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Material loss of infiltrated W-10wt.%Cu by alumina particles propelled by a high-velocity-oxy-fuel system

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ABSTRACT

W-Cu Composites were fabricated by three powder particles with average particle sizes of 2, 6 and 8 μm at compressing pressure between 350 and 550 MPa. Sintering and infiltration rout was employed as fabrication method. Erosion test was done by means of HVOF at 2400 °C at the velocity of 1200 $m.s^{-1}$. The obtained results were discussed based on microstructure evolution, conductivity and hardness. It was found that, there is an indirect relation between erosion resistance and electrical resistivity. Also, composites prepared by fine particles exhibit higher erosion resistance due to higher hardness. Studied composites show erosion loss ratio in the range of 65–95%.

1. Introduction

Alumina particle erosion and high temperature are two main factors which affect the performance of materials used in hard condition application such as rocket nuzzles [1,2]. W-10wt.%Cu composites are an interesting candidate to use in these applications due to high melting point and high strength of tungsten as well as high conductivity of copper phase [3]. Since the W-10w.%Cu composites are produced by powder metallurgy and infiltration of molten copper through tungsten porous skeleton [4], enhanced knowledge of infiltrated W-Cu composites response to actual erosive service conditions is critical key to the design of fabrication process and parameters, such as composition, compaction pressure, and sintering and infiltration temperature. Regardless the studies carried out by same co-authors [5–7], the erosion of tungsten-copper composites certainly at temperatures above 2000 °C has received no coverage in the literature due to difficult erosion laboratory test setups. Theretofore, high temperature erosion behavior of tungsten base alloys and composite was covered by means of conventional methods such as oxyacetylene flame jet [8], plasma jet [9] and even electrical arc reaction [10] which not be able to establish exalt erosion condition on the test specimen. Generally, erosion resistance of materials is a function of several parameters such as materials parameter (i.e. hardness, toughness and etc.) and test parameters (i.e. incident velocity, angle, particle morphology and etc.) [11]. In this paper, for first time, the erosion behavior of W-10 wt% composites was studied against impact of high velocity alumina particles blasted by high velocity oxygen flame (HVOF) at 2400 °C and the velocity about 1200 $m.s^{-1}$.

2. Experimental procedure

Three tungsten powders with average particle sizes of 2, 6 and 8 μm were used as initial powders (Fig. 1a). 0.1 wt% Ni was added to powders as sintering activator. Powder mixture compacted at pressures in the range of 350–550 MPa by Cold Isostatic Press (CIP). Green compacts sintered at 1200–1550 °C in hydrogen atmosphere to reach skeleton density of 80pct. Sintered skeletons infiltrated by molten copper at 1300 °C for 2 h in hydrogen atmosphere (Fig. 1b). The process parameters are given in Table 1. Sintered and infiltrated densities were measured according ASTM B328 standard. SEM and EDS were used to studying microstructure details. Samples resistivity was determined using the four-point probe C.A6250 ohmmeter. The hardness of composite was measured by Brinell hardness method. Erosion test was carried out by means of alumina entrained HVOF at temperature of 2400 °C and particles velocity of 1200 $m.s^{-1}$ (Fig. 2a,b). Erosion loss ratio was calculated as the ratio of volume loss to initial volume of samples.

3. Results and discussion

The results of density measurement after compacting, sintering and infiltration are presented in Table 1. SEM micrographs from fracture surface of three specimens compacted at 550 MPa, are illustrated in Fig. 1b. The W grains appear light and the copper phases appear darker in these pictures. Also, inter-granular and trans-granular fracture of tungsten skeleton is indicated in these images. Tungsten particles mainly have demonstrated inter-granular brittle fracture. W-W inter-

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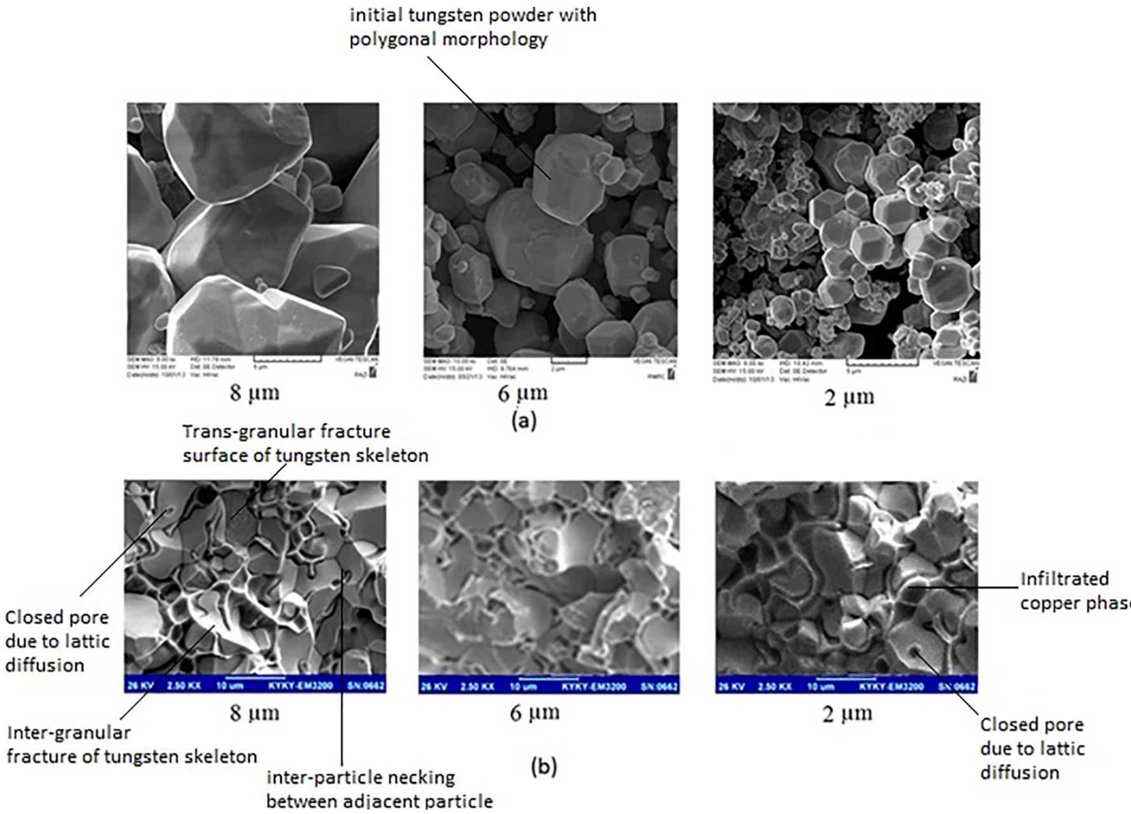

Fig. 1. (a) SEM micrographs of initial powders, (b) fracture surface of infiltrated composite at 550 MPa.

Table 1
Fabrication parameter, measured density, electrical resistivity and hardness of samples.

Sample	Compressing pressure (MPa)	Sintering temperature (°C)	Green density (%)	Sintered density (%)	Electrical resistivity (μΩ.mm)	Hardness (HB)
2W450	450	1200	73	79	353	269
2W550	550	1200	75	78	403	268
6W450	450	1400	76	80	470	229
6W550	550	1400	79	79	460	240
8W350	350	1550	75	79	450	265
W8550	550	1550	82	82	335	262

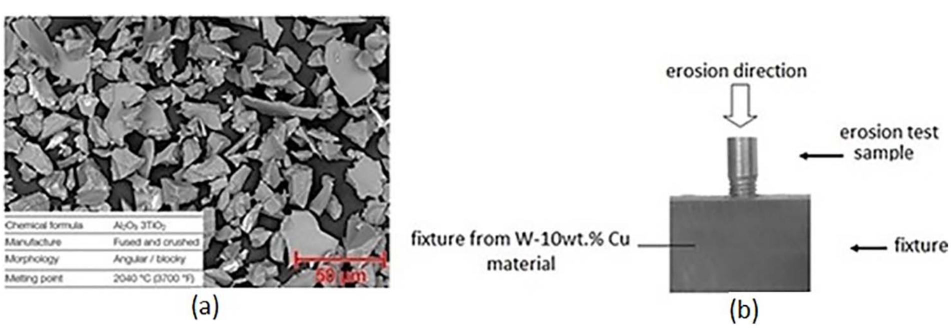

Fig. 2. (a) alumina particles used in HVOF erosion test and (b) the geometry of erosion test sample.

granular fracture is intimately related to the so-called complete and incomplete wetting of tungsten-tungsten boundaries by the molten copper [12]. Low W-W interfacial strength can be attributed to hydrogen absorption and formation of some closed pores (Fig. 1b). The only active diffusion mechanisms for sintering of tungsten can be surface and grain boundary diffusions [13]. The lattice diffusion of atoms from the grain boundary to the neck allows the boundary to act as a site for vacancy annihilation [14]. By this sintering mechanism, a central pore formation between two particles occurs. The other tungsten surface, prominent in Fig. 1b, is a typical river pattern indicative of cleavage or trans-granular fracture.

The measured amounts of electrical resistivity and hardness of specimens are presented in Table 1. As illustrated, electrical resistivity of composites is increased in the sequence of 2 μm → 8 μm → 6 μm. Since the main microstructural features will be determined during sintering stage, it can be said that inter-particle contact quality has an important role in physical properties of infiltrated composites. Infiltration efficiency as well as connectivity of copper phase is two other effective parameters. The electrical conductivity of sintered tungsten skeleton is related to inter-particles contact area per each particle. It

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