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Influence of laser substrate pretreatment on anti-adhesive wear properties of WC/Co-based TiAlN coatings against AISI 316 stainless steel

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ABSTRACT

To improve the anti-adhesive wear properties of WC/Co-based TiAlN coatings, a laser substrate surface pretreatment was examined. The cemented carbide substrates were textured with a Nd:YAG laser, in three different scanning speeds, and then coated with a PVD TiAlN film. The anti-adhesive wear properties of each surface were evaluated via the ball-on-disk wear test and turning experiments. Additionally, characterization tests such as variable depth scratch test were also performed in order to verify the coating adhesiveness and to explain the results of the wear and machining tests. The results reveal that the anti-adhesive wear properties of the three TiAlN coated textured samples are significantly improved over that of the conventional one; the adhesion of TiAlN coatings is greatly improved by using Nd:YAG laser substrate pretreatment. Moreover, laser-scanning speed has a profound effect on the adhesion strength of the pretreated samples. In the experiments, the lowest scanning speed (5 mm/s) is most effective in providing a greater mechanical locking of the coatings upon the substrate and a more matching chemical property between substrate and coating materials, thus increasing the critical load of the coatings. Meanwhile, the adhered workpiece material layer is more stable on the pretreated sample irradiated at 5 mm/s. Hence, potential wear protecting properties of the in-situ formed layer can be conserved.

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1. Introduction

Coated cemented carbide is currently a material with a broad range of applications, especially as cutting tools for machining several kinds of difficult-to-machine materials, such as metallic alloys [1]. In general, TiAlN based thin films traditionally belong to the group of wear resistant coatings which, together with others single- or multi-component transition metal nitrides, are used when improvement of performance and wear life of a mechanical component or cutting tool is expected. TiAlN coatings can significantly enhance the high-temperature performance of the tribosystems because the presence of Al in TiAlN coatings forms a superficial layer of composite ceramic (Al_2O_3) at high friction temperatures, which helps minimize negative effects of oxidation and reduces wear with prolonged service life [2].

With regard to the coating damage in the tribosystems, two failure modes must be considered: flaking of the coating material as the result of adhesion (adhesive damage) and flaking of the coating material with adhering substrate material (cohesive damage) [3]. Thus, the performance of TiAlN coatings deposited on a mechanical component or cutting tool that is subjected to changes in mechanical and thermal stresses of the friction process depends, above all, on a good adhesion of the film on the substrate. Good coating adhesion is critical because the tribosystem with coatings of insufficient adhesion may behave worse than one without coatings. Poor coating adhesion favors fragmentation and release of hard abrasive particles between the contact faces. These particles interact with the surfaces of the component, accelerating its wear and decreasing its life [4]. In addition to having available new deposition processes, better control of the deposition processes, and appropriate properties between substrate and coating materials, pretreatment of the substrate before coating deposition is essential for the durability of a coating system. In published research and in industrial practice, several processes have been employed to treat the substrate before applying the coatings to increase the interfacial bond toughness like water peening [5], chemical etching [6], grinding, micro-blasting [7,8], cathodic arc ion etching and magnetron sputtering [9,10]. As we know, one of the most usual processes is sandblasting, which is an economic and effective process that can create optimized surface roughness, remove excessive cobalt binder and promote compressive residual stresses, all of which may increase the adhesion strength of the substrate-coating interface, thereby prolonging the tool lifetime [11]. However, regardless of its extensive use and efficiency, the sandblasting process poses environmental and operator health risks, produces random roughness of difficult control, and is labor intensive and time-consuming [12,13].

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Table 1
Properties of the cemented carbide materials.

Composition (wt.%)	Density (g/cm^3)	Hardness (GPa)	Flexural strength (MPa)	Fracture toughness ($MPa\cdot m^{1/2}$)	Thermal conductivity (W/(m·K))	Thermal expansion coefficient (10^{-6}/K)
WC + 6%Co	14.6	16.0	2300	14.8	75.4	4.51

In recent decades, laser surface texturing has attracted attention for substrate precoating preparation because it allows for precise material removal with minimal thermal impact on adjacent zones and high process stability, since no tool wear occurs [14]. Laser ablation is also easily automated, does not produce waste effluents and can be used for treating three-dimensional tools like drills and saws [4]. In laser texturing, a laser with short pulses and a high repetition rate induces nano- or micro-structures through modulated laser intensity distribution on the surface, allowing a better anchoring of the coatings. Macroscopically, the surface roughness increases, generally due to the formation of craters originated from the melting and ablation of the materials, which can probably contribute to increasing coating adhesion [15]. Laser pretreatment improves the adhesive strength of PVD- or CVD-deposited coatings on laser-irradiated cemented carbide substrates in general as showed in the papers of [15–17]. Here, the positive effects of textured surfaces are pointed out with a high potential for different tribosystems. Neves et al. [15] demonstrated that the optimal laser parameters produced better adhesive strength for PVD coatings on cemented carbide substrate, measured by the Rockwell C test, compared to the one obtained with the commercial micro-sandblasted tool. In the turning experiments, the PVD coated laser-textured tool also showed better performance than the standard tools. Lin et al. [16] examined the adhesion of diamond coatings on pulsed-UV-laser treated cobalt-cemented tungsten carbide tool in the cutting process of aluminium alloys. It was shown that the adhesion of diamond coatings grown on tungsten carbide was greatly improved compared with diamond coatings deposited using traditional acid-etching pretreatment. In face milling of compacted graphite cast iron laser pretreatment is applied to improve the adhesive strength of PVD coatings on the cutting tools. Here, Viana et al. [17] textured the TiAlN and AlCrN coated tool by laser texturing for face milling to improve tool life in a lubricated regime. In addition to the improved coating adhesion, several other physical mechanisms such as wear debris entrapment, local increase of lubricant supply by fluid reservoirs and also increase of load carrying capacity by a hydrodynamic effect may also be achieved by laser surface texturing [18–21].

So far, the influence of substrate surface texture on coating anti-adhesive wear has not been examined in detail. Furthermore, in order to fully understand how laser pretreatment modifies the performance of the coatings, it is essential that the coatings are analyzed in friction and wear tests, machining tests as well as in materials testing to characterize their properties, morphology, microstructure, and especially their adhesiveness to the substrate. Thus, the main aim of this study is to further this research and to provide data which will give more technical support to the viability of using this technology on different tribosystems. In this work, the laser irradiation technique was used to prepare the substrate surface of carbide inserts subsequently coated with TiAlN by physical vapor deposition (PVD). Operating parameters such as laser power, pulsing frequency and scanning velocity also influence the surface-dependent engineering properties. Particularly, laser scanning speed has a significant influence on the resultant micro-structure, and hence on the mechanical properties of the modified layers [22]. Thus, different surfaces, produced with various scanning speeds, were considered. The anti-adhesive wear properties of each surface were evaluated using the ball-on-disk wear test and turning experiments. Characterization tests such as variable depth scratch tests and phase analysis were also performed to verify the coating adhesiveness and to explain the results from the wear and machining tests.

2. Experimental details

2.1. Specimen preparation

In this study, square tungsten carbide (WC/Co) substrates (Zhuzhou Cemented Carbide Cutting Tools Co., Ltd.) with an average grain size of 2–3 μm and a dimension of 16 mm × 16 mm × 5 mm were used. The composition and properties of the tool material are listed in Table 1. The tool rake face and flank face were finished by grinding and polishing to the roughness Ra of <0.02 μm, and then cleaned ultrasonically in alcohol and acetone for 30 min each. Some of the tools were subjected to laser surface texturing (LST) on the rake face before coating deposition. Afterwards, the polished and LST-treated specimens were coated with a thin wear resistant TiAlN coating by PVD.

The substrate surfaces were textured using a Nd:YAG laser system (DP-H50, Jinan Xinchu Co., Ltd., China) with wavelength of 1064 nm, pulse length of 10 ns and spot diameter of about 30 μm. The main components of the laser system comprise the laser, an iris diaphragm for laser intensity control, a computer controlled scanning head to guide the laser beam over the workpiece, and the necessary optics to direct the laser energy onto the workpiece surface. The texturing of the inserts was carried out on its entire rake face in an area of 16 × 16 mm_2. Fig. 1 shows the laser irradiation dynamics applied to the surface. Laser texturing was performed by scanning the tool surface with parallel laser tracks and was applied in an open atmosphere. To control texturing of the entire surface, the distance between the centers of two neighboring pulses was 20 μm. The processing parameters for the regular textures on the substrate surface were as follows: pump current of 7.5 A, frequency of 5000 Hz and 1 overscan. The controlled input parameter for laser texturing was scanning speed, and three scanning speeds were used for different specimens: 20, 10 and 5 mm/s. The cemented carbide substrate samples irradiated with scanning speeds of 20, 10 and 5 mm/s were named LT-1, LT-2 and LT-3, respectively. And the only polished substrate was named LS.

After laser irradiation, TiAlN films were coated on the textured substrate samples by the cathode arc-evaporation PVD process. Before

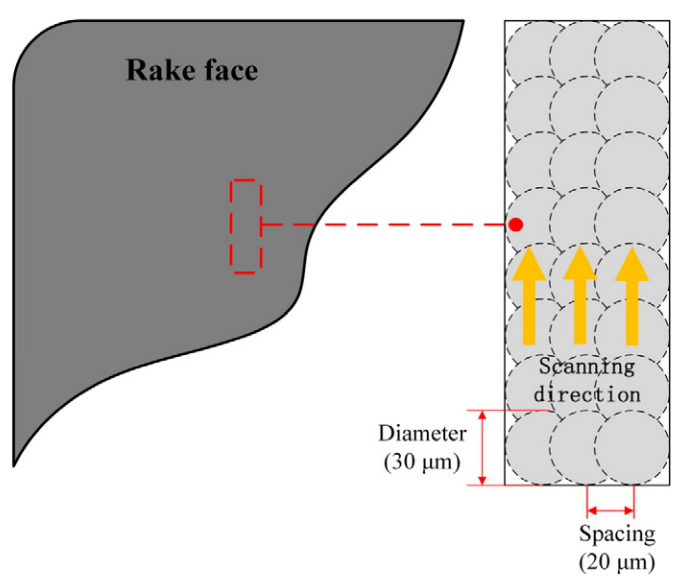

Fig. 1. Schematic diagram of laser irradiation dynamics utilized on substrate sample.

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