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ARTICLE

Mechanical Behavior and Microstructure of WCu Alloy under Hot Compression

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Abstract: Considering the application of WCu alloy at elevated temperature, hot compression was applied on WCu alloy and W skeleton to analyze the microstructure and mechanical behaviors at different temperatures and strain rates. The results show that the stress-strain behavior of WCu alloy is affected mainly by the temperature. The sintering necks disappear mostly after hot compression. The plastic flow of WCu alloy appears at 300 ℃ while W particles are mostly homogeneous approximately at 900 ℃. In addition, the strength of W skeleton declines slightly at high strain rate, while round grains and cracking appear at the substructure of W particle under different strain rates.

Key words: WCu alloy; W skeleton; hot compression; stress; microstructure

Applied as high voltage electrical contacts, high temperature mold and shaped charge liner, WCu alloy usually works under large compression deformation at elevated temperature[1-4]. However, the mechanical properties of partial WCu alloy decline, which affect the reliability of the entire component due to the inner damage during hot compression.

The deformation of WCu alloy has been studied more in recent years. After plastic deformation at room temperature, microstructures of WCu alloy was observed and localized deformation was mostly homogeneous but heterogeneous deformation occurred in some regions[5]. The quasi-static deformation behavior of WCu alloy caused by volume fraction and particle size was studied by M. Korthäuer et al [6]. Severe plastic deformation by high-pressure torsion at different temperatures on WCu alloy causes a strong refinement of W particles[7]. Though the tungsten and copper based composites under hot compression were more studied[8-10], the damage behaviors and mechanism of WCu alloy under hot compression have not been revealed effectively[11].

The main objective of the present paper is to bridge between the hot compression experiment and the mechanical behavior of WCu alloys. The microstructure was analyzed to reveal the mechanism of damage that will benefit the design and reliability of the material.

1 Experiment

WCu alloys used for hot compression in this study were fabricated by infiltrating the copper phase into a tungsten skeleton which was sintered from tungsten powder (purity of 99.8%, size of 4~6 μm) at a hydrogen atmosphere in a sintering furnace. 0.9 wt% activated sintering element Ni powder was added into pure tungsten powder. The nominal mass fraction of tungsten and copper was 70% and 30%, respectively. Due to the melting and splash of copper phase, only tungsten skeleton was prepared for hot compression at 1100 ℃. After annealing, the materials were fabricated.

The hot compression experiments were implemented with Gleeble3500 thermal-mechanical simulator. Specimens were prepared with diameter 6 mm and height 9 mm firstly and then welded with a thermocouple to measure the temperature, as seen in Fig.1a. Deformation of 60% was applied on the specimens at different elevated temperatures with the heating

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rate of 10 ℃/s and then held for 5 min followed by water quenching at 20 ℃ for about 3 s. The WCu alloys were tested with the temperature of 300, 900 ℃ and strain rate of 1.0 and 5.0 s^{-1}, while the temperature of 1100 ℃ was applied on the tungsten skeletons with the same strain rate. The hardness of WCu alloy was tested by MH-3 Vickers hardness tester, the electrical conductivity of WCu alloy was measured with D60K conductivity meter, and the microstructure of the materials was observed by Quants FEG 450 scanning electron microscope.

After hot compression, plastic deformation appeared obviously on WCu alloy which changed from cylinder to drum shape, while the tungsten skeleton was crushed completely, as shown in Fig.1b and 1c.

2 Results and Discussion

2.1 Mechanical and electrical behavior of WCu alloy

The stress-strain behavior of WCu alloy during hot compression are shown in Fig.2. The strengths of compression for WCu alloy decline with the increase of temperature. The ultimate strength is only 185 MPa at 900 ℃, and 522 MPa at 300 ℃ compared with 574 MPa at room temperature under static compression, yet the stress-strain curves are affected hardly by the strain rate partly because of the dominate role of tungsten skeleton. However, the plastic deformation of WCu alloy is varied by both of the temperature and strain rate, as seen in Fig.3. The cross section expansion rate increases with the increasing of temperature while it decreases with the increasing of strain rate.

The hardness and electrical conductivity of WCu alloy are also affected by the temperature and strain rate after hot compression, as seen in Fig.4. Compared with the original HV hardness 2.57 GPa and electrical conductivity 29.5%IACS, both of the hardness and electrical conductivity of WCu alloy decrease with the increasing of temperature, especially under the lower strain rate load. Therefore, we conclude that the temperature plays a major role in the variety of hardness, while the electrical conductivity is affected by the strain rate mainly especially at 300 ℃.

2.2 Microstructure of WCu alloy after hot compression

The microstructure of WCu alloys after hot compression is shown in Fig.5, in which the dark region is covered with copper phase and the rest is constructed with tungsten skeleton. With the large plastic deformation, lots of sintering necks are broken off and tungsten particles are separated each other mostly; however, the tungsten particles do not crack and there is no obvious difference at the strain rate of 1 and 5 s^{-1}. The plastic flow of copper phase is exhibited with the distribution of tungsten particles and any sintering necks hardly appear perpendicular to the direction of plastic flow at 300 ℃, and the orientation of most tungsten particles deflect along the plastic flow, as shown in Fig.5a and 5b. The tungsten particles are mostly homogeneous at 900 ℃, as shown in Fig.5c and 5d. This

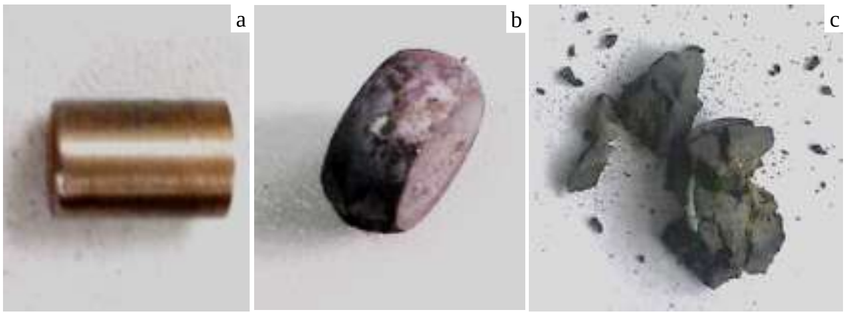

Fig.1 Specimens of WCu alloy for hot compression (a), after hot compression (b), and tungsten skeleton after hot compression (c)

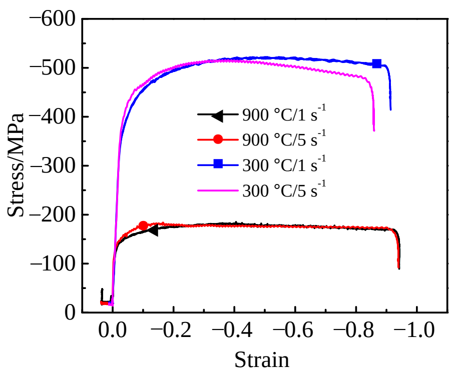

Fig.2 Stress-strain curves of WCu alloy during hot compression

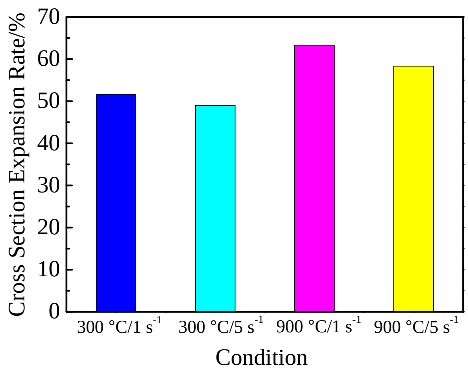

Fig.3 Cross section expansion rate of WCu alloy after hot compression

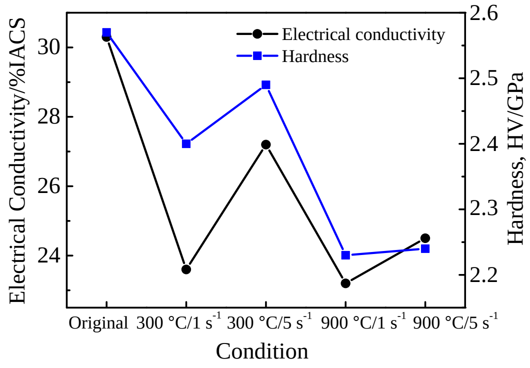

Fig.4 Electrical conductivity and hardness of WCu alloy after hot compression

is the results of the dynamic recovery and recrystallization of copper phase so that no obvious deflection of tungsten particles appear at higher temperature[9]. It is also found that the tungsten particle fragmentation during hot compression follows the fractal distribution and demonstrates a multi-fractal behavior[12].

2.3 Mechanical behavior of W skeleton under hot compression

Considering of the almost useless on strength of WCu alloy with the melting copper phase at elevated temperature, hot compression behaviors of tungsten skeleton were studied at 1100 ℃. Compared with the WCu alloy, the strain rate begins to affect the mechanical behavior of tungsten skeleton a little during hot compression, as shown in Fig.6. The strength of tungsten skeleton under 1 s^{-1} is higher than that under 5 s^{-1}, while the two stress-strain curves are similar and little plastic deformation is found.

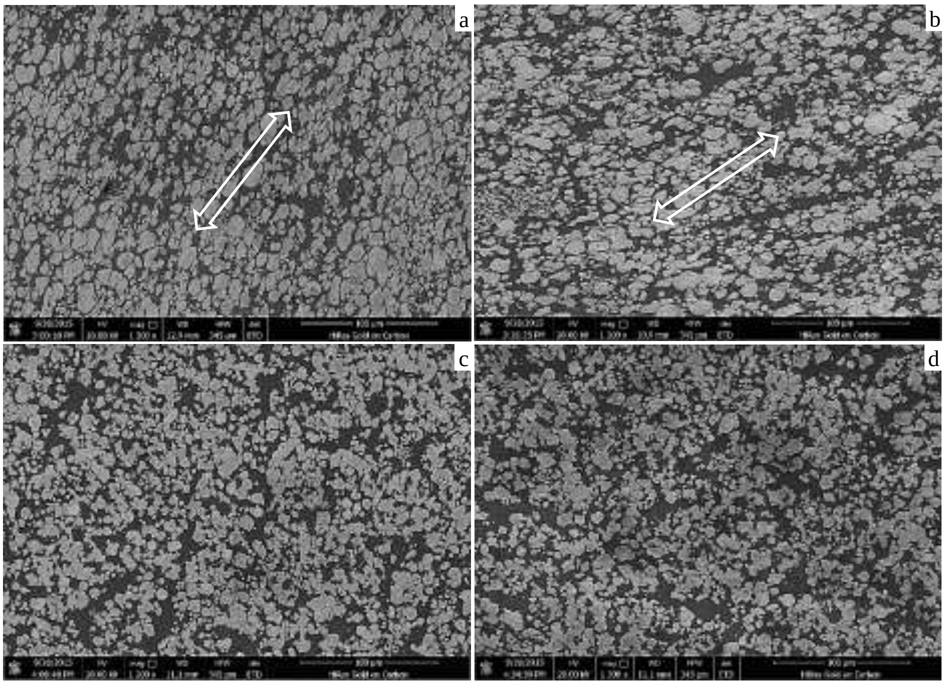

Fig.5 Microstructures of WCu alloy after hot compression with different temperatures and strain rates: (a) 300 ℃/1 s^{-1}, (b) 300 ℃/5 s^{-1}, (c) 900 ℃/1 s^{-1}, and (d) 900 ℃/5 s^{-1}

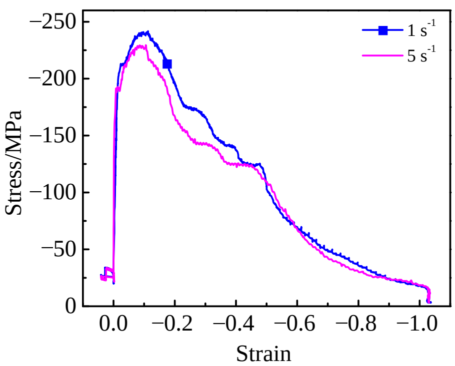

Fig.6 Stress-strain curves of W skeleton during hot compression at 1100 ℃

The fracture morphologies of tungsten skeleton after hot compression at 1100 ℃ are exhibited in Fig.7. Smooth and small grains distribute throughout every tungsten particle on the fracture surfaces under the strain rate of 1 s^{-1}, and cracks appear on the tungsten particles under the strain rate of 5 s^{-1}, as shown in Fig.7a and 7c, while the internal morphology is still inter-crystalline cleavage fracture of tungsten particles[13], as shown in Fig.7b and 7d. The features of fracture surfaces are ascribed to the interfaces activity of tungsten grains at elevated temperature, and faceted boundaries are replaced by the round grains of tungsten particle substructure because of the activated sintering[4, 14]. The sintering necks become disconnected slowly

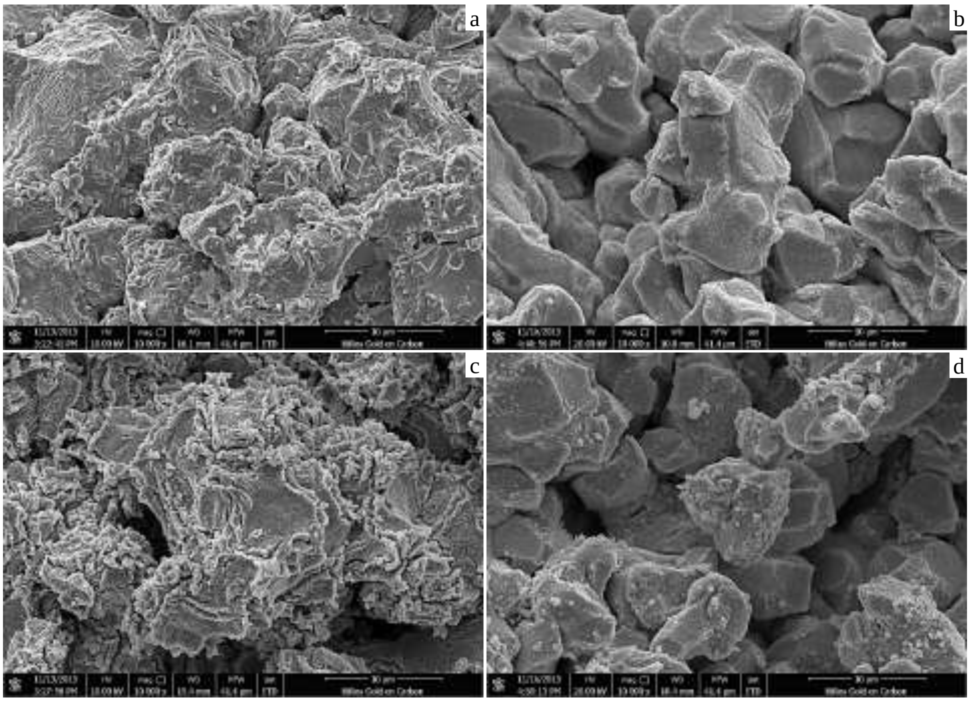

Fig.7 Morphologies of W skeleton after hot compression at 1100 ℃: (a) fracture morphology, 1 s^{-1}; (b) internal morphology, 1 s^{-1}; (c) fracture morphology, 5 s^{-1}; (d) internal morphology, 5 s^{-1}

under the strain rate of 1 s^{-1} so that activated sintering takes place on tungsten grains, cracks and ductile tear appear at the interfaces of tungsten grains under higher strain rate of 5 s^{-1}. The mechanism of fracture of tungsten skeleton will be studied further more later.

3 Conclusions

1) The stress-strain behaviors of WCu alloy under hot compression is mainly affected by the temperature compared with the strain rate. The strength of W skeleton declines under the higher strain rate load at elevated temperature.

2) The strength, hardness, electrical conductivity of WCu alloy after hot compression decrease with the increase of temperature, especially under the higher strain rate. Damage appears at WCu alloy under large deformation.

3) Plastic flow appears at the WCu alloy during hot compression at 300 ℃ for the plastic deformation of copper phase, and the tungsten particles are mostly homogeneous at 900 ℃ because of the recovery and recrystallization of copper phase. The deformation and fracture of W skeleton at 1100 ℃ are attributed to the activity of grains interfaces.

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热压缩下 WCu 合金的力学性能及组织

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摘　要：考虑到高温下的应用，对 WCu 合金及钨骨架施加热压缩载荷，分析不同温度及应变速率下 WCu 合金的组织及力学行为。结果表明：WCu 合金的应力-应变行为主要取决于温度的变化，热压缩后组织内大部分烧结颈消失，WCu 合金在 300 ℃的热压缩下出现明显的塑性流，而在 900 ℃下钨颗粒基本均匀分布。另外，高应变速率下钨骨架的强度有所减小，不同应变速率下的钨颗粒出现光滑的晶粒及开裂。

关键词：WCu 合金；钨骨架；热压缩；应力；组织

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