Effect of Interfacial Layers on Stress Depth Profile of Ceramic Layers for Cutting Tools

Cemented carbide inserts with coatings of ceramic such as Al_2O_3, TiN and TiCN are widely used as cutting tools. In recent years, the speed of the cutting operation has been increased to improve the efficiency of the machining process. The high-speed operation results in high temperatures at the cutting edge and therefore causes large creep deformation of the cemented carbide substrate. The deformation enhances delamination of the coated film, which shortens the life of the tool. To prevent such delamination, it is known that reducing of the residual stress near the interface between the film and the substrate is effective [1,2].

The main component of residual stress in the CVD-deposited ceramic films is the thermal stress caused by the difference in the thermal expansion coefficient (TEC) between the film and the substrate. Figure 1 shows an example of a TiCN layer coated by a conventional CVD method. There is an interfacial layer (not visible in the SEM micrograph) between TiCN and WC. The typical material used for the interfacial layer is TiN, which has large TEC of 9.4×10^{-6} in comparison with the WC substrate. In this study a new interfacial layer of TiC was adopted as it has a lower TEC of 7.4×10^{-6}. The small TEC mismatch in the TiC interfacial layer system was expected to result in a low residual stress near the interface.

The stress depth distribution, however, cannot be revealed by a conventional residual stress measurement using a laboratory X-ray diffractometer. Therefore, a new measurement technique, which can yield a precise stress depth profile, is needed to elucidate the stress near the interface. We adopted a constant-penetration-depth method as it is less sensitive to preferred orientation, which is frequently observed in the case of thin film. This method is a combination of iso-inclination and side-inclination methods of the ordinary 2θ-$\sin^2\psi$ technique, wherein different ψ angles can be set without changing the X-ray penetration depth [3].

Stress depth profiles of the two TiCN layers schematically shown in Fig. 1 were measured using a multi-axis diffractometer at beamline **BL19B2**. A Soller slit and a sample spinner were employed to improve the 2θ resolution and to increase the number of crystallites that contribute to the diffraction, respectively. The energy of the incident X-ray was 11 keV. The TiCN (331) plane was used for the measurement.

Figure 2 shows the effect of controlling the X-ray irradiation area on the stress depth profile. The data acquired from a constant-irradiation area (fixed at 9 mmϕ) showed much lower scattering than that from a variable-irradiation area (varied from 4 to 10 mmϕ). This is attributed to a stress distribution in the TiCN layer towards the in-plane direction.

The obtained stress depth profiles are shown in Fig. 3(a). The sample with the TiC interfacial layer appeared to exhibit higher stress over the entire depth

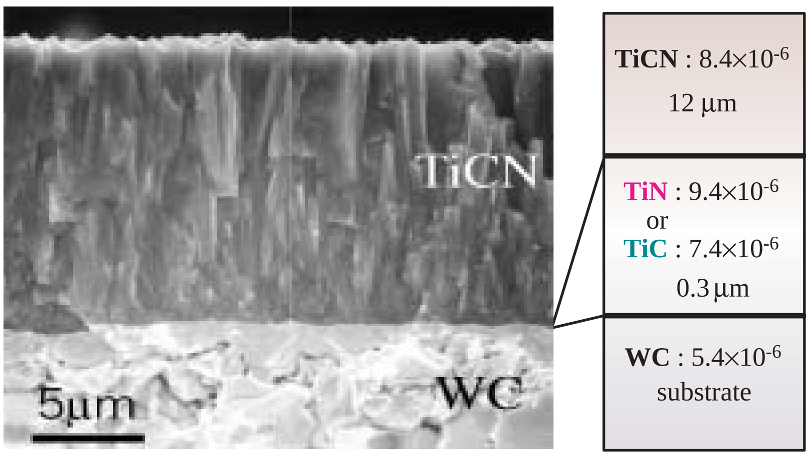

Fig. 1. Cross-section SEM image (left) and thermal expansion coefficient and thickness of each layer (right).

range. However, this was due to the peculiar axes of the plot, i.e., X-ray penetration depth on the horizontal axis and weighted average stress from the surface to the penetration depth on the vertical axis. Figure 3(b) shows the depth profiles with commonly used axes. The conversion was based on the fitting curves shown in Fig. 3(a).

The stress near the interface of the TiC layer is clearly lower than that of the TiN layer in Fig. 3(b). Chemical composition analysis using an Auger electron spectroscope and electron probe microanalyser showed no fluctuation through the entire film thickness for both TiCN layers. Hence the difference in the stress near the interface is ascribed to the TEC difference between the TiC and TiN interfacial layers.

In conclusion, a small mismatch in TEC at the interface is considered to be the major cause of the low stress near the interface. Hence the manipulation of TEC can be applied to control residual stress in cutting tools. The constant-penetration-depth method with a constant-irradiation area was effective for measuring the stress depth distribution.

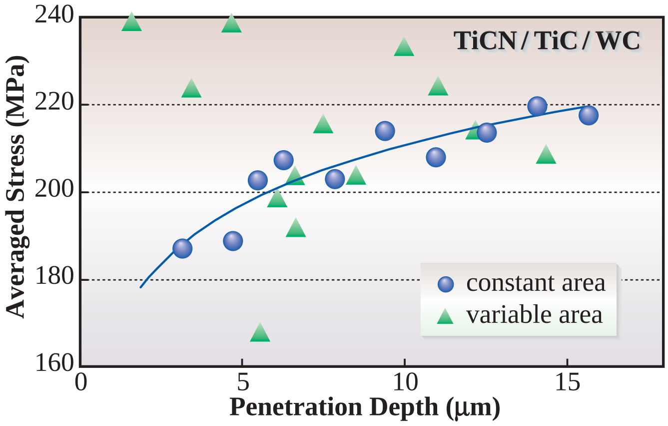

Fig. 2. Stress depth profiles of constant-irradiation area and variable-irradiation area. The sample and the diffraction plane are identical for both measurements.

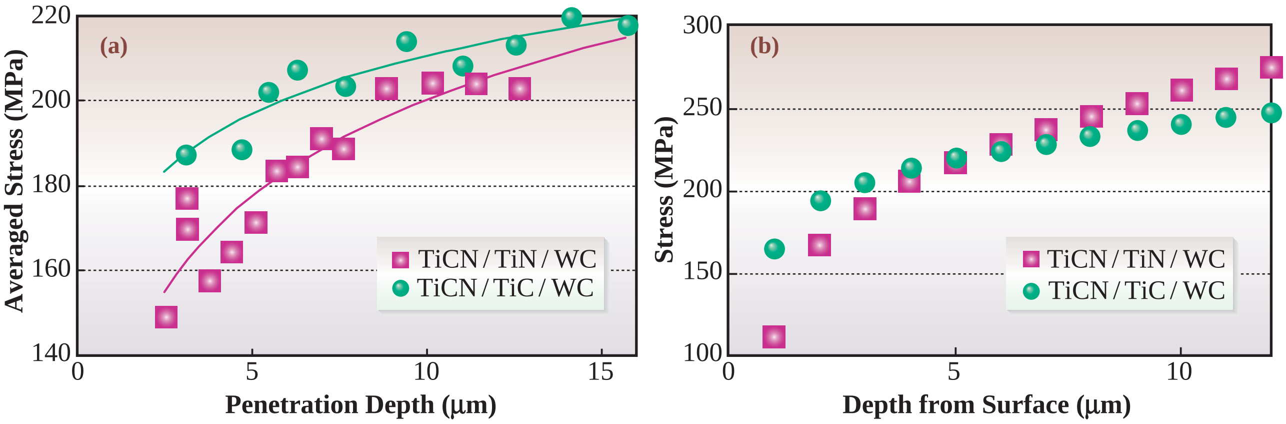

Fig. 3. **(a)** Experimental stress depth profiles of TiCN layers deposited on different interfacial layers. **(b)** Calculated depth profiles from fitting curves shown in **(a)**. Axes are converted from penetration depth to depth from surface and from averaged stress to stress at the depth, respectively.

Shin Tsuchiya

Mitsubishi Materials Corp.

E-mail: tsuchiya@mmc.co.jp

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