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# Effectiveness of Minimal Quantity Lubrication in Machining Processes

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A minimal quantity lubrication (MQL) machining is able to achieve both functions of cooling and lubrication with an extremely low quantity of a cutting fluid and a large amount of air blow. Using a biodegradable ester oil, turning tests were carried out to evaluate the effectiveness of the MQL system. It was found that the performance of MQL cutting was equivalent to, or better than, that of conventional cutting, because the MQL system tends to prevent the heat damage of the tool tip and, if an effective lubricant such as a particular polyol ester is applied to the system, it can avoid the extensive transfer of workpiece materials on to the tool surface.

**Keywords** : Environment-friendly machining, Turning, Minimal quantity lubrication, Cutting fluid, Biodegradable ester

## 1. INTRODUCTION

Recently, programs regarding the environmental issues, such as the ozone layer destruction and the global warming effect, are rising all over the world. In Japan, for example, the regulations including the environmental impact assessment law, the pollutant release and transfer register and the law concerning special measures against dioxins are being strengthened. In metal working, environmental issues have necessitated dry and semi-dry cutting operations, and minimal quantity lubrication (MQL) is probably the most representative and the practically well-recognized application of semi-dry cutting [1]. The purpose of this paper is therefore to demonstrate the effectiveness of the MQL system in machining processes particularly with a biodegradable synthetic ester used as a cutting fluid.

## 2. MQL System

The MQL system supplies a very low quantity of a lubricating oil and a large amount of, normally, compressed air to the cutting point. The compressed air is used to remove chips and to cool a tool and the minimal quantity of lubricating oil is used to lubricate. Since the lubricating oil is usually supplied at a rate of 2 to 30 ml/h, the amount of the lubricant can be reduced drastically. And it is possible to reduce largely the energy consumption of machines because the lubricant pump which consumes much electric power is not needed [2]. Thus, not only MQL cutting is the environment-friendly operation but also it is the energy and cost saving operation.

Lately, the MQL operation has been put to practical use in the manufactures. In intermittent cutting such as milling with conventional cutting fluid supply, the repetitions of heating up during cutting and cooling down by the fluid during intervals may cause a severe damage of the tool. In the MQL system, however, the tool tip is not so much cooled because of a very little fluid, resulting in longer tool life [3]. In the case of continues cutting such as turning, although it has long been believed that a cutting fluid should find difficulty in accessing the cutting zone through the gap between the tool rake face and the chip or between the tool flank face and the workpiece, the effective MQL operation can achieve success in some turning processes [4].

## 3. Experimental

### 3.1 Materials

Table 1 shows the lubricants used in this study. A cutting lubricant of the MQL system should not contain any harmful material and should not have any unfavorable influence on environment. Such fluids may therefore be required to have high biodegradability, leading to vegetable oils and some synthetic polyol esters as a candidate [5]. It is also taken into account that, since MQL oil mist particles can easily be stuck on the surfaces of machine tools, workpiece and other facilities, its lubricating oil must have high stability. In this meaning, vegetable oils are unfavorable mainly because their low oxidation stability may eventually change them into adhesive materials, resulting in inferior working environment. On the other hand, since synthetic polyol esters comprise saturated molecular structures, they can show much better oxidation stability and storage characteristics [6].

**Table 1** Physical property of the test lubricants

| | Conventional cutting fluid (Neat oil) | Polyolester A |
|---|---|---|
| Density (15°C) $g/cm^3$ | 0.87 | 0.95 |
| Viscosity (40°C) $mm^2/s$ | 11.0 | 19.1 |
| Flash Point (COC) °C | 166 | 250 |
| Pour Point °C | −17.5 | <−45 |
| Sulfur Content % | 3.5 | None |
| Biodegradability (CEC) % | 20∼30 | 100 |

### 3.2 Turning Test

Using a tool with advanced ceramic coatings, the cutting performance of the MQL system was compared with that of dry cutting in the case of turning JIS S45C steel workpiece.

Table 2 shows test conditions. The coefficient of friction on the tool rake face and the roughness of surface finish are obtained in order to evaluate the performance of the MQL cutting in turning operations.

**Table 2** Test conditions

| | |
|---|---|
| Tool | WC with TiCN-Al2O3-TiN layer |
| Workpiece | JIS S45C steel |
| Cutting speed | 200m/min |
| Feed | 0.1mm/rev |
| Depth of cut | 1.0mm |
| MQL system | Pressuer of compresed air : 0.3MPa<br>Rate of oil supply: 25ml/h |

## 4. Results and Discussion

Figure 1 shows the representative results of the coefficient of friction during turning and the surface roughness of workpiece after turning. The results of these turning tests show that, compared with the case of dry cutting, the coefficients of friction are low in both cases of MQL cutting with polyol ester A and conventional cutting with a neat oil type fluid containing 3.5% of sulfur. The values of surface roughness are also in the same magnitude for MQL cutting and conventional cutting. It is surprising that, even in turning tests, MQL cutting has shown the same degree of performance as that of conventional cutting and the better performance than dry cutting. As shown in Figure 2, the observation of the tool tip demonstrated no wear and no failure in MQL cutting. On the other hand, the surface of the tool tip in dry cutting showed the damaged features including some evidence of chipping. This may also have caused the somewhat rougher surface finish of the workpiece, presumably because of poor lubrication. Figure 3, which was the SEM magnification of tool tip, indicated the evidence of crack on the rake surface in the case of conventional cutting. Such crack may possibly be caused by some heat damage due to a large amount of the cooling oil supply on to the heated tool surface.

With the aid of SEM-EDX analysis, Table 3 shows the intensity of iron adhering on the rake and flank surfaces of the tool. It was found that the intensity of iron in dry cutting is much larger than that in conventional cutting with the neat oil type fluid. Since the additive in the neat oil type fluid were able to form a lubricating film easily on the surface, the adhesion of iron was successfully restrained. In the similar way, MQL cutting with polyol ester A shows the considerably small intensity of iron, indicating effective adsorption of the ester on the surface. These results suggest that the combination of MQL system with advanced coatings on the tool surface can provide preferably extended tool life even in the turning operations.

## 5. CONCLUSION

Using the turning test, the cutting performance of the MQL system with polyol ester A was evaluated in comparison with other cutting methods such as dry cutting and conventional cutting with neat oil type fluid. It was found that the performance of MQL cutting was equivalent to, or better than, that of conventional cutting, because the MQL system tends to prevent the heat damage of the tool tip and can avoid the extensive transfer of iron on to the tool surface.

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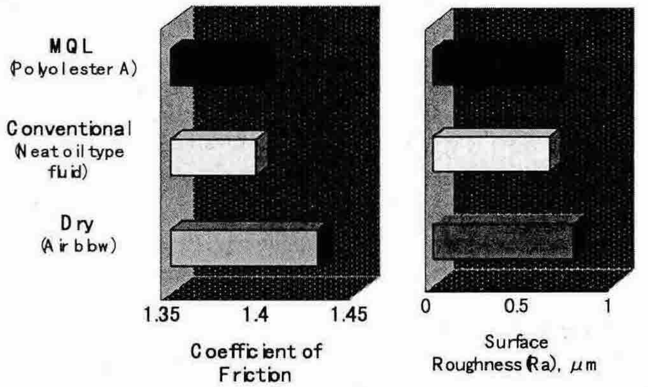


**Fig. 1** Cutting performance of turning test

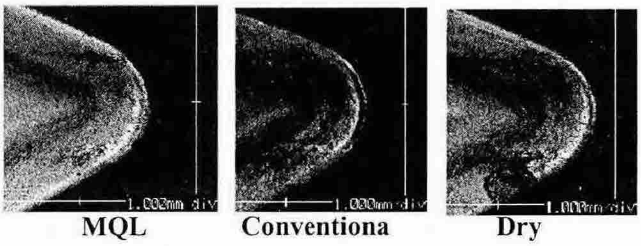


**Fig. 2** Surface of Tool Tip after the Tests

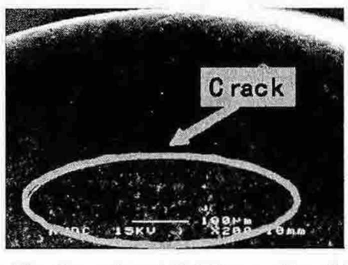


**Fig. 3** Magnification of tool tip(Conventional Cutting)

**Table 3** Results of Fe analysis by SEM-EPMA

| | Intensity of the Iron (CNT) | |
|---|---|---|
| | Rake | Flank |
| MQL (Polyol ester A) | 50 | 15 |
| Conventional (Neat oil type fluid) | 25 | 5 |
| Dry (Air blow) | 410 | 30 |