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Negative impacts of diamond magnetism on the microstructure of co-deposited composites and the effective solution

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Abstract

In a paper, we reported that incorporation of diamond into composite coatings could cause microstructural deteriorations (e.g., roughening the coating surface, coarsening the matrix grain and reducing the mechanical retention of diamond grains in the matrix), and suggested that all the impacts were caused by diamond magnetism resulting from metallic inclusions trapped in it. To confirm this, further microstructural observations were conducted on composites containing diamond particles that experienced different treatments before being planted, i.e., magnetization (strengthening diamond magnetism by a strong magnet) and demagnetization (weakening diamond magnetism by an alternating magnetic field), as well as on composites fabricated in the presence of an external alternating magnetic field in the vicinity of the cathode. It is shown that advance demagnetization treatment reduces the impacts while advance diamond magnetization treatment does the opposite. Moreover, the impacts could be more effectively reduced by superimposition of the external alternating magnetic field which may exert effects not only on demagnetization of the diamond grains, but also on cations' deposition process since the external magnetic field is much stronger than that produced by diamond.

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1. Introduction

Diamond particles are increasingly attracting considerable scientific and technological interest because of their unique mechanical and tribological properties including high hardness, low friction coefficient and inertness to chemical attack [1]. By co-depositing with metal, both fine and coarse diamond particles or polycrystalline diamond particles could be incorporated into metal coatings to form metal-composite coatings that are usually designed for grinding, wear resisting and corrosion resisting [1–5]. It has been reported that the microhardness and wear resistance of a nickel-diamond composite could be about 4.5 and 14 times, respectively, higher than that of a nickel coating without any reinforcement [2]. Moreover, in the past two decades, electroplating of diamond tools has become an accepted industrial production technique [3,5,6]. The diamond-dispersed composite tools are in great demand for processing advanced materials such as grinding and machining superalloys and high performance ceramics, metalworking hardened steel, bi-metals or metal matrix composites, sawing or drilling stone and concrete from huge quarries, shaping wood and laminates, and grinding glass.

From microstructural observation of diamond composite coatings, we found [7] that the incorporation of diamond significantly worsened the microstructure, like coarsening matrix grain, inducing gaps between matrix and diamond, and promoting emergence of nodules, valleys and over-plating cases on matrix surface. We suggested that all the deterioration phenomena were caused by metallic inclusions that were trapped in diamond crystals during their synthetic process. They made diamond grains magnetic during their magnetic separation that was aimed at removing diamond particles containing too many metallic inclusions that would degrade the diamond's properties, particularly the compressive strength and thermal stability. As a result, Lorentz forces were generated due to the electromagnetic interaction between the

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magnetic field induced by the magnetic diamond grains and the electric current (moving cations) during electrodeposition.

Fig. 1 shows the generated Lorentz forces acting on cations that move in the vicinity of a magnetic diamond grain. Fig. 1 (a) and (b) show, respectively, two possible positioning patterns for magnetic poles of the magnetic diamond grain. In Fig. 1 (a), the cations, driven by electrical force F_e, leave anode for cathode. When they move in area above the diamond middle, a Lorentz force F_{ro} is first induced by interaction of electric current and magnetic field (considering the flux density component perpendicular to the ions' moving direction). F_{ro} drives the ions to rotate counterclockwise around the diamond. As a result of the interaction between the rotating movement and magnetic field (another flux density component parallel to F_e but perpendicular to the ions' rotating direction), another Lorentz force F_{re} directing away from the grain—called repelling force—is produced. When the cations move in area below the diamond middle, both of the Lorentz forces—F_{ro} and F_{re}—change to opposite direction because of direction change of the magnetic field. Hence, the ions rotate clockwise around the magnetic grain (driven by F_{ro}) with a decreasing radius (due to the attracting force F_a directing toward the grain). As for Fig. 1 (b) where the two diamond magnetic poles (N and S) swap, similar movement pattern could also be concluded except the different rotating direction. Therefore, illustrations provided in later part of the present article just show the positioning pattern in Fig. 1 (a).

In order to confirm that all the phenomena really arise from diamond magnetism, we investigated the microstructural differences between composites that contained diamond experiencing different treatments. It was found that the reported deterioration phenomena could be worsened by diamond magnetization treatment and be lessened by demagnetization treatment. Furthermore, superimposition of an external alternating magnetic field during the preparation process of the diamond composites was found more effective on eliminating the deterioration phenomena than diamond demagnetization treatment before diamond is planted into the composite. This article reports all the facts and gives explanations.

2. Experiment

The metal matrix of composite coatings investigated in this work was Ni–Co alloy produced from a solution consisting of nickel sulfate (250 g/l), nickel chloride (40 g/l), boric acid (40 g/l) and cobalt sulfate (20 g/l). Boric acid was used as a buffer to maintain the bath pH in the range of 4.4–4.6, i.e., varying from 4.4 at the beginning of the deposition to no more than 4.6 at the end. The solution was kept at a constant temperature of 30 ± 1 °C while ambient temperature fluctuated from 20 to 25 °C. Low temperature was chosen in case water evaporation would cause solution composition varying. Other plating conditions for samples preparation and observation were described in detail in a previous article [7].

All the diamond grains, with an approximately grain size of 100–150 μm (mostly 120–130 μm) and single grain compressive strength of 8–9 kg, were provided by Chinese National Abrasives Corporation. Before being used, the diamond grains were immersed into a mixed acid for 8 h (HNO_3: H_2SO_4 = 1:9), then were rinsed up several times, and finally immersed into distilled water for further treatment.

The diamond was then divided into three parts for comparison purpose. The first part was magnetized (called SM-diamond) by being exposed to a magnet (1.0 T) which was put under the steel-made container. At the beginning, the container (together with the attached magnet) was shaken gently to make the grain layer cover the container bottom as thinly and uniformly as possible so that every grain could be exposed to the magnetized bottom. Afterwards, no vibration was allowed until the magnet was removed in order to prevent the grain's position from changing during the magnetization process.

The second part of diamond was demagnetized (named WM-diamond) by being placed in an alternating magnetic field produced by an electrical coil, an original component of an AC contactor (CJ20A). The coil, consisting of 8750 turns of Φ0.09 mm copper wire, was connected with the domestic power supply (220 V, 50 Hz). The peak magnitude of magnetic

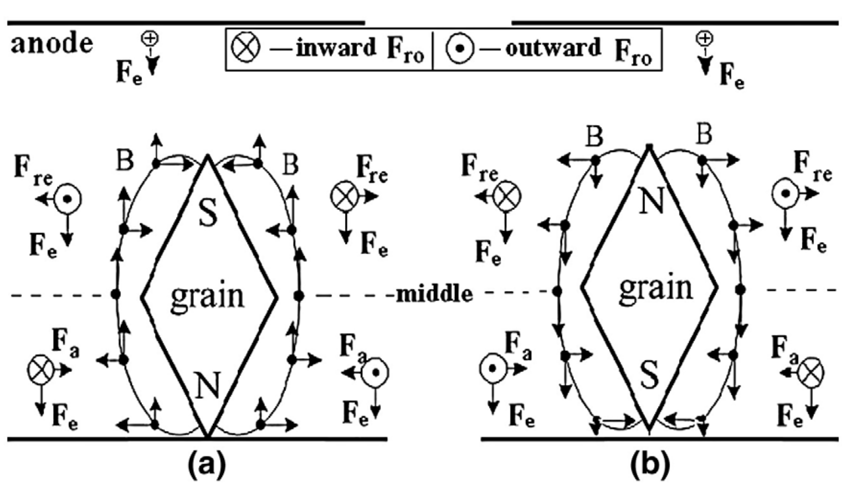

Fig. 1. Lorentz forces acting on cations when they move in the vicinity of a magnetic diamond grain during their deposition process. (a) and (b) show, respectively, two possible positioning patterns for magnetic poles of the magnetic diamond grain. (F_e refers to electrical force, F_a to attracting force, F_{re} to repelling force, F_{ro} to rotating force; ⊙ indicates an outward direction for F_{ro}, ⊗ an inward direction for F_{ro}; ⊕ indicates a cation).