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The Effect of Co and Fe on Densification and Microstructure of W-25wt%Cu Composites Prepared by Direct Liquid Infiltration

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Abstract— During this study, full-density W-25wt.% Cu composites were prepared by conventional method (liquid phase sintering and liquid infiltration). Experiments were carried out to evaluate the effect of Co and Fe additives in the range 0.3 to 3 wt.% on the densification of W- 25Cu composites. The sintering temperatures were performed at 1050ºC and 1250ºC for 2h under vacuum. The experimental results showed that, near full density has been achieved at 1250ºC and the values of sintering density were between 97%-99% of theoretical density. In addition, the densification was depended on the concentration of transition elements and sintering temperature. The Microstructures and density were characterized using scanning electron microscope (SEM) and water displacement method, respectively.

Keywords— Transition Elements; Densification; Liquid phase sintering and Liquid infiltration.

الملخص— خلال هذه الدراسة، تم تحضير مركبات W-25wt. % Cu كاملة الكثافة بالطريقة التقليدية (تلبيد الطور السائل والتشريب). تم إجراء تجارب لتقييم تأثير إضافات كل من عنصر Co وعنصر Fe في حدود 0.3 إلى 3 وزن٪ على تكثيف مركب W-25Cu . وتم إجراء ايضا التلبيد عند درجات حرارة 1050 و 1250 درجة مئوية لمدة 2 ساعة باستخدام فرن مفرغ الهواء. نتائج التجارب في هذه الدرسة بينت أن الكثافة الكاملة تحققت تقريبا عند 1250 درجة مئوية وكانت قيم كثافة التلبيد بين 97% - 99% من الكثافة النظرية. بالإضافة إلى ذلك، كان التكثيف يعتمد على تركيز العناصر الانتقالية ودرجة حرارة التلبيد. تم الكشف عان البنى المجهرية والكثافة للعينات المختلفة عن طريق جهاز الماسح الإلكترون الميكروسكوبي (SEM) وطريقة إزاحة الماء (تقنية ارخميدس)، على التوالي.

الكلمات المفتاحية—العناصر الانتقالية؛ التكثيف؛ تلبيد الطور السائل مع الترشيح.

1. Introduction

A big difference of density (over 10 g/cm^3) and melting point (2326˚C) between tungsten and copper elements make powder metallurgy (PM) as the key route to fabricate W-Cu composite materials [1]. The conventional PM technique includes powder characterization, tooling, processing, testing and properties [2]. The low thermal expansion coefficient of W (4.6ppm/˚C) and high thermal conductivity of Cu (403W/m.˚C) makes W-Cu composite suitable for electrical and electronic applications. The composites with high fraction of W (75-95 wt.%) is very important in electrical and electronic applications such as heat sink [3,4]. Moreover, the fraction of hard metal between (60-80wt.) is used for electric contact material in industry [5,6].

The most common method for the fabrication of W-Cu composites are by infiltration process of tungsten skeleton with liquid copper [7], and liquid-phase sintering of compact powder [8]. These two elements (W and Cu) are almost completely immiscible in both solid and liquid phases. Therefore, it is difficult to attain full or near full densification of W-Cu composites via liquid phase sintering [9,10]. The densification of W-Cu composite materials can be improved by addition of group VIII transition metals [11,14]. These activated elements improve the wet-ability and decrease the sintering temperature. Adding small concentration of Fe and Co to W-Cu system lead to form inter-metallic layer of (Fe_7W_6) and (Co_7W_6) around W grain respectively [15,16].

The objective of this study is to investigated the effect of Co and Fe elements on the sintering of W-Cu composites under vacuum and at sintering temperatures of 1050 ºC and 1250 ºC.

2. Experimental

The properties of main raw materials tungsten (W) and Copper (Cu) and transition elements of Co and Fe were selected for this study as shown in Table 1. The morphology of as received powders are shown in Fig. 1. Specimens were prepared by mixing tungsten, copper and additives powder. The mixing was carried out manually for 20 minutes in alumina mortar. The concentrations of Fe and Co additives added were in the range 0.3-3 wt.%. The W–25wt% Cu powder mixtures with and without additives were die-pressed at 400 MPa. Ejection specimens were in the form of cylindrical disc of compact powder with 13 mm in diameter and 2.5 mm in height. Sintering was conducted under vacuum furnace at temperatures 1050˚C, and 1250˚C for 2 hr. The heating and cooling rate were 7°C/min respectively in all cases. The sintering density of the specimen was measured using water displacement (Archimedes technique) and the microstructure was analyzed by scanning electron microscope (SEM).

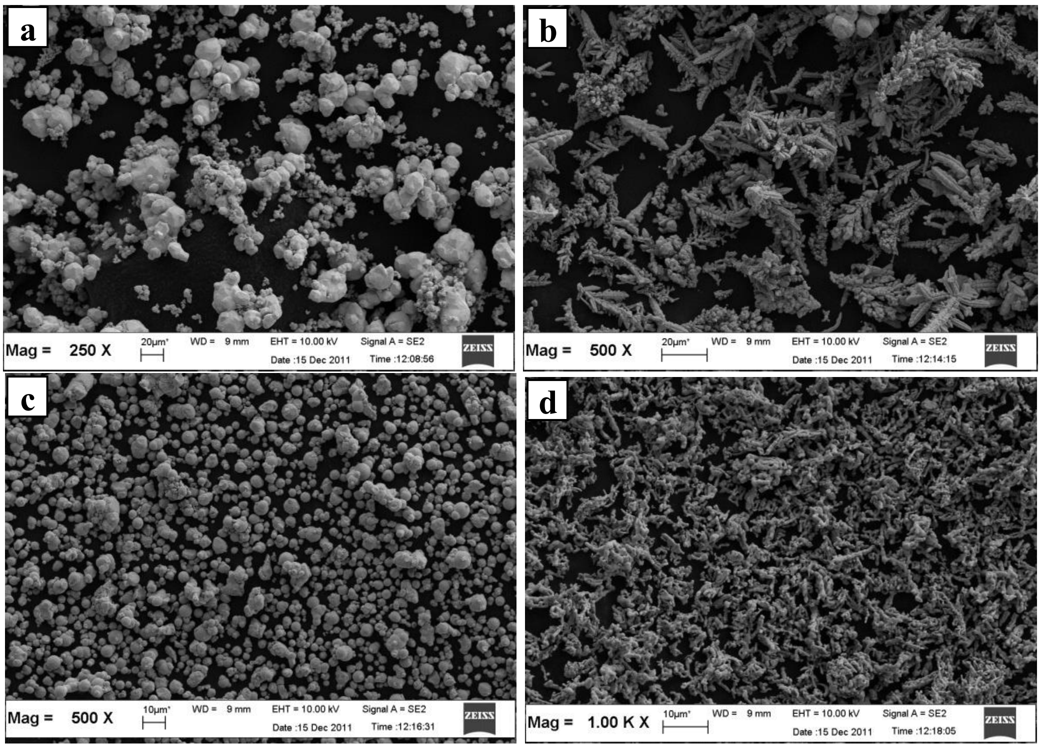

Figure 1. SEM micrograph of raw material, (a) as-received Tungsten powder, (b) as-received Copper powder, (c) as-received Iron powder and (d) as-received Cobalt powder.

Table 1. The properties of raw materials

	Tungsten (W)	Copper (Cu)	Iron (Fe)	Cobalt (Co)
Supplier	Strem chemicals	Merck	BDH laboratory supplier	Fluka chemika
Particle size [µm]	12	<63 (>230.mesh ASTM)	2.1	2.7
Purity [%]	99.9	99.7	99	99.8
Density [g/cm3]	19.3	8.9	7.9	8.9

3. Result and discussions

3.1 Microstructure

Fig.2. shows the microstructures of W-25wt% Cu sintering compact at 1050˚C with different concentration of Fe and Co (0.5 and 2 wt. %) and without additives. Bright and dark areas represent tungsten and copper phases, respectively. As shown in Fig. 2. (a), (c) and (e) respectively, high level of porosity was observed for specimens with 0.5 and 2wt. % Fe and without additives respectively. However, low percentage of porosity and W flatted were observed for specimens with cobalt addition at the same processing conditions as shown in Fig.2. (b) and (d). These results are in good agreement with the earlier results reported by Ahangarkani and co-authors [17].

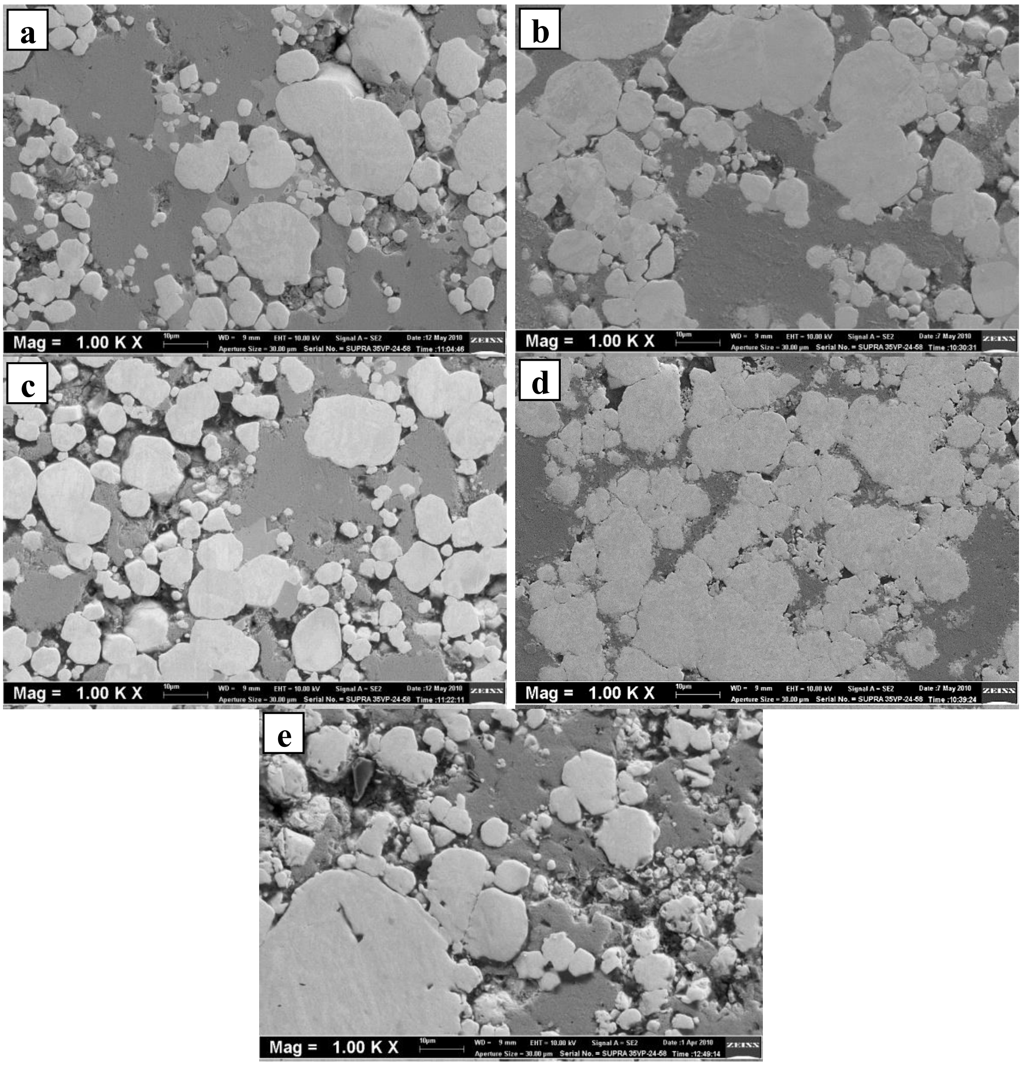

Figure 2. SEM micrographs of W-Cu sintering compacts at 1050˚C with different concentration of Fe wt. % and Co wt. % (a) 0.5 Fe, (b) 0.5 Co, (c) 2 Fe, (d) 2 Co and (e) without additives

Fig.3, shows the SEM micrographs of W-Cu sintering compacts at 1250˚C under vacuum with different concentration of Fe and Co (0.5 and 2 wt. %) and no additives. The microstructures of W-Cu composites with added Fe and Co have low level of porosity as shown in Fig.3 (a), (b), (c) and (d). On the other hand, high percentage of porosity was observed for specimen without transition elements as shown in Fig. 3.e. These results indicated that the effect of the addition cobalt as activator is better than Fe during solid state sintering. However, added low concentration of Fe to W-Cu composites led to decrease porosity level during liquid phase sintering compared during solid state sintering process.

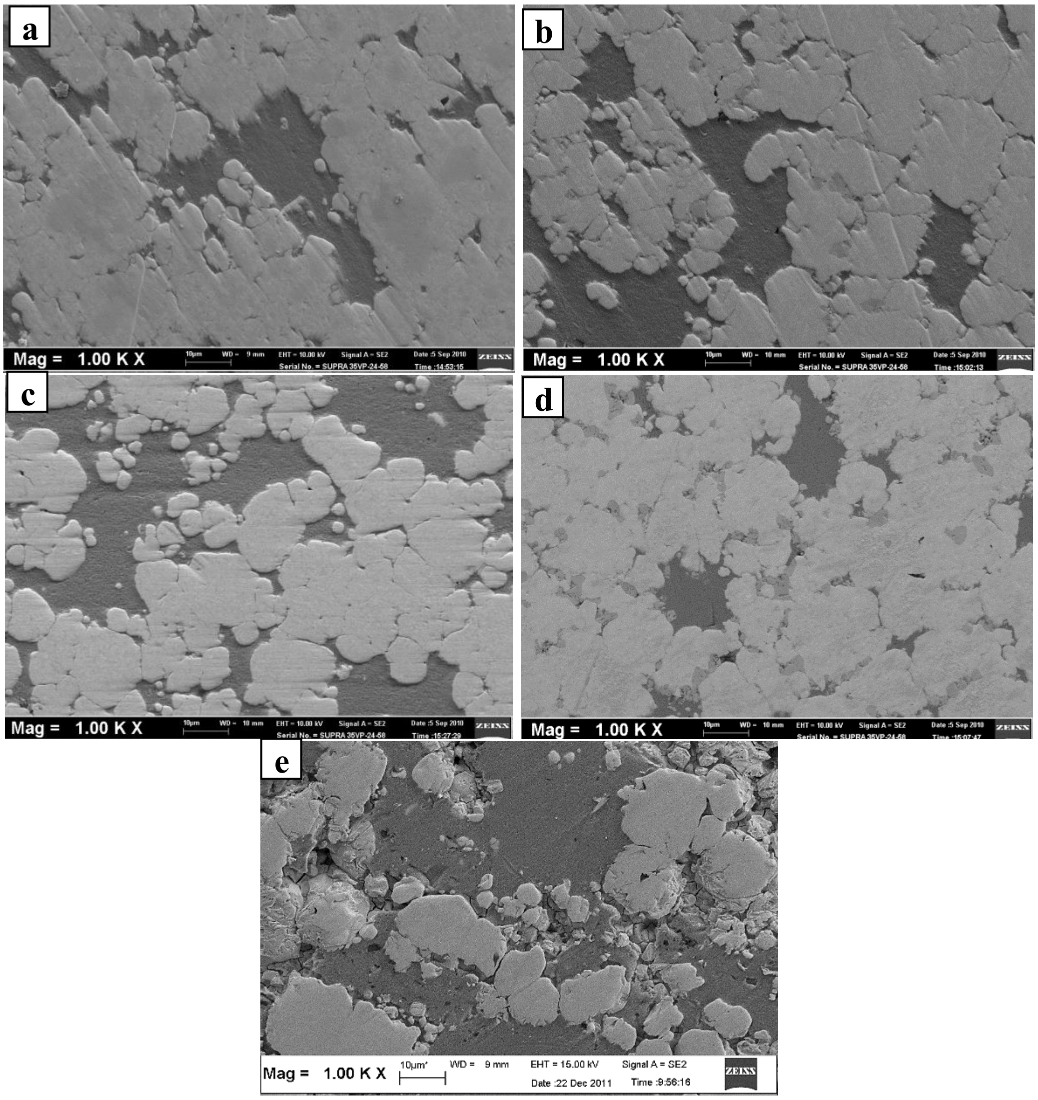

Figure 3. SEM micrographs of W-25wt% Cu sintering compacts at 1250˚C with different concentration of Fe wt.% and Co wt.% (a) 1 Fe, (b) 1 Co, (c) 2 Fe, (d) 2 Co and (e) No additives

3.2. Densification

Many researchers confirmed that the addition of low concentration of transition elements such as Ni, Pd, Co and Fe enhance the densification of W–Cu composites materials [12,18,19,21,23]. Johnson and German declared that low concentration of transition elements such Fe or Co, considerably improve the relative density of W–Cu compacts sintered by liquid phase sintering [11].

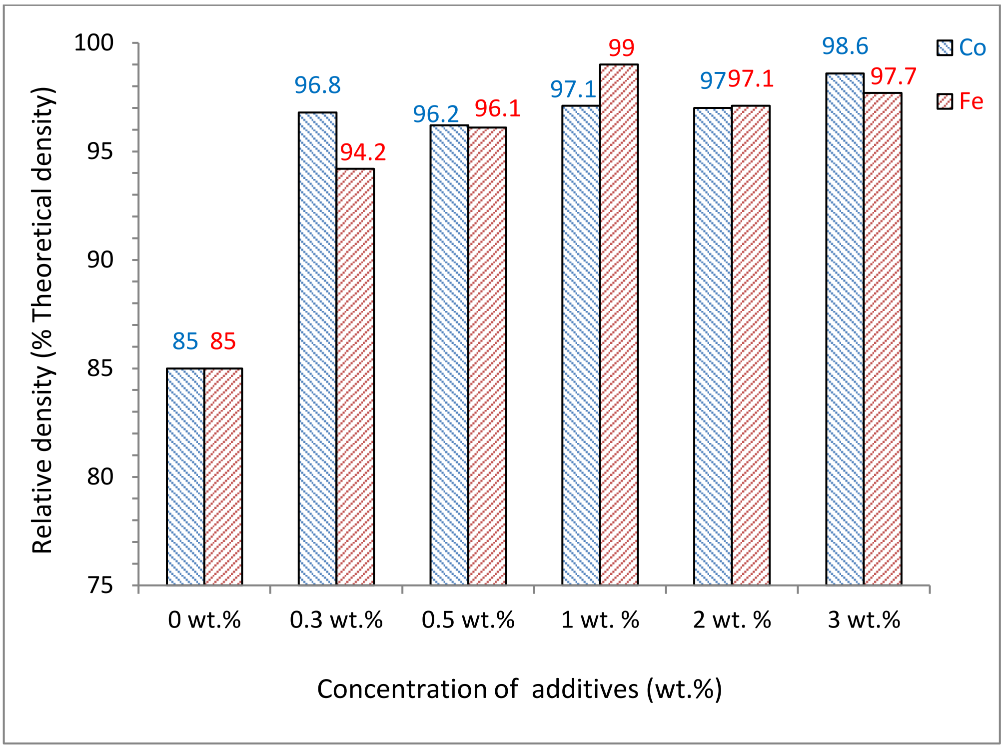

Figure 4. Effect of activator concentration on sintering density of W-Cu composites at 1250˚C.

Fig.4. shows the effect of activator concentration (Fe and Co) on sintered density of W-25wt% Cu composites at 1250˚C. The highest density (99% of theoretical density (TD)) was obtained by adding 1wt.% Fe, but the relative density reaches 98.6%TD by adding 3wt.% Co prepared by direct infiltration method. In addition, the lowest relative density was obtained without additive and its value was 85%TD under vacuum as environmental furnace. This result indicated that, the crucial factor to achieve near full density is the addition of low concentration up to 1wt. % of Fe and 3wt. %Co to W-25wt% Cu compact prepared by conventional method. In the W-25wt% Cu compact powder without additives, the solubility of tungsten in copper is not sufficient enough to give enhance liquid phase sintering mechanism by solution–reprecipitation. The key densification occurs only in rearrangement process [20,22]. Therefore, addition of Fe and Co to tungsten–copper system enhances the solid-state sintering of tungsten particles before the liquid-phase formation. Subsequently, the increase in the solubility of W in liquid phase sintering, also enhance the densification of W-25wt% Cu sintering compact by providing high diffusivity segregation of W_6Fe_7 and W_6Co_7 around W grain [11,14].

Conclusion

In this study the effect of some transition elements (Co and Fe) on the densification and microstructure of W-25wt% Cu composites prepared by liquid phase sintering and liquid infiltration was addressed. The experimental result shows that the densification of W-25wt% Cu composites with additives is better than without one. The full density of W-25wt% Cu sintering compacts can be obtained with added 1wt. % Fe to the composites, and it attained 99% of theoretical density. Also the addition of Co enhanced the densification during solid state sintering better than Fe addition.

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