A machinability of porous Si₃N₄ ceramics composed of columnar β-Si₃N₄ grains was evaluated by turning and milling with cemented carbide cutting tools to investigate a possibility of application of the porous Si₃N₄ to machinable ceramic use. The porosity and the flexural strength of specimens were about 45% and 270 MPa, respectively. The machinings were carried out with a cemented carbide throw-away tip of K-10 grade. The condition of turning was cutting speeds of 50 to 150 m/min, feed rates of 0.05 to 0.40 mm/rev, and a cutting depth of 0.5 mm, and that of milling was cutting speeds of 20 to 200 m/min, feed rates of 0.05 to 0.20 mm/rev and a cutting depth of 0.5 mm. Machinability was judged from the maximum surface roughness, \( R_{\text{max}} \), after machining; it was defined that a material was machinable when \( R_{\text{max}} \) was below 10 \( \mu \)m. In the case of turning, the \( R_{\text{max}} \) increased with increasing cutting speed and feed rate. \( R_{\text{max}} \) below 10 \( \mu \)m was obtained under conditions that satisfied both a cutting speed of 50 m/min and feed rates below 0.1 mm/rev. In the case of milling, although the \( R_{\text{max}} \) increased with increasing feed rate, serious cutting speed dependence of \( R_{\text{max}} \) could not be seen. \( R_{\text{max}} \) values below 10 \( \mu \)m were obtained at feed rates below 0.1 mm/rev, independent of cutting speed.

From a different point of view, it is apparent that porous ceramics are typical machinable ceramics due to their low Young’s modulus. However, satisfactory strength for engineering applications has not been obtained since the strength of porous ceramics decreases exponentially with the increase in porosity. Recently, we reported that porous Si₃N₄ ceramics having both high strength and high thermal shock resistance could be fabricated by the powder metallurgy process, and could be machined easily with a cemented carbide drill.

When the porous Si₃N₄ ceramics are used as machinable ceramics, their surface roughness after machining is of critical important because of their roughened surfaces. In this paper, we report the machinability of the porous Si₃N₄ using a cemented carbide cutting tool.
3. Results and discussion

Hamazaki reported the surface roughness of a mica-based glass-ceramic after turning (tool of K-10 grade, cutting speed of 55 m/min, feed rate of 0.04 to 0.4 mm/rev, and cutting depth of 0.5 mm). In the paper, they demonstrated that $R_{\text{max}}$ below 10 $\mu$m was obtained at feed rates below 0.075 mm/rev.\(^2\)

Figure 3 shows the relation between feed rate and the $R_{\text{max}}$ of the porous Si$_3$N$_4$ in turning. The $R_{\text{max}}$ at the feed rate of zero shows that before machining. The $R_{\text{max}}$ increased with increasing cutting speed or feed rate. At a cutting speed of 150 m/min, the $R_{\text{max}}$ of all the specimens was over 10 $\mu$m despite feed rate. At a cutting speed of 50 m/min, which was almost the same as the above machining speed for the mica-based glass-ceramic, $R_{\text{max}}$ below 10 $\mu$m was obtained at feed rates below 0.1 mm/rev. At a feed rate of 0.05 mm/rev, there was no difference in surface roughness before and after machining. At these low feed rates, the $R_{\text{max}}$ values were almost the same as those of the mica-based glass ceramic.

Figure 4 shows the relation between feed rate and the $R_{\text{max}}$ of the porous Si$_3$N$_4$ specimen in milling. Serious cutting speed dependence of $R_{\text{max}}$ could not be seen. The $R_{\text{max}}$ depended on feed rate rather than cutting speed; there was no difference in surface roughness before and after machining at feed rates below 0.1 mm/rev. Thus, high-speed cutting of 200 m/min was available in milling.

From the above results, we consider that the porous Si$_3$N$_4$ ceramics have potential as high-strength machinable ceramics. Figure 5 shows the example of machined porous Si$_3$N$_4$ ceramics.
Si₃N₄ ceramics.

Higher strength is required to apply the porous Si₃N₄ ceramics to expand engineering applications. Although decreasing porosity is effective for the higher strength, the correlation between porosity and machinability is also important because the decrease in porosity might start to form closed pores in the porous body, decreasing machinability. We are investigating the structural control for the higher-strength porous Si₃N₄ ceramics.

4. Conclusions

The turning and milling test of a porous Si₃N₄ ceramic having a porosity of 43%, which is composed of columnar β-Si₃N₄ grains, was carried out with a cemented carbide throw-away tip of K-10 grade, and the maximum surface roughness ($R_{\text{max}}$) of the porous Si₃N₄ was measured after machining. We can conclude as follows:

(1) In turning, the $R_{\text{max}}$ of the porous Si₃N₄ increases with increasing cutting speed and feed rate. $R_{\text{max}}$ below 10 μm can be obtained under the conditions that satisfies both a cutting speed of 50 m/min and feed rates below 0.1 mm/rev.

(2) In milling, serious cutting speed dependence of $R_{\text{max}}$ cannot be seen in a cutting speed range between 20 to 200 m/min $R_{\text{max}}$ below 10 μm can be obtained at feed rates below 0.1 mm/rev, despite cutting speed.

(3) The porous Si₃N₄ has potential as a high-strength machinable ceramic.

References