

Tensile Behavior of High Temperature Cu-Cr-Zr Alloy

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Abstract—The tensile behavior of Cu-Cr-Zr alloy was investigated at different temperatures. The material investigated was heat treated to the following condition: solutionizing 980 °C-40 min then water quenching, aging 460 °C-4 h. The test temperature was ranged from room temperature to 600 °C at intervals of 100 °C. Curves describing the tensile properties were obtained. The Vickers hardness, microstructure and fracture surface of the tested alloys were also studied. The results reveal that the tensile strength of Cu-Cr-Zr alloys decreases with the increase of temperatures. Additionally, due to fully recrystallization, a combination of a high tensile strength with a fairly good plasticity can be achieved at 200 °C. The suitable working temperature of Cu-Cr-Zr alloy ranges from room temperature to 300 °C. The results also indicate that the mechanism of Cu-Cr-Zr alloy fracture is the nucleation, growth, extension and join of microvoid caused by second phase particle.

Keywords—Cu-Cr-Zr alloy; tensile properties; high temperature; fracture pattern

I. INTRODUCTION

Cu-Cr-Zr alloy, as one of the most promising functional materials, has been extensively researched in recent years [1-4]. With the combination of excellent electrical and thermal conductivity, good thermal stability at high temperature, relatively high strength, good fatigue resistance, outstanding resistance to corrosion and ease of fabrication [5-11] it has been widely used in the applications such as moulds for continuous caster, heat transfer materials, diverter target materials and other important industrial parts [12-15]. Under high temperature and alternating stress, fracture that caused by high temperature is the main factor leading to the final material failure. Therefore, to expand the application extension, there is an urgent need to study tensile fracture characteristics and mechanism of Cu-Cr-Zr alloy from room temperature to high temperature.

At home and abroad, the research of Cu-Cr-Zr alloy mainly concentrated in the preparation method, heat treatment process, and mechanical properties at room temperature, precipitates and microstructure during the last two decades [16-18]. However, there is still dearth of research on tensile behavior of

Cu-Cr-Zr alloy from room temperature to high temperature. The purpose of this study is to develop a better understanding of high temperature tensile properties by investigating the changes of microstructure and the observation of surface morphologies after tension to shed some light on the mechanism of Cu-Cr-Zr alloy fracture.

II. EXPERIMENTAL

The material used in the present investigations was a precipitation hardened Cu-Cr-Zr alloy. The alloy was supplied with a composition of Cu-0.84% Cr-0.15% Zr. The chemical composition of Cu-Cr-Zr alloy in wt% is listed in Table 1. The material received a solution annealing followed by an aging according to: 40 min at 980 °C, water quenched, 4 hours at 460 °C, water quenched. The microstructure of heat treated Cu-Cr-Zr alloy is shown in Fig. 1. Apparently, the grains are near equiaxial after solution and aging treatment. There still remains a large amount of Cr precipitates both at grain boundaries and inside grains.

Tensile specimens were machined with the gauge length of 20 mm and an oblong cross-section of 2×3mm² as shown in Fig. 2, according to Standard GB/T228-2002 “metallic materials tensile testing at ambient temperature”. The tensile tests were conducted on an Instron-8801 machine combined with a resistive furnace. The test temperature was ranged from room temperature to 600 °C at intervals of 100 °C, and the strain rate was of 4.3×10^{-4} s⁻¹. The loading speed was 0.5 mm/min; the maximum load was 10 KN.

After the tension tests, the Vickers hardness of the tested specimens was determined, the microstructure was examined by an ‘Olympus PMG3’ optical metallographic microscope. By the help of SEM, surface morphologies after fatigue were investigated as well.

TABLE I. CHEMICAL COMPOSITIONS OF THE CU-CR-ZR ALLOY.

Chemical element	Cu	Cr	Zr	Fe
Mass fraction [%]	Balance	0.83-0.84	0.15-0.20	0.03

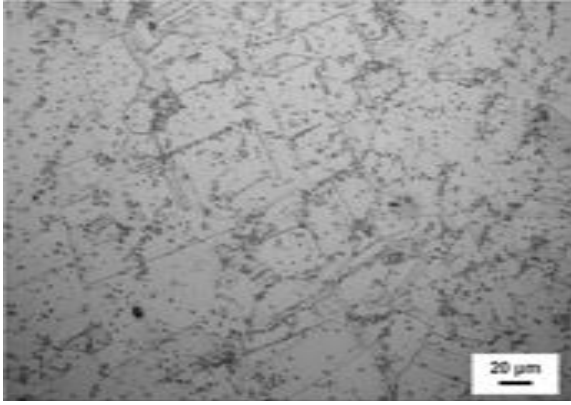


FIGURE I. INITIAL MICROSTRUCTURE OF CU-CR-ZR ALLOY.

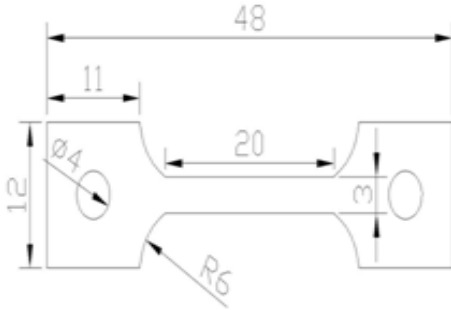


FIGURE II. DIMENSION OF TENSILE SPECIMEN.

III. RESULTS

A. Effect of Temperature on the Tensile Properties of Cu-Cr-Zr Alloy

Tensile tests at different temperatures were performed to figure out the effect of temperature in the mechanical performance of the Cu-Cr-Zr alloy. Fig. 3 shows the tensile stress-strain curves obtained from the tension tests at room temperature, 200 °C, 300 °C, 400 °C, 500 °C, and 600 °C at a fixed strain rate. Data for ultimate tensile strength (UTS) and elongation to failure are summarized in Fig. 4. As can be seen from Fig. 3 and 4, with the increasing of temperature, the tensile strength decreases gradually from room temperature to 600 °C. Moreover, it can be found an interesting phenomenon about the evolution of elongation-to-failure: it first decreases from 18% to 14% continuously from 200 °C to 400 °C, but it dramatically increases with the reaching of 500 °C. And it is up to 27% at 600 °C. In addition, it is found in Fig. 3 at high temperature the uniform deformation stage represents more than half, almost 50% of the deformation. As a whole, with the increasing of temperature, uniform deformation also increases. It indicates that the plasticity of Cu-Cr-Zr alloy is good. The value of ultimate tensile strength is 308 ± 15 MPa at 300 °C. It would ensure that Cu-Cr-Zr alloy has enough strength to be applied under the high temperature condition. Compared to the two curves in Fig. 4, the alloy has good strength and plasticity at the same time at room temperature to 300 °C. So the suitable working temperature of Cu-Cr-Zr alloy ranges from room temperature to 300 °C. All the results above reveal that temperature has remarkable effect on tensile strength and elongation.

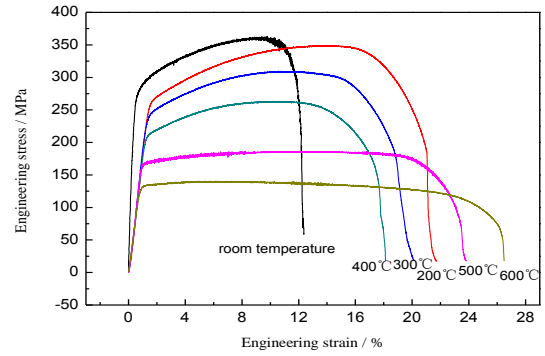


FIGURE III. ENGINEERING STRESS-STRAIN CURVES OF CU-CR-ZR ALLOY AT ROOM TEMPERATURE, 200 °C, 300 °C, 400 °C, 500 °C, AND 600 °C.

Hardness tests were performed to figure out of the effect of the high temperature in the mechanical performance of the Cu-Cr-Zr alloy. The results are shown in Fig. 5. As shown in Fig. 5, it can be seen that the temperature has great effect on the hardness of the alloy. The hardness of the alloy increases with the increase of temperature, and reaching the peak of 143.4HV at 200 °C. Then with the rising of temperature, the hardness decreases by degrees. The hardness of the alloy at 300 °C and 400 °C are very close. The hardness decreases rapidly at 600 °C. In summary, the temperature does have a big influence on the hardness of Cu-Cr-Zr alloys.

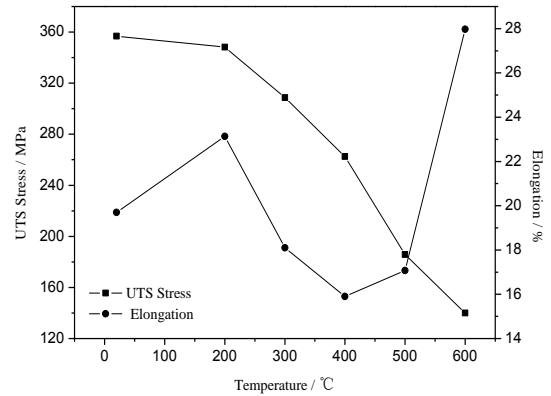


FIGURE IV. THE TENSILE STRENGTH AND THE ELONGATION OF CU-CR-ZR ALLOYS AT DIFFERENT TEMPERATURES.

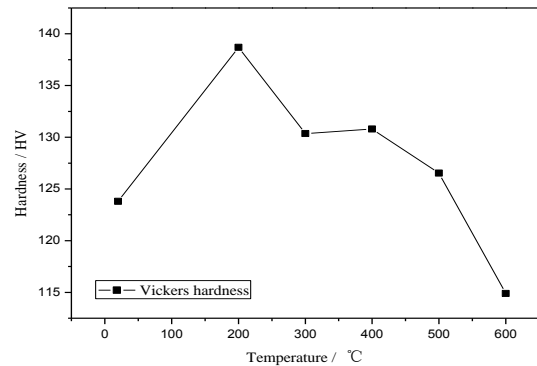


FIGURE V. THE HARDNESS OF CU-CR-ZR ALLOYS AT DIFFERENT TEMPERATURES.

B. Effect of Temperature on the Microstructure of Cu-Cr-Zr Alloy

The microstructures near tensile fracture of Cu-Cr-Zr alloys under different temperatures are shown in Fig. 6. It can be seen that at room temperature, the twin crystal occurred. Flake twin can be clearly observed in the matrix. When the temperature is 200 °C, material is fully recrystallized and organization uniformity is good. The grain size is relatively small. So the tensile strength of Cu-Cr-Zr alloys is lower, while elongation is increased at 200 °C. When the temperature reaches to 300 °C, part of the material is recrystallized, the uniformity of the organization is poor. So the elongation is lower than 200 °C. From Fig. 6(d) we can see, complete recrystallization happened with an equiaxed grain structure. The grain size is bigger than 200 °C. Therefore, the tensile strength at 600 °C is lower but the elongation is increased.

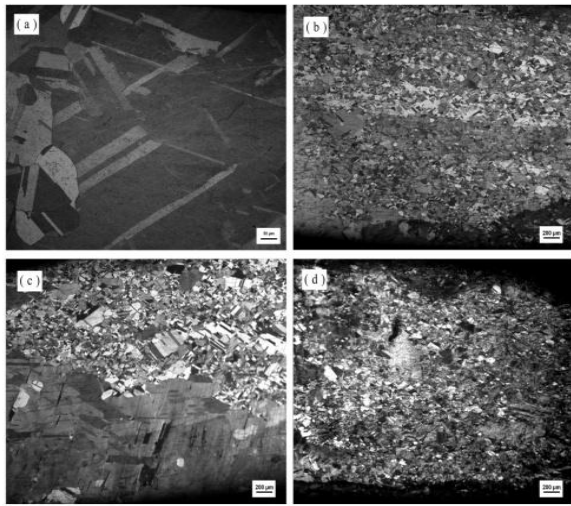


FIGURE VI. THE MICROSTRUCTURES NEAR TENSILE FRACTURE OF CU-CR-ZR ALLOYS UNDER DIFFERENT TEMPERATURES, (A) ROOM TEMPERATURE, (B) 200 °C, (C) 300 °C, (D) 600 °C.

C. Effect of Temperature on the Fracture Appearance of Cu-Cr-Zr Alloy

The fracture surfaces of Cu-Cr-Zr alloys are shown in Fig. 7, respectively, as a function of temperature. Compared with the fracture appearance of Cu-Cr-Zr alloy at different temperatures, the mechanism of fracture can be figure out. The tensile is ductile fracture. The dimples appeared are the characteristic of the typical microvoid coalescence fracture. The fractures are mainly caused by broken particle, a large number of microvoids in different sizes and shapes, dimples and tearing ridges, which are taken as ductile fracture features. Under the condition of high temperature dimples vary in size and shape, accompanied by a small amount of cracks. While under the condition of low temperature, dimples are relatively uniform, showing Cu-Cr-Zr alloy has better plasticity. The mechanism of Cu-Cr-Zr alloy fracture is the nucleation, growth, extension and join of microvoid caused by second phase particle.

Can be seen from Fig. 7, the microstructures of fracture are mainly about dimples. With the increase of temperature, dimples grow up along the tensile direction, microvoids

deepened, new small dimples occurred inside of the original dimples. From room temperature to 300 °C, dimples are small and shallow. When the temperature is above 300 °C, dimples become relatively bulky and deep, with a few of cracks.

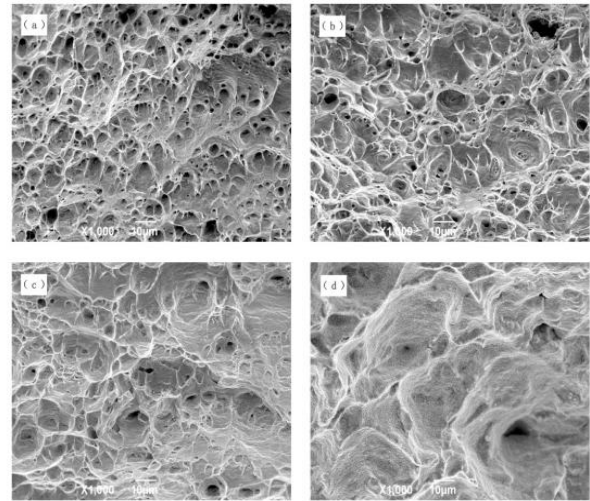


FIGURE VII. THE FRACTURE APPEARANCES OF CU-CR-ZR ALLOYS UNDER DIFFERENT TEMPERATURES, (A) ROOM TEMPERATURE, (B) 200 °C, (C) 300 °C, (D) 600 °C.

IV. CONCLUSIONS

The effect of temperature on the tensile properties, mechanical performance, microstructures and fracture appearances of Cu-Cr-Zr alloys was investigated at ambient and high temperatures. From the analysis of the results, the following conclusions can be drawn:

1. Tensile strength of Cu-Cr-Zr alloys decreases with the increase of temperature. The alloy results in good material strength and hardness, while its ductility remains sufficient. So the suitable working temperature of Cu-Cr-Zr alloy ranges from room temperature to 300 °C.
2. The hardness of the alloy increases from room temperature to 200 °C. Then with the rising of temperature, the hardness decreases by degrees.
3. Recrystallization happens in Cu-Cr-Zr alloys with increase of temperatures, which leads to the tensile strength decreasing.
4. A typical ductile fracture mode with dimples is observed on the high temperature tensile fracture surface. The mechanism of Cu-Cr-Zr alloy fracture is the nucleation, growth, extension and join of microvoid caused by second phase particle.

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