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Infiltrated W–Cu composites with combined architecture of hierarchical particulate tungsten and tungsten fibers

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ABSTRACT

In this article, novel W–Cu composites reinforced with topologically-inserted tungsten fibers (W_f) have been fabricated by hot-press sintering and infiltration method. By pre-sputtering of ~100 nm thick chromium layer onto the surface of W_f, the contiguity or connectivity between W_f and neighboring tungsten particles (W_p) or Cu after sintering and infiltration was enhanced. Combined SEM, TEM and STEM techniques confirmed that the intact interfaces of W_f/W_p and W_f/Cu free from precipitates, impurities and porosities would provide desirable strength and ductility. Further mechanical tests also validated its superior compressive strength and plasticity at various temperatures, together with significantly improved tensile strength (by 23.6%) and hardness (by 9.3%) for the W–Cu composite after reinforcement with Cr-coated W_f, which promotes the engineering application of the composite greatly.

1. Introduction

Tungsten–copper (W–Cu) composites are appropriate candidates in power and nuclear engineering applications such as high-voltage electric contacts, arcing resistant electrodes and deviator plates for fusion reactors, benefiting from the high thermal and electrical conductivity of Cu combined with the wear resistance and refractory characteristic of W. However, the inherent mutual immiscibility, as well as the large discrepancy in density, melting point and coefficient of thermal expansion between W and Cu usually results in weak interface bond strength [1,2]. To date, the predominant techniques for the production of W–Cu composites are through the infiltration of a tungsten skeleton with copper melt [3] and liquid phase sintering [4]. Besides, minor addition of nickel as the sintering activator can improve the wetting and adhesion of W and Cu [5]. It should also be noticed that the strength of various composites has been successfully improved using fiber reinforcement [6–8], including the ultrahigh-strength of bulk metallic glasses further enhanced through addition of tungsten fibers (W_f) [9,10]. Consequently, it can be predicted that the infiltrated W–Cu composites would be strengthened by topologically-inserted W_f to withstand the enduring impact or friction during high-frequency switching.

The addition of W_f into W–Cu composites would introduce two kinds of new interfaces, i.e. the interface between W_f and neighboring tungsten particles (W_p), and the one between W_f and Cu. Generally, the fiber/matrix bonding or a strong interaction is required to ensure an appropriate transfer of stresses and satisfactorily physical properties [11]. According to previous simulation and experimental work [12,13], it has been proved that the damage induced crack initiated from the vertex of W grains and grew along W/Cu interfaces, then propagated into the Cu phase. Therefore, in order to increase the critical bonding strength between W_f and W_p in the target composites, chromium (Cr) can be selected as the bonding activator because Cr forms an isomorphous system with W at both liquid and solid state with bcc structure [14]; furthermore, it has been demonstrated that the addition of Cr resulted in a solid solution transition layer among W_p and improved the sinterability of W_p [15]. In this regard, W–Cu composite reinforced with Cr-coated W_f was fabricated by hot-press sintering and liquid infiltration routes; the traditional infiltrated W–Cu composite and the composite reinforced with uncoated W_f were also prepared for comparison. The resulted microstructure and mechanical properties of these composites were systematically investigated.

2. Materials and methods

W powders (4–6 μm, purity >99.8 wt.%), 15 wt.% Cu powders (50–70 μm, purity >99.8 wt.%), and minor trace addition of nickel (Ni) powders (25–30 μm, purity >99.9 wt.%) as the sintering activator were blended in a V-type mixer for 6 h. Commercial W_f networks with the diameter of 40 μm (Fig. 1(a)) were immersed in 20% HF liquor to remove the surface oxide film, followed by ultrasonic clean in acetone and alcohol respectively. Then, the surface Cr coatings on the W_f were deposited by a closed field magnetron sputtering ion plating system to be

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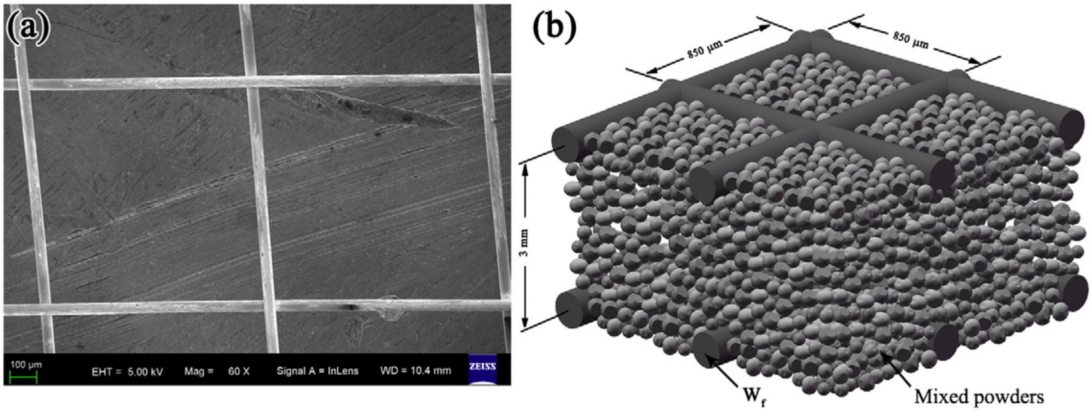

Fig. 1. SEM image of the commercial W_f network (a) and schematic architecture of the composite (b).

~100 nm thick according to a synchronously-placed chip of silicon as reference. The W_f networks were assembled straightly into the pre-mixed powders with an average depth distance of 3 mm layer by layer to prepare the composite compacts, as illustrated in Fig. 1(b). The samples were firstly hot-press sintered under a uniaxial pressure of 20 MPa for 30 min at 970 °C, then held at 1300 °C for 2 h, and finally cooled to room temperature with furnace cooling. Subsequently, liquid infiltration route of molten Cu into the sintered performs was carried

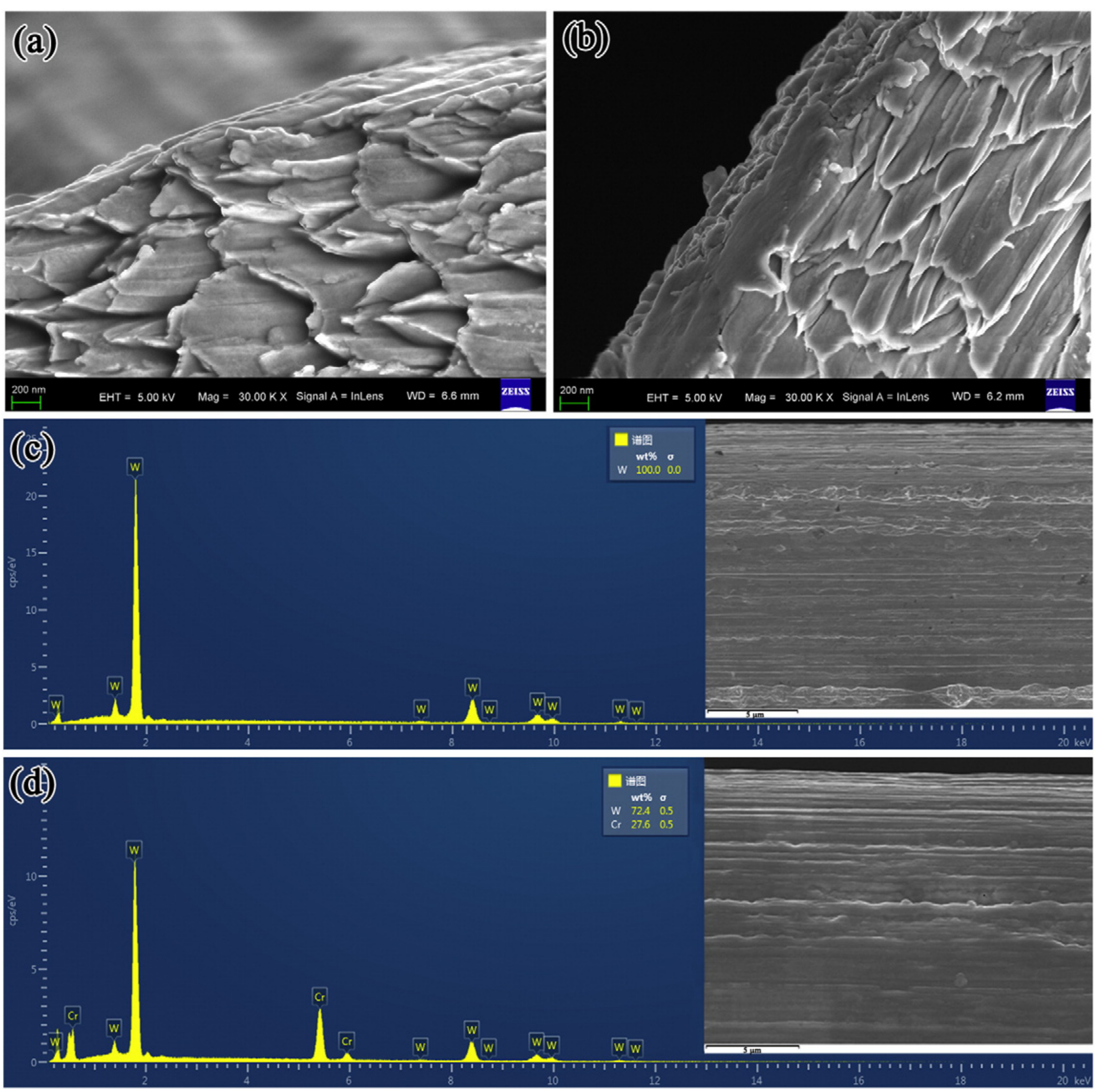

Fig. 2. Secondary electron SEM images of transverse section of the W_f before (a) and after (b) sputtering, as well as the EDS results with inserted surface morphologies of the W_f before (c) and after (d) sputtering.