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ARTICLE

Simulation of Meso-scale Accumulated Damage and Induced Crack Behaviors of CuW Alloy

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Abstract: Considering the relationship between Meso-scale accumulated damage and microstructure, external cyclic strain load was applied on 2D representative volume element (RVE) of CuW alloys, and the accumulated damage and induced crack behaviors of CuW alloy were stimulated using Darveaux model. The results show that the plastic slip bands appear on the copper phase at the beginning. Damage and induced cracks of CuW alloy initiate at the corners and then propagate along the edges of tungsten grains with the increase of cyclic number. The propagation path of micro-cracks is affected by the distribution of tungsten grains mainly, while the sintering necks slow down the propagation speed of micro-cracks to some extent.

Key words: CuW alloy; Meso-scale; accumulated damage; crack

Combining the high electrical and thermal conductivity of copper with the refractoriness and high strength of tungsten, CuW alloy is widely used as high voltage electrical contacts, welding electrodes, electric discharge machine, and heat sinks[1-3]. Under the thermal cyclic load, accumulated damage and induced cracks appear in CuW alloy and then the service life of the material is reduced.

The accumulated damage process of material can be subdivided into microcosmic and macroscopic phases and the vast majority of service life lies within the microcosmic phase of the damage process in many cases[4,5]. Because of the absence of effective test methods on micro-damage observations, the study of damage and induced mic-cracks behaviors were conducted numerically at meso-scale level mostly[6-8]. With the numerical prediction, the damage mechanism of materials are clarified and then experimental investigation will be implemented effectively.

Under cyclic load, the fatigue life of materials decrease because of the ratcheting effect induced by the plastic strain accumulation along the mean stress, and the damage processing is mainly controlled by the ratcheting damage caused by the ratcheting deformation[9]. Usually, the ratcheting cyclic failure life is predicted by the accumulative damage and the combined energy density [9,10]. As we know, the mechanical behaviors of CuW alloy is affected by its grains features, such as volume fraction and particle distribution[8,11]. Applied with different cyclic loads, elastic shakedown, plastic shakedown or plastic ratcheting effect appear on CuW alloy.

In this study, the meso-scale model was built based on the microstructure of CuW alloy. The initiation mechanism of accumulated damage and the propagation behaviors of induced cracks for CuW alloy under cyclic load were investigated with the damage model.

1 Simulation Model

1.1 Darveaux model

The traditional approach for determining the fatigue life

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for a structure is to establish the *S-N* curves of the materials[12]. However, the relationship between the cycle number and the degree of damage or crack length is not clear by the above method. With the hysteresis energy damage theory, Darveaux model is applied to study the relationship between the damage or crack and cyclic number and implemented well by Abaqus software [13]. Darveaux model was given as follows[13,14].

$$N = N_0 + \frac{D}{\mathrm{d}D/\mathrm{d}N} \tag{1}$$

where N is the fatigue life, N_0 is the cyclic number when damage initiate, and *D* is the damage degree.

The initiation criterion of damage is characterized by the accumulated inelastic hysteresis energy per cycle ΔW. The cycle number in which damage is initiated is given by

$$N_0 = c_1 \Delta W^{c_2} \tag{2}$$

where c_1 and c_2 are the material contacts.

Once the damage initiation criterion is satisfied at some positions of the material, the value of damage is calculated and updated based on the inelastic hysteresis energy for the stabilized cycle. The rate of the damage in a material point per cycle is given by

$$\frac{\mathrm{d}D}{\mathrm{d}N} = c_3 \Delta W^{c_4} \tag{3}$$

where c_3 and c_4 are the material constants.

1.2 Representative volume element (RVE) of CuW alloy

CuW alloy used in this study was fabricated by infiltrating the pure copper (99.90%) into a tungsten skeleton which was activated and sintered by tungsten powder (4~6 μm) and 0.9 wt% activated sintering element Ni powder. After annealing CuW alloy was fabricated, and the microstructure is shown in Fig.1a, in which the dark region is coved with copper phase and the rest is constructed with tungsten skeleton. The nominal mass fraction of tungsten and copper are 70% and 30%, respectively.

The meso-scale geometry model of CuW alloys is based on the microstructure of CuW alloy. Generally, the Meso-model is represented with the representative volume element (RVE) via finite element method (FEM). The Meso-model of CuW alloy is built by 2D Voronoi diagram which consists of a number of convex polygons. Here, the original set of randomly distributed seeds of Voronoi structures is generated with program Pathon and the needed Voronoi diagrams are constructed with the program Qhull[8,15]. Thus, the meso Model of CuW alloys is achieved by the distinguishing of copper and tungsten phases, as shown in Fig.1b.

Considering the damage of a material is most likely induced by tensile load under thermal cyclic load [8], cyclic biaxial tensile strain load with different amplitude was applied on the meso model of CuW alloy. The finite element analysis was conducted using Abaqus 6.9.

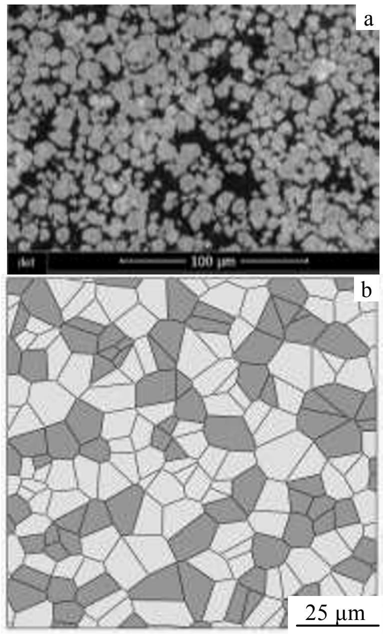

Fig. 1 Microstructure (a) and Meso model (b) of CuW alloys

2 Material Properties

Though expressed as classic brittle material, as dislocation activity becomes important at high temperatures, the tungsten begins to show ductile behavior, characterized by a marked plastic deformation [16,17], and the elongation rate is 9.5% at 1505 K[18]. The mechanical properties of the tungsten and copper, such as modulus of elasticity, Poisson's ratio, and yield strength are listed in Table 1.

The low cycle fatigue behaviors and related parameters of tungsten studied rarely were given by R. E. Schmunk et al. at 1088 K[20], and the constants of c_1, c_2, c_3 and c_4 of tungsten were calculated using the trust region algorithm in MATLAB software under the confidence of 95%, as listed in Table 2.

3 Results and Discussion

3.1 Initiation of accumulated damage

Table 1 Mechanical properties of tungsten and copper

Material	Young's modulus/GPa	Poisson Ratio	Yield Strength/ MPa	Ultimate Strength/MPa
Tungsten	378[19]	0.28	411[20]	428[20]
Copper [a]	110	0.345	57	219.2

Note: a-from pure copper tension experiment