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The effect of interface modification on fracture behavior of tungsten fiber reinforced copper matrix composites

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ABSTRACT

W_f/Cu composites, W_f(Ni)/Cu composites and $W_f/Cu_{82}Al_{10}Fe_4Ni_4$ composites were fabricated by penetrating casting method. Bending strength and dynamic compressive strength of the composites were tested. Fracture mode and microstructure were investigated by scanning electron microscope (SEM) and transmission electron microscope (TEM). The result showed that the interface strength of W_f(Ni)/Cu composites and $W_f/Cu_{82}Al_{10}Fe_4Ni_4$ composites were higher than W_f/Cu composites. In W_f(Ni)/Cu composites, nickel plated on the surface of tungsten fibers has diffused into the inner of tungsten fibers, and a large number of tungsten grains and Ni_4W intermetallic compounds appeared within tungsten fibers. In $W_f/Cu_{82}Al_{10}Fe_4Ni_4$ composites, Fe–Ni solid solutions precipitated on the interface between matrix and tungsten fibers, and tungsten has diffused into the Fe–Ni solid solutions. Dynamic compression test showed that the dynamic compressive strength and plasticity of $W_f/Cu_{82}Al_{10}Fe_4Ni_4$ composites were highest among the three kinds of composites.

1. Introduction

As the development of kinetic energy penetrator to high speed, high strength and high density, the demand to mechanical property of the material used in kinetic energy penetrator also increase, so traditional materials are not adapted to new military requirements [1,2]. Composites are composed of two or more kinds of materials reasonably and possess better performance than single materials, therefore many countries start to research kinetic energy penetrator of the composites in recent years [3–5]. Due to the high melting point, high density and high mechanical property of tungsten fiber, it is selected as reinforcement of the new generation of composites fabricated penetrator [6]. California Institute of Technology [7–9] has developed tungsten fiber reinforced Zr-based bulk metallic glass composites, and many research institutions have done a lot of researches in the preparation and mechanical property of the composites. The result indicates that the addition of tungsten fiber will greatly enhance the mechanical property of the composites and change fracture characteristic of the composites. So we selected tungsten fiber as reinforcement of the composites in this paper. Because copper alloy possesses the properties of high density and high strength and W–Cu composites has been successfully used in electronics, military and aerospace fields, copper and its alloy were selected as the matrix of the composites in the research [10–13]. When the reinforcement and matrix of the composites are determined, the interface will be the key to transfer the load effectively. Appropriate interface reaction can effectively improve the wettability, and enhance the composites' interface strength and mechanical properties; but excessive interface reaction can weaken the interface, and reduce the composites' mechanical properties. Because the wettability between tungsten and copper is poor and interface strength is low, the interface of W–Cu composites is modified by means of plating nickel on the surface of tungsten fiber and adding iron and nickel in copper matrix [14,15]. Then the interface strength, dynamic mechanical property and fracture mode of the composites are investigated in this paper.

2. Experimental procedure

Pure copper and $Cu_{82}Al_{10}Fe_4Ni_4$ alloy were selected as matrix of the composites. The tungsten fibers with the diameter of 0.25 mm and 0.5 mm were selected as reinforcement of the composites at three-point bending test and dynamic compression test respectively. After straightening, tungsten fibers were cut into 100 mm long and immersed in 40% hydrofluoric acid to remove the surface oxide film, then they were cleaned by ultrasonic in acetone and alcohol respectively to get pure surface. The prepared tungsten fibers were put straightly into the clean quartz tube and the master alloy was set above the tungsten fibers, then the composites were fabricated by means of penetrating casting method. Three kinds of composites were prepared in this paper. The first is W_f/Cu

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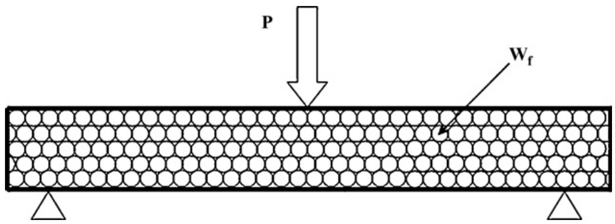

Fig. 1. Tungsten fibers arrangement of three-point bending samples.

composites which is composed of copper and tungsten fibers. The second is W_f(Ni)/Cu composites which is composed of copper and nickel-plated tungsten fibers, on which 5 μm nickel layer was plated. The third is $W_f/Cu_{82}Al_{10}Fe_4Ni_4$ composites which is composed of $Cu_{82}Al_{10}Fe_4Ni_4$ alloy and tungsten fibers. The volume fraction of tungsten fibers is 80% in the three kinds of composites. The samples with the dimension of 5 mm × 5 mm × 35 mm of three-point bending test were made by linear cutting machine. The arrangement of tungsten fibers in the composites is shown in Fig. 1. The size of impacting samples is Φ4 mm × 4 mm. The dynamic compression test was performed by Split Hopkinson pressure bar (SHPB) at the strain rate of $2000\,s^{-1}$. To ensure the reliability of test data, each group test would be done at least three times. The interface reaction of the composites was analyzed by transmission electron microscope (TEM), and the fracture of the composites was analyzed by scanning electron microscope (SEM).

3. Results and discussion

3.1. Microstructure observation

SEM microstructure at interface in W_f/Cu composites is shown in Fig. 2a, from which obvious gaps and micropores can be observed. SEM microstructure at interface in W_f(Ni)/Cu composites is shown in Fig. 2b, from which recrystallization of tungsten fibers can be observed. The size of tungsten grains generated by recrystallization are about 10 μm. Fig. 2c is the TEM microstructure of the area among the tungsten grains shown in Fig. 2b. There exists lots of grains in Fig. 2c, and the selected area electron diffraction pattern (SADP) insert shows the grains are Ni_4W intermetallic compounds. SEM microstructure at interface in $W_f/Cu_{82}Al_{10}Fe_4Ni_4$ composites is shown in Fig. 2d, from which interfacial reaction products on the surface of tungsten fibers can be observed, and energy disperse spectroscopy (EDS) insert shows tungsten, iron and nickel are the major elements of interfacial reaction products. Fig. 2e is TEM microstructure of $W_f/Cu_{82}Al_{10}Fe_4Ni_4$ composites at interface, the SADP insert indicates that the interfacial reaction products are Fe–Ni solid solutions. The EDS and SADP analysis indicate that tungsten diffuse into Fe–Ni solid solutions on the interface of $W_f/Cu_{82}Al_{10}Fe_4Ni_4$ composites. At the same time, there also exists other phase in matrix as shown in Fig. 2f, and the SADP insert indicates that is Al_3Ni intermetallic compound.

3.2. Test of interface strength

The interface strength of the composites is tested by means of three-point bending test. Fig. 3 is the bending stress-displacement curves of the three kinds of composites. The result indicates that bending strength of W_f/Cu composites is lowest, while that of $W_f/Cu_{82}Al_{10}Fe_4Ni_4$ and W_f(Ni)/Cu composites are obviously higher. As shown in Fig. 4a, copper is completely peeled from tungsten fibers and the surface of tungsten fibers keep integrally, which indicate that the fracture of W_f/Cu composites occurs at the interface between matrix and tungsten fibers. While the fracture of $W_f/Cu_{82}Al_{10}Fe_4Ni_4$ and W_f(Ni)/Cu composites occur within tungsten fiber as shown in Fig. 4b and c. The result indicates that

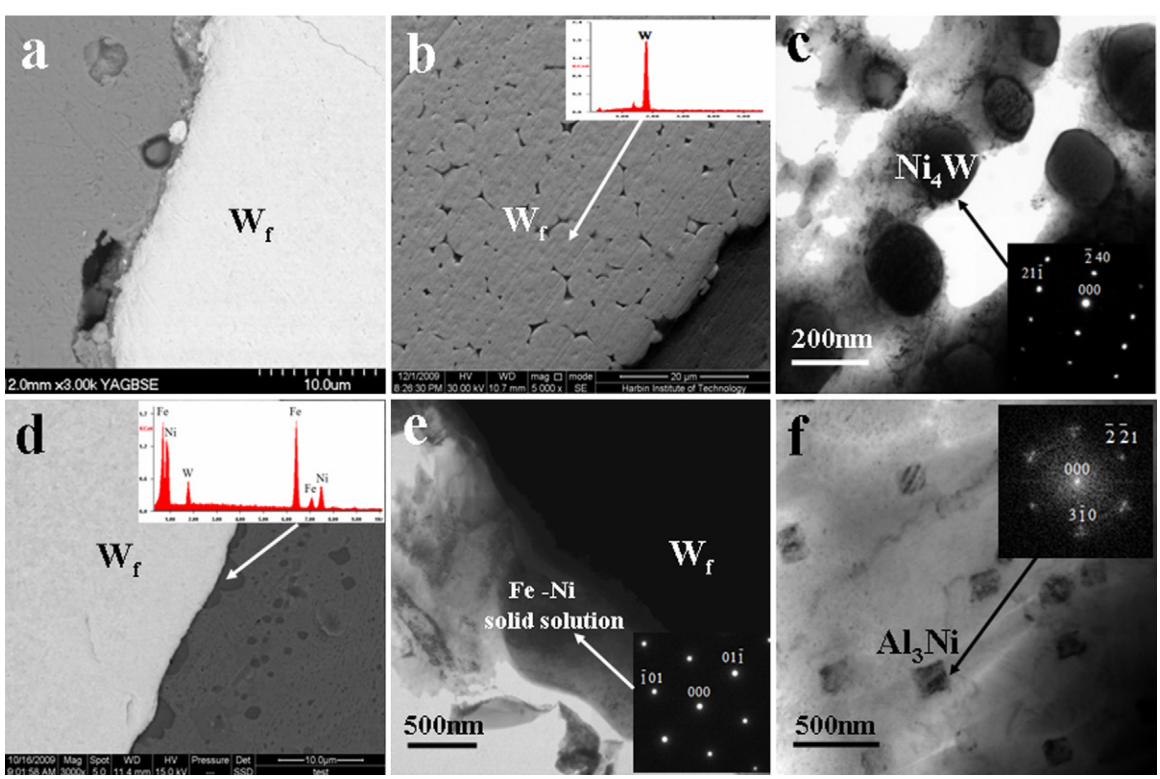

Fig. 2. Microstructure of the three kinds of composites. (a) SEM image at interface in W_f/Cu composites. (b) SEM image at interface in W_f(Ni)/Cu composites. (c) TEM image of the area among the new generation tungsten grains shown in (b). (d) SEM image at interface in $W_f/Cu_{82}Al_{10}Fe_4Ni_4$ composites. EDS insert shows the elements of interfacial reaction product. (e) TEM image at interface in $W_f/Cu_{82}Al_{10}Fe_4Ni_4$ composites. SADP insert shows interfacial reaction product is Fe–Ni solid solution. (f) TEM image of $W_f/Cu_{82}Al_{10}Fe_4Ni_4$ composites in matrix. SADP insert shows Al_3Ni intermetallic compound exists in matrix.