

# Cutting Performance of CVD Diamond Coated Tool in Machining of Green Body of Silicon Nitride Ceramics - Wear Mechanism of Diamond Coated Tool to the Milling Operation -

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## 1.Introduction

Many attempts have been made to apply ceramic materials to machine parts used under high-temperature conditions, as these materials have excellent characteristics in terms of heat and wear resistance at elevated temperatures. The production process of this material consists of powder treatment, forming and sintering to make the finished products. Generally, a grinding process is used to finish the sintered parts to end products, as the material is extremely hard to machine[1, 2]. Especially, in case of large and complicated parts, the application of a cutting process may be effective, as a certain degree of volume elimination is required to shape the part. To arrange the shape of material, therefore, cutting process must be applied to the green body  $\text{Si}_3\text{N}_4$  ceramics before sintering. Up to this moment, it has been clarified that diamond coated tool is effective in terms of tool life, since the green body  $\text{Si}_3\text{N}_4$  ceramics is an aggregate of ceramics particles having high hardness characteristic[3]. However, the tool life using diamond coated tools varies depending on the difference in the thickness of the diamond coated film, and sufficient tool life cannot be obtained at present.

In this paper, the wear mechanism of a diamond coated tool and the effect of the deposit condition of diamond coated film on tool life were investigated in machining of green body  $\text{Si}_3\text{N}_4$  ceramics.

## 2.Experimental procedure

The workpiece material was the green body of silicon nitride ceramics, which consists of an agglomeration of silicon nitride ceramic particles and an organic binder before the sintering process(**Fig. 1**). The silicon nitride ceramic particles are  $1\ \mu\text{m}$  or less. The shape and geometry was a rectangular solid shape of  $40 \times 90 \times 130$  mm. The tools tested are shown in **Table 1**. As shown in this table, diamond coated film was generated under different deposit conditions by using the microwave plasma chemical vapor deposition (CVD) method[4-5]. The deposit condition were varied: deposit temperature:1123K, density of methane gas: 1 and 3% , density of carbon monoxide gas: 0 and 10%, and deposit time: 24, 32, 48 and 72 h. All of the diamond coated tools were used silicon nitride ceramics for the substrate material[6].

The type of tool was TPMN160304. This tool was attached to a milling holder with the specifications of 25mm, A.R. +7 degrees and R.R.-4 degrees. The cutting conditions were as follows: cutting speed (V): 2.0 m/s, feed rate (Sz): 0.10 mm/tooth, depth of cut (t): 2.0 mm, and dry condition. The tool life was determined by measuring the width of nose wear (VBc) or flaking on the flank face. The limited value of VBc to determine the life was set as  $\text{VBc}=0.2\ \text{mm}$ .

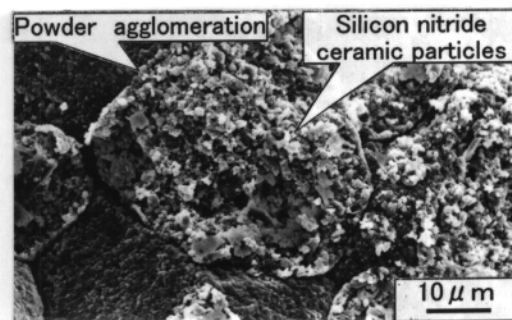


Fig.1 SEM micrograph of cross section for green body of  $\text{Si}_3\text{N}_4$  ceramics

Table 1 Deposit condition of diamond film

Tool type	CH <sub>4</sub> Gas conc. (cc/min)	CO Gas conc. (cc/min)	H <sub>2</sub> Gas conc. (cc/min)	Deposit time (h)	Temperature of substrate (K)	Thickness of diamond film (μm)
SC100-L	1	0	99	72	1123	44.0
SC100-LP				24		40.0
SC100-S				32		14.1
SC110-M				24		7.5
SC310-S	24	13.6				
SC310-M	48	30.4				
	3	10	87			

Type of tool:TPMN160304 P:Polishing

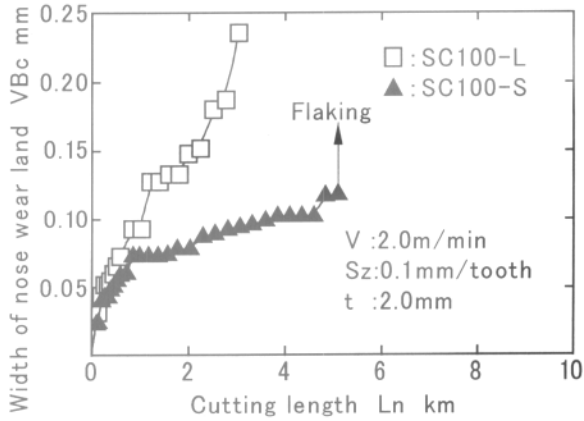


Fig.2 Comparison of VBc-Ln curves for diamond coated tools in different thickness

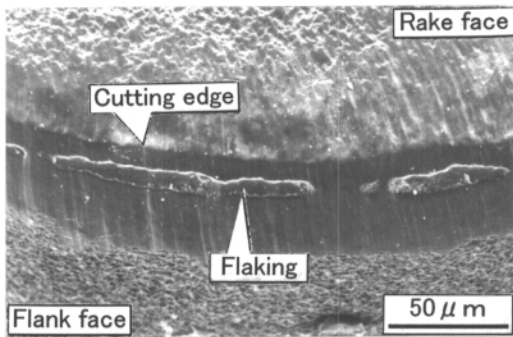


Fig.3 SEM micrographs of typical flaking pattern of the SC100-S tool

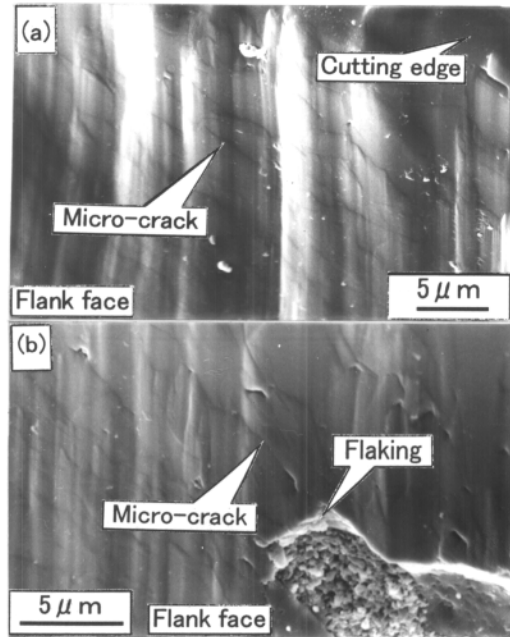


Fig.4 SEM micrographs of typical flank wear part with diamond coated tool; (a) before flaking and (b) after flaking

### 3. Results and discussion

#### 3.1 Wear mechanism of diamond coated tool for difference in the thickness of coating film

Fig. 2 shows the test results regarding the effect of the thickness of diamond coated film on the tool life. As shown in this figure, the SC100-S tool performed better in terms of wear resistance than the SC100-L tool. However, the tool life of the SC100-S tool was determined by the flaking at cutting length of 5km(Fig. 3). And in the case of the SC100-L tool, the wear rate was remarkable, as the width of nose wear land exceeded 0.2mm with a short cutting length. Fig. 4 shows SEM micrograph of comparison between the flank wear part before and after flaking in detail. As seen in Fig. 4(a), many micro-cracks on the flank wear in parallel with the cutting edge were observed, and the occurrence position of these micro-cracks corresponds with the flaking position (Fig. 4(b)). It is considered that the occurrence of flaking on the flank wear face is caused by residual stress.

On the other hand, the wear development rate of both SC100-L tool is higher, but the occurrence of flaking on the flank face cannot be observed. A comparison of the cutting edges between the SC100-S tool and SC100-L tools is shown in Fig. 5. As seen in this figure, in the case of the SC100-S tool, small diamond particles with good crystallinity are uniformly distributed on the head surface of the diamond coated film (Fig. 5 (a)). In the case of the SC100-L tool, the diamond particles grow very big, and uniform diamond particles are also generated among these particles are observed (Fig. 5 (b)). In addition, the convex portion of the diamond

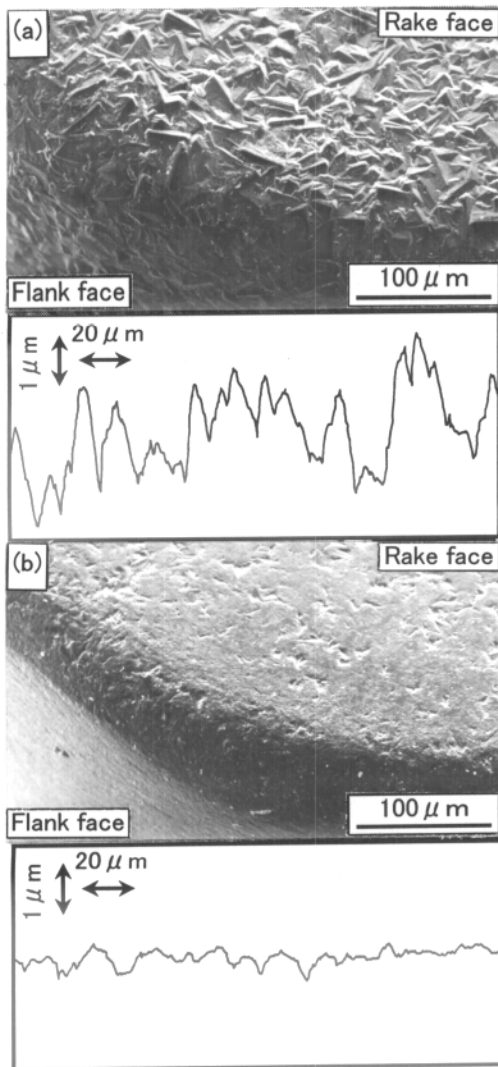


Fig.6 SEM micrographs of cutting edges and surface profile of the diamond coated tool comparison between before and after polishing; (a)the SC100-L tool and (b)the SC100-LP tool

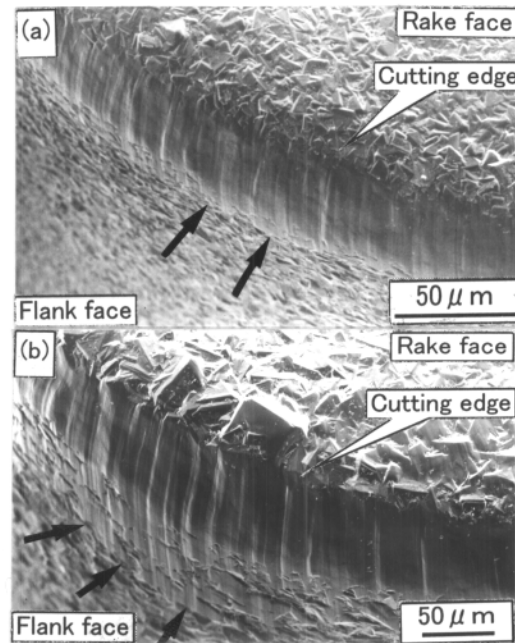


Fig.5 Comparison of the wear mode of cutting edge;(a) the SC100-S tool and (b) the SC100-L tool

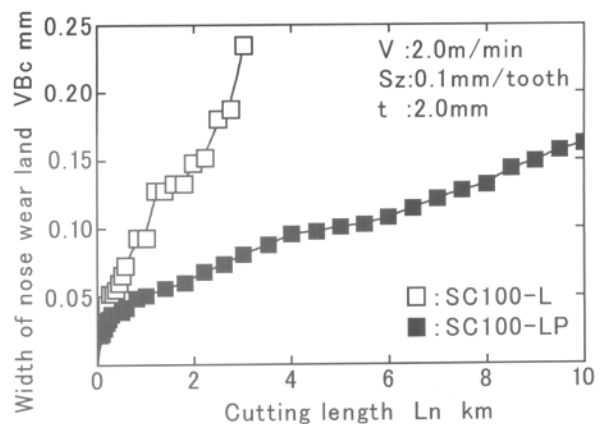
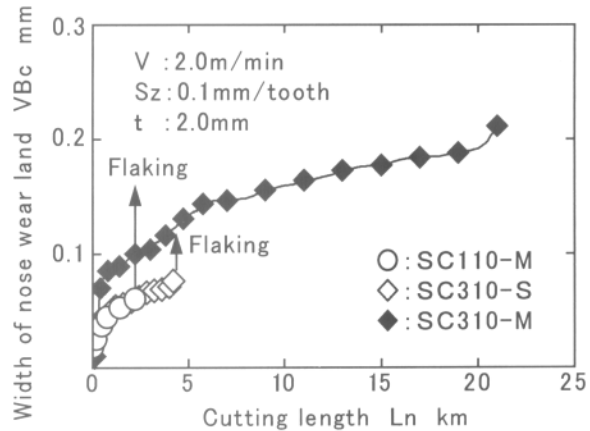


Fig.7 Increase of width of nose wear land (VBc) with cutting length(Ln) both as coating tool(SC100-L) and polishing tool(SC100-LP)

particles wears at first, and then the width of the flank wear increases (portion indicated with arrow). In particular, the SC100-L tool is inferior in wear resistance, which is typical of tool that have larger diamond particles. In order to solve the cause of wear using diamond coated tool, the effect of difference in the ruggedness on the head surface of diamond film was investigated.

**Fig. 6** shows SEM micrographs and surface profile of comparison between cutting edge of the SC100-L tool before and after polishing (the SC100-LP tool). The ruggedness of the SC100-LP tool is improved significantly, the tool life is approximately 4.5 times longer than that of the SC100-L tool (**Fig. 7**).



**Fig.8** Increase of width of nose wear land ( $VB_c$ ) with cutting length( $L_n$ ) for the SC110-M tool, the SC310-S tool and the SC310-M tool

### 3.2 Effect of deposit condition of diamond film on tool life

As mentioned in a previous section, the wear mechanism of the diamond coated tools varies depending on the difference in the coating thickness and ruggedness on the head surface of diamond film. A study of the possibility of improving tool life by increasing the thickness and decreasing the ruggedness of diamond coated film was investigated.

The diamond coated film of the SC310-S tool and the SC310-M tool is generated by increasing the density of methane to 3% under the deposit conditions for the SC110-S tool. In three tools, carbon monoxide gas has been added to 10% in order to attempt that it tries growth suppression and equalizing of the particle[7]. As seen in **Fig. 8**, the SC310-M tool shows the long life without accompanying by the occurrence of flaking, though the initial wear is bigger than other tool. In this respect, the wear resistance and flaking resistance of the SC310-M tool is remarkably improved, the tool life was extended to 20km.

### 4. Conclusion

In machining of the green body of silicon nitride ceramics using a diamond coated tool, the wear mechanism and effect of deposit condition of diamond film on tool life were investigated. The results obtained can be summarized as follows:

- (1) The life of the SC100-S tool with the thin diamond film is determined by the occurrence of flaking on the flank wear face.
- (2) The convex portion of the diamond particles wears first, and then the width of the flank wear increases
- (3) The occurrence of flaking and the wear resistance in the SC310-M tool is improved significantly by the control of the formation speed and particle size of diamond coated film.
- (4) The tool life of the SC310-M was extended to a cutting length of approximately 20km.

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