Effects of high pressure heat treatment on mechanical and sliding wear properties of Cr phase in Cu51.36Cr48.64 alloy

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Abstract. Cu51.36Cr48.64 alloy was treated at 940℃ for 15min under different pressures, the Cr phase in Cu51.36Cr48.64 alloy was observed by optical microscope, scanning electron microscope and transmission electron microscopy, and its mechanical and sliding wear properties were measured by means of nanoindenter and micro-hardness tester, the effects of high pressure heat treatment on mechanical and sliding wear properties of Cr phase in Cu51.36Cr48.64 alloy were investigated. The results show that high pressure heat treatment can enhance the compactness of Cr phase, increase its hardness and elastic modulus, when the pressure was over 3GPa, the hardness of Cr phase increase slightly with the increase of pressure. Meanwhile, high pressure heat treatment can also decrease its friction coefficient.

1. Introduction

The CuCr alloy has higher compressive strength, good electrical conductivity and resistance to fusion welding. It is a good material preparation of vacuum switch contact etc [1-4]. With the development of large capacity vacuum switch, the higher voltage resistance strength and arc ablation resistance performance has been put forward for CuCr alloy. The infiltration process is the method that used often in the preparation of CuCr alloy, but the compactness of CuCr alloy prepared with the method is poorer [5], and the compressive strength is low. According to the reports in the literature [6], Cr phase in CuCr alloy is the weak electric breakdown phase, the morphology, density and intensity of Cr phase will influence the voltage resistance strength of CuCr alloy electric properties. Therefore, the research of improving the of morphology and mechanical properties of Cr phase in CuCr alloy gets the attention. High pressure heat treatment can increase the density of metal materials, improving the organization and performance [7-9]. Recent studies have shown that high pressure heat treatment can improve the microstructure, mechanical properties and thermal physical properties of CuCr alloy [10-12]. But the study about Cr phase in CuCr alloy after high pressure heat treatment is less. Therefore, this paper examines the morphology and density of Cr phase in melt infiltration state Cu51.36Cr48.64 alloy after high pressure heat treatment, and the effect of high pressure heat treatment on micro mechanical properties of the Cr phase was studied.

2. Experiment

The tested material is Cu51.36Cr48.64 alloy (mass fraction,%) which is prepared by vacuum infiltration method. Firstly, the sample with Φ10mm×12mm of Cu51.36Cr48.64 alloy is sealed in graphite sleeve, and then the graphite sleeve is put into pyrophillite mould, with pyrophillite as the medium to transfer pressure, heating with electrical resistance. Heat treatment was done on CS-IB type six-anvil high-pressure equipment, and the pressures are 1GPa, 2GPa, 3GPa, 4GPa, 5GPa, respectively. After heating at 940 ℃ and lasting for 15 minutes, shutting off power and cooling to room temperature on holding up pressure, the circulating water flux of cooling pressure head is about

1.2L/min. FM-ARS-9000 microhardness tester is used to test microhardness of the samples before and after high pressure treatment. The micro mechanical properties of Cr phase in Cu51.36Cr48.64 alloy before and after high pressure treatment is tested using Triboindenter Nano mechanics test system. Nano hardness andelastic modulus are tested through nanoindentation by using Berkovich indenter. The headcurvature radius is 150 nm, load resolution is 50 nN, displacement resolution is 0.01 nm, exert maximum load is 1000 μN, loading and unloading rate is 100 μN/s, the load duration at the maximum load is 10s. The experimental result is the average of five test results. In addition, the hardness and elastic modulus under different pressure depth are obtained through continuous loading and unloading at one point on the surface of Cr phase. The friction coefficient of Cr phase is obtained through nano scratch experiment by using Conical indenter, the head curvature radius is 2μm, the head load is 1000μN, and the lateral movement speed is 0.33μm/s. Finally, with the help of Axiovert200MAT metallographic microscope, S-3400N scanning electron microscope and JEM-2010 transmission electron microscope, Cr phase in Cu51.36Cr48.64 alloy before and after high pressure heat treatment was analyzed.

3. Experiment results and discusssion

3.1 Microstructure structure

Fig.1 shows the microstructure of the Cu51.36Cr48.64 alloy before and after high pressure heat treatment. As can be seen, the two state of the Cu51.36Cr48.64 alloy microstructure are composed of Cu matrix and granular Cr phases, Cr grain of Cu51.36Cr48.64 alloy after high pressure heat treatment changed into round shape. Backscatter electron image by SEM is seen as Fig.2, Cr phase in Cu51.36Cr48.64 alloy after high pressure heat treatment is denser, and the porosity is small. According to the observation of TEM (see Fig.3), the number of dislocations increase in the Cu51.36Cr48.64 alloy treated by high pressure heat treatment. It is the high pressure that generate high strain in Cu51.36Cr48.64 alloy internally and induce distortion of lattice, which lead to the number of dislocations increment, but also can make alloy internal micropores bridge, resulting in reduction for the number of microscopic holes and increment for alloy compactness.

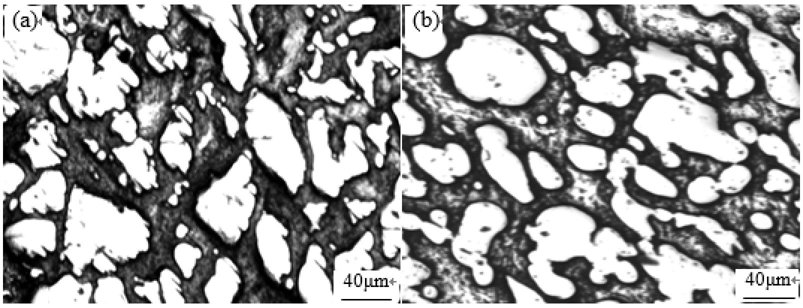


Fig.1 Microstructure of Cu51.36Cr48.64 alloy: (a) original, (b) 3GPa treatment

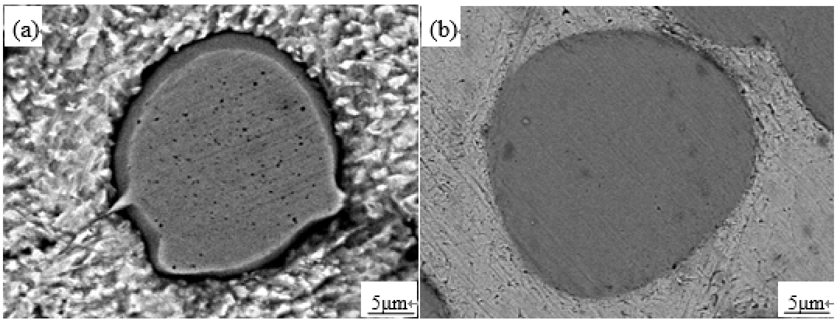


Fig.2 SEM- BSE images of Cu51.36Cr48.64 alloy: (a) original, (b)

3.2 Micromechanical properties

Microhardness. Fig.4 shows the relationship between hardness and pressure of Cr phase in Cu51.36Cr48.64 alloy. As can be seen, the hardness of Cr phase increases with the increase of pressure in the range of 1~5 GPa. The hardness of Cr phase is 201 Hv when the pressure is 3 GPa, increasing by 15.52% compared with the melt infiltration state alloy, when the pressure was over 3 GPa, the hardness of Cr phase increase slightly with the increase of pressure.

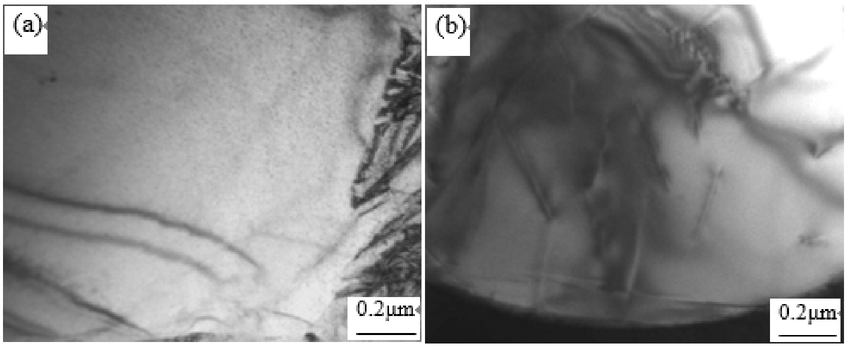


Fig.3 TEM images of Cr phase in Cu51.36Cr48.64 alloy：(a) original,

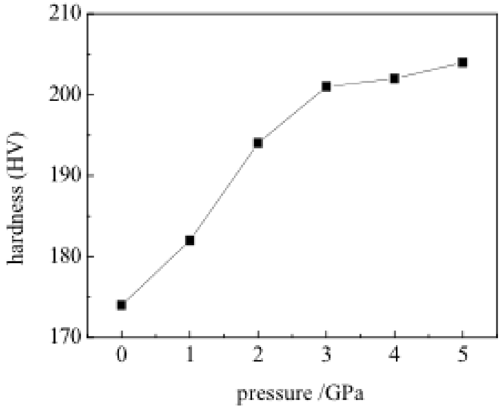


Fig.4 Relationship between the hardness of Cr phase of the Cu51.36Cr48.64alloy and pressure

Nano hardness andelastic modulus

Fig.5 shows the relationship curve between load and displacement of Cr phase in Cu51.36Cr48.64 alloy before and after high temperature and high pressure processing. As can be seen, the loading and unloading curves of the two state of Cr were not overlap, indicating that the two state of Cr phase occurred plastic deformation. The plastic of Cr phase is measured by elastic recovery coefficient (R) in order to characterize the size of the plastic deformation, $R = \frac{h_{\max} - h_f}{h_f} \times 100\%$, $h_{\max}$ and h_f the maximal displacement and residual displacement after unloading under 1000μN load. The micro mechanics performance test results of Cr phase are shown in Table 1. It can be seen that the nano indentation hardness, elastic modulus, elastic ratio and coefficient of elastic recovery of Cr phase after the high temperature and high pressure treatment were 6.47 GPa, 235.47GPa, 0.027 and 122.20%, respectively, 14.51%, 5.52%, 5.52% and 14.51%relatively higher than those of Cr phase before high temperature and high pressure treatment. In addition, the Fig.6 shows that there are heaped up around the indentation of Cr phase before and after high temperature and high pressure processing, and the heaped up of Cr phase after high temperature and high pressure processing is smaller, and the indentation depth is small. Usually the deeper indentation depth, material compressive deformation ability is poor. It can be concluded that high temperature and high pressure treatment can improve the compressive deformation ability of Cr phase. Although the nanoindentation range is small, but the result of this paper is the average of the measured value, the basic experiment data can reflect the average performance of Cr phase. Fig.7 shows the relationship between the nanoindentation hardness, elastic modulus and indentation depth of Cr phase in Cu51.36Cr48.64 alloy. As can be seen, nanoindentation hardness of Cu51.36Cr48.64 alloy before and after high temperature and high pressure processing decreased gradually with the increase of indentation depth, and the nanohardness indentation “size effect” phenomenon occurred [13]. The elasticity modulus fluctuated with the change of indentation depth, and the fluctuations were smaller after high temperature and high pressure processing, there was no obvious “size effect” phenomenon.

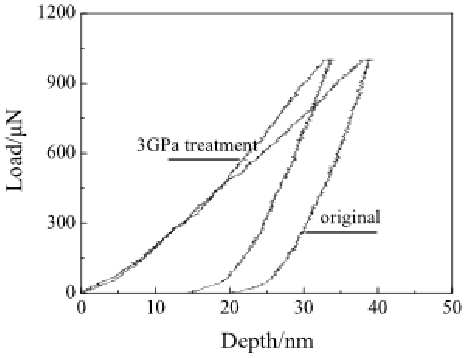


Fig.5 Load-displacement curves for nano-indentation tests of Cr phase in Cu51.36Cr48.64 alloy

Table 1 Nanoindentation results of Cr phase in Cu51.36Cr48.64 alloy

Sample	H/GPa	Er/GPa	H/Er	h_{max}/nm	h_f/nm	R/%
Original	5.65	223.15	0.025	42.94	22.43	91.44
3GPa treatment	6.47	235.47	0.027	34.13	15.36	122.20

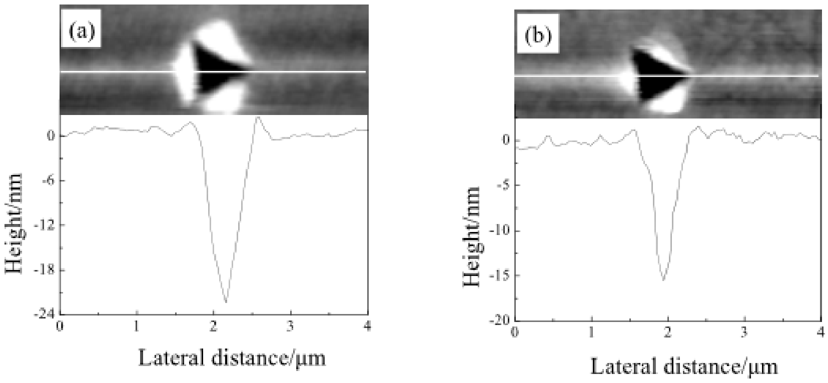
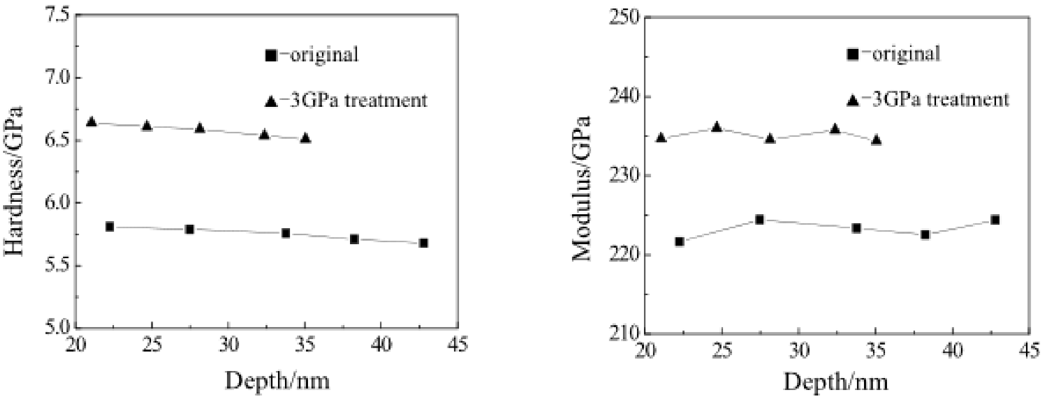


Fig.6 Morphology around indentation and sectional analysis of Cr phase in Cu51.36Cr48.64 alloy:(a) original, (b) 3GPa treatment



(a) Hardness-depth curves； (b) Modulus-depth curves

Fig.7 Hardness, elastic modulus profile curves of Cr phase in Cu51.36Cr48.64 alloy along depth

High temperature and high pressure treatment can reduce micro holes of Cr phase, improve its compactness, and it also can increase the number of internal dislocation of Cr phase d, increasing the hardness of Cr phase. the relation between elasticity Modulus (E) and the material porosity is $E = E_0(1-1.9P+0.9P^2)$ [14], where P is porosity ($0 < P < 1$), E_0 is elasticity modulus of no pore materials. As can be seen, the more material internal porosity, the smaller the elastic modulus. The more uniform material organization is, the smaller the fluctuations of elastic modulus. High temperature and high pressure treatment can reduce the internal porosity of Cr phase, resulting in Cr phase become more uniform and compact, so the elastic modulus increased and the elastic modulus value fluctuation decreased after high pressure heat treatment.

Friction coefficient

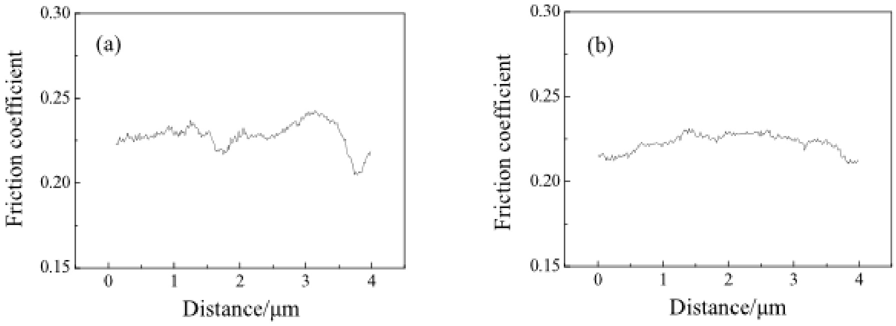


Fig.8 Fiction coefficients of Cr phase in Cu51.36Cr48.64 alloy: (a) original, (b) 3GPa treatment

Fig.8 shows the scratch morphology and surface friction coefficient of Cr phase in Cu51.36Cr48.64 alloy before and after high temperature and high pressure processing. It can be seen that the high temperature and high pressure treatment can reduce the average friction coefficient and the fluctuation of friction coefficient of Cr phase in Cu51.36Cr48.64 alloy. According to the test result, the friction coefficient are 0.228 and 0.228, respectively, before and after high temperature and high pressure processing. The more material internal defects such as micro hole, crack, the greater the fluctuation of the friction coefficient. High temperature and high pressure treatment can reduce micro holes of Cr phase, improve its compactness, therefore, the fluctuation of friction coefficient decreases after high temperature and high pressure treatment. The greater hard elastic ratio, the better material wear-resisting performance is [15-16]. High temperature and high pressure treatment can increase the hardness and hard elastic ratio of Cr phase, reduce the friction coefficient, indicating that high temperature and high pressure treatment can improve the wear resistance of Cr phase.

4. Conclusions

(1) High temperature and high pressure treatment can increase the density of Cr phase in Cu51.36Cr48.64 alloy, increasing the number of dislocation of Cr phase, enhance the compressive deformation capacity, effectively improve the micro mechanical properties of Cr phase.

(2) The hardness of Cr phase increases with the increase of pressure in the range of 1~5 GPa, when the pressure was over 3 GPa, the hardness of Cr phase increase slightly with the increase of pressure.

(3) The nano indentation hardness, elastic modulus, elastic ratio and coefficient of elastic recovery of Cr phase after the high temperature and high pressure treatment at 950℃ for 20min were 6.38 GPa, 235.61GPa, 0.027 and 103.77%, respectively, 17.93%, 5.37%, 8.00% and 50.20% relatively higher than those of Cr phase before high temperature and high pressure treatment, however, the friction coefficient is reduced.

Acknowledgements

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