International Journal of Refractory Metals & Hard Materials 77 (2018) 105–112

Contents lists available at ScienceDirect

International Journal of Refractory Metals & Hard Materials

journal homepage: www.elsevier.com/locate/IJRMHM

High temperature friction and wear behavior of tungsten – copper alloys

Youting Huang[a,b,*], Xiaolong Zhou[a,b], Nengbin Hua[a,b], Wumei Que[a,b], Wenzhe Chen[a,b]

[a] *School of Materials Science and Engineering, Fujian University of Technology, China*
[b] *Fujian Provincial Key Laboratory of Advanced Materials Processing and Application, Fuzhou 350108, China*

ARTICLE INFO

Keywords:
WCu alloys
Wear behavior
Wear mechanisms
High temperature properties

ABSTRACT

In this paper, high temperature creep and frictional wear behaviors of WCu pseudo-alloys were investigated using scanning electron microscopy, X-ray diffraction and X-ray fluorescence. Results showed that the Cu binder phase was uniformly distributed around the W skeleton in the WCu alloys. The W80Cu20 alloys exhibited a good creep resistance. The creep life of the WCu alloys was gradually reduced with a decrease in W content of the alloy. Copper tungstate ($CuWO_4$) was formed during the high-temperature friction and wear processes, and was found to be beneficial to improve the wear resistance of the WCu alloys. An increase in the content of Cu was found to be helpful to enhance the cohesiveness of W-Cu phases, improve the deformability of W, restrain the formation of WO_3, and promote the formation of $CuWO_4$. In addition, the friction coefficient was decreased with an increase in both the Cu content and applied load. Therefore, W70Cu30 alloys demonstrated a better high temperature wear resistance than W80Cu20 alloys. The worn surface of the WCu alloys exhibited pits, furrow, micro-sized pores, fatigue cracks and wear debris. Wear mechanisms of the WCu alloys were identified to be a combination of adhesive wear, abrasive wear, oxidation wear, fatigue wear and evaporation of copper.

1. Introduction

W-Cu pseudo-alloys are usually fabricated by powder metallurgy technology. They are specially suitable for the manufacture of high temperature components where the combined properties of high electrical and thermal conductivity, high heat resistance and high temperature wear are required, for the key components such as high power electrodes and high temperature electric machining molds, etc. These wide range of applications for the W-Cu alloys are due to the high hardness of W at high temperature and the high melting point of W, as well as formation of a layer of lubricating film at high temperatures owing to the low melting point of Cu, which result in a reduction in the friction coefficient [1–3]. In addition, the heat produced in the process of friction and wear can be quickly dissipated because of the good thermal conductivity of WCu alloys, thus the surface temperature of the alloys is decreased, and hence the service life of engineering structure components is prolonged [4–8].

Recently, wear behavior of the WCu alloys has attracted significant attention. Hashempour et al. fabricated the W75Cu25 alloys by thermochemical co-precipitation method [9] and they reported that the wear rate was increased with an increase in the normal load, while the friction coefficient was decreased by increasing the load. They suggested that the decrease in the friction coefficient was attributed to the formation of mechanically mixed layers and surface work hardening. Xu et al. [10] investigated the wear resistance of W reinforced Cu matrix composite. Results showed that the composite exhibited an excellent wear-resistance with a wear volume loss of only 0.72 mm^3. Wang and co-workers [11] examined the wear resistance of WCu alloys prepared by a laser shock processing technology. They found that the wear resistance of WCu layer after laser surface remelting was increased by 1.55 times than that of the untreated Cu-W alloys under the same wear conditions. Dry-sliding tribological characteristics of W80Cu20 alloys under a magnetic field were also studied by Wang et al. [12]. Test results showed that the wear debris of W80Cu20 alloys was spiral in shape without applying any magnetic field, and the main wear mechanism was adhesive wear. However, with an increase in the intensity of magnetic field, the adhesion layer became thinner, and the wear loss of W80Cu20 alloys was decreased and the friction coefficient of WCu alloys was reduced gradually. The wear debris appeared to be flakes or granules, and the main wear mechanism was adhesive wear and oxidation wear.

Up to now, few papers have investigated the wear behavior of WCu alloys at high temperature. Due to the high temperature applications of the WCu alloys, it is quite important and urgent to study the evolution of microstructure and wear mechanisms of WCu alloys at high temperatures. In this paper, WCu alloys fabricated by an infiltration

* Corresponding author at: School of Materials Science and Engineering, Fujian University of Technology, China.
E-mail address: fzbld@sina.com (Y. Huang).

https://doi.org/10.1016/j.ijrmhm.2018.08.001
Received 25 May 2018; Received in revised form 23 July 2018; Accepted 6 August 2018
Available online 07 August 2018
0263-4368/

Table 1
The physical and mechanical properties of the WCu alloys.

Alloy composition	Density (g/cm^3)	Relative density (%)	Electric conductivity (% IACS)	Hardness (HB)
W80Cu20	15.15	96.68	34	220
W70Cu30	13.80	96.43	42	175

sintering technology were used to evaluate the wear behavior of WCu alloys at high temperatures under various applied loads, and their wear mechanisms at high temperature was identified.

2. Experimental

Commercially available Cu powders (99.7% purity and particle size < 80 μm) and W powders (purity ≥99.9% and average particle size of 5–7 μm) were ball-milled for 24 h using agate balls with diameters of 2 mm in a stainless steel container. The mixed powders were then compacted into either cylinder or rectangular samples under a pressure of 600 MPa. The cold-pressed W80Cu20 and W70Cu30 alloys were subsequently fabricated using the infiltration sintering at 1350 °C for 90 min under H_2 atmosphere. The physical and mechanical properties of the alloys are listed in Table 1.

W80Cu20 and W70Cu30 alloys were used for the investigation of wear behavior at high temperatures under various applied loads. An HT-100 type pin-on-disc high temperature wear tester was used to evaluate the wear behavior of WCu alloys. The wear test was conducted under a dry sliding condition at 900 °C, with applied loads of 5 N and 20 N, respectively. Cylindrical samples with a dimension of Ø5 mm × 10–12 mm and rectangular samples with a dimension of 4 mm × 4 mm × 10–15 mm were cut out using a wire-cutting machine. According to the standard given in GB/T 3960–1983, HT250 gray cast iron with a dimension of Ø50 mm × 5 mm and a hardness value of HB 190 was chosen as frictional pair materials.

High temperature creep test was carried out at 900 °C with an applied stress of 300 MPa in air using a high temperature creep testing machine. Samples with a dimension of 9.0 mm × 8.1 mm × 4.7 mm were used for the creep test. Microstructures of the WCu alloys were characterized using an optical microscopy (OM, OLYMPUS-GX71). Crystalline phases of the WCu alloys was characterized using X-ray diffractometer (XRD, XRD-7000) at an operating voltage of 40 kV and current of 30 mA. The Cu target was used and the scanning was performed in 2θ range of 30–90° with a scanning speed of 8°/min. After performing the friction and wear test, the worn surfaces and wear debris of the samples were examined using a scanning electron microscope (SEM, JSM-840). Wear debris was also studied via an energy dispersive spectrometry (EDS) to analyze its compositions. The percentage of oxygen of wear surface was measured using an X-ray fluorescence (XRF, XRF-1800) microscope.

3. Results and discussion

Fig. 1(a) and (b) are optical micrographs of W80Cu20 and W70Cu30 alloys, respectively, fabricated by infiltration sintering technology. The atomic number of W is higher than that of Cu, therefore, the bright regions in Fig. 1 are tungsten phase and the dark regions are copper phase together with a small number of pores. It can be observed that the tungsten particles are uniformly surrounded by copper phases, indicating a good combination of hard W skeleton with deformed copper binder phase. As a result, a good densification of WCu alloys was obtained after the process. By comparing Fig. 1(a) with Fig. 1(b), it is noted that the amount of W skeletons in the W80Cu 20 alloys is much more than that in the W70Cu30 ones, on the contrary, the amount of copper binder phase in W80Cu20 alloys is less than that in the W70Cu30 ones.

Fig. 2 shows representative curves of deformation strain (ε) as a function of time (t) obtained at 900 °C under an applied stress of 300 MPa for W80Cu20 and W70Cu30 alloys. As can be seen from Fig. 2, both the W80Cu20 and W70Cu30 alloys have experienced a slow plastic deformation with an increase in time at the high temperature of 900 °C, although they have different rates of deformation. This time dependent plastic deformation at high temperatures is linked with creep. It can be observed that the creep life of WCu alloys decreases with a decrease in W content. The creep life of the W70Cu30 alloy is 63.2 h, whereas the creep life of the W80Cu20 alloy is prolonged to 87.2 h. By comparing the steady-state creep stage in curve (a) with curve (b) in Fig. 2, the slope of creep curve exhibits a tendency to decrease with an increase in the W content, which suggests that the steady-state creep strain rate decreases with an increase in W content in WCu alloys. The steady-state creep strain rate of the W70Cu30 alloy was calculated to be 0.00112 h^{-1}, while it was 0.00069 h^{-1} for the W80Cu20 alloy. This proves that the WCu alloys containing a higher content of W have a better creep property at the same loading time and stress. The reasons for the better creep property of alloys with a higher W content can be explained as follows: the higher the content of high melting point element, the lower the self-diffusion activation energy [13], and the higher the ability of the alloys to withstand creep deformation before rupture under high temperatures and high stresses, and hence the better the creep resistance of the alloys. Copper with its low melting point has little effect on the high temperature performance of the alloys.

Fig. 3(a) and (b) present the variation of friction coefficient as a function of sliding time of W70Cu30 and W80Cu20 alloys, respectively, tested at 900 °C under different applied loads (5 N and 20 N). It can be seen that there is a gradual increase in the friction coefficient with an increase in time at the beginning of the wear process, followed by a relatively stable stage with a nearly constant value of friction

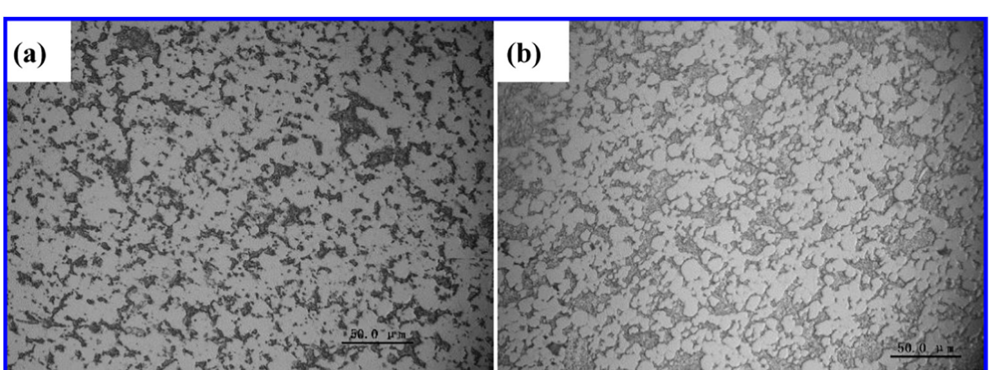

Fig. 1. Optical micrographs of WCu alloys fabricated by infiltration sintering technology: (a) W80Cu20; (b) W70Cu30.