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Effect of direct current and pulse plating on the EDM performance of copper-zirconium diboride composites

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Abstract: Direct current and pulse plating of copper-zirconium diboride (ZrB_2) composites were studied and the effects of current density (DC) and pulse duty cycle (PC) on the EDM performance of the composites were investigated. With increasing current density, the effect of grain refinement on the electro-discharge machining (EDM) performance of the composites compensates that of the decrease of ZrB_2 content in the composites, which improves the spark-resistance of the material. Under the same average current density and other experiment conditions, a lower duty cycle yields better EDM performance probably because more ZrB_2 particles are incorporated in the composites in this condition. However, at a still lower duty cycle (10%), the particle agglomeration and the microcracks of the copper matrix occur, which considerably deteriorate the spark-resistance of the composites.

Key words: composites; pulse plating; electro-discharge machining (EDM); electrode

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1. Introduction

The electrolytic codeposition of inert particles with metals from the plating bath provides a method to fabricate metal matrix composites (MMCs) at low temperature and pressure. By selecting proper particles and metal matrix and controlling deposition conditions, composites with desirable properties can be obtained. The first application of an electrodeposited composite coating was the Ni/SiC coating used as wear-resistant improvement in the Wankel engine by Metzger *et al.* in 1970 [1]. Over the past decades, composite coatings with various functions have been developed. Wear-resistant coatings have attracted most investigators attention. In these investigations, the particles used are usually SiC, Al_2O_3, WC, and diamond, and the elements of the metal matrix are Ni, Cr, and Co [2-5]. These kinds of particles and others, such as, Cr_3C_2, SiO_2, and ZrO_2, have also proved to be capable of enhancing the anti-corrosion and anti-oxidation properties of the coatings [6-8]. Composite coatings are also used in solving antifriction problems. With the entrapment of particles such as, graphite, MoS_2, and PTFE, composite coatings with self-lubricating or anti-stick properties can be obtained [9-11].

This study extends the application of electrodeposited composites to a new field, namely electro-discharge machining (EDM). EDM is used extensively in manufacturing injection mould cavities, which generally is an expensive and time-consuming process. Typically, the major cost and time component of EDM comes from the manufacture of electrodes, which may account for over 50% of the total machining costs [12]. From the beginning of the 1990s, attempts to apply rapid prototyping (RP) and copper electroforming technology to fabricate EDM electrodes more quickly and economically have been made [12-16]. In the above investigations, the main problem that limits the application of electroformed copper electrodes is the relatively higher tool wear ratio (TWR), which leads to electrode breakage and the failure of the EDM process. To solve this problem, a kind of ceramic particle, that is, ZrB_2, is selected to enhance the spark-resistance of electroformed copper electrodes in the present study. ZrB_2 is selected as the second phase of the composite for the reason that it has a metallic-type of electrical and thermal conductivity as well as excellent thermal shock resistance. This article presents the effect of deposition conditions, that is, direct current (DC) and pulse current (PC), on the EDM performance of $Cu\text{-}ZrB_2$ composites.

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2. Experimental

The plating bath for electrodeposition of Cu-ZrB_2 composites was copper nitrate solution with addition of ZrB_2 powder, typically 40 g/L. The ZrB_2 powder used in this study had an average particle size of 3 μm. The electrodeposition was performed in a cuboid plating cell and the powder was kept in suspension by using the 'plate-pumper' method of agitation [17]. The substrates were copper plates that were mechanically and chemically polished and cleaned before deposition.

The composition of the plating solution and the plating parameters are as follows: $Cu(NO_3)_2 \cdot 3H_2O$, 400 g/L; $CuCl_2$, 0.4 g/L; additive agent, 10 ml/L; ZrB_2, 40 g/L; temperature, 25°C; current density, 2-8 A/dm^2; duty cycle, 10%-90%; pulse frequency, 500 Hz.

Scanning electron microscopy (SEM, JSM-6360LV) and optical microscopy (Olympus MX40) were used for the study of the surface morphology and microstructures of the deposits. The composite deposits were analyzed chemically (wet method) to determine the percentage of ZrB_2 incorporated in the deposits.

After deposition, the composites were sliced together with the copper substrates by a wire-cut EDM machine to the dimension of 10 mm×10 mm, and then soldered as tips to copper rods, with the machining surface polished. The electrode experiments were performed on a Sodick A50R Die Sinking EDM machine using a tool steel workpiece, NAK80. The EDM parameters used in the experiments were as follows: discharge ignition voltage 180 V, peak current 6 A, pulse duration 60 μs, duration of interval 20 μs, and negative polarity. Material removal rate (MRR) and TWR were calculated from the measured machining time and the respective weights of the electrode and the workpiece, before and after the EDM test.

3. Results and discussion

3.1. Effect of current density (DC) on the EDM performance of Cu-ZrB_2 composites

As shown in Fig. 1, increasing the current density increases MRR and decreases TWR of the electrode. In fact, current density can have two different effects on the EDM capacity of these composites. On the one hand, it can change the microstructure of the copper matrix of the composites, which in turn alters the coating spark-resistance. Fig. 2 shows the SEM micrographs of the surface of as-plated Cu-ZrB_2 composite coatings deposited at 2 and 5 A/dm^2 respectively. Obviously, the coating plated at 5 A/dm^2 has a smaller crystalline microstructure than that of the coating treated at 2 A/dm^2. This result may be attributed to the higher cathode overpotential under a high current density condition, which improves the nucleation rate of electrodeposition. The grain refinement can contribute to the improvement of spark-resistance of the composites and lead to low TWR.

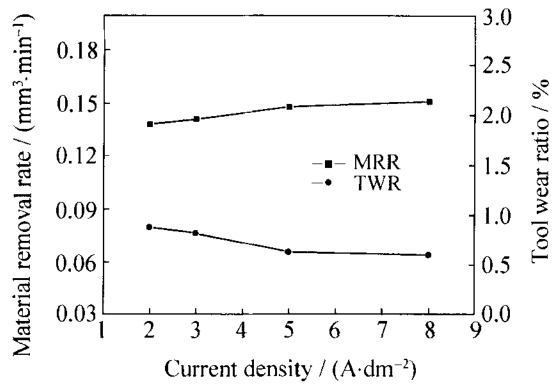

Fig. 1. Effect of current density (DC) on the MRR and TWR of Cu-ZrB_2 composites.

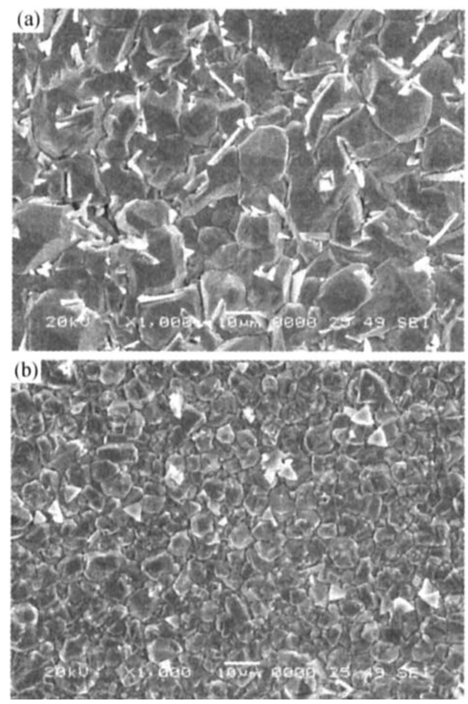

Fig. 2. SEM micrographs of the surface of as-plated Cu-ZrB_2 composite coatings deposited at current densities (DC) of 2 A/dm^2 (a) and 5 A/dm^2 (b).

On the other hand, current density can also influence the content of ZrB_2 incorporated in the composites. Fig. 3 depicts the relationship between current density and ZrB_2 content in the composites. It is shown that the amount of codeposited ZrB_2 particles slightly decreases with an increase in current density. This may indicate that the reduction of copper ions occurs under diffusion control and the entrapment of the particles occurs only when the copper ions absorbed on the particles are reduced at the cathode [18-