OPTIMIZING THE EFFECTIVE PARAMETERS OF TUNGSTEN – COPPER COMPOSITES

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Abstract
Tungsten – Copper composites are generally used for electrical contact materials. These composites are suitable for hard working conditions such as intensive electrical sparks, gouging spark erosion, surface melting, welding, material transfer etc. The aim of the present article is to determine optimum processing conditions to improve the mechanical and physical properties of W-Cu composites with the view to increase their lifetime. W-Cu specimens are produced using powder material and the liquid infiltration process. Chemical composition, pressing machine pressure, infiltration time and temperature are variable parameters for specimen production. By optimizing the amount of cobalt addition, shaping pressure, time and temperature of production process, optimum values for mechanical and electrical properties such as density, hardness and resistivity are obtained.

OPTIMISATION DES PARAMETRES EFFECTIFS DANS LES MATERIAUX COMPOSITES DE TUNGSTEN-CUIVRE

Résumé
Les matériaux composites de Tungsten-Cuivre sont généralement utilisés pour les surfaces qui sont en contacte électrique. Ils conviennent surtout pour les conditions de travail extrèmement dur, comme par exemple les arcs électriques, l'érosion par arc électrique, soudure, transfert des matériaux, etc. Le but de cette étude est de déterminer les conditions optimales du processus de fabrication pour augmenter les propriétés physiques et mécaniques des matériaux composites et augmenter leur vie utile. Les échantillons de W-Cu ont été produits avec les matériaux en poudre et le processus d'infiltration de liquide. La composition chimique, la pression de la machine de pression, le temps d'infiltration, et la température sont parmi les paramètres importants pour la fabrication des échantillons. En contrôlant la quantité de Cobalt ajoutée, la pression, le temps et la température de production, les valeurs optimales des propriétés électriques et mécaniques comme la densité, la dureté, et la résistivité ont été obtenues.

Introduction:

Generally speaking, tungsten-copper composites are employed for electrical contacts and breakers in power electrical circuits.

Because of hard working conditions that these composites have to endure, they must have superior mechanical and physical properties such as high thermal and electrical conductivity, high melting point and high hardness and wear resistant. Therefore optimized selection of composition and production conditions is very important to increase their lifetime.

Because of the high melting point of tungsten and immiscibility in melted copper, It is not possible to use conventional casting methods to produce W-Cu composites. Thus, powder metallurgy methods such as infiltration may be utilized. In the infiltration process, by pressing tungsten powder, porous tungsten skeleton is prepared, then melted copper fills voids in structure by capillary force until achieving maximum density.

R.M.German (1984) has studied the tungsten-copper properties [1]. Factors affecting electrical contact materials, tungsten- copper and tungsten-silver were considered by Kothari [2]. In 1998, German noticed densification and dilation of sintered W-Cu composites [3], and in this field Kadam has used various methods of powder metallurgy.[4]. Infiltration can be considered the most important method to produce W-Cu composites [5]. Details and mechanisms of this method and quality control of electrical contact materials have been reported by Wang [6]. Penetration of a melt into sintered tungsten skeleton is discussed by Lizanski and Rotowski [7].

Another parameter that affects on W-Cu composites is cobalt addition [8,9], That in optimized amount in composition, we can produce full density composites. [10].

In this article, the effects of chemical composition and processing parameters such as pressing machine pressure, time and temperature of the infiltration process on final properties are studied.

Selection of pressing machine pressure is related to the chemical composition of W-Cu composites, thus the time and temperature during the infiltration process should be properly selected so that melted copper has good fluidity to fill the pores and doesn't bilge to out of the skeleton structure.

In practice, the very large wetting angle of tungsten by copper allows to achieve high density near to the theoretical one.

However adding cobalt powder to tungsten powder in optimum amount results in the formation of inter-metallic compound Co_7W_6 on tungsten particles. This intermediate phase increases the wettability of tungsten particles by melted copper thereby reducing the overall porosity in the structure and improving the mechanical properties of the final product.

Research Method

In this research, specimens with 22 millimeter diameter and 7 millimeter height were prepared from tungsten-copper and tungsten-copper-cobalt composites. In order to prepare specimens, Merck experimental tungsten powder with chemical composition shown in table 1 was used. The medium particle size of tungsten powder was 4 micrometer. Mixing the powder was performed in a ball mill, which improves its deaglomeration and homogeneity. Finally, some Phenol-Formaldehyde was mixed with the powder and a determined amount of the mixture was poured in a SPK steel mould. To produce specimens with cobalt, experimental cobalt powder with low impurities and 0.5 micrometer particle size was mixed with tungsten powder. Compositions comprise 0.2, 0.5, 0.7 and 1 percent cobalt.

Table 1: Composition of Merk experimental tungsten powder

Element	W	P	C	Fe	Al	Cu	Zn	Si	Cd	Sn
Percent	99.98	0.002	0.003	0.004	0.001	0.001	0.001	0.001	0.001	0.001

Pressing the powder

Pressing the powder was performed in a double action press. Zinc stearat lubricant was used to lubricating the inner surface of the mould. Copper percent in composition varies with the amount of pores in the skeleton or the pressure of the pressing machine. Specifically, 129, 194 and 336 Mpa pressures were used to compact the powder. These pressures were used for 30, 25 and 20 weight percent copper respectively.

Infiltration Process

Infiltration process was performed by using an electrical furnace with tungsten elements. The amount of copper that each specimen needed was put on top of the green specimen. Green specimens were placed on temperature resistant steel plates into the furnace. Furnace atmosphere was hydrogen gas, test temperatures of 1220, 1280 and $1350^\circ C$, and duration times of was 1 and 1.5 hours were employed . After infiltration process the surface of the specimens was machined.

Performed tests

After machining, specimen's density was measured by Archemid method, according to ASTM D1217 standard. Theoretical density of specimens was measured from this formula:

$$\frac{1}{\rho_t}=\frac{\%W_w}{\rho_w}+\frac{\%W_{Cu}}{\rho_{Cu}}+\frac{\%W_{Co}}{\rho_{Co}} \quad (1)$$

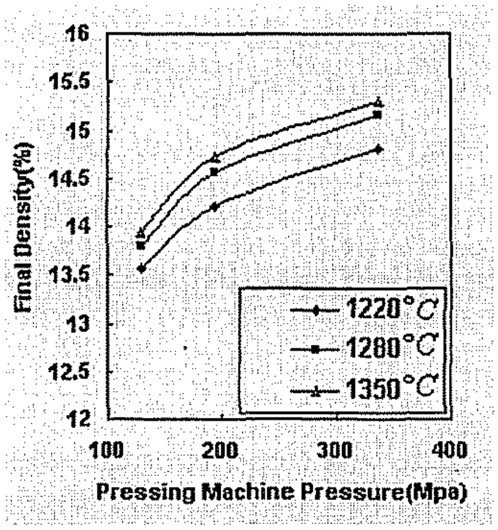
Where ρ_t is the theoretical density, W_w, W_{Cu}, W_{Co} are tungsten, copper and cobalt weight percent, ρ_w, ρ_{Cu} and ρ_{Co} are tungsten, copper and cobalt density respectively.

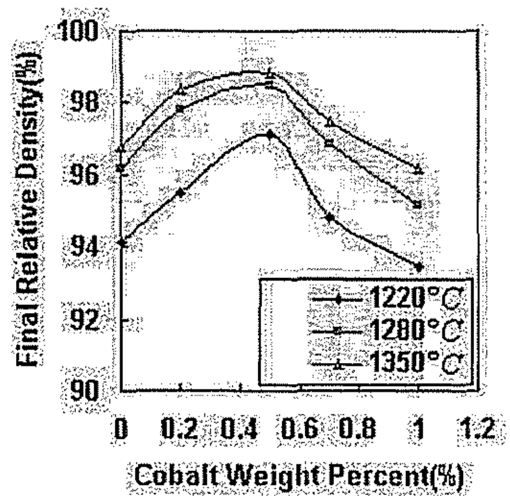
The relative density of the specimens was obtained by dividing the actual density by the theoretical one. Specimens' hardness was measured by Brinell hardness test using 2.5 millimeter steel indentor and 187.5 kilogram force according to BS240 standard. Resistivity was measured using a 2002-model multimeter with an accuracy up to 100 nΩ.

In order to investigate microstructure, optical metallugraghy and scanning electron microscopy were used. Also x-ray diffraction and EDS tests were performed.

Results and Discussion

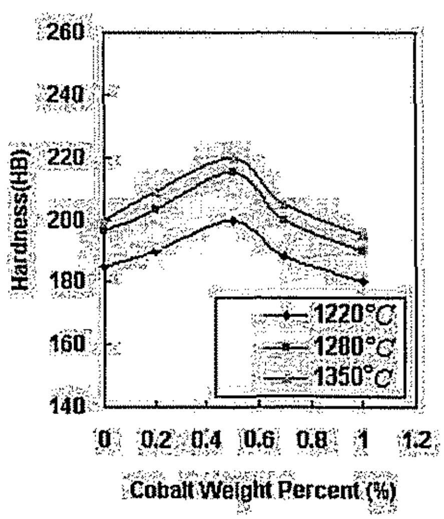
By increasing pressing machine pressure, final density of specimens increases. (fig.1). Increasing the pressure results in the particle rearrangement, more disintegration of tungsten particles and reduction in the porosity of structure [1]. Therefore, further increase in pressure would increase the volume fraction of the tungsten phase so that density, hardness and resistivity will increase [2,3,4]. The goal of infiltration of W-Cu composites is to achieve the maximum density by filling the porosity and more densification of the parts. More densification of the composites means more elimination of porosity, increasing density, hardness and electrical conductivity [5,6].

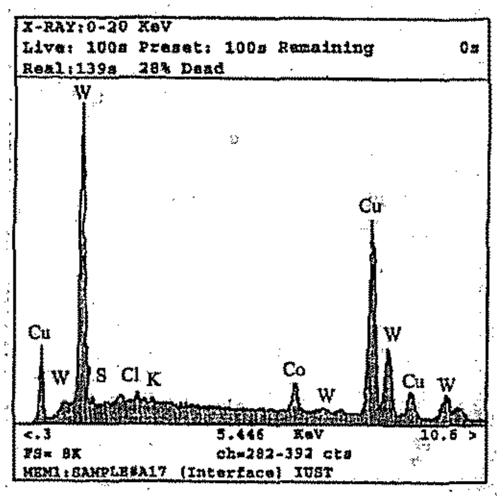




pa)

Increasing the infiltration process temperature from 1220 to 1280°C results in improvement of the properties (fig 2,3), but increasing more from 1280 to 1350°C has very small effect on properties. By increasing the temperature, the fluidity of melted copper increases, therefore capillary action and properties will improve. But by increasing temperature above 1280°C , more copper is absorbed and more excluded simultaneously to outside of the structure. Cobalt in tungsten structure promotes the formation of Co_7W_6 inter-metallic compound. This phase forms on tungsten particle surfaces that can be clearly reveaded in XRD and EDS tests (fig. 4 & 5). Formation of this compound on tungsten particle surfaces results in better wetting of particles. Thus infiltration process acceleration causes higher densification, lower porosity and increases the hardness (fig. 2,3 & 6) [9].





Cobalt weight percent
(Pressing Machine pressure is 194.23 Mpa)

Of tungsten and copper phases for
75W-24.5Cu-0.5Co.

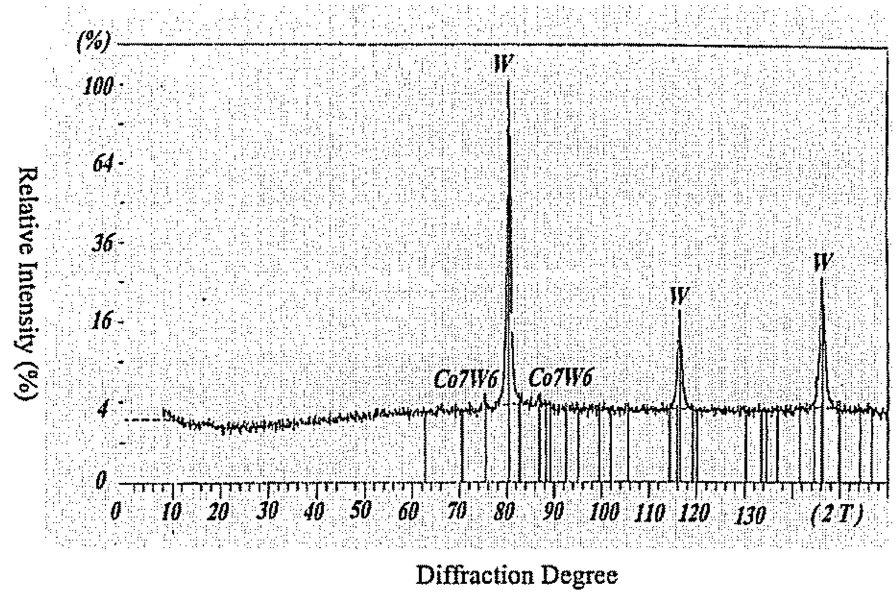
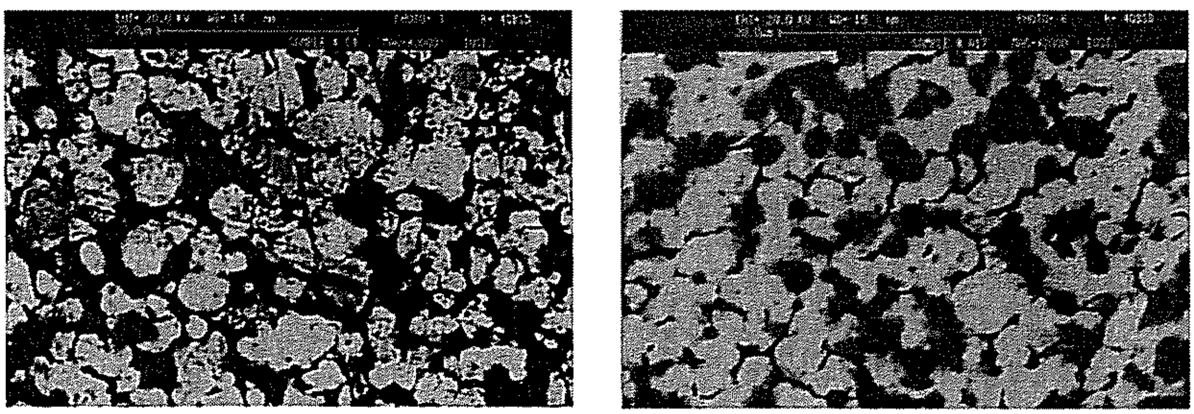


Fig 5: Relative intensity versus diffraction degree for sintered Tungsten specimen (W-1%Co).



(A) (B)

Fig 6: Microscopic picture of two composite specimens.
A: 80W-20Cu B: 80W-19.5Cu-0.5Co

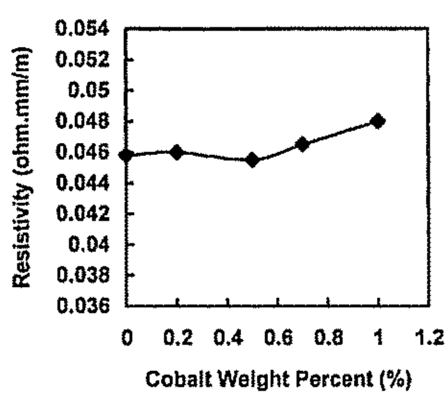


Fig 7: Resistivity of W-Cu-Co specimens versus cobalt weight percent

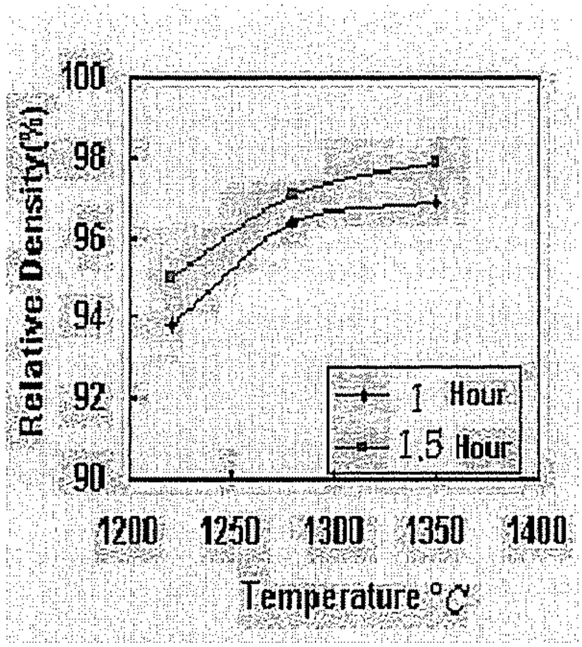


Fig 8: Relative density of W-Cu composites versus infiltration process temperature

Adding cobalt more than 0.5 weight percent result in reducing properties because of the increase in intermetallic compound thickness and reducing the diffusion of tungsten atoms from the layer [10]. It can be seen from figure (8) that increasing the process time from 1 to 1.5 hours will improve the composite properties. But if cobalt is used in optimum amount, this increase of time has no effect on properties. In fact, melt diffusion process is a time-dependent process. Thus increasing the process time will result in more elimination of porosity. Although there is no need to increase the time more than one hour.

Conclusions

1. By increasing the pressing machine pressure, the density, relative density, hardness and electrical conductivity of tungsten copper composites will be increased.

2. Rising the temperature from 1220 to $1280^{\circ}C$ results in increasing the density, relative density, hardness, and decreasing resistivity of composites, but it has no appreciable effects on properties.

3. If the temperature rises more than optimum amount, it causes more absorption of copper and more exudation of it.

4. Increasing infiltration process time from 1 to 1.5 hour results in improvement of properties but it has no appreciable effect more than it.

5. Increasing cobalt weight percent up to 0.5 percent, improves properties such as density, densification and hardness but increasing more, decreases the properties.

6. Formation of Co_7W_6 inter-metallic compound on tungsten particle surfaces causes acceleration of infiltration process and better wetting of tungsten particles.

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Nomenclature,

where,

ρ_t =Theoritical density

ρ_w =Tungesten density

ρ_{Cu} =Copper density

ρ_{Co} =Cobalt density

W_w = Tungesten weight percent

W_{Cu} =Copper weight percent

W_{Co} =Cobalt weight percent