Experimental Study of a New Type of Cutting Fluid Based on Superlubricity Theory

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Abstract. Superlubricity theory brings a new idea and direction to solve the wear and friction problem during high-speed cutting. Based on the superlubricity theory, a new type of glycerine-acid cutting fluid with excellent anti-friction and anti-wear performance is developed. Using of the existing superlubricity agent, the glycerol-acid is added to the cutting fluid, and a new environmentally friendly water-based cutting fluid is designed. Furthermore, taking the titanium alloy as the object, the high-speed cutting test of the new type of cutting fluid is carried out. Finally, a large number of comparative analyses are carried out based on the test results. The research shows that the new type of cutting fluid has better cooling and lubrication performance, and can play a good role in reducing the cutting tool friction and improving workpiece surface quality. The optimum concentration range for new type of cutting fluids is 6%–10% glycerol and 9%–13% boric acid.

Introduction

During metal cutting process, the wear of cutting tools often occur, and the temperature of cutting zone increase sharply, leading to greatly reduce of the productivity and increase of the processing cost [1-2]. The traditional cutting fluid has the poor performance in reducing the friction and wear. Therefore, a new cutting fluid that can greatly reduce the friction between workpiece and cutting tool is urgently needed [3]. Superlubricity is defined as lubrication with a friction coefficient of 0.001 or lower, which is one of the advanced scientific theories with broad application prospects in the field of tribology for more than 20 years, and has great significance in solving friction problems [4-6]. Based on the superlubricity theory, this paper innovatively combines superlubricity agent and cutting fluid to develop a new cutting fluid, providing theoretical basis and technical support for solving the problem of rapid tool wear.

High Speed-Cutting Test

The base solution is sodium carbonate solution with mass fraction of 2.5%. The basic additives are 15% triethanolamine, 2% dimethyl silicone oil and 5% polyethylene glycol. Glycerol and boric acid are added to the cutting fluid, the mass fraction of glycerol and boric acid is 8% and 5% glycerol.

The cutting tool was 20mm vertical milling insert carbide tool with 3 teeth, the workpiece material was titanium alloy, the Wintec mv-80 CNC milling machine processing center is adopted, and the type ydx-iii9702 piezoelectric milling dynamometer is used.

The four cutting speeds selected in the test are respectively: 600r/min, 1100r/min, 1600r/min, 2100r/min. Feed speed is selected as 300mm/min. The three-way dynamometer is fixed and connected as shown in Figure 1 and 2:

Test Results Analysis

Analysis of Cutting Force and Friction Coefficient

The three-way cutting force and friction coefficient are shown in Table 1 when cutting speeds are: 600r/min, 1100r/min, 1600r/min, 2100r/min.
It can be seen from the table that different friction coefficients will be produced between the tool and the workpiece by using the same cutting fluid at different cutting speeds. At 600 r/min and 2100 r/min, relatively large friction coefficients appear, reaching 1.04 and 1.08, respectively. At the speed of 1100 r/min, the friction coefficient decreases slightly to 0.964; at the cutting speed of 1600 r/min, the friction coefficient reaches the minimum value of this group, which is 0.785. Because different cutting forces and heat will be produced at different cutting speeds, the oil film produced by cutting fluid in the cutting area where the tool contacts with the workpiece will appear different shapes. When the cutting force is large, the oil film will be squeezed, and the thickness of the oil film will be reduced or even broken. When the cutting heat is large, the performance of the cutting fluid will change and the nature of the oil film will be changed, and the role of the cutting fluid will be reduced.

### Analysis of Tool Wear

The tool used in this experiment is tungsten-cobalt cemented carbide insert tool. The wear of the three cutting edges of the tool tip, the flank and the main cutting edge are observed respectively. Tool wear with glycerine-acid cutting fluid is shown in Figure 3:

As can be seen from Figure 3, when the tungsten-cobalt-inlaid carbide tool is used to cut titanium alloy, the tool wear is not too serious, and there is basically no wear on the back cutter surface,
indicating that the workpiece and the tool are suitable, and the above rule is consistent with the overall performance of the friction coefficient.

**Study on the Formulation Optimum**

To optimize, four kinds of different glycerine-acid cutting fluids are used and as follows:

| No.  | Base additive | glycerin | boric acid |
|------|---------------|----------|------------|
| No.1 | sodium carbonate | 2.5 | 15 | 2 | 5 | 2 | 5 |
| No.2 | sodium carbonate | 2.5 | 15 | 2 | 5 | 5 | 8 |
| No.3 | sodium carbonate | 2.5 | 15 | 2 | 5 | 8 | 11 |
| No.4 | sodium carbonate | 2.5 | 15 | 2 | 5 | 11 | 14 |

Table 2. Composition details of four different glycerine-acid cutting fluids.

The milling force for four kinds of cutting fluid are measured using dynamometer, and the change curve of friction coefficient is shown in Figure 4.

Figure 4. The friction coefficient curves of glycerol - acid cutting fluid with different concentrations.

From Figure 4, it can be seen that the friction coefficient decreases gradually with the increasing concentration of glycerol and boric acid, reaching at the concentration of 8% glycerol and 11% boric acid. When the concentration of glycerol and boric acid continues to increase, the friction coefficient increases slightly to 0.759 at point 4.

When the concentration of glycerol and boric acid is low, the lubrication effect is not very good, which indicates that the concentration of glycerol and boric acid has a decisive influence on the performance of this cutting fluid. When the concentration of glycerol and boric acid is increased, the friction coefficient decreases obviously, and then increases slowly, which indicates that the friction coefficient is better. The ratio of glycerol to boric acid in lubrication state has a certain range, and there will be saturation. When the boric acid concentration is too high, there will be supersaturation. At this time, the lubrication effect will be reduced slightly.

The results show that the optimum concentration range of cutting fluid with glycerol-acid supersynovial fluid is 6%–10% glycerol and 9%–13% boric acid.

**Conclusion**

In this paper, a new type of cutting fluid is developed by introducing glycerine-acid superlubricity agent based on the theory of superlubricity.

High-speed cutting experiment is constructed and the cutting force and friction coefficients for four cutting speeds are obtained. The experimental results show that the friction coefficient decreases when the cutting speed reaches a certain value. The new cutting fluid has good cooling and lubricating effect, and can play a good role in reducing friction of the tool and surface quality of the workpiece. The tool wear shows that the tool wear is not very serious, and the flank is basically
not worn. The cutting fluid with glycerol-acid super-slip agent has better tool friction reduction effect.

The optimum concentration range of new type of cutting fluid with glycerol-acid super-sliding fluid is 6%–10% glycerol and 9%–13% boric acid.

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