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# Friction and wear behaviors of TiCN coating based on electrical discharge coating

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**Abstract:** Titanium carbonitride (TiCN) coating was prepared on 45# carbon steel by electrical discharge coating (EDC), and the compositions, morphology and microstructure of the coating were studied. In addition, its friction and wear behaviors relative to the physical vapor deposition (PVD) TiN coating were investigated. The results show that the TiCN coating features a thickness of 15 μm with a primary phase of $TiC_{0.3}N_{0.7}$. The wear rates of the two coatings have no clear distinction at low applied loads. However, severe abrasive wear appears in the PVD TiN coating when the applied load exceeds 30 N, while the TiCN coating features better wear resistance. The abrasive wear with coating peelings is found to be the predominant wear mechanism at high applied loads.

**Key words:** electrical discharge coating; titanium carbonitride; mechanical properties; friction and wear

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## 1 Introduction

In the past several decades, cermet coatings have proven to be most effective in increasing the durability of tools [1,2]. There are many fabrication techniques for cermet coatings, such as physical vapor deposition (PVD) [3], chemical vapor deposition (CVD) [4] and laser cladding [5]. Among those coatings, TiC and TiN coatings have been extensively used as wear resistance layers based on their high hardness and excellent tribological performance [6]. As a solid solution of TiC and TiN, titanium carbonitride (TiCN) has attracted more attention in industrial applications due to its excellent mechanical properties of high hardness, low friction coefficient and corrosion resistance [7]. However, conventional CVD and PVD techniques need severe conditions and expensive apparatus [8]. For instance, the PVD and CVD hard coatings are normally processed at high temperatures (500−1000 °C) and possess unsatisfactory thin coating thickness (2−5 μm) as well as low adhesive strength. Furthermore, some poisonous precursors have been used in the CVD technique [9,10].

Electrical discharge coating (EDC) is a revolutionary technique, by which various cermet coatings can be created with an electrical discharge machining (EDM) tool using particular electrodes and dielectric fluid [11]. Compared with CVD and PVD, the superiority of EDC is to prepare hard coatings at room temperature under simple conditions, which are characterized with adjustable thickness and a metallurgical bonding to the substrate. Binary hard coatings such as titanium carbide (TiC) [12] and titanium nitride (TiN) [13] have been created via EDC. Using multi-layer electrodes (MLE) composed of titanium and graphite layers, HWANG et al [14] successfully formed a titanium carbide (TiC) layer on the surface of a nickel workpiece, the effects of Gr layer on the MLE were discussed as well, and the results were compared with coatings prepared by conventional bulk electrode. By using a fluid dielectric oil which was mixed with titanium powder, JANMANEE and MUTTAMARA [15] coated a titanium layer with increased microhardness and few micro-cracks onto a tungsten carbide surface, and discussed the parameters affecting the surface coating.

However, all the studies focus on the fabrication of EDC TiC coating, and few works deal with EDC ternary cermet coatings [16]. Till now, there has been no investigation on the preparation of TiCN coating by EDC, especially on its friction and wear behaviors. In order to investigate the tribological prosperities of TiCN coatings based on EDC, the wear tests sliding against $Si_3N_4$ balls using the ball-on-disc tribometer at different applied loads were carried out. In addition, the comparative wear

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characteristics and wear mechanisms between the EDC TiCN coating and PVD TiN coating were investigated.

## 2 Experimental

### 2.1 Coating preparation

The workpiece material was 45# steel (carbon steel, Chinese standard GB699−88, with dimensions of 20 mm × 20 mm × 5 mm). Before deposition, the substrates were polished to mirror surface and then ultrasonically cleaned in acetone and ethanol three times. The nitrogenous medium consisted of 900 mL ethanolamine ($NH_2$—$CH_2$—$CH_2$—OH) (Tianjin Fuyu Chemical Co., Ltd.) and 100 mL deionized water. 17.5 g potassium chloride (Sinopharm Chemical Reagent Co., Ltd.) was also added to improve the fluidity. The investigated TiCN coatings were prepared by a JXD7125 accurate shaping electrical discharge machining tool. The cuboid smelted titanium was used as the tool electrode. The preparation system includes the tool electrode and substrate, and the ethanolamine solution was placed into a closed container. The optimized EDC conditions are summarized in Table 1.

**Table 1** Deposition conditions for EDC process

| Parameter | Value |
|---|---|
| Polarity | Electrode(+) |
| Reference voltage/V | 60 |
| Pulse duration/μs | 390 |
| Duty factor/% | 50 |
| Discharge current/A | 20−25 |
| Machining time/min | 20−30 |

In contrast, conventional PVD TiN coatings were prepared by a direct current magnetron sputtering (MS) system with a single titanium target (99.95% purity). The substrate was the same as that of the EDC process. The distance between the target and substrate was held at 85 mm, and the target current was 0.3 A. The total flow rate of $N_2$ and Ar gas was set at 30 $cm^3$/min to keep the work pressure at 0.3 Pa.

### 2.2 Characterization and wear tests of coatings

X-ray diffraction (XRD) was performed by an X-ray diffractometer with Cu $K_\alpha$ radiation (D/max-$\gamma$ A10, Rigaku, Japan). The surface and cross-sectional morphologies of coatings were examined by an S−3400N−II scanning electron microscope (SEM) and the microstructure was examined using a transmission electron microscope (TEM) (JEM−2100, JEOL, Japan). The microhardness was tested by an AKASHI MVK−H3 Vickers hardness tester with an indenting load of 1.96 N. Friction and wear tests were performed on a CFT−I tribometer developed by Lanzhou Institute of Chemical Physics, China, and the ball-on-disc configuration was used. In this test, $Si_3N_4$ balls with a diameter of 4 mm and hardness of HV 1800 were chosen as the counterpart, and the reciprocating friction was applied. All wear tests were performed under dry sliding conditions in air at 20−26 °C with a relative humidity of 40%−50%. The profiles of the wear tracks were observed by a Dektak150 profilometer. All the wear samples were cleaned with acetone and then weighed with an accuracy of ±0.1 mg before and after every sliding wear tests. The wear mass loss was then identified by subtracting the remained mass from the original mass. The wear testing parameters are summarized in Table 2.

**Table 2** Tribological test parameters.

| Parameter | Value |
|---|---|
| Normal load/N | 10, 20, 30, 40 |
| Sliding distance/mm | 5 |
| Sliding speed/(m·min$^{-1}$) | 50 |
| Wear time/min | 30 |

## 3 Results and discussion

### 3.1 Microstructure and phase of TiCN coatings

The XRD patterns of two coatings are shown in Fig. 1. It reveals that the as-prepared TiCN coating consists mainly of $TiC_{0.3}N_{0.7}$ phase, and few $Fe_3N$ and $Ti_2N$ phases are also identified. According to the characteristics of EDC process, activated Ti atoms from the electrode react with C and N atoms ionized by the dielectric medium, forming the TiCN coating on the surface of the substrate. $Fe_3C$ comes from the substrate, because the depth of investigation of XRD can reach dozens of micrometers. $Ti_2N$, $Fe_3N$ and TiCN are the reaction products during the EDC processing [17]. As for the PVD TiN coating, because of its thin thickness, the

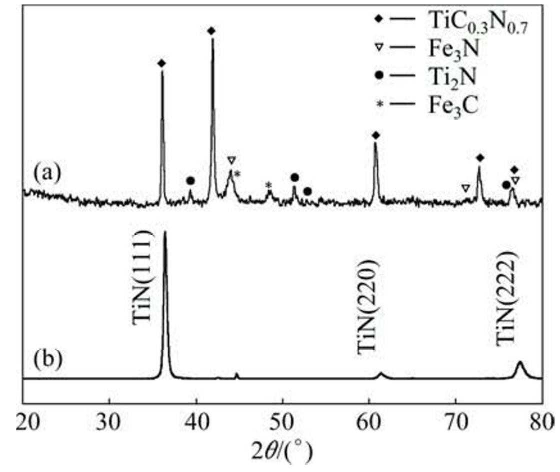

**Fig. 1** XRD patterns of TiCN coating (a) and TiN coating (b)