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Influence of different cemented carbides on fabricating periodic micro-nano textures by femtosecond laser processing

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ABSTRACT

Periodic micro-nano textures are fabricated by femtosecond laser processing on different cemented carbides. Five different cemented carbides are used in femtosecond laser machining to study the influence of different cemented carbides on fabricating. Surface topography and cross sectional profiles are examined. The results show that the periodic micro-nano textures fabricated on YS8 cemented carbide by femtosecond laser processing are the most continuous, uniform, and orderly, and have the fewest cracks and holes. Flexural strength, grain size, and phase composition of cemented carbide are found to be the primary factors affecting the continuity and uniformity of periodic micro-nano textures that form on cemented carbide. Meanwhile, the influence of different cemented carbides on the texture period, texture depth, and surface roughness are also investigated through the experiments.

1. Introduction

Functional surfaces with periodic micro-nano structures have been used in various fields during the last few years, such as bionics [1,2], microelectronics [3,4], and biomedicine [5,6]. These periodic micro-nano structures have many functions, such as changing the hydrophilicity and hydrophobicity of the surface [7,8], increasing the surface area to improve heat dissipation performance [9,10], and improving the wear resistance of the friction pair [11].

According to recent research, femtosecond laser has been extensively used to investigate these functional periodic micro-nano structures on various materials [12–17]. Guo et al. [4] fabricated periodic nanostructures on the surface of ZnO single crystals by femtosecond laser irradiation. Their results indicated the induced second order harmonic of the exciting laser is responsible for the characteristic size of the nanostructures growing in a self-organized manner. Miyaji et al. [17] used femtosecond laser pulses to fabricate periodic nanostructure on the surface of DLC thin film. Their experimental results showed that to induce the periodic enhancement of local fields in the surface layer, the formation of periodicity can be attributed to the excitation of surface plasmon polaritons. So far, several mechanisms have been proposed to explain the formation of these periodic micro-nano structures induced by femtosecond laser pulses, such as interference between the incident laser light and the surface scattered wave [18], self-organization [19], second harmonic generation (SHG) [20], excitation of surface plasmon polaritons [17], and Coulomb explosion [21].

Currently, researchers have found that applying micro-nano functional structures to cutting tool surfaces can improve the cutting performance [22–27]. With elevated hardness and brittleness, cemented carbide is the primary cutting tool used in high speed machining [28–32]. Dumitru et al. [33] used femtosecond laser to ablate Ti (C, N) and WC-Co. They found ripples on the surface of Ti (C, N) and WC-Co after femtosecond ablation, as well as discovered that Ti (C, N) and WC-Co had the same spatial period (0.6 μm). This fact correlated [34] with the laser wavelength (0.8 μm) [33]. Kawasegi et al. [35] fabricated nanoscale textures on the surface of cemented carbide tools (WC-Co) by femtosecond laser processing. Nanoscale periodic textures of 150 nm deep with a pitch of 800 nm were fabricated over a 10-μm wide area, caused by the interference of the *P*-polarization of the femtosecond laser [36] when the laser operated near the ablation threshold fluence [35]. By the use of femtosecond laser scanning, we [37] have successfully prepared periodic and uniform nanogratings on YS8 (WC + TiC + Co) cemented carbide. We also studied the influence of pulse energy, scanning speed, and scanning spacing on the period and the uniformity of the formed nanogratings [37]. However, there are various types of cemented carbides with different compositions and physical and mechanical properties. Few researchers have studied femtosecond laser micro-nano texturing on different cemented carbides.

In this paper, femtosecond laser processing is used to report on the fabrication of periodic micro-nano textures on different cemented carbides. The influence of cemented carbide types on the periodic micro-

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nano textures produced by femtosecond laser is investigated. The periodic micro-nano textures are characterized by the scanning electron microscope (SEM) and scanning probe microscope (SPM).

2. Experimental

It is shown that different periodic micro-nano textures were formed on different materials by femtosecond laser processing [38,39]. Five common types of cemented carbides (YG6A, YG8, YS8, YT15 and YW1) are selected to study the influence of different cemented carbides on fabricating periodic micro-nano textures by femtosecond laser machining. Table 1 shows the composition and the physical and mechanical properties of the five cemented carbides. Each sample is mechanically polished and washed in an ultrasonic cleaner with acetone for 30 min. The surface roughness of the cemented carbide sample is <10 nm. The sample is fixed on a three-dimensional motorized translation stage with a positional accuracy of 100 nm.

The cemented carbide sample is irradiated in the air with linearly polarized, 800 nm, 120 fs laser pulses from a Ti: sapphire regenerative amplified laser system (Coherent Inc.) operated at a repetition rate of 1 kHz. The polarization direction and laser power can be adjusted by a polarizer and an attenuator, respectively. In the experiment, the femtosecond laser with a pulse energy of 2 μJ focuses on the sample surface through a microscope objective with a focal length of 23.5 mm and numerical aperture of 0.15. The laser spot size is estimated to be 6.51 μm in diameter and the laser fluence on the sample is estimated to be 2.61 J/cm^2. The test is carried out with the following parameters: laser scanning speed $V = 1000$ μm/s, scanning spacing $D = 5$ μm, and number of scans $N = 1$. As shown in Fig. 1, the same femtosecond laser processing parameters are used in this study to scan a circle of 0.4 mm in diameter on the surface of different cemented carbides. The orientations of the laser beam polarization and laser scanning direction are perpendicular to each other. A scanning electron microscope (SEM) is used to examine the surface morphology of the sample after fs laser treatment. Additionally, a scanning probe microscope (SPM) is used to characterize the texture period, texture depth, and surface roughness.

3. Results and discussion

3.1. Surface topography

Fig. 2 shows the periodic micro-nano textures that formed on the five cemented carbide samples. Fig. 2a shows that periodic micro-nano textures are formed by femtosecond laser scanning while many cracks and holes can be found on the surface of YG6A cemented carbide. The formation of these cracks and holes is related to the cemented carbide material, and they are expected to reduce the strength and cutting performance of cutting tools. YG6A cemented carbide contains three material components: WC, TaC, and Co. Although the heat affected zone of femtosecond laser machining is very small, different materials with different physical properties (such as elastic modulus and thermal expansion coefficient, shown in Table 1) will create the thermal residual stress, resulting in the generation and expansion of cracks and holes. Additionally, it is known that smaller grain size can lead to higher flexural strength, which means the grains inside the material are bound together more closely. Laser processing refers to the removal of material by the thermal effect produced by the laser beam projected onto the surface of the material. The laser ablation produces fewer cracks and holes when the grains are bound together more closely. Therefore, higher flexural strength and smaller grain size can prevent the generation and expansion of cracks and holes. From Fig. 2b, we can see that the cracks and holes on YG8 cemented carbide are more than that on YG6A cemented carbide. Table 1 shows that the grain size of YG8 cemented carbide is 3–5 μm, which is larger than the grain size of YG6A cemented carbide (1–2 μm). However, the hardness of YG6A (91.5 HRA) is higher than that of YG8 (89 HRA). Previous research also found similar results [32,40]. Compared with YG6A cemented carbide, YG8 (WC + Co) cemented carbide has fewer carbide phases and higher flexural strength, but more cracks and holes due to bigger grain size. It can be concluded that grain size in cemented carbide plays a more important role than carbide phase and flexural strength in the formation of periodic micro-nano textures. Fig. 2d shows that YT15 cemented carbide has fewer cracks than both YG6A and YG8 cemented carbide. However, some black ablation areas and more holes can be observed on YT15 cemented carbide than on both YG6A and YG8 cemented carbide. From Fig. 2e we can see that periodic micro-nano textures formed on YW1 cemented carbide are not continuous because they are blocked by many holes and cracks. It can be seen from Fig. 2c that among the five tested cemented carbides, periodic micro-nano textures fabricated by femtosecond laser on YS8 cemented carbide are the most continuous, uniform, and orderly, with the fewest cracks and holes. This may be due to YS8 cemented carbide having the smallest grain size (<0.5 μm) and the largest flexural strength (1720 MPa) compared to all of the tested cemented carbides. Additionally, the main component of YS8 cemented carbide is WC with a small amount of Co + TiC, as shown in Table 1. From the above analysis, it is noticeable that YS8 cemented carbide shows the best effect on forming periodic micro-nano textures by femtosecond laser processing. Furthermore, grain size, flexural strength and composition of cemented carbide are found to be the main factors that affect the continuity and uniformity of the periodic micro-nano textures formed on cemented carbide by femtosecond laser machining, especially the grain size of cemented carbide.

Fig. 3 shows the enlarged topography of periodic micro-nano textures formed by femtosecond laser processing on the surface of five cemented carbides. Fig. 3a shows that the periodic micro-nano textures formed on YG6A cemented carbide have some holes. Fig. 3b shows that the morphology of the periodic micro-nano textures formed on YG8 cemented carbide is not clear and the gap between adjacent periodic micro-nano textures is fuzzy. The black area in Fig. 3d shows that the surface of YT15 cemented carbide is over ablated. Meanwhile, over ablation discontinues the periodic micro-nano textures. Fig. 3e shows the fuzziness of the morphology of periodic micro-nano textures fabricated on YW1 cemented carbide. Fig. 3c shows that the morphology of periodic micro-nano textures on YS8 cemented carbide is the best among all five tested samples. Furthermore, the periodic micro-nano textures on YS8 cemented carbide has the best continuity, uniformity, and regularity of when compared with the other four samples.

3.2. Texture period

The scanning probe microscope characterizes the texture period, texture depth and surface roughness. Fig. 4 shows the SPM and cross sectional profile of periodic micro-nano textures formed on YS8

Table 1
Composition, physical, and mechanical properties of five cemented carbides.

Cemented carbide	Composition	Hardness (HRA)	Flexural strength (MPa)	Elastic modulus (GPa)	Thermal expansion coefficient ($\times 10^{-6}$ °C^{-1})	Grain size (μm)
YG6A	WC + TaC + Co	91.5	1370	630	5	1–2
YG8	WC + Co	89	1500	650	4.5	3–5
YS8	WC + TiC + Co	92.5	1720	550	5.5	<0.5
YT15	WC + TiC + Co	91	1150	510	6.51	3–5
YW1			WC + TiC + TaC + Co	91.5	1200	500
5.3	1.5–3					