STUDY OF MECHANICAL PROPERTIES ON COPPER TUNGSTEN COMPOSITES FOR RESISTIVITY APPLICATIONS

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ABSTRACT:

Tungsten copper (W-Cu) composites, as a traditional refractory material, are promising materials for manufacture of electrical contacts and electrodes, heavy duty electronic contacts, welding and electro-forging dies, heat sinks, packaging material, arcing resistance electrodes and thermal management devices owing to their excellent properties. This critical review presents and discusses the current progress of W-Cu composites. Fabrication of net-shape tungsten–copper (W–Cu) composites has attracted more attention in recent years due to its good performance for wide applications, In this research, W–Cu composite including 20 wt.%, 25 wt.%, or 30 wt.% Cu. was produced by powder metallurgy technique using wet mixtures of elemental powders. Cold compaction was carried out under pressures from 300 to 1200 MPa, while sintering was achieved in vacuum at 1400 °C for 1 h, and 2 h. The particle size and shape of powders, as well as the microstructure after wet mixing, compaction, and sintering were investigated by using SEM.

Keywords: Tungsten-copper composites, Preparation method, Modification, Application

1.0 Introduction

Tungsten-copper (W-Cu) composites is a typical composite consisting of high strength tungsten (W) and low melting copper (Cu) phases, which are promising materials for manufacture of electric contact parts, heat sinks in high-power microelectronic devices, arcing-resistant electrodes, deviator plates for fusion reactors, anti-ultra-high temperature erosion nuzzles, etc. Their use in these applications is based on a combination of properties (as shown in Table 1), including the high hardness, erosion and electric-erosion resistance, the low coefficients of thermal expansion and wear resistance of W, and the outstanding electrical and thermal conductivity of Cu Furthermore, W-Cu composites exhibit better machinability compared with pure W. Powder Metallurgy (P/M), however, offers a reasonably good solution to W fabrication problems exploiting its near net-shaping capability

Tungsten particle-reinforced copper composites:

One promising class of W–Cu materials of interest with regard to PFC applications are Wp article-reinforced Cu (Wp–Cu) composites. Such materials can be produced by means of Cu melt infiltration of powder metallurgically produced open porous W skeletons. Following such an approach, the typically realisable material composition ranges from 60 wt.%W–40 wt.% Cu to 90 wt.%W–10 wt.% Cu which corresponds to approximately 40 vol. %W–60 vol.% Cu to 80 vol.% W–20 vol.% Cu. It has long been recognised that such composite metals offer an interesting combination of material properties Nowadays, Wp–Cu composites are for example used as contact materials in high voltage applications due to their high thermal and electrical conductivity, their high temperature stability, as well as their high ablation resistance

2.0 LITERATURE REVIEW:

Hamidi AG, Arabi H, Rastegari [1] typical micrographs of a Wp–Cu composite with 60 wt.%W–40 wt.%Cu (W–40Cu) are shown. The two different phases can clearly be distinguished. Furthermore, it can be seen that the material is fully infiltrated with Cu and that it does not show any plainly visible porosity which is a prerequisite for acceptable thermophysical and mechanical properties of the material.

Wang C, Lin YC [2] W–Cu composite materials are promising candidates regarding the application to the heat sink of highly loaded PFCs. The present contribution summarises recent results regarding the manufacturing and characterisation of such W–Cu composite materials produced by means of liquid Cu melt infiltration of open porous W preforms. On the one hand, this includes composites manufactured by infiltrating powder metallurgically produced W skeletons

Jigui C, Lei W, Yanbo C [3] the electrical, mechanical and physical properties of Cu-WC composites are presented. The composites of copper alloy containing 0–8 weight % WC were prepared using liquid metallurgy route by stirring molten alloy to obtain vortex using a steel stirrer coated with alumina and rotated at 500 rpm. The experimental results showed that the density of the composites increase with increased WC content and agrees with the values obtained through the rule of mixtures.

Hashempour M, Razavizadeh [4] Metal matrix composites (MMCs) are materials which consist of metal alloys reinforced with continuous fibers, whiskers or particulates. They are designed to combine the desirable attributes of metals and ceramics. Their properties are an intermediate between matrix alloy and ceramic reinforcement

3.0 MATERIALS AND METHODS

Composite materials are mainly known for the simultaneous benefiting of different properties of non-identical materials. Metal matrix composites (MMC's) have gained great importance over the last two decades and their applications have increasingly become popular Due to a unique combination of the high electrical and thermal conductivities of copper, and the low coefficient of thermal expansion (CTE), high hardness, high melting point (3410 °C), low vapor pressure, and high arc erosion resistance of tungsten, these elements are very good candidates for production of composites having suitable thermoelectrical and arc resistance properties Tungsten–copper composites have a high corrosion and erosion resistances, and act as good conductors for both current and heat, and have low coefficient of thermal expansion (CTE). They also exhibit excellent mechanical properties and homogeneous microstructure. Hence, they are needed for high performance, and referred to as advanced engineering materials W–Cu composites have been widely used for thermal and electrical applications, as arc resistant electrodes, ultrahigh-voltage electric contact materials, microwave packages, heavy duty electrical contacts, in microelectronics devices, heat sink materials for high density integrated circuits, welding electrodes for electro discharge machining (EDM), and high ablation resistance

Figure: the effect of processing parameters, such as mixing, compaction, and sintering, on the properties of W–Cu composites.

Experimental work:

Raw powders of W (99.95 wt.%, and 0.25–1 μm) and Cu (99.99 wt.%, and 10–60 μm), from Buffalo Tungsten Inc, and Sherwood Medical, respectively, were used as raw materials. Mixtures containing 20 wt.%, 25 wt.%, and 30 wt.% Cu were prepared by wet rod milling, Fig. 1. The wet rod milling was performed by using stainless steel cylindrical rods, at weight ratio of rods to powder of 10:1. The volume of the container to the volume of rods was 3:1. Mixing was carried out at 140 rpm for 6 h. Besides, the powders were mixed with 0.5 wt.% paraffin wax as a lubricant to reduce friction during compaction. Cold compaction of specimens with different compositions was then carried out at room temperature under various pressures; 300, 600, 900 and 1200 MPa. The green compacts were sintered in a vacuum furnace with graphite heating elements under vacuum (10−2 Torr), Fig. The samples were first heated at a rate of 3 °C/min up to 450 °C. To dry any moister content in through 120 °C, and expel any gases captured in the pores, the samples were kept at 450 °C for 30 min. The temperature was then raised to 850 °C for 30 min to facilitate solid phase sintering.

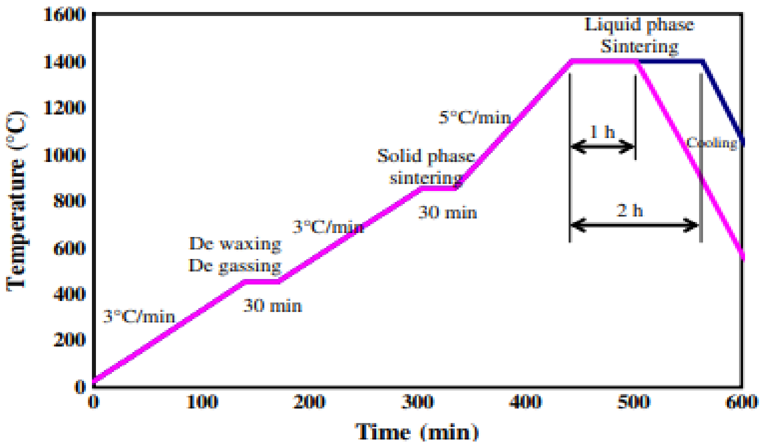

Figure: Heating cycle for the vacuum sintering process

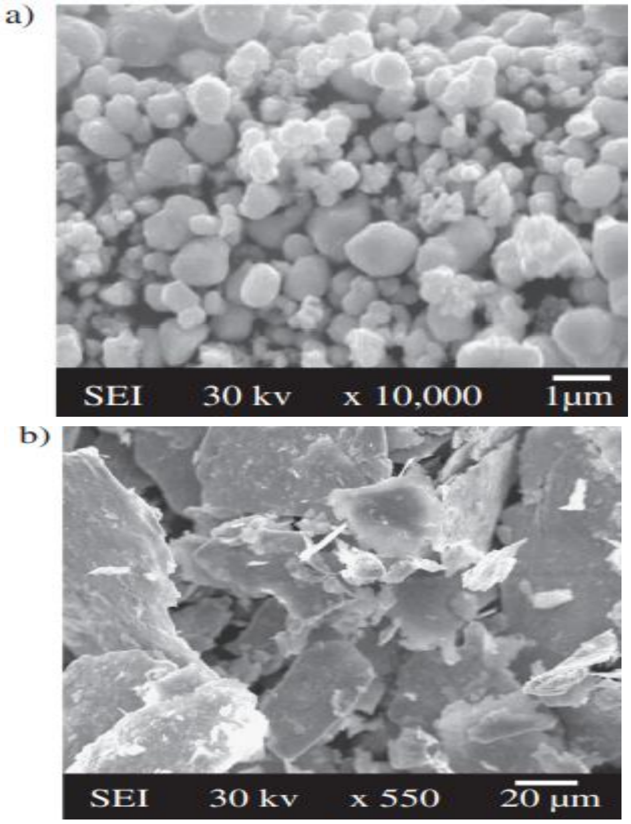

Figure: SEM photographs of investigated powders. (a) Pure tungsten powder, (b) pure copper powder used in present study.

liquid phase sintering process. In both cases, the temperature was raised again to 1400 °C. The first group was sintered for 1 h, while the second group was sintered for 2 h. Finally, the furnace was turned off and the sintered specimens were cooled over 8 h using a water-cooling system. To calculate the volume shrinkage of each specimen, 11 mm diameter and 7 mm thick green compacts, the dimensions of the cold compacts and those of the sintered specimens were measured using a dial gauge micro meter of 1 µm sensitivity. Then, the samples were polished with 3 µm diamond paste. The microstructure of the polished samples was investigated by optical microscopy and composites microstructure was studied by using scanning electron microscope (SEM).

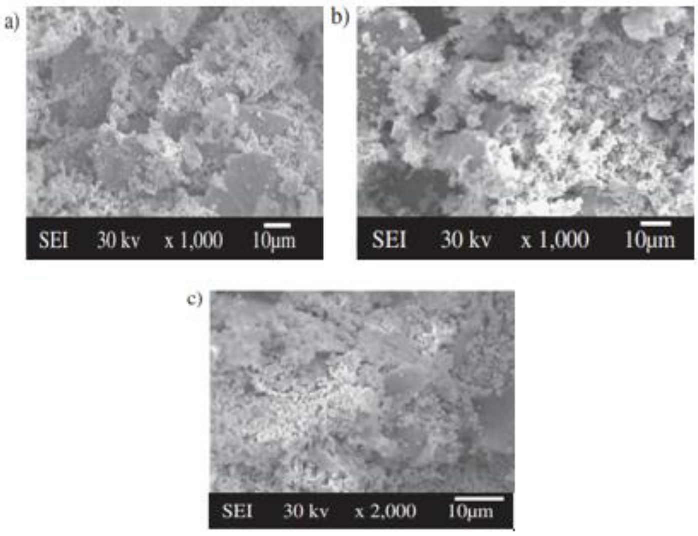

Figure: SEM photographs after wet mixing of investigated powders: (a) W-25wt.%Cu, (c) W-20wt.%Cu. W-30wt.%Cu, (b) W-25wt.%Cu, (c). W-20wt.%C.

4.0 Results and discussion

SEM micrographs of pure W and pure Cu powders are shown in Fig. Tungsten particles have fine spherical structure with a size range of approximately 0.5–1 μm. Cu-powders have fine flake structure with a particle size between 10 and 60 μm. Fig. shows (SEM) photographs after wet mixing of investigated powders. The figure reveals relatively homogeneous distribution of both copper and tungsten powders. It is also observed that the fined spherical tungsten particles (0.5–1 μm) cover the relatively large copper flakes (10–60 μm). Moreover, the W–Cu mixtures where analysed using this energy dispersive X-ray spectroscopy (EDS), as shown in Fig. which existence confirms spectra of both W and Cu.

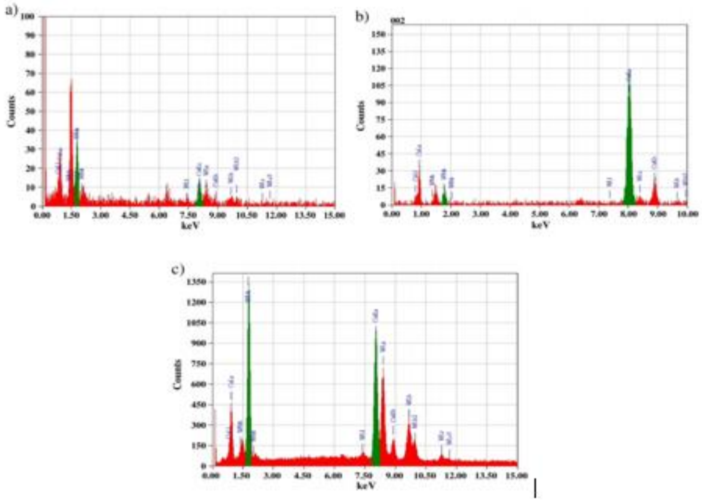

Figure: EDS analysis of W–Cu mixtures, (a)W-30wt.%Cu, (b) W-25wt.%Cu, (c) W-20wt.%Cu.

rearrangement, decreasing pores, and increasing contact regions. The flake shape of copper powder may have facilitated the increase of density at higher pressure. Figs. show the relative sintered density as a function of compaction pressure for the W–Cu specimens after sintering for 1 h and 2 h at 1400 °C. It is obvious that, the relative sintered density increases with increasing compaction pressure, copper percentage and the highest densification occurs under 1200 MPa. Also, it is clear that the density increases with sintering time due to the increase of fluidity time of the melt, which expands the contact between the particles and reduces the pores between them.

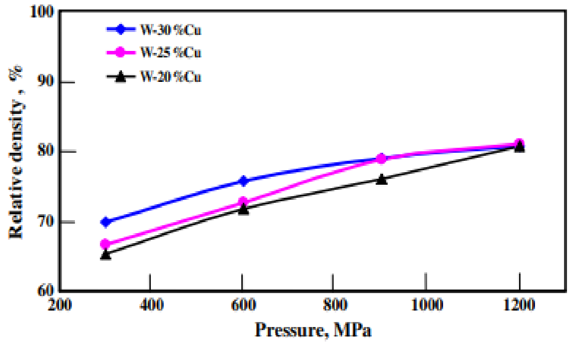

Figure: Relative green density versus compaction pressure of W–Cu mixture

Structural features:

Scanning electron microscopy (SEM) of the W–Cu composites, Fig. illustrate W–Cu mixtures (W-20wt.%Cu), (W-25wt.%Cu) and (W-30wt.%Cu) after compaction, respectively. According to Radomysei'skii, during consolidation of powder several sequential stages may take place: slip of non-deformed particles, deformation in the contact regions, and particle extrusion in the inter-connected pores. The initial transition with pressurization is from a loose array of particles to a closer packing and rearrangement of the particles,

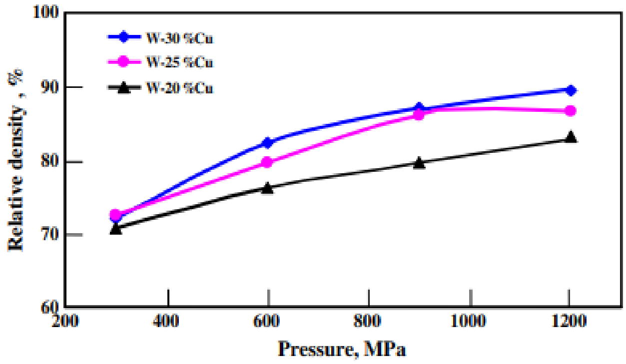

Figure: Relative density of W–Cu composites versus compaction pressure after sintering at 1400 °C for 1 h.

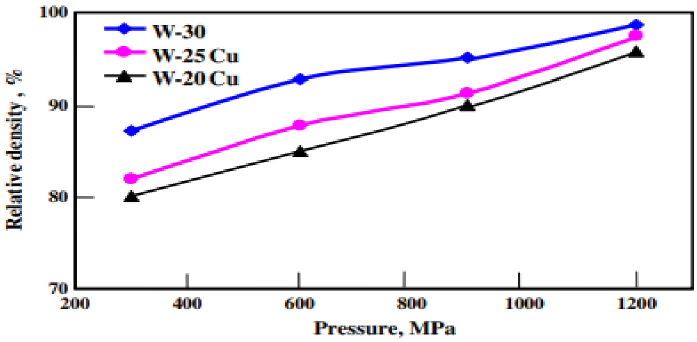

Figure: Relative density of W–Cu composites versus compaction pressure after sintering at 1400 °C for 2 h.

subsequently the point contacts deform as the pressure increases, and finally the particles undergo extensive plastic deformation Sintering densification of the W–Cu composites depends greatly on sintering temperature and sintering time. As sintering time and sintering temperature raise, sintered density of the W–Cu samples increases. The relative density of W–Cu composites containing 20 wt% Cu, 25 wt% Cu, and 30 wt% Cu was found to the about 82.75%, 86.27%, and 88.98% respectively when sintered for 1 h at 1400 °C. However, sintering for 2 h at 1400c increased the relative density of the same composites to about 96.06%, 97%, and 98.01% respectively. In this case, enough time is available for liquid-phase sintering and homogeneous redistribution of solid W particles in the presence of Cu liquid phase is possible.

Compressive strength:

The compressive strength of W–Cu composites is shown in Fig. It increases with the increase of copper content. In addition, the compressive strength increases with increasing sintering time.

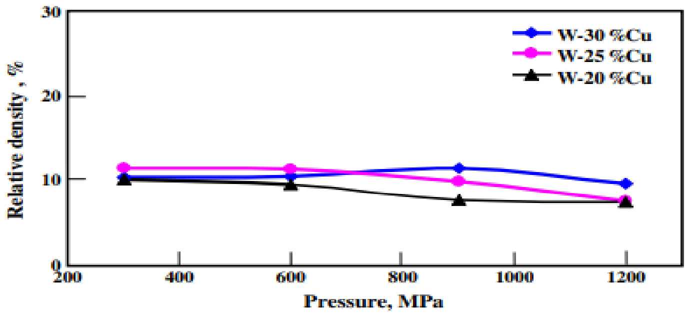

Figure: Volume shrinkage versus compaction pressure of W–Cu composites after sintering at 1400 °C for 1 h.

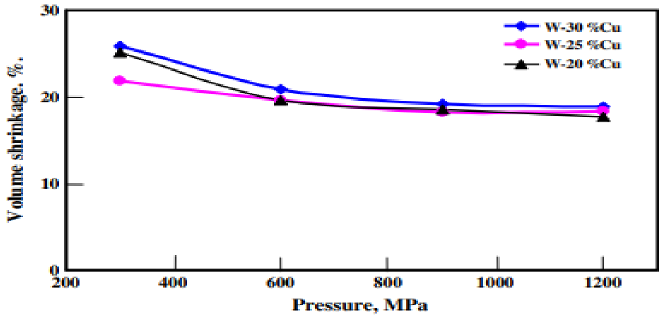

Figure: Volume shrinkage versus compaction pressure of W–Cu composites after sintering at 1400 °C for 2 h

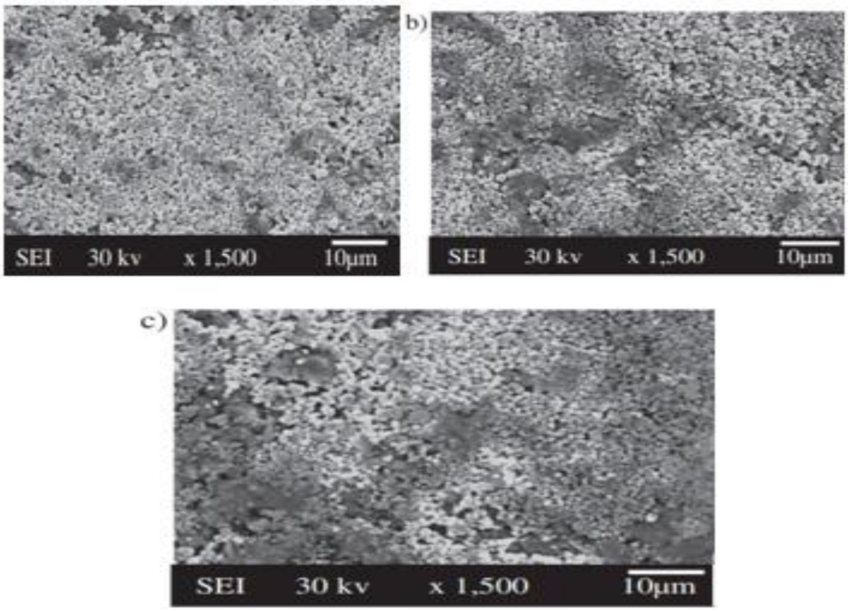

Figure: SEM photographs of compacted W–Cu mixtures: (a) W-20wt.%Cu, (b) W-25wt.%Cu, (c) W-30wt.%Cu. at compacted pressure-is-1200 MPa.

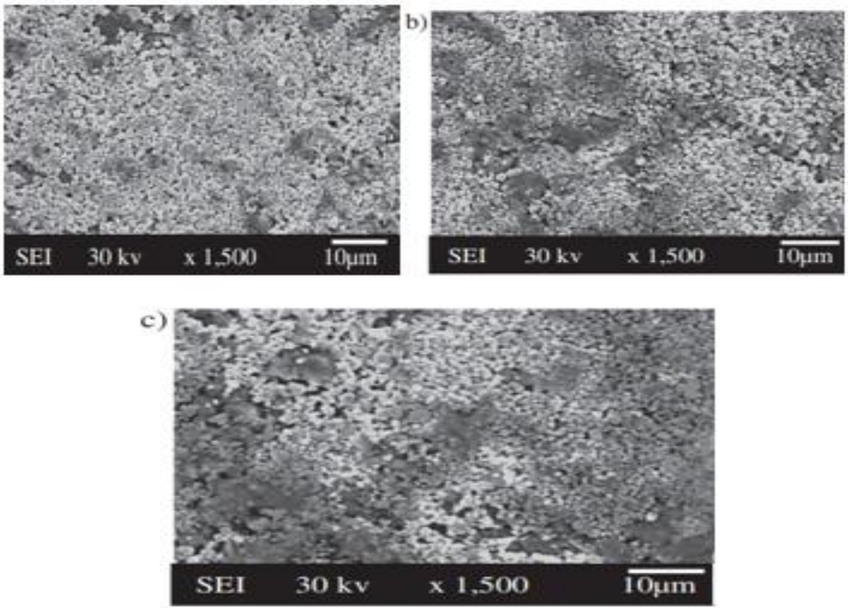

Figure: SEM photographs of W–Cu composites: (a) W-20wt.%Cu, (b) W-25wt.%Cu, (c) W-30wt.%Cu. Compacted under 1200 MPa, and sintered atat 1400 °C for 2 h.

results can be attributed to the effect of copper and porosity content of the sintered composites. The porosity of W–Cu composite increases with the increase of W content

Conclusion:

powder metallurgy materials, W-Cu composites have been widely used in many fields, such as structural, electrical, and thermal management materials due to excellent properties. However, the obstacle of low mutual solubility and wettability of W and Cu still exists during the manufacturing of W-Cu composites; it will have an important impact on density, microstructure, grain size, hardness, and strength. Although many possible novel techniques have been adopted to prepare finer structures with greater densities in recent years, there are some challenges for future

- Wet mixing of powders facilitates homogeneous structure, and semi-coating of copper flakes by fine tungsten spherical particles.
- Increasing compaction pressure and copper content increase the relative green density and the relative sintered density of W–Cu composites.
- Increasing of sintering time from 1 to 2 h increases the relative sintered density, hardness, compression strength and adversely affects the electrical resistivity.
- Highest relative density was achieved under compaction pressure of 1200 MPa and at sintering temperature of 1400 °C for 2 h

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