Effect of Compaction Pressure on Microstructure and Properties of Copper-based Composite Prepared by Mechanical Alloying and Powder Metallurgy

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Abstract In this study, copper-tungsten carbide composite was produced by mechanical alloying and powder metallurgy. The compaction pressures were varied from 100 to 600 MPa for observation on microstructure and properties of the composite. The result showed the microstructure was densified with the increased of compaction pressure. Within compaction pressure no fracturing was occurred. Increasing compaction pressure increased the density, hardness and electrical conductivity of the composite which related to the reduced of porosity area.

Introduction

Good electrical conductivity from Cu matrix and high strength as well as excellent wear and corrosion resistance from tungsten carbide makes copper-tungsten carbide composite very useful in electrical with good wear resistance application. For instance, a potential candidate for contact material that used in welding electrodes. Copper-tungsten carbide composite has a very close electrical conductivity value (52% IACS) [1] with that of Ag-based electrical contact (52.5% IACS) [2]. Over the years, copper-based composite has been synthesized by internal oxidation method. Al_2O_3 reinforced Cu is common composite produced by this method. Powder metallurgy involves of milling, compaction and sintering. The ability to disperse very fine reinforced particles into Cu, leading to a better control of microstructure makes the powder metallurgy the most promising method for Cu strengthening process. On the other hand, a recent developed method combining both powder metallurgy and mechanical alloying introduces excellent result on particle dispersion strengthening.

In mechanically alloyed powder, the compressibility is affected by powder morphology and work hardening of hard particles within the composite. The spherical powder shape and smaller particle size is easier to be compact than the irregular powder and coarser particle size one. Higher work hardening may lower powder compressibility. It was shown that work hardening at high compaction pressure leads to reduce in compressibility of mechanically alloyed Cu-SiC composite [3] powder. It is also that higher applied pressure had increased the strength of Al-Al_2O_3 composite as a result of work hardening due to composite response for plastic deformation has been restricted by the presence of Al_2O_3 particles [4]. In literatures, the compaction behavior of mechanically alloyed copper-tungsten carbide composite is mostly unavailable. In this present work, copper-tungsten carbide composite was produced by mechanical alloying and powder metallurgy. The microstructure and properties of composite will be discussed according to the variation of pressure during compaction.

Experimental procedure

Elemental copper (Cu; 99.8% purity; average particle size 22.3 μm), tungsten (W; 99.9% purity; average particle size 11.4 μm) and graphite powders (C; 99.8% purity; average particle size 17.0

μm) were used in this study. The powder mixtures were milled for 40 h at 400 rpm speed in a planetary ball mill (Fritsch Pulverisette 5) in an argon environment with a ball-powder ratio of 10:1 with 10 mm ball. The powders were then compacted at several compaction pressures (100 to 600 MPa) and sintered under argon atmosphere at 900°C for 1 hour. The characterization for microstructure of sintered composite was scanning electron microscopy (SEM). The density of composite was determined according to Archimedes' principle. Hardness and electrical conductivity were characterized using Vicker's microhardness tester and four point probe, respectively.

Results and discussion

SEM images of sintered compact SEM images in figure 1 are utilized to explain the effect of compaction pressure on the microstructure of sintered composite. It is clearly seen that morphology of sintered composite changes with variation of compaction pressures. The powder pressed at 100 MPa exhibited large amount of porosity compared to those compacted at 600 MPa. It seems that, at lower compaction pressure, the powder particles tend to slide and restacking, leading to the rearrangement from loose to close packed structure. However, the applied pressure of 100 MPa was insufficient to cause high deformation. With increasing compaction pressure (200 and 600 MPa), the particles exposed to continuous deformation mechanism. In this copper-tungsten carbide composite system, two deformation mechanisms can be proposed; plastic deformation of soft Cu matrix and fracturing of tungsten carbide particles. However, within compaction pressure from 200 to 600 MPa only plastically deformed morphology was observed whereas fracturing was not obtained. There is no change in particle orientation within studied compaction pressure, indicating that little or no fracturing had occurred even though high compaction pressure of 600 MPa has been applied. It indicates that fracturing of hard W particles only occurs if very high deformation is obtained.

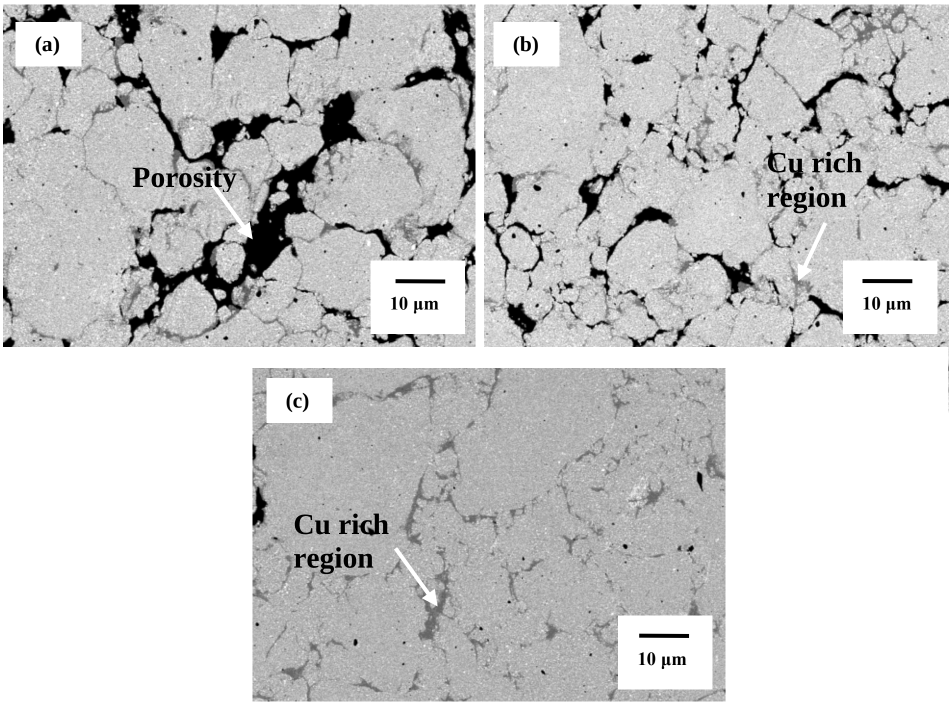

Fig. 1: SEM images of powder compacted at (a) 100 MPa (b) 400 MPa and (c) 600 MPa and sintered at 900°C

Properties of sintered compact Figure 2 shows applying high compaction pressure increased green density (GD) and sintered density (SD). The applied pressure of 100 MPa was insufficient for good powder packing since it only contributes to particle rearrangement. High compaction pressures (200 to 300 MPa) provides particles fragmentation which makes them becomes easier because deformation has been enhanced. Under much higher compaction pressure, the composite experience high plastic deformation that continuously increased GD and SD. The composite which was pressed by high pressure had less porosity owing to it having higher number of point contact and contact area. This situation is observed between 400 to 600 MPa. In this compaction range, work hardening only has a little influence on GD since plastic deformation still dominates the consolidation mechanism.

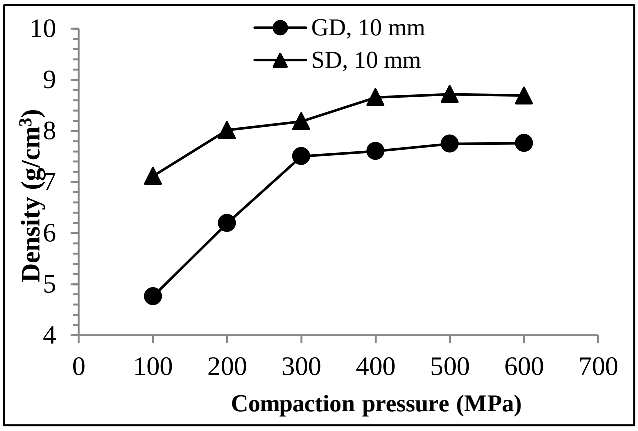

Fig.2 : Green density (GD) and sintered density (SD) of sintered composite with different compaction pressures

Variation in hardness with compaction pressures of sintered composite is shown in Figure 3. The hardness of composite was increased with increasing compaction pressure. This was supported by microstructure changes in Figure 1, where low pressure has higher porosity. Low applied pressure is unable to reduce the interparticle distance hence the voids might be formed between them. These regions are then likely to act as stress concentration center. Whereas, at higher pressure, the particle contact able to reorganized in order to occupy the voids and pores during sintering, resulting in denser composite. At this condition, higher hardness can be obtained owing to less porosity.

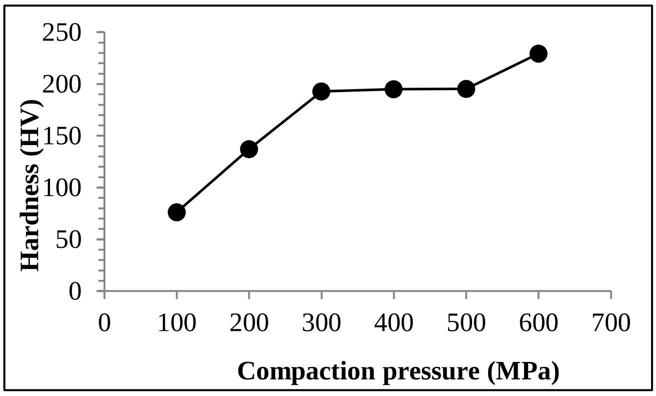

Fig. 3 : Hardness of sintered composite with different compaction pressures

Figure 4 shows the variation of sintered composite electrical conductivity with different compaction pressures. Increasing compaction pressure had positively affects the electrical conductivity. Such variation is reflected from slight increased of density at higher compaction pressure where the porosity was slightly lowered. With increasing pressure, the interface particle contact was constantly reduced which relatively increased the current-conducting contact. Hence, the conductivity of composite increased with the increased in compaction pressure. However, at lower compaction pressure, the presence of large amount of pores in low densified composite restricts the movement of conduction electron, leading to lower the electrical conductivity [5].

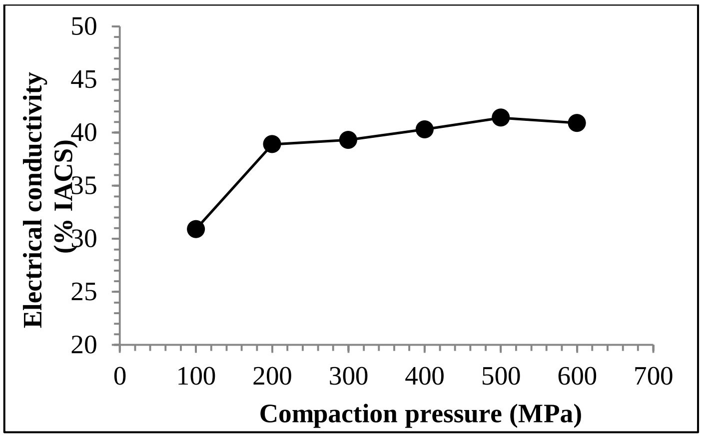

Fig. 4 : Electrical conductivity of sintered composite with different compaction pressures

Conclusion

The microstructure of copper-tungsten carbide composite was found change with compaction pressure. Lower pressure shows a little plastic deformation whereas within compaction pressure of 200 to 600 MPa improved plastic deformation indicating that no fracturing is occurred. Increasing compaction pressure increased the density and hardness of the composite due to reduce of porosity region. Electrical conductivity also increased when the compaction pressure is increased due to the movement of conduction electron has been not restricted by large area of porosity.

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