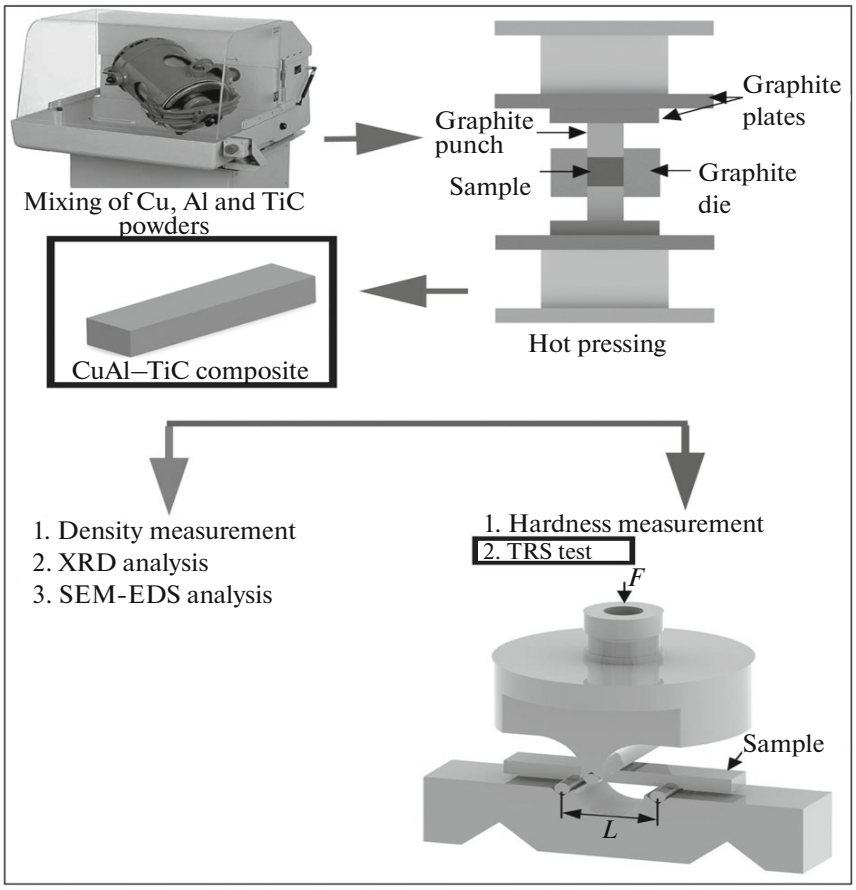


Fig. 1. Schematic presentation of CuAl–TiC composites production and characterization.

2. MATERIALS AND METHODS

CuAl alloys were prepared by blending pure Cu powder (purity 99.9%, particle size 10 μm) and pure Al powder (purity 99.9%, particle size 10 μm) to form the Cu-5 wt% Al. The aim of Al powder addition was to form a liquid phase and aid in densification during hot pressing. Cu-5 wt% Al matrix alloy and TiC (grain sizes 0.2, 4 and 20 μm) powder were mixed with the addition of a 1 wt % of paraffin wax, at a speed of 20 rpm, for 30 minutes in an ∞ shape rotary mixer. TiC powders were added to the CuAl matrix at the amount of 5 wt % percents. Then, the mixture was hot-pressed in graphite moulds for 5 min at 700°C with an applied pressure of 35 MPa on an automatic hot pressing machine. 5 min sintering time was selected as optimum time because of literature research and experiences of the author team. When time was more than five minutes, it was observed that aluminum component infiltrated in the mold.

The relative density and hardness of the composites were determined. The relative densities of composites were measured by Archimedes' principle. Hardness measurements were performed using a Brinell scale with a ball diameter of 2.5 mm and a load of 62.5 kg. The three-point bending tests were performed to determine the transverse rupture strength (TRS) of the composites. TRS was measured in accordance with ASTM B528-83a using an equipment Instron 4411 universal testing machine, at a loading rate of 1 mm/min, at room temperature. The sizes of the hot-pressed composites for the three-point bending test was 40 × 7 × 3.2 mm. The microstructure properties of composites were evaluated by SEM (Carl Zeiss Ultra Plus Gemini FESEM, Australia). Chemical composition of composites was done by means of energy dispersive spectrometry (EDX) in the SEM. Phase constitution of the obtained samples were identified by X-ray diffraction (XRD, RIGAKU ULTRA IV XRD, Cu target, $K\alpha$ radiation (40 kV and 20 mA)), with a scanning rate of 0.02°/s. Figure 1 illustrates schematic presentation of CuAl-TiC composites production and characterization.

3. RESULTS AND DISCUSSION

3.1. Microstructure

Cu-Al and Cu–Al/TiC composites were successfully produced using the hot pressing method together with a 5-minute sintering time at 700, under pressure of 35 MPa. Figure 2 illustrates SEM images of CuAl

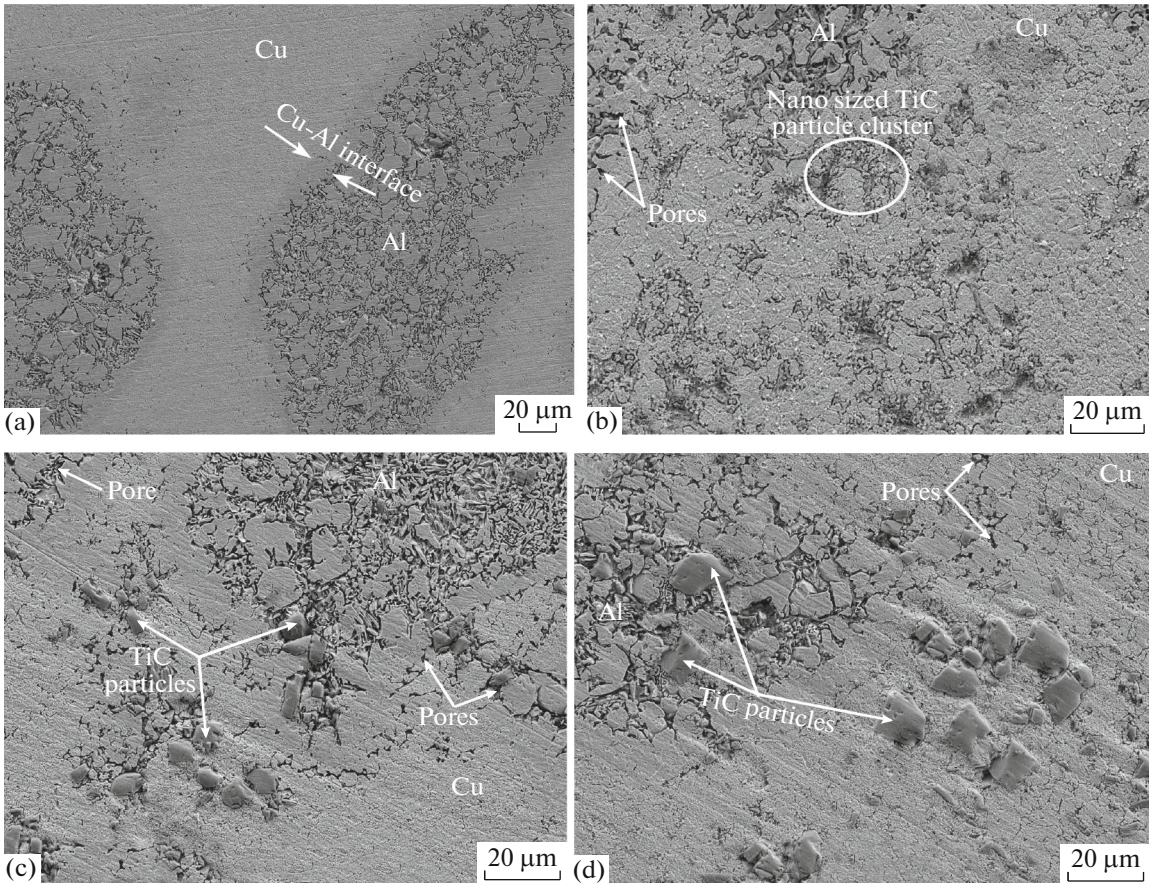
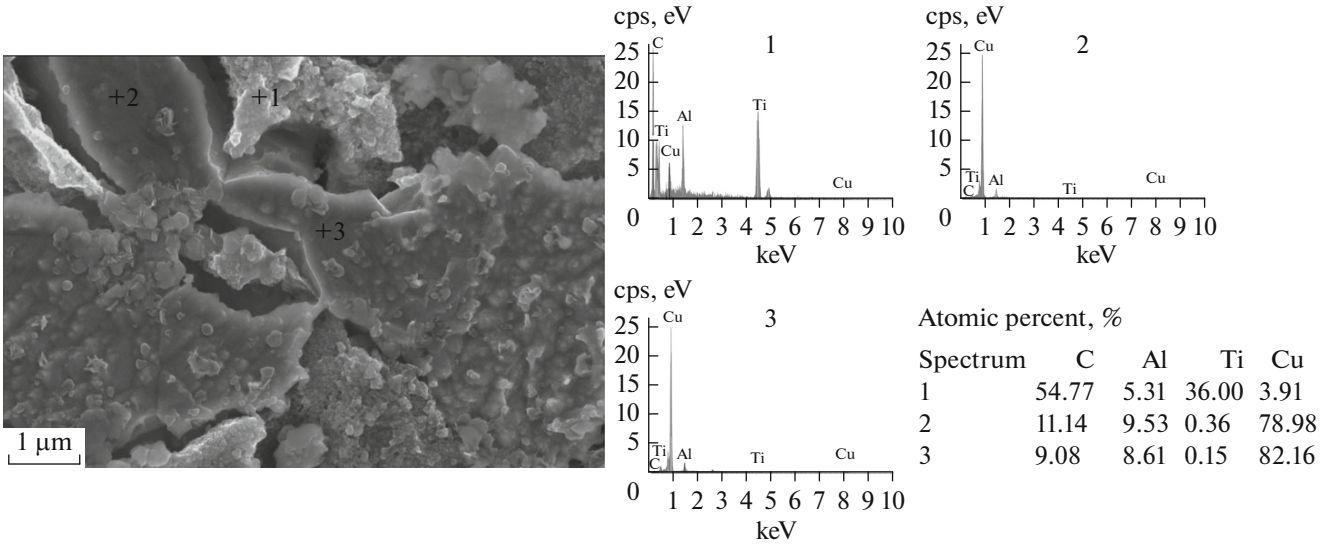


Fig. 2. SEM images of CuAl-TiC composites with different particle size: (a) CuAl un-reinforcement, (b) 0.2 μm, (c) 4 μm and (d) 20 μm.

and CuAl–TiC composites. Al liquid phase formed due to 700°C sintering temperature. Al liquid phase is seen as islets in the microstructure. This liquid phase fills the pores in the microstructure. Besides, due to the liquid phase, at the interface of Cu and Al occurred the good wettability (Fig. 2a). The TiC particles were relatively homogeneously distributed in the microstructure. In micrographs, the light gray areas indicate Cu, the medium gray areas indicate Al, and dark gray and cornered shapes indicate the reinforcement component TiC. The TiC having 0.2 μm particle size distributed in the form of clusters (Fig. 2b). This situation is due to agglomeration of TiC powder during mixing of powders. TiC particles were positioned as embedded since they were within grain borders of ductile Cu and Al. Since the large TiC particle reduce the contact area between the Cu–Al particles, addition of TiC having 4 and 20 μm grain sizes to the Cu–Al matrix lead to higher porosity than composite with TiC having 0.2 μm grain size (Figs. 2c–2d).

EDX analyses of CuAl-TiC composites are given in Figs. 3 and 4. It is clear that the nano sized TiC particles (0.2 μm) enter as agglomerated between of matrix particle in composites (Fig. 3). Point 1 in Fig. 2 represents nano-sized TiC particles. Small amounts of CuAl were daubed onto the TiC particles. It was found that point 2 and 3 consist of Cu and Al. According to EDX data of TiC having 4 μm reinforced composites, it was seen that transition interface (point 4) between the Cu and the Al formed, chemical composition of which was 77.27 at % Cu, 13.24 at % Al and 9.48 at % C. It is thought that carbon content of 9.48 at % stems from either carbon coating or bakelite particles contaminated onto samples. When the EDX analysis of this region and the XRD pattern of the sample (Fig. 7) were considered, it was thought that the transition interface region which had a thickness of about 15 μm (Figs. 1a, 1c and 1d) was consisted of a Cu_9Al_4 phase. This phase formed due to solid state diffusion between the Cu and the Al. Al_2Cu phase may be formed towards aluminum-rich regions [12–15].

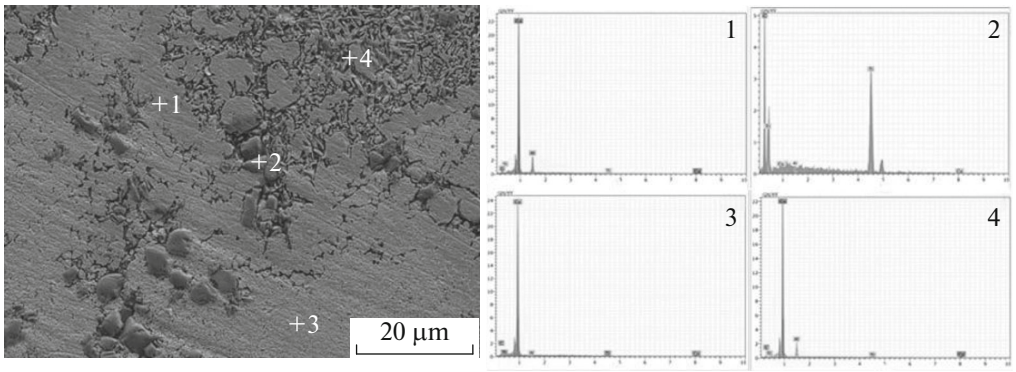
It is very important to obtain other homogeneous components in the matrix in order to improve properties of materials [16, 17]. Figures 5 and 6 show images of MAP analysis of CuAl–5 wt % TiC composite. As seen in Fig. 4, the nano sized TiC particles entered gaps between Cu and Al particles. The nano powders moved into gaps in the form of network. This situation



Atomic percent, %

Spectrum	C	Al	Ti	Cu
1	54.77	5.31	36.00	3.91
2	11.14	9.53	0.36	78.98
3	9.08	8.61	0.15	82.16

Fig. 3. EDX results for CuAl-TiC composite (TiC having 0.2 μm).



Atomic percent, %

Spectrum	C	Al	Ti	Cu
1	9.83	14.46	0	75.71
2	54.63	0.18	45.06	0.13
3	21.62	0	0.09	78.30
4	9.48	13.24	0	77.27
Mean value:	23.89	6.97	11.29	57.85
Sigma:	21.26	7.96	22.51	38.50
Sigma mean:	10.63	3.98	11.26	19.25

Fig. 4. EDX results for CuAl-TiC composite (TiC having 4 μm).

is due to fact that nano sized powders formed clusters. A fairly good dispersion of the nano sized TiC particles was achieved although some small TiC clusters still existed into the CuAl matrix (Fig. 4). The SEM image illustrates fairly homogeneous distribution of TiC in CuAl. EDX image shows the main spectrums of Cu, Al and Ti elements at all locations.

Figure 7 shows XRD patterns of the CuAl–TiC composite. Cu, Al, Cu_9Al_4, $CuAl_2$ and TiC phases are detected in the microstructure. This implies that chemical change partially occurred in the sintered CuAl-TiC composite at 700°C temperature. For the Cu-Al system, Murray [18] has shown that five intermetallics, i.e., Al_4Cu_9, Al_2Cu_3, Al_3Cu_4, AlCu and

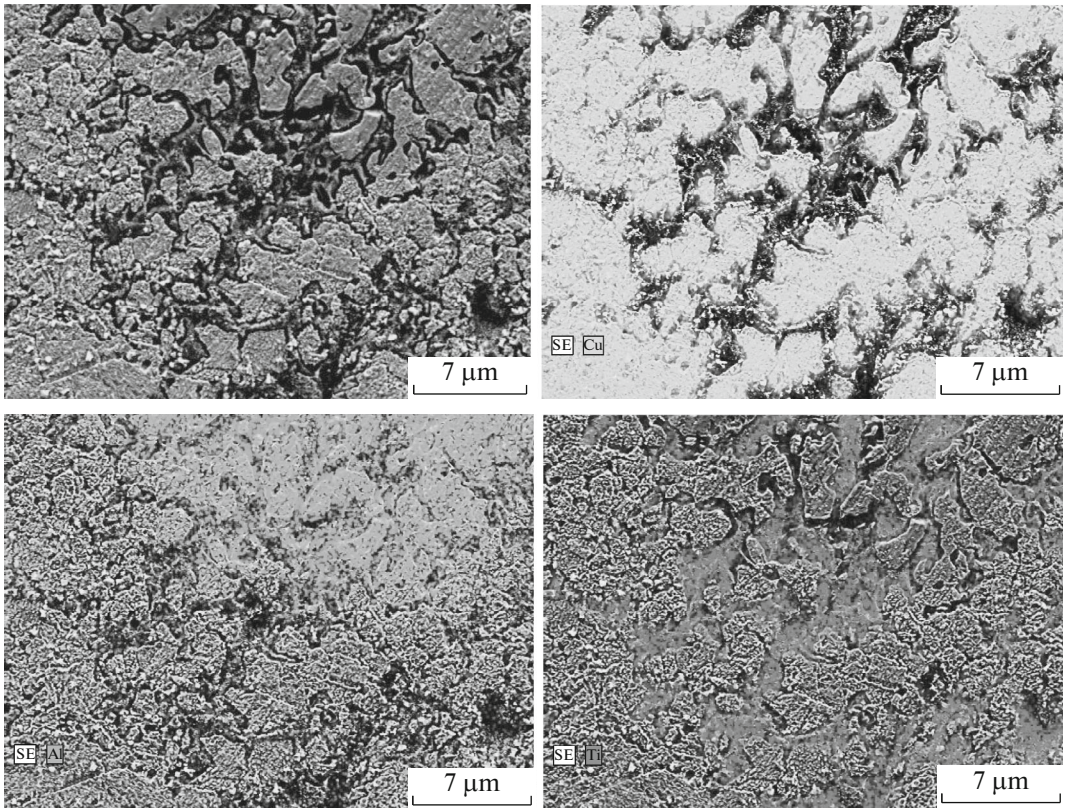


Fig. 5. MAP analysis showing element distribution for composite with TiC having 0.2 μm.

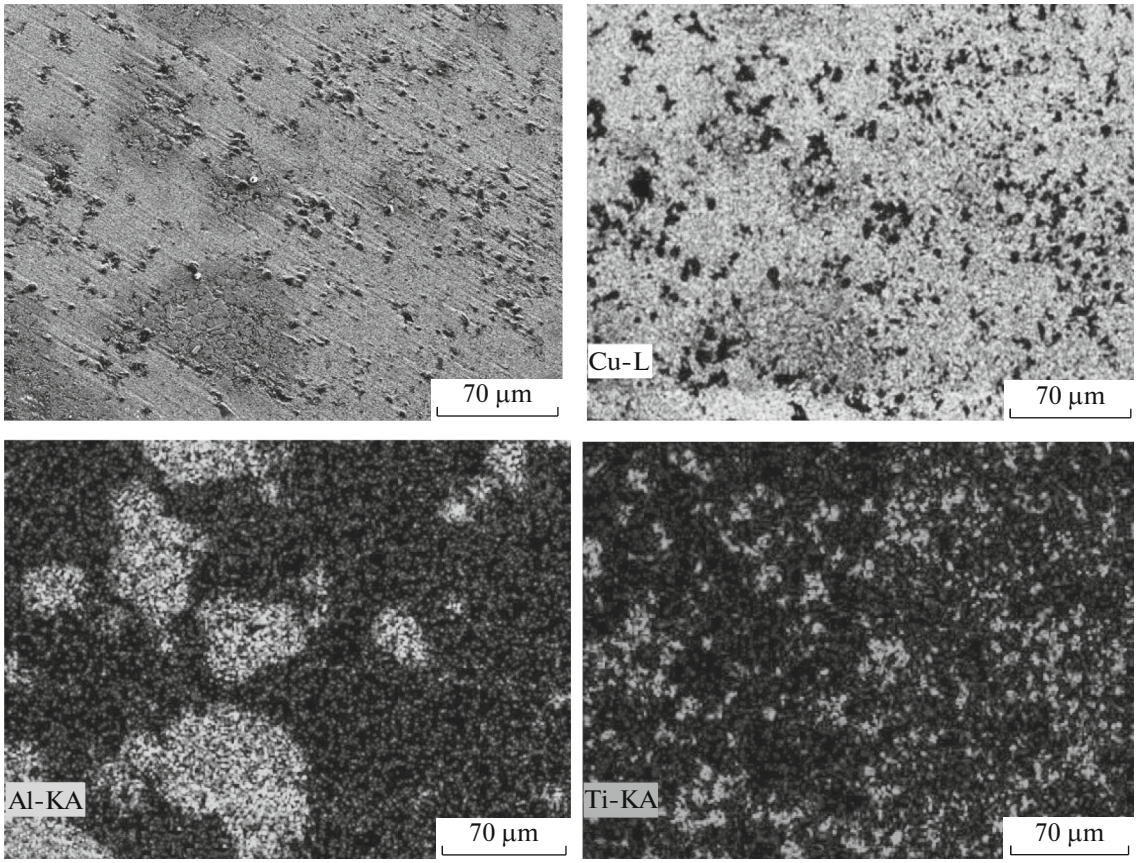


Fig. 6. MAP analysis showing element distribution for composite with TiC having 20 μm.

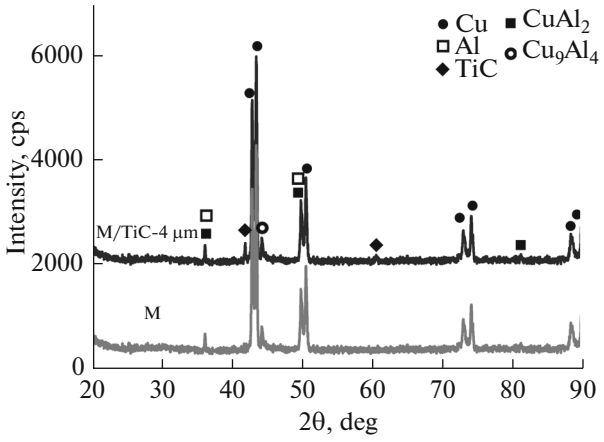


Fig. 7. XRD pattern of CuAl–TiC composite (M represents the Cu–5 wt % Al).

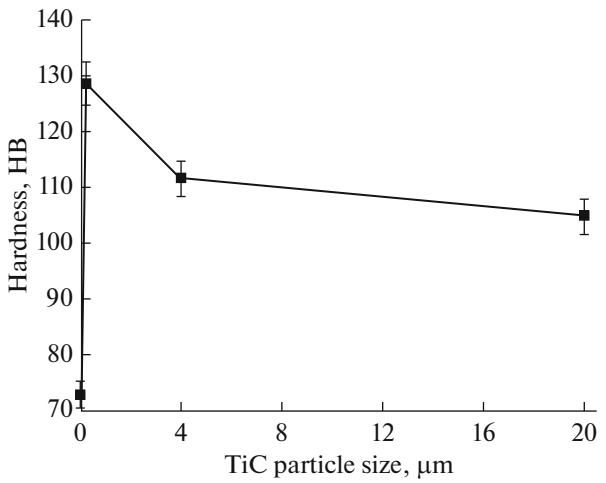


Fig. 8. The effect of TiC particle size on composite hardness.

Al_2Cu, can form at temperatures below 548°C. As shown in Fig. 6, in the composite didn't occur oxidation.

3.2. Density and Hardness of Composites

Table 1 illustrates the effect of TiC particle size on densities of composites. The sintered and theoretical densities of composites were used to determine their relative density. When TiC was introduced to the CuAl matrix, it decreased the sintered density. This was due to the fact that the density of titanium carbide was lower than that of CuAl. The density of TiC was 4.93 g/cm^3, while the density of CuAl was 8.62 g/cm^3. Relative density of composite decreased as the TiC particle size increased. It can be concluded that two concurrent consolidation mechanisms act between the ceramic phase and the metal one, in which lower TiC particle size leads to the less porosity is achieved. Moreover, large TiC particles reduce the contact area between the matrix particles. For this reason, in the microstructure of composite occurred high porosity. By the addition of more coarse-grained TiC particles to the matrix the relative density of composites decreases because the presence of porosity is related to density [19–21].

Figure 8 shows the effect of the size of reinforcement particle on the hardness of Cu–Al/TiC composites. Five measurements for each composite specimen were carried out in the hardness test for reproducibility. The hardness of CuAl without TiC was measured as 73 HB. Hardness of the composite increased by adding TiC particle. This may be explained by rule of mixture, applied to composite materials [22, 23]. The hardness of CuAl–TiC composites was 129 HB for TiC having 0.2 μm particle size, 112 HB for TiC having 4 μm and 105 HB for TiC having 20 μm particle sizes. Hardness was found to decrease with increasing TiC particle size. This phenomenon can be evaluated at various viewpoints. Researchers have attributed this to greater interfacial area between the reinforcement particle and the matrix [1]. Furthermore, the defects (pores and cracks) in the coarse-grained particles are more than the fine-grained ones [2]. The grain size has a strong influence on metal strength since the grain boundaries can hinder the dislocation movement. This is due to the different orientation of adjacent grains and to the high lattice disorder characteristic of these regions, which prevent the dislocations from moving in a continuous slip plane [24].

3.3. Transverse Rupture Strength (TRS) of Composites

Figure 9 illustrates the effect of TiC particle size on the TRS. Test was repeated five times for each group. Differences in measurement were given as error bars in the graph. The TRS of the composites decreased together with the increase in the particle size. The TRS values of composites with particle sizes of 0, 0.2,

The effect of TiC particle size on the densities of the composites

Samples	Theoretical density, g/cm^3	Sintered density, g/cm^3	Relative density, %
M*	8.63	7.87	91.25
M/TiC 0.2 μm	8.43	7.43	88.18
M/TiC 4 μm	8.43	7.39	87.67
M/TiC 20 μm	8.43	7.07	83.85

* M represents the Cu–5 wt % Al.

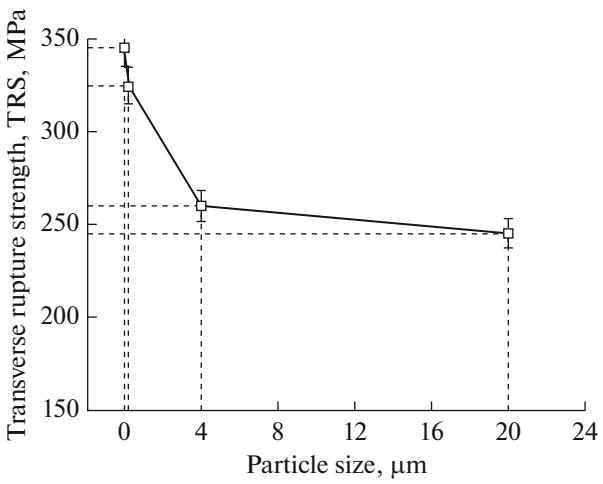


Fig. 9. The effect of TiC particle size on the TRS of CuAl–TiC composites.

4 and 20 μm TiC was measured as 345, 325, 260, and 225 MPa, respectively. Bocchini [25] and Sánchez et al. [26] have explained in two ways this situation in their works. First, larger particles originate larger pores and these act as stress raisers. Second, specific surface increases as particle diameter decreases; therefore, the number of metallurgic bonds increases when small particles are sintered.

4. CONCLUSIONS

CuAl–TiC composites were successfully produced using the hot pressing method. The micron sized TiC particles were relatively homogeneously distributed in the CuAl matrix. A fairly good dispersion of the nano sized TiC particles was achieved although some small TiC clusters still existed into the matrix. According to XRD, Cu, Al, Cu_9Al_4, Al_2Cu and TiC phases were detected in the microstructure. With the decreasing of TiC particle size, the hardness, relative density and TRS values of composites increased.

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