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MICROSTRUCTURE AND PROPERTIES OF VACUUM HOT-PRESS SINTERED W/Cu-Al_2O_3 COMPOSITE

B.H. Tian, X.W. Zhang, R.L. Zhao, Y. Liu, S.G. Jia and F.Z. Ren

School of Materials Science and Engineering, Henan University of Science and Technology, Luoyang 471003, China and Henan Key Laboratory of Advanced Non-ferrous Metals, Luoyang 471003, China

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Abstract. W-Cu alloys have been broadly applied as contact materials in high voltage load switches. In this work, the tungsten (W) particulate reinforced Al_2O_3 dispersion strengthened copper base composites were successfully fabricated by using vacuum hot-press sintering furnace. The microstructures of the W/Cu-Al_2O_3 composite were analyzed with scanning electron microscope. The bending strength, electric conductivity and micro hardness of the composites were determined with universal material tester, vortex conductivity tester and digital micro hardness indenter respectively. The density of the composites was measured with the Archimedes method. The plastic deformation behavior of the composites at elevated temperature was investigated by using physical simulator of thermo-mechanical processes of the model 1500D Gleeble system. The results show that the microstructure of the W/Cu-Al_2O_3 composites is consisted of the matrix of the Al_2O_3 dispersion strengthened copper base and the reinforced phase of homogeneous distributed W particles. The composite has relative theoretical density of 99.8%. The bend fracture mechanism is brittle clevage and interface seperation. The true stress-strain curves of the W(50)/Cu-Al_2O_3 composite possess the steady rheological characteristic and dynamic recrystallization features.

1. INTRODUCTION

W-Cu composite consists of tungsten with high melting point and high hardness and copper with high electroconductivity and high heat conductivity. It has been applied widely as contact materials for vacuum switchers and electrode due to its excellent electrical arc erosion resistance, welding resistance, high strength and high hardness. There are a lot of methods to produce high density W-Cu composites such as activating liquid state sintering method, solid state sintering method, dual-step sintering method and reduplicate sintering method [1-10]. Because copper can not dissolve each other with tungsten, it results in the worse sintering characterization. It is difficult to obtain complete densification and homogeneous microstructure. The expansion during the solid state sintering processing is harmful to the composite densification [2].

In this paper, the internal oxidation method was adopted to fabricate the composite matrix of Al_2O_3 dispersion strengthened copper with high wear resistance, high electrical wear resistance, high strength and high hardness [3]. At the same time of the vacuum sintering, the normal load pressure was applied on the powder mixture to balance the expansion to produce high dense structure. The W-Cu composite were fabricated by means of the vacuum sintering method with the feedstocks of tungsten powder, Cu-Al alloy powder and Cu_2O powder in this paper. The effects of the vacuum hot-press sintering processing and dispersion strengthened phase Al_2O_3 on the microstructure and properties were investigated briefly.

Corresponding author: B. H. Tian, e-mail: bhtian007@163.com

2. EXPERIMENTAL

The tungsten powder used in this work is model FW-1 with -200 meshes and purity of 99.99%, which is accorded with the standard of GB/T 3458-2006. The Cu-0.44%Al alloy powder atomized with the water atomizing method with +270 meshes is accorded with the standard of GB/T 5246-2007. The +400 meshes Cu_2O powder was selected as the oxidant.

The mixed powders were blended with model QQM/B ball mill for 3-5 hours. The vacuum hot-press sintering routes are as follows, powders blending, charging, evacuation, heating up, temperature holding for 20 min, pressing for 10 min and pressure relief, temperature holding, pressing for 50 min and cooling. The main processing parameters are as follows, vacuum of 1×10^{-2} Pa, sintering temperature of 950 °C, holding time of sintering for 2 hrs , load pressure of 30 MPa, total holding time of pressing for 60 min.

The vacuum hot-press sintering was carried out with model VDBF-250 vacuum hot-press sintering furnace. The density of the composites as sintered was determined by the Archimedean method. The microstructure and fractograph analysis were carried out with model JSM-5610LV scanning electron microscope (SEM). The electrical conductivity was measured with model 7510 vortex conductivity meter. The Vickers's hardness was determined with HVS-1000 type micro hardness tester according to the standard of GB/T 5586-1998 with load of 200 grams and holding time of 10 s. The bend test was determined by means of model AG-I 250kN precision universal material tester according to the standard of GB/T 5586-1998 with the specimen size of 50 mm×10 mm×4 mm and the loading speed of 0.1 mm/min.

The compression simulation test was carried out by means of model Gleeble1500D simulation tester with the cylinder specimen of ∅8 mm×12 mm in size. Before the test, the graphite powder was coated on the both ends surface of the specimen. The test parameters are as follows, the test temperature of 650, 750, 850 and 950 °C respectively, the strain rate of 0.01, 0.1, 1 and 5 s^{-1} respectively, the total true strain of 0.7 with the maximum deformation of about 50%, heating up speed of 10 °C/s, holding time of 3 min before the compression. The compressed specimens were water cooled rapidly after the compression.

3. RESULTS AND DISCUSSION

The SEM microstructure of the vacuum hot-press sintered W (50)/Cu-Al_2O_3 composite is shown in Fig. 1. It is found that the gray particulate tungsten phases distribute uniformly on the dark gray dense copper matrix. No obvious pores are found on the copper matrix. There are some fine Al_2O_3 particles found in the interface between the tungsten particle and the copper matrix. The chemical formula to form the fine Al_2O_3 particles is as follows,

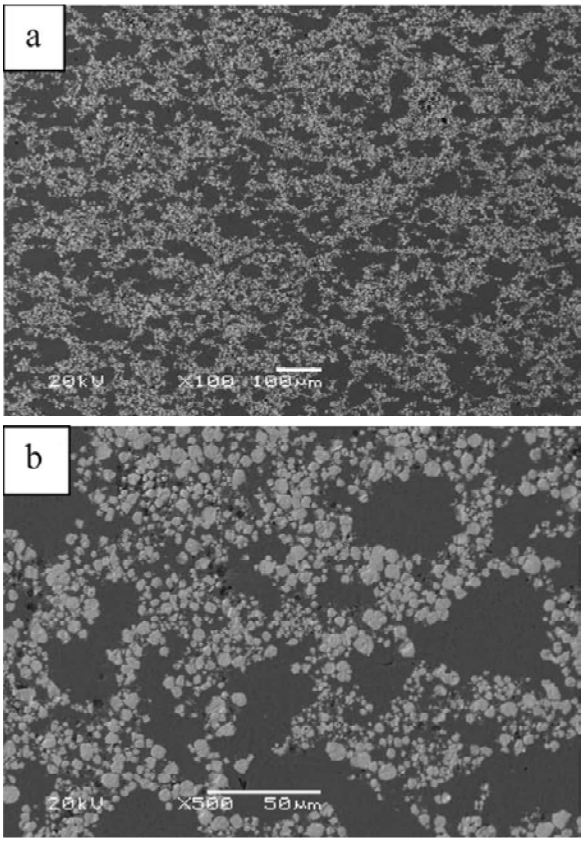

Fig. 1. SEM microstructure of the vacuum hot-press sintered W (50)/Cu-Al_2O_3 composite (holding 2 hrs at 950 °C under loading for 60 min).

$$3\,Cu_2O + 2\,Al \rightarrow Al_2O_3 + 6\,Cu.$$

It is considered that the dispersion distributed Al_2O_3 particle and the interval of particles have great effects on the dislocation density during the cold deformation. Some researches show that the sintering temperature and holding time have great effects on the performance of the W-Cu composite during the solid state sintering process. The higher sintering temperature and the longer holding time, the coarser grain and the more degradation performance. On the contrary, the lower temperature and the shorter holding time retard the densification and the internal oxidation processes [4,5]. The experiment shows that the sintering temperature of 950 °C and holding for 2 hrs can guarantee the completion of the densification and the internal oxidation.

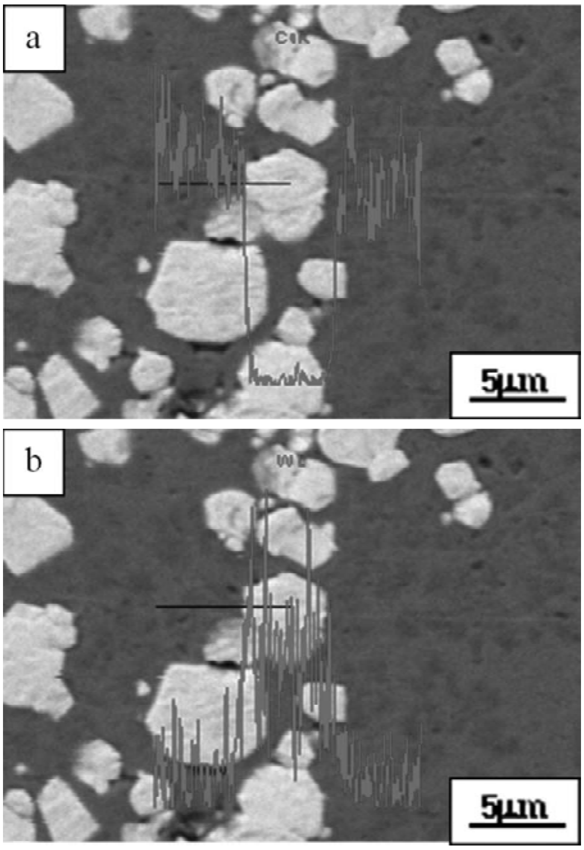

Fig. 2. Linear chemical composition profiles of the W (50)/Cu-Al_2O_3composite. (a) Cu element profile; (b) W element profile.

The linear chemical composition profiles of the vacuum hot-press sintered W (50)/Cu-Al_2O_3 composite are shown in Fig. 2. It is found that the copper and the tungsten linear composition profile changes obviously at the interface. To a certain degree, it is considered that the inter-diffusion occurred at the W-Cu interface during the vacuum hot-press sintering process.

The properties of the W(50)/Cu-Al_2O_3 composite are listed in Table 1. It is found that the vacuum hot-press sintering can fabricate excellent comprehensive performance of the W(50)/Cu-Al_2O_3 composite with electrical conductivity of 46% IACS, relative theoretical density of 99.8%, Vickers hardness of 135 HV and bend strength of 291 MPa. Except for the electrical conductivity, the hardness and the density of the vacuum hot-press sintered composite are obviously higher than those of the same composition composite fabricated by other methods.

The two main sintering densification mechanisms of the vacuum hot-pressing process are as follows, one mechanism is diffusion, including the diffusion under the role of the surface energy of particles and the diffusion under the role of the external pressure. Research shows that the eliminating of fine pore is mainly by the way of diffusion. Another way of the densification is mainly due to the plastic sliding between particles, i.e., under the action of external forces the plastic sliding occurs between particles resulting in rapid densification. While the eliminating of large pores in the composite is mainly through the plastic sliding [6,7,10]. According to the above points, the densification mechanism of the W (50)/Cu-Al_2O_3 composite fabricated by the vacuum hot-press sintering is mainly through the diffusion and plastic sliding between particles.

In addition, during the vacuum hot-press sintering process, the vacuum makes the pressure difference between the internal and external of the composite compact, which is benefit to reduce the gas resulting in low porosity and improves the material density [8].The Al_2O_3 with high thermal stability and high hardness as dispersed evenly distributed in the copper matrix can obviously increase the composite hardness. And as the dislocation source in the deformation, it increases the matrix dislocation density, thus improves the comprehensive mechanical properties.

The SEM morphologies of the composite bending fracture surface are shown in Fig. 3. It can be seen clearly from Fig. 3, there are a lot of tearing ridges and flat cleavage surface distributed on the bending fracture surface of the composite. On the fracture surface, most W grains are complete seperated on the grain boundries and a part of W grains fracture with cleavage feature. It is because Cu phase occurs in tear ridges due to the plastic deformation under the action of the bending load. The Cu phase fills in the framework of W grains. To a certain degree of deformation, the separation happens between the interface of copper and the tung-

Table 1. Properties of W(50)/Cu-Al_2O_3 composite.

Density, (kg/m^3)	Relative density, (%)	Microhardness, HV	Electrical conductivity, (% IACS)	Bending strength, (MPa)
11920	99.8	135	46	291.3

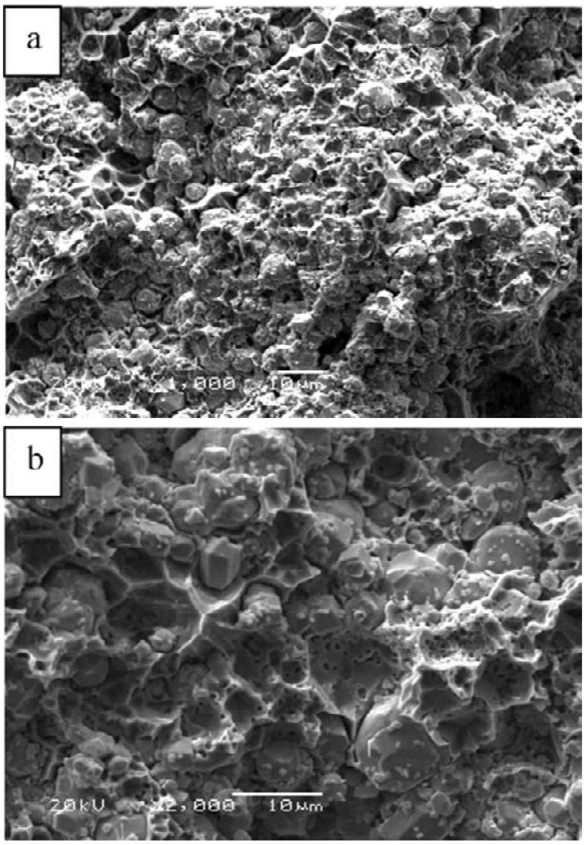

Fig. 3. SEM morphologies of the composite bend fracture surface. (a) Low magnification; (b) high magnification.

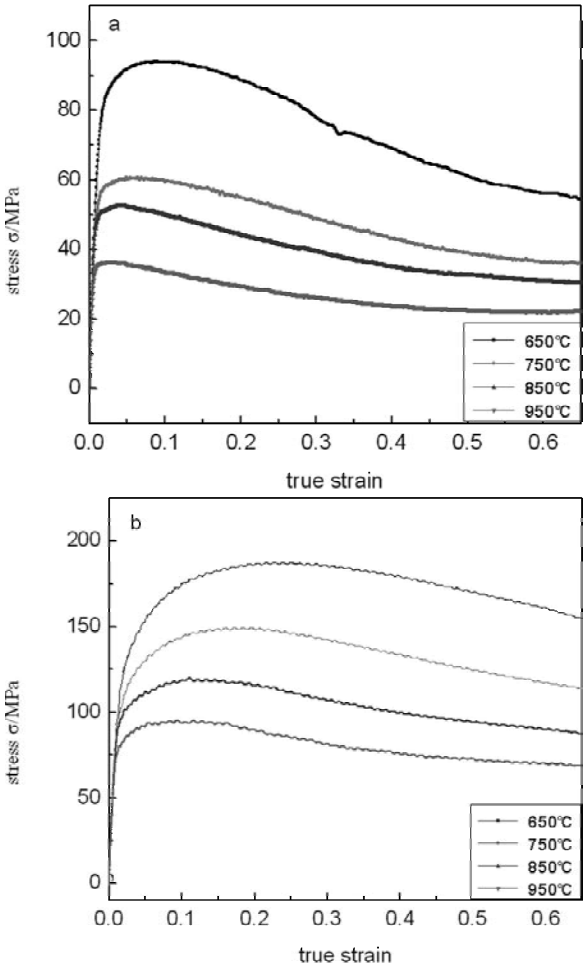

Fig. 4. True stress-true strain curves of W(50)Cu-Al_2O_3 alloy by hot compression under different condition:(a) 0.01 s^{-1} and (b) 5 s^{-1}.

sten to form lots of tearing ridges. When the load is further increased, W grains begin to occur a fraction of deformation and cleavage fracture occurs inside the W grain. It is concluded that the bending fracture mechanism of the W-Cu composite is brittle fracture of the Al_2O_3 dispersion strengthened copper matrix at ambient temperature accompanied by the separation of interface between the W and Cu particles, and a part of the W grains fracture in cleavage feature.

The true stress-strain curves of the W (50)/Cu-Al_2O_3 composite under different compressive deformation temperature and different deformation rate are shown in Fig. 4. The peak flow stress under different deformation conditions is listed in Table 2. The results show that there are similar change trends of the steady rheological characteristics to the composite under different compressive deformation conditions.

In the same strain rate, the flow stress of the W (50)/Cu-Al_2O_3 composite apparently decreases with increasing the testing temperature and the peaks flow stress move to right hand side. With the increase of temperature, the density of the vacancy

Table 2. Peak flow stress of W (50)/Cu-Al_2O_3 alloy by hot compression under different conditions.

$\dot{\varepsilon}$ (s^{-1})	Peak flow stress (MPa)			
	650 °C	750 °C	850 °C	950 °C
0.01	95.116	61.477	53.402	37.147
0.1	127.15	94.459	74.555	56.338
1	157.26	126.17	102.48	81.738
5	189.64	151.45	122.02	97.587

and soluted interstitial atoms increase and the dislocation motion resistance decreases. It results in the high sensitivity to the deformation temperature of the W (50)/Cu-Al_2O_3 composite. In the same deformation temperature, the flow stress increases with increase of the strain rate of the composite, which indicates the positive sensitivity to the strain rate [8]. Namely, the lower temperature and the higher strain rate, the greater the deformation resistance of the composite.

4. CONCLUSIONS

The W (50)/Cu-Al_2O_3 composite was successfully fabricated by using the vacuum hot-press sintering method. The Al_2O_3 particles dispersion strengthened the copper matrix of the composite, and on the matrix the W phases evenly distributed. In the experimental conditions, the fabricated W (50)/Cu-Al_2O_3 composite has excellent comprehensive performance with the relative theoretical density of 99.8%, Vickers hardness of 135 HV, electrical conductivity of 46% IACS, and bend strength of 291 MPa.The bending fracture mechanism of the W-Cu composite is brittle fracture of the separation of interface between the W and Al_2O_3 dispersion strengthened Cu, and a part of the W grains cleavage fracture. Under the test conditions, the true stress-true strain curves of the W (50)/Cu-Al_2O_3 composite possess the steady rheological characteristic and dynamic recrystallization features.

REFERENCES

[1] J. L. Fan, D. J. Yan and B. Y. Huang // *Powder Metallurgy Industry* **13** (2003) 9.

[2]Y. M. Yu, Y. C. Yang and H. L. Li // *Powder Metallurgy Technology* **18** (2000) 252.

[3] L. Zhang, *Study of the densification of W/Cu powder (PhD Thesis)* (Materials Science degree in Haerbin Institute of technology, 2005).

[4]S. H. Liang, L.Xu and L. Fang // *Acta Sinica* **40** (2004) 309.

[5] B. H. Tian, H. L. Zhou and Y. Liu // *Special Casting & Nonferrous Alloys* **29** (2009) 166.

[6] N. Q. Zhao, F. G. Zhou and M. F. Chen // *Powder Metallurgy Technology* **18** (2000) 265.

[7] X.L. Shi, G.-Q. Shao and X.-L. Duan // *Materials for Mechanical Engineering* **31** (2007) 37.

[8] J P Poirier, *High temperature plastic deformation of crystals, translated by D.L. Guan* (Dalian University of Science and Technology Press, Dalian, l989).

[9] L. J. Kecskes, M. D. Trexler and B. R. Klotz // *Metall. and Mater. Trans. A* **32** (2001) 2885.

[10] B.G. Qian, H.R. Geng and Z.Q. Guo // *Materials for Mechanical Engineering* **28** (2004) 7.