TiC nano-coating and their tribological properties were deposited by dual-ion beam sputtering on the tool surface

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Abstract: By using the method of dual-ion beam sputtering deposition, N element is injected with ions to assist sputtering deposition of TiC to prepare the TiC nano-coating with high binding strength. SEM, XRD, dynamic ultra-micro hardness tester, friction and wear testing machine were used to characterize and analyze TiC properties. The results show that the TiC coating prepared by double ion beam sputtering deposition has high hardness, high bonding strength, good friction and wear performance, and improves tool service life.

1. Introduction

In order to further improve the surface properties of materials, ion implantation technology is widely used in mechanical, semiconductor, corrosion resistance, friction and wear and other fields[1]. Ion implantation technology can obtain high supersaturated solid solution, metastable phase and amorphous structure on the surface of materials. The injection process is not limited by thermal equilibrium conditions and solid solubility, and the dose and energy of the injected elements can be precisely adjusted, thus effectively ensuring the uniformity of the injected elements on the surface of the matrix material[2]. Ion implantation technology can significantly improve the hardness and wear resistance of the film, change the microstructure of the injected layer and its adjacent areas[3], and combine ion implantation technology with the hard film, thus further improving the performance of the film. Atsushi Mitsuo et al.[4] found that the friction coefficient and wear amount of TiN films could be reduced and the wear resistance of TiN films could be improved after being injected with C ion. Jerzy Narozczyk et al.[5] found that Al and N ion implantation into TiN films could effectively improve the hardness of the films. Purushotham et al.[6-7] injected Zr+ into TiN and CrN films under the condition of 2×10¹⁷ ions /cm² and 280keV, and found that ZrN fine crystal phase was formed on the surface layer, resulting in self-lubrication and irradiation damage enhancement, and the friction factors were decreased with the increase of film hardness. In order to improve the binding force between DLC film and matrix, Liu Cui et al.[8] doped Ti ion DLC film with MEVVA source and found that the surface roughness of DLC film significantly decreased, the microhardness increased from 14GPa to 20GPa, and the friction factor decreased to 0.15. After the injection of high dose Mo+Co+ and Nb+ into TiN films, ultrafine composite structure layers of grain refinement and amorphous/nanocrystalline were generated on the surface of the materials, which improved the hardness of the materials and greatly reduced the friction factor, among which Mo+ injection effect was the best[9]. In cemented
carbide surface strengthening technology, the coating prepared by traditional magnetron sputtering, multi-arc ion plating and other methods has the disadvantages of poor membrane base adhesion, high particle sputter and low ionization efficiency. At present, in the relevant studies of ion implantation, the vast majority of ions are directly injected into the substrate surface or nano film. In this paper, the method of double ion beam is adopted to assist sputtering deposition TiC to prepare the nano-coating with high binding strength on the cemented carbide surface, and the tribological properties of the coating are tested.

2 Materials and Methods
The tool matrix material used in this experiment is fine grain cemented carbide YG8, for coating cutters, the interfacial stress load transfer and material properties are affected by the physical matching between coating and substrate and between different coatings [10]. TiC thin films are widely used in many industrial fields due to their high hardness, moderate elastic modulus and strong oxidation resistance. When amorphous carbon (a-c) matrix phase co-exists with crystalline TiC, the frictional wear performance is significantly improved [11-13]. Before the tool was coated with PVD-TiC, the sample was soaked with an aqueous ethanol and the surface was cleaned with an ultrasonic cleaning machine (time: 30min). Ion implantation to the matrix was performed on a multifunctional ion implantation and deposition system developed at the Chengdu tongchuang material surface technology engineering center. N-ion implantation was accompanied by assisted sputtering deposition of TiC. The vacuum degree of ion implantation was 2.0×10-3pa, the injected energy was 40KV, and the injected dose was 2.4×1018/cm2. SEM was used to test and analyze the cross section morphology of TiC coating. XRD was used to analyze the crystal structure of TiC coating. The injection Angle was 0.6°, the detection Angle was 20° ~ 100°, and the step length was 0.02(°)/s. The microhardness test was carried out on DUH-211S dynamic ultra micro-hardness tester. The load was 0.025kg and the load duration was 15s. Tribological tests were carried out on hit-2 ball-disc friction test machine, and the wear volume was obtained by laser confocal microscope. The friction mode was circular motion, the friction time was 15min, the load was 50N, the friction speed was 100r/min, and the wear mark radius was 12mm. Aluminum oxide ball was used for dry friction.

3 Results & Discussion
3.1 Composition and mechanical properties of cemented carbide after double ion beam injection
The XRD pattern of YG8 cemented carbide samples after double ion beam injection is shown in Fig.1. It can be seen from Figure 1 that in addition to the WC diffraction peak of cemented carbide substrate, the diffraction peak is 35.7, 41.5 and 60.2 at 2θ at the same time. TiC coating is composed of (111), (200) and (220) crystal surface diffraction peaks of TiC. The hardness of the non-treated hard alloy was 1672HV, and the hardness of the injected hard alloy was 2238HV. The surface hardness was greatly increased, which was due to the formation of a certain thickness of TiC nano-coating on the surface modification layer.

Fig.1. XRD patterns of YG8 cemented carbide samples after double ion beam injection
3.2 **Micro morphology**

Fig.2 is the SEM diagram of the cross section of the cemented carbide tool before and after the double ion implantation. Compared with the observed images, it can be seen that the fracture surface of the carbide tool without ion implantation has many cracks and scratches, and the surface is rough. However, in the fracture morphology of cemented carbide tool after injection, the surface crack notch and scratch are relatively few, and the surface roughness is reduced. After TiC coating is formed, the surface hardness of cemented carbide tool is not only improved, but the anti-crack ability is also improved.

![Fig.2. SEM images of the profiles of cemented carbide tools before and after double ion implantation](image)

3.3 **Tribological properties**

3.3.1 **Friction coefficient**

Friction coefficient represents the relative movement of two contact surfaces in terms of physical elasticity and friction characteristics. According to the friction theory, friction is mainly the sum of shear resistance and furrow resistance\(^{[14]}\). Fig.3 shows before and after ion implantation modification alloy samples of the friction coefficient changes, not into alloy samples of the average friction coefficient is 0.482, dual ion implantation after YG8 cemented carbide sample average friction coefficient is 0.283, from the graph, the friction coefficient matrix of the curve "noise" is very big, this is caused by the uneven surface. After ion implantation, the friction coefficient of the sample was nearly doubled compared with the matrix, and the "noise" was reduced, which was consistent with the SEM fracture morphology, indicating that the surface morphology had a benign change. Nouri et al.\(^{[15]}\) found in their study that different surface hardness of materials would lead to differences in friction factors. The higher the surface hardness of materials, the lower the friction factor value and the better the wear resistance. In the process of ion implantation, the interaction between high-energy atoms and matrix atoms leads to cascade collisions, resulting in ion irradiation damage, surface high-density
defects and lattice distortion, and resulting in dislocation enhancement\cite{16}. This is due to TiC particles could effectively improve the surface hardness and deformation resistance of the material.

![Friction coefficient of YG8 cemented carbide before and after double ion implantation](image)

**3.3.2 Friction volume**
The wear volume of YG8 cemented carbide sample before and after double ion implantation is shown in Fig. 4. It can be seen from the figure that the grinding marks of cemented carbide without coating are wide and deep, while cemented carbide with TiC coating has almost no grinding marks and no accumulation of grinding chips. This is because the hardness of TiC coating is very high and the bonding strength with the base is high, so the samples are almost not worn out during grinding. A small amount of grinding chips are also discharged in time due to lubrication. The cross section area of the grinding mark of the sample without coating was 3812.896\(\text{um}^2\), while the cross section area of the grinding mark of the sample with TiC coating was 90.535\(\text{um}^2\). Compared with the two samples, it could be seen that the surface area of the grinding mark after the double ion beam injection was reduced by 97.6\%, indicating that the abrasion resistance of the alloy samples after ion implantation was greatly improved.

![Wear optical photomicrograph of cemented carbide](image)

**Fig.4. Wear optical photomicrograph of cemented carbide (a) No coating (b) TiC coating**

Based on the comprehensive friction coefficient and wear rate, the cemented carbide tool with double ion beam sputtering deposition TiC coating has good wear resistance performance, which can effectively improve the service life of the tool.

**4 Conclusion**
(1) TiC nano-coating with high hardness and high binding strength can be prepared on the tool surface by double ion beam sputtering deposition, which provides experimental reference for the preparation of TiC nano-coating tools with better properties.

(2) TiC coating can effectively improve the friction and wear performance of cemented carbide tool, effectively reduce the friction coefficient and significantly reduce the wear volume, thus increasing the service life of the tool.
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