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# Machining property by ultra fine bubble coolant

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*Our research group has been studying the application of micro bubbles (MB: several μm~50μm in diameter) generated in the working fluid for removal machining. Currently, the research has developed into the application of UFB coolant generated ultra fine bubbles (UFB) with the diameter of less than 1μm. It is known that UFB coolant improves tool wear in turning and grinding machining, but the mechanism is still unknown. In this study, we applied a UFB generator using a micro-porous-ceramics that the UFB conditions can be changed. And the relationship between changes in the physical property of the working fluid mixed UFB and machining characteristic was investigated. As a result, it was found that the viscosity of coolant was reduced when UFB was mixed into coolant. Furthermore, when the UFB coolant was applied to turning of stainless steel, the tool wear and the surface roughness were improved.*

## 1. Introduction

The authors have been studying the application of microbubble coolant with micro bubbles of several microns to 50 microns in water-soluble machining fluids for cutting and grinding [1-4], and are now working on the application of Ultra Fine Bubbles (UFB) smaller than 1 micron. We have found that UFB is effective not only in increasing tool life, reducing machining resistance, and improving surface roughness, but also in preventing spoilage of the machining fluid and improving the removal of contaminants, and we are working to elucidate the mechanism of these effects. In our previous study, we measured the bubble diameter and density of UFB and investigated the relationship between them and the machining performance, but the bubble diameter and density are not directly related to the reason why the machining characteristics are improved. Therefore, we focused on the change of the viscosity of the machining fluid by UFB. In this study, the UFB generator using Ultrafine pore ceramics was used to investigate the change in viscosity when UFB was generated in various machining fluids, and to evaluate the machining performance when applied to the turning of stainless steel.

## 2. UFB generator using Ultrafine pore ceramics

Figure 1 shows two types of UFB generators using Ultrafine pore ceramics. The principle of the UFB generation is that the gas accumulation on the surface of the Ultrafine pore ceramics is detached by the liquid flow at high speed and the UFB is generated [5]. The in-line type depends on the liquid flow speed of the fluid passing through the rod-shaped ceramic element installed in the circular tube and the tube, and the rotary type depends on the rotation speed of the cylindrical ceramic element. In the rotary type, it depends on the rotation speed of the cylindrical ceramic element. In this study, an in-line type UFB generator was used.

## 3. Effect of UFB on the viscosity of various process fluids

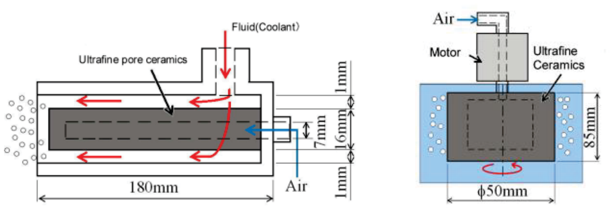
### 3.1 Change in viscosity of various process fluids by UFB

A tube (inner diameter: 6.5 mm, length: 1.5 m) filled with glass beads (middle diameter: 6 mm) as shown in Fig.2 was flowed with a constant flow rate and the changes of pressure drop and flow rate with time were measured. The viscosity coefficient $\mu$ was derived from the Dulcie-Weisbach equation, and the apparent viscosity was investigated as a function of UFB. The fluids were diluted by 5% with pure water. 15 L of the fluids were fed with air at a rate of 1 L/min using an in-line UFB generator and the UFB was generated for 10 min. In the case of pure water, 0.5 L of the UFB-generating fluid was added to the glass bead-filled tube at a height of 1.9 m. In the case of cutting fluid, 1 L of UFB-generating fluid was added to the tube, and after apparently all the fluids were replaced by UFB-generating fluids, non-UFB-generating fluids were added again. The results of the change in viscosity with time are shown in Fig. 3-5.

In the case of pure water (Fig.3), the viscosity decreased with the addition of UFB-generated water and the ratio of UFB-generated water increased, and apparently, when all the water was replaced by UFB-generated water (at 3h), the viscosity decreased by 7% from the initial value. Similarly, for the emulsion cutting fluid (Fig.4), $\mu$ decreased as the proportion of UFB-generated fluid increased, and when all the UFB-generated fluid was replaced (at 1.2 h), $\mu$ decreased by 2% from the initial value. For the soluble cutting fluid (Fig.5), the value of $\mu$ also decreased as the percentage of UFB-generating fluid increased, with a maximum decrease of 3%. For both emulsion and soluble cutting fluids, the value of $\mu$ increased after 1.2h when the proportion of UFB-generating fluid was reduced by changing to non-UFB-generating fluid. The contact angle of the UFB-generated droplets is smaller than that of the pre-generated droplets, suggesting that the improved wettability of the liquid is responsible for the reduced viscosity.

### 3.2 Change in physical properties when various gases are mixed with UFB

Figure 6 shows the relationship between the dissolved oxygen content of pure water (high resistivity water) and soluble cutting fluid and the dissolved oxygen content when various gases are mixed as UFBs at a supply rate of 1 L/min in an inline UFB generator. In pure water, the dissolved oxygen content was reduced from 8 mg/L to less than 2 mg/L after 30 minutes when nitrogen and carbon dioxide UFBs were generated. On the other hand, when oxygen was added, the dissolved oxygen immediately exceeded the upper limit of 20 mg/L. In soluble fluids, the dissolved oxygen could be reduced to 2.6 mg/L after 30 minutes by generating nitrogen UFB.




(a) Inline type (b) Rotary type

Fig.1 UFB generator using ultra-fine porous ceramics

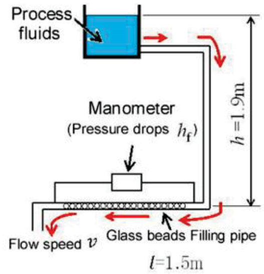



Fig. 2 Viscosity measuring device

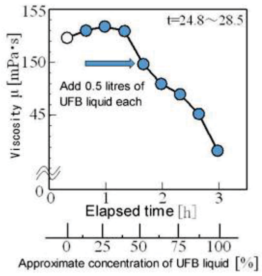



Fig. 3 Viscosity trend graph of pure water

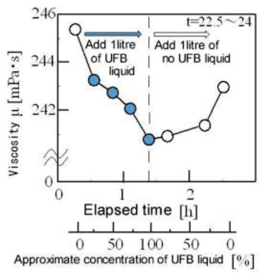



Fig. 4 Viscosity trend graph of emulsion cutting fluid

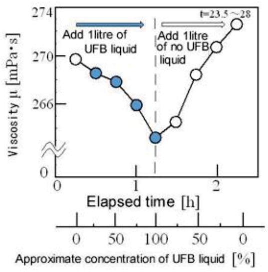
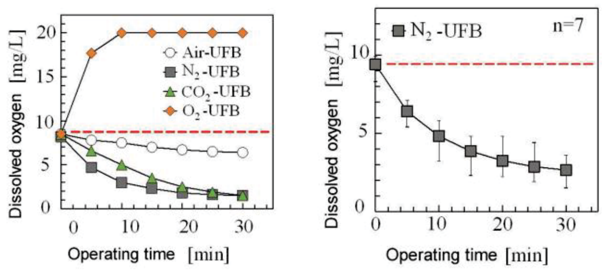



Fig. 5 Viscosity trend graph of soluble cutting fluid




(a) Pure water (b) Soluble cutting fluid

Fig. 6 Effect of inert gases on dissolved oxygen in coolant

## 4. Application to the turning of stainless steel

UFB coolant generated by an in-line UFB generator in various machining fluids (15L) for 30 minutes was applied to the turning of stainless steel SUS304 (ϕ50mm) at $V_C$=100m/min, $t$=1mm, $f$=0.2mm/rev up to $L_C$=0.7km. Turning experiment device and condition are listed in Table 1. Figures 7 to 9 show the results of turning to $L_C$=0.7km.

### 4.1 In the case of pure water (Fig.7)

The flank wear width after machining ($L_C$=0.7 km) was $V_B$=75 µm when UFB was generated for 30 min, compared to $V_B$=94 µm without UFB, a reduction of about 20% compared to the case without UFB. The surface roughness of the workpiece was reduced by about 8% from $R_a$=2.6 µm without UFB to $R_a$=2.4 µm with UFB for 30 minutes at $L_C$=0.7 km.

### 4.2 In the case of emulsion cutting fluid (Fig.8)

The flank wear width was reduced by about 19% from $V_B$=116µm without UFB to $V_B$=94µm when UFB was applied for 30 minutes. Under the present conditions, the surface roughness of the workpiece without UFB was lower than when UFB was applied for 30 minutes. This may be related to tool wear.

### 4.3 In the case of Soluble emulsion cutting fluid (Fig.9)

The flank wear width after machining was reduced by about 12% from $V_B$=92 µm without UFB to $V_B$=81 µm when UFB was applied for 30 min. The surface roughness of the workpiece after machining was reduced from $R_a$=2.6 µm without UFB to $R_a$=2.2 µm with UFB for 30 minutes, a reduction of about 15%.

To investigate the effect of the amount of dissolved oxygen in the machining solution, the wear width of the front clearance surface was reduced to $V_B$=75 µm when nitrogen was used as UFB for 30 minutes. The surface roughness of the workpiece was $R_a$=2.2 µm. A further reduction in the amount of dissolved oxygen would have had a greater effect. The effect of UFB on cutting and frictional forces was not observed for any of the fluids, although this is not shown in the figure.

## 5. Conclusions

It was found that the apparent viscosity of the various fluids was reduced by the generation of UFB. Since it was found that the change in the properties of the fluids due to UFB can be compared with the apparent viscosity, we would like to investigate the relationship between the UFB generation conditions and the machining performance to clarify the machining mechanism.

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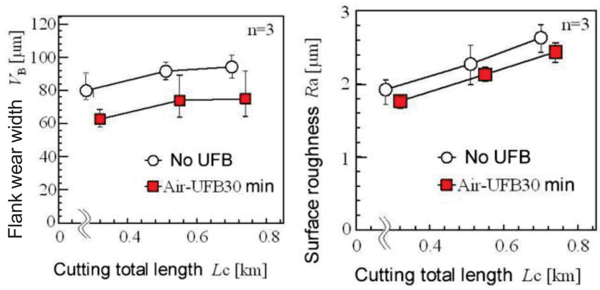
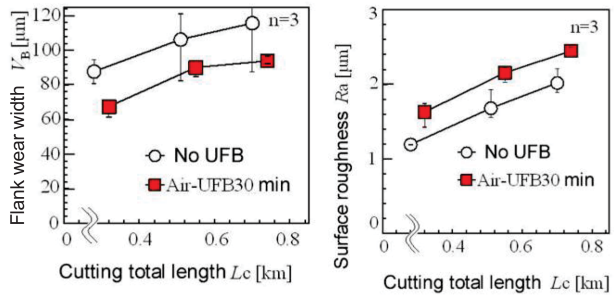


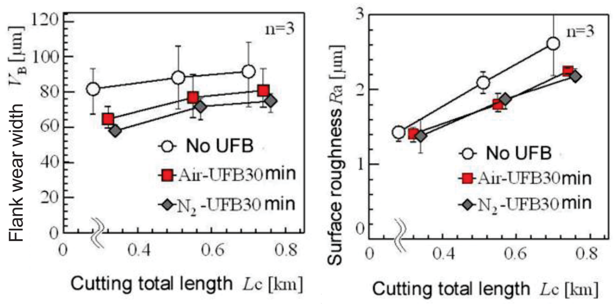

(a) Flank wear width $V_B$ (b) Surface roughness $R_a$

Fig. 7 Effect of UFB coolant on turning characteristics in the case of pure water




(a) Flank wear width $V_B$ (b) Surface roughness $R_a$

Fig. 8 Effect of UFB coolant on turning characteristics in the case of emulsion cutting fluid




(a) Flank wear width $V_B$ (b) Surface roughness $R_a$

Fig. 9 Effect of UFB coolant on turning characteristics in the case of soluble cutting fluid

| | |
|---|---|
| Machine | CNC turning center (SQT-15M, Yamazaki Mazak) |
| UFB device | Ultrafine pore ceramics type (ANZAI Kantetsu) |
| Cutting tool | Non-coat cemented carbide<br>CNMG120408-SM (SANDVIK)<br>Nose R0.8mm, Rake angle 5°<br>Clearance angle 11° |
| Workpiece | Stainless steel, 304 (SUS304 in JIS)<br>50×100mm |
| Turning condition | $Vc$=100 m/min, $f$=0.2 mm/rev, $t$=1mm<br>$Lc$=0.7 km |
| Working fluid | Purer water (22 µS/cm)<br>Emulsion type (CFS-100PA, Neos)<br>Soluble type (NTF-100S, Neos)<br>Dilution ratio: 5%, Flow rate: $q$=0.6 L/min |

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