



Cathode spot movement on a continuous carbon fiber reinforced Cu matrix composite in vacuum



Chengyu Zhang^{a,*}, Yiwen Liu^a, Zhimao Yang^b, Lujie Chen^c, Shengru Qiao^a

^a Science and Technology on Thermostructural Composite Materials Laboratory, Northwestern Polytechnical University, Youyi West Road, Xi'an 710072, China

^b School of Science, Xi'an Jiaotong University, Xi'an 710049, China

^c Singapore University of Technology & Design, 138682 Singapore, Singapore

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ABSTRACT

The cathode spot movements on a carbon fiber reinforced copper matrix composite (C_f/Cu) were investigated by a scanning electron microscope and a digital high-speed video camera. The composite was prepared by infiltrating a Cu alloy doped with Ti and Cr into a porous carbon/carbon composite in vacuum. It is found that the carbon fibers have a higher ability to withstand the vacuum arc erosion than the Cu matrix. The cathode spot walks randomly on the matrix, rather than on the carbon fibers. The cathode spots are restricted on the Cu matrix in C_f/Cu. The directional movement in the high-speed images is caused by the restricted random walk of the cathode spots. A gradient distribution in the size and density of the cathode spot is present on the Cu matrix. The average arc spreading velocity is estimated to be about 0.36 m/s and the transient arc spreading velocity is in the range of 0.12–0.7 m/s.

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1. Introduction

Carbon fiber reinforced copper matrix composites (C_f/Cu) are expected to be used as electronic components and wall surface shields in fusion devices [1–4], due to the unique combination of its physical and chemical properties. Generally, the mass loss and property degradation of the materials mainly result from arc erosion, during which the cathode spots move on the surface, when the composites are faced to plasma or electric arc [5]. Without an external magnetic field, the cathode spots move stochastically on the cathode surface. A spot stays at one place for a short time and then jumps to another place. The direction of each jump is normally random [6]. The microstructure of the materials has apparent influences on the characteristics of cathode spot motion. Rao et al. investigated the arc velocity and erosion rate of pure Cu with different grain sizes [7,8]. It is found that the arc erosion values measured on the fine-grained Cu showed higher arc velocities and lower erosion rates, compared with copper cathodes with coarse grains. Furthermore, the craters formed on the fine-grained Cu were smaller than those formed on conventional Cu. Our previous works show that a sub-directional motion of cathode spots could be observed on an amorphous Cu–Zr–Ti alloy and could not be found

on common crystalline materials [9]. Cathode spots can directionally move a long distance on a nanostructured CuCr alloy at a higher velocity, whereas, the cathode spots walk randomly on a coarse crystalline CuCr alloy with a lower velocity [10]. On carbon composites reinforced by continuous carbon fibers (C/C), the cathode spot motion can be conducted by the architecture of carbon fibers in the C/C composites [11]. The cathode spot motion is restricted on the matrix, rather than on the carbon fibers. The cathode spots move along the direction of the carbon fibers in the C/C and change their moving direction when they meet the end of the carbon fiber and the fiber cross-point. It suggests that the properties of the C_f/Cu composites should be improved significantly if the carbon fiber can adjust the cathode spot movement. Therefore, the characteristics of the cathode spot movements on the C_f/Cu were investigated by a high-speed camera and a scanning electron microscope (SEM). Meanwhile, the cathode spot movements on a commercial Cu/C composite, prepared by impregnating the Cu into packed graphite powders under the pressure, were also studied to reveal the effects of the carbon fiber on the cathode spot movement. In addition, the average velocity of the spots was estimated.

2. Experimental

C_f/Cu composites, investigated in the works, were prepared by a vacuum infiltration technique. To improve the wettability between the carbon fiber and Cu matrix, a Cu alloy containing Ti and

* Corresponding author. Tel./fax: +86 29 88492084.

E-mail addresses: cyzhang@nwpu.edu.cn, ccyzhang@163.com (C. Zhang).

Cr were used. Moreover, that modification of the wettability involves a chemical reaction of the doping alloying element with the carbon fibers. The reaction definitely consumes the carbon fibers and degrades the properties of the composites to some extent. To avoid the shortage, a porous carbon/carbon (C/C) composite, rather than bare carbon fibers, was applied to prepare the C_f/Cu . For the porous C/C, the carbon matrix was coated on the fibers by pyrolyzation of the infiltrated thermosetting phenolic resin. During infiltration of the melted alloy, the doped Ti or Cr could react with the carbon matrix. Hence, the carbon fiber could keep intact. The detail preparation processes can be found in Liu's work [12]. To reveal the characteristics of the cathode spot movement on the C_f/Cu , a commercial Cu/C were also used, whose content of Cu is about 46.3%. Cu/C was prepared by powder metallurgy, in which the blend of Cu and graphite powders was hot pressed in vacuum.

The specimens, cut from the prepared materials, were ground using sand papers with the SiC grain size from 6 μm down to 0.25 μm , and then polished using silk. After polishing, the samples were heated to 120 $^{\circ}C$ in a vacuum oven until they were taken out and mounted into the vacuum chamber as the cathodes, shown in Fig. 1. The base pressure of the vacuum chamber was less than 1.0×10^{-3} Pa. A capacitor C of 0.5 μF , connected to the vacuum gap via a resistor R_1 (0.6 k Ω), was charged to a voltage of ~ 9.6 kV dc. The cathodes attached to the sample holder could move upwards and downwards, the above anode was made of a pure tungsten needle. The currents were fed to the arc discharge by coaxial leads. The arcs were ignited by driving the cathode upwards to the anode at a velocity of 0.2 mm/min, discharges occurred when the anode–cathode gap was less than 1 mm.

The arc current and discharge duration were recorded by a Tektronix TDS-2024B digital memory oscilloscope, whose bandwidth was 200 MHz. A digital high-speed video camera, Phantom V9, with a Nikon Micro-105 mm lens, was settled outside a window of the chamber to record the cathode spot motion between the electrodes. The applied resolution of the camera was 192×64 dpi. The magnification was 32 μm per pixel. The exposure time was set as 5 μs and the exposure interval was 50 μs . After a single discharge, the samples were taken out. The morphology of the composites before and after the discharges was observed using a SEM (HITACHI S-4700, Hitachi, Japan).

3. Results and discussion

3.1. Microstructure of C_f/Cu

Fig. 2 shows the microstructures of both C_f/Cu and Cu/C composites. The carbon fibers (dark phase) can be found in the Cu matrix (light phase) for C_f/Cu and the Cu phase occupies the space

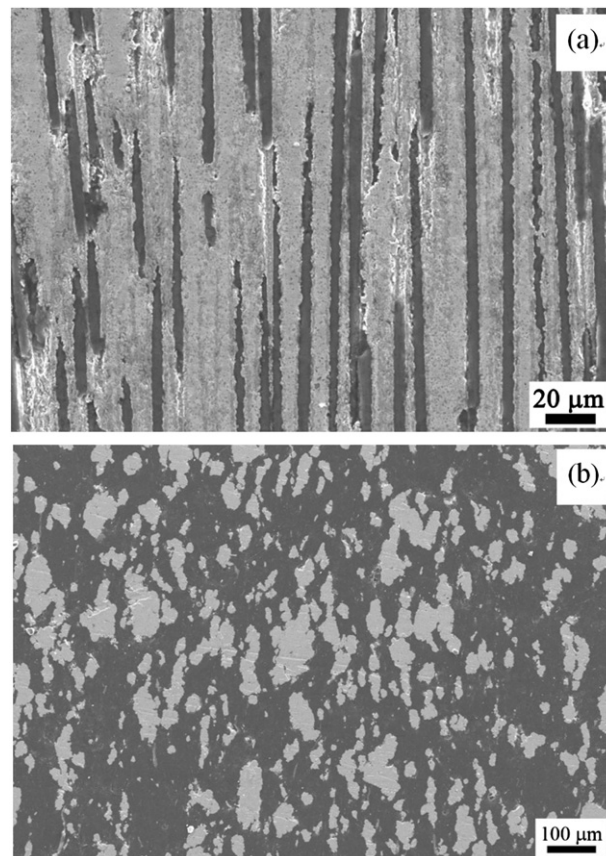


Fig. 2. Microstructure of the investigated composites. (a) C_f/Cu , (b) Cu/C.

among the carbon fibers, show in Fig. 2(a). Both carbon fibers and Cu phase are continuous in the C_f/Cu composite. Previous results indicated that Ti and Cr mainly distributed along the interface of the carbon fiber/Cu matrix. A 1–3 μm thick TiC reaction layer was determined at the carbon fiber/Cu matrix interface [12]. The presence of TiC could reduce the wetting angle between the melted Cu alloy and the carbon fibers. Therefore, a good interfacial bonding between carbon fibers and Cu matrix could be reached by addition of Ti and Cr. However, the copper phase is distributed in form of 'island' within the graphite matrix for conventional Cu/C, seen in Fig. 2(b). Due to the insolubility and rather poor wettability between C and Cu up to very high temperatures [13], it is rather difficult to produce good bonding between the graphite and graphite.

3.2. Arc current

Fig. 3 shows the current versus the discharge duration curve of C_f/Cu composite. It is found that the arc currents gradually degraded during arcing where the peak arc current is about 16 A. The arcs extinguish when the arc current becomes smaller than a critical value, called 'chopping current' [14]. It can be seen that the chopping current is about 0.8 A, similar to that of pure graphite (0.72 A) [11]. The value is higher than that of C/C composites (0.16–0.31 A), and much lower than of pure copper (2–10 A) [14] and CuCr alloy (4 A) [15]. The chopping current of Cu/C is almost same as that of C_f/Cu . The chopping current is closely correlated with the arc instability [16]. The smaller chopping current indicates a more stable vacuum arc. Therefore, the stability of the arcs on the C_f/Cu and Cu/C composite are superior to Cu alloys and inferior to C/C.

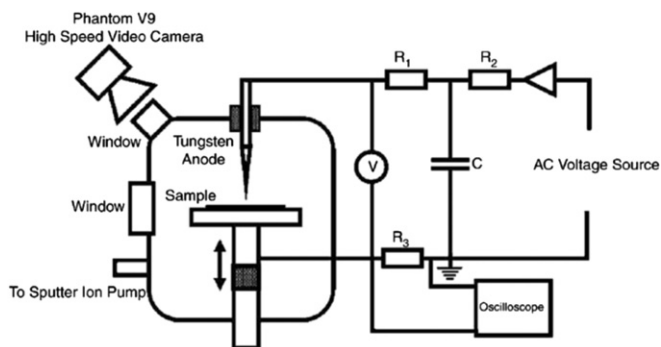


Fig. 1. Schematic illustration of the experimental apparatus. C is a capacitor. R_1 , R_2 and R_3 are resistors.

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