Structural and Mechanical Properties of Multilayered CVD TiC/TiCN Coatings with Variations of Multilayer Period

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Abstract

Multilayered coatings on tungsten carbide cutting tools are widely used for enhancing cutting performance. In this paper, we review the CVD TiC/TiCN multilayer as a function of the multilayer period. The TiC/TiCN multilayers in initial stage show preferred (220) orientation but shifts to (200) orientation with decreasing multilayer period. The nanohardness of TiC/TiCN multilayers were found to increase with decreasing multilayer period and shows a maximum of 23.8 GPa at a period = 33.5 nm.

Keywords : multilayered coatings, TiC/TiCN, CVD, Cutting tools

1. Introduction

CVD and PVD coatings on cemented carbide cutting tools are widely used for extending tool life. PVD multilayered TiN/AlN [1], TiN/NbN, TiN/CrN and TiN/TaN [2] coatings have demonstrated increased hardness and wear resistance compared with single layers. In recent years, CVD coated TiCN/TiN [3] and TiCN/ZrCN [4] multilayers have interesting properties compared with single layers. Multilayer periods of PVD coated multilayers are about 2 ~ 20 nm [1,2]. But those of CVD TiCN/TiN, TiCN/ZrCN are about 100 ~ 350 nm [3,4].

In this study, we investigated the possibility of multilayered CVD coatings with 10 ~ 100 nm multilayer period and the effects of multilayer period of multilayered TiC/TiCN coatings on structural and mechanical properties.

2. Experimental and Results

Deposition of the TiC/TiCN multilayer coatings was carried out in a computer-controlled hot-wall CVD reactor (BERNEX). TiC and TiCN were deposited from the $TiCl_4$-CH_4-H_2 and $TiCl_4$-CH_4-N_2-H_2 system at a pressure of 100 ~ 700 mbar and 1000 ~ 1100 °C. All multilayers had the total thickness of 12 ~ 16 μm. The number of TiC/TiCN mutlilayers was varied with 12, 24, 48, 60, 120 and 480, and are referred to as CCN12, CCN24, CCN48, CCN60, CCN120 and CCN480 later in the text. The substrate was commercial cemented carbide insert (CNMG423) containing 80 ~ 85% WC and 6 ~ 8% Co, the balance being cubic carbides (TiC, TaC and NbC). The thickness, smoothness, crystal structure, hardness and adhesion of the multilayer were measured by optical microscopy, atomic force microscopy (PSI), X-ray diffraction (Rigaku, D/MAX-RC), nanoindentation (MTS, Nano Indentor XP) and scratch tester (CSEM), respectively.

The thickness of CCN12, CCN24, CCN48, CCN60, CCN120 and CCN480 are 11.1, 15.6, 15.0, 11.1, 13.2 and 16.0 μm, respectively. The multilayer period (Λ) is 925.0, 650.0, 312.5, 185.0, 110.8 and 33.5 nm, respectively.

Fig. 1 shows the XRD patterns of TiC/TiCN multilayers. TiC/TiCN multilayers in CCN12 show preferred (220) orientation but shifts to (200) orientation with decreasing multilayer period. Pelleg et al. [5] have proposed a model of correlation between surface energy and strain energy of film to explain the mechanism resulting in a preferred orienatation. In the case of CNC480, the presence of satellite peaks confirms periodical structure of multilayers, and multilayer period [Λ] is calculated as follows:

$$\Lambda = \left(\frac{n\lambda}{\sin\theta^{+n} - \sin\theta^{-n}} \right) \qquad (1)$$

where, λ is the X-ray wavelength(Cu k_α=1.5406Å) and +n, -n is the order of the superlattice reflection. The period measured by optical microscopy is 33.5 nm and the calculated period using Eq. 1 is 31.5 nm.

AFM was used to evaluate the conventional R_{rms}, root mean square surface roughness of TiC/TiCN multilayers. As the number of multilayers increases, the surface roughness decreases to 22.5 nm at CCN120. The lower roughness of TiC/TiCN multilayer is attributed to the grain refinement that results from the extremely thin multilayer deposition sequence. The crictical load (L_c), i.e., the normal load at the first coating failure as detected using an acoustic emission detector, is used as a measure of the coating quality. TiC/TiCN multilayers display small cohesive failures at the rim the crack. The critical load of multilayers decreases as the number of multilayers increases, ranging from 50.1 to 33.9 N.

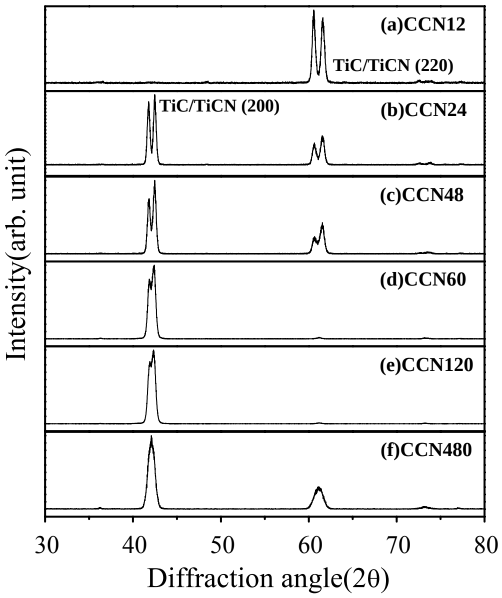

Fig. 1. XRD patterns of TiC/TiCN multilayers.

Nanohardness and Elastic modulus of TiC/TiCN multilayers were measured using an indentation load-depth sensing apparatus attached to commercially available Nanoindenter [6]. Fig. 2 shows the nanohardness of TiC/TiCN multilayers. The nanohardness of TiC/TiCN multilayers increases with decreasing multilayer period (Λ) and shows a maximum of 23.8 GPa for CNC480. This increase in hardness can be explained based on the Hall-Petch models. The Hall-Petch relationship that relates the grain size of a polycrystalline material to its mechanical properties has been known for many systems [7]. The elastic modulus of multilayers shows a maximum of 476.7 GPa for CNC120 and decreases to 426.0 GPa for CNC480. TiC and TiN have a NaCl structure which is highly anisotropic with calculated elastic moduli given by E_{100} : E_{110} : E_{111} = 460.8 : 419.7 : 407.6 for TiN [8] and E_{100} : E_{110} : E_{111} = 476.2 : 440.0 : 429.2 for TiC [9]. The elastic modulus of multilayers is in good agreement with the changes of preferred orientation in Fig. 1. Therefore, the nanohardness of multilayers can be said to greatly affected by grain refinements, and only slightly affected by the elastic modulus.

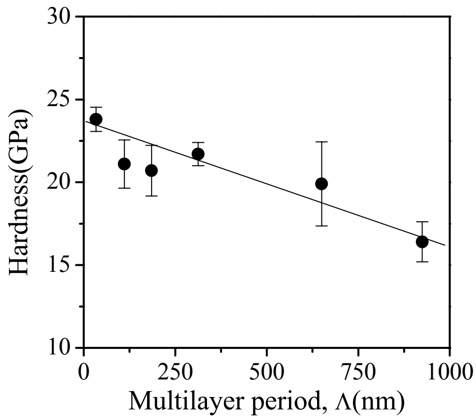

Fig. 2. Hardness of TiC/TiCN multilayers as a fuctions of multilayer period(Λ).

3. Summary

In this work, multilayered CVD TiC/TiCN coatings on cemented carbide substrates have been evaluated with respect to structural and mechanical properties. Thin multilayers approaching individual layer thickness of 10 ~ 100 nm can be deposited using conventional CVD system with 200 ~ 1000 single layers of alternating TiC and TiCN. The nanohardness of TiC/TiCN multilayers increases with decreasing multilayer period and shows a maximum of 23.8 GPa at a period = 33.5 nm. In the future, we plan to test wear resistance of TiC/TiCN multiayers coated cutting tools.

4. References

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