Research on A New Type of Antifriction and Antiwear Cutting Fluid Based on Superlubricity Theory

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Abstract. Based on the superlubricity theory, a new type of cutting fluid with excellent anti-friction and anti-wear effects is developed. Using the existing superlubricity agent, several new environmentally friendly water-based cutting fluids have been formulated; Further, the high-speed cutting tests of a new type of cutting fluid were carried out for titanium alloy. Finally, a large number of comparative analyses were performed based on the test results. Studies have shown that the friction coefficient obtained using the cutting fluid with solid lubricant is generally large, however, the lower friction coefficient can be obtained when using the cutting fluid with glycerol-acid and hexadecyl dimethyl ammonium bromide, also the better cooling and lubricating effects were obtained.

Keywords. Metal cutting; Cutting fluid; Superlubricity theory.

1. Introduction
In the process of metal cutting, the tool used will wear away gradually, greatly reducing the production efficiency and raising the the cost of production [1-2]. The cutting fluid has four kinds of functions: cooling, lubrication, rust prevention and cleaning [3-4]. At present, due to the increasing demand for environmental protection, environmental-friendly water-based cutting fluid has become the focus of development [2]. However, the environmentally friendly water-based cutting fluid is still in its development stage, and its performance is deficient in many aspects, especially in friction reduction and lubrication effect, which leads to the problem of rapid wear of high-speed cutting tools for difficult-to-machine materials. Overslip refers to the lubrication condition in which the friction coefficient is 0.001 or lower. It is one of the advanced and promising theories in the field of Tribology for more than 20 years. It has great significance in solving friction problems and provides possibility for getting rid of the bondage of friction and wear [5-7]. The emergence and development of super-slip theory has brought new ideas and directions to the problem of rapid wear of high-speed cutting tools for difficult-to-machine materials. Based on the theory of Tribological super-slip, this paper innovatively combines the formulation design of super-slip agent and cutting fluid to develop a new cutting fluid with excellent anti-friction and anti-wear effect, which provides theoretical basis and key technical support for effectively solving the problem of rapid tool wear.

2. Experiment
Several kinds of super-slip agents were introduced into cutting fluid, and several new environmentally friendly water-based cutting fluids were developed. The cutting parameters of cutting speeds used in the experiment are 600r/min, 1100r/min, 1600r/min and 2100r/min respectively, and the feed speed is
300mm/min.

3. Results and Analyses

3.1. Data Output and Analysis of Basic Cutting Fluid Experiment

![Figure 1](image1.png)

Figure 1. Continuous variation curve of milling force for basic cutting fluid.

The continuous variation of cutting forces in three directions at a cutting speed of 600 r/min is shown in figure (Fig.1). It can be seen from the figure that the force in the X direction and the force in the Y direction change periodically in the milling process.

The milling force and friction coefficient are shown in table (Table 1).

|          | 600r/min | 1100r/min | 1600r/min | 2100r/min |
|----------|----------|-----------|-----------|-----------|
| F<sub>X</sub> /N | 313.9    | 273.4     | 215.8     | 303.4     |
| F<sub>Y</sub> /N | 361.1    | 317.3     | 244.0     | 340.6     |
| μ        | 1.235    | 1.224     | 1.257     | 1.266     |

From the table, we can see that the friction coefficient of cutting with basic cutting fluid is larger at four speeds.

3.2. Data Output and Analysis of Cutting Fluid Experiment with Glycerol-acid

![Figure 2](image2.png)

Figure 2. Continuous variation curve of milling force for glycerol-acid.

Figure (Fig.2) shows the change of milling force when the cutting speed is 1100 r/min using glycerol-acid super-slip agent. The continuous change of milling force at four cutting speeds output by three-way dynamometer is obtained.

The milling forces and friction coefficients are shown in table (Table 2).
Table 2. Milling Force and Friction Coefficient of Cutting Fluid with Glycerol-acid Supersoiling Agent.

| Speed (r/min) | FX (N) | FY (N) | μ    |
|--------------|--------|--------|------|
| 600          | 347.3  | 473.4  | 1.045|
| 1100         | 231.3  | 343.7  | 0.964|
| 1600         | 137.1  | 256.3  | 0.785|
| 2100         | 203.3  | 267.9  | 1.080|

It can be seen from the table that different friction coefficients will be produced between tool and workpiece by using the same cutting fluid at different cutting speeds. At 600 r/min and 2100 r/min, relatively large friction coefficients will appear, reaching 1.04 and 1.08, respectively. At 1100 r/min, the friction coefficients will decrease slightly. At the cutting speed of 1600 r/min, the friction coefficient reaches the minimum value of 0.785.

3.3. Data Output and Analysis of Cutting Fluid Experiment with Hexadecyl Dimethyl Ammonium Bromide

Figure (Fig.3) shows the change of milling force when cutting fluid with hexadecyl dimethyl ammonium bromide is introduced at a cutting speed of 1100 r/min. It has been pointed out that some substances will change their molecular state during high-speed shear, which greatly reduces the friction coefficient and even reaches the super-slip state. This phenomenon can occur in hexadecyl dimethyl ammonium bromide.

Figure 3. Continuous variation curve of milling force for hexadecyl dimethyl ammonium bromide.

The milling force and friction coefficient are shown in table (Table 3).

Table 3. Milling Force and Friction Coefficient of Cutting Fluid with hexadecyl dimethyl ammonium bromide.

| Speed (r/min) | FX (N) | FY (N) | μ    |
|--------------|--------|--------|------|
| 600          | 247.7  | 364.2  | 0.973|
| 1100         | 160.1  | 239.4  | 0.958|
| 1600         | 128.4  | 247.2  | 0.766|
| 2100         | 170.7  | 283.4  | 0.871|

It can be seen from the table that the friction coefficient will be larger at lower speed when using this cutting fluid. As shown in table 3, the friction coefficient will be 0.97 and 0.96 at cutting speeds of 600 r/min and 1100 r/min, while the friction coefficient will decrease relatively when the speed continues to increase, and it will be 0.7 at 1600 r/min. When the speed continues to increase, the friction coefficient increases, and at 2100 r/min, the friction coefficient is 0.87.

3.4. Data Output and Analysis of Cutting Fluid Experiment with Graphite

Figure (Fig.4) shows the change of three-way milling force when the cutting fluid with graphite is used at a cutting speed of 1100 r/min.
Figure 4. Continuous variation curve of milling force for graphite.

The milling force and friction coefficient are shown in table (Table 4).

**Table 4.** Milling Force and Friction Coefficient of Cutting Fluid with Graphite.

|       | 600r/min | 1100r/min | 1600r/min | 2100r/min |
|-------|----------|-----------|-----------|-----------|
| F_X   | 301.1    | 293.3     | 170.9     | 203.4     |
| F_Y   | 440.8    | 335.7     | 230.5     | 219.3     |
| μ     | 0.977    | 1.247     | 1.056     | 1.320     |

It can be seen from the table that there is a minimum friction coefficient at 600r/min. In the overall trend, with the increase of cutting speed, the friction between tool and workpiece becomes more and more intense, and the friction coefficient also increases gradually. Then, when the cutting speed continues to increase to 1600 r/min, the friction is more severe because of chip overflow.

3.5. Data Output and Analysis of Cutting Fluid Experiment with Molybdenum Disulfide

Figure (Fig.5) shows the cutting condition when molybdenum disulfide is added to the cutting fluid at 1100 r/min.

Figure 5. Continuous variation curve of milling force for molybdenum disulfide.

When the cutting speed is 600 r/min, 1100 r/min, 1600 r/min and 2100 r/min, the milling force and friction coefficient are shown in table (Table 5).

**Table 5.** Milling force and friction coefficient of cutting fluid with molybdenum disulfide.

|       | 600r/min | 1100r/min | 1600r/min | 2100r/min |
|-------|----------|-----------|-----------|-----------|
| F_X   | 396.5    | 443.4     | 497.3     | 426.7     |
| F_Y   | 463.3    | 507.7     | 543.7     | 489.3     |
| μ     | 1.215    | 1.241     | 1.301     | 1.239     |

It can be seen from the table that the friction coefficient does not change much when the cutting fluid with molybdenum disulfide is used for cutting.
3.6. Comprehensive Analysis of Friction Coefficient for Five New Cutting Fluids with Friction Reduction and Wear Resistance

Friction coefficients of five new anti-friction and anti-wear cutting fluids are shown in Figure 6.

It can be seen from the figure that the curves obtained by using the cutting fluid with solid lubricant and the basic cutting fluid with molybdenum disulfide are basically the same. Molybdenum disulfide can not play its antifriction effect in this cutting fluid. Comprehensive analysis shows that molybdenum disulfide and this cutting fluid have the same antifriction effect. The friction coefficient curve of cutting fluid with graphite is basically below the basic cutting fluid, but it is almost equal to the basic cutting fluid in several ranges. Therefore, graphite can reduce friction under specific cutting conditions, but it is not suitable in general. In summary, adding solid lubricant to the basic cutting fluid will produce mixtures that are not suitable for cutting. Although graphite has better performance than molybdenum disulfide in this basic cutting fluid, solid lubricant is not suitable for this cutting fluid system.

4. Conclusion

(1) In this paper, several kinds of cutting fluids are prepared by using the general method of water-based cutting fluids preparation, introducing superlubricity theory: (a). Preparing basic cutting fluids without any lubricant; (b). Preparing new cutting fluids with glycerol-acid super-sliding agent, boric acid used in this acid; (c). Preparing new cutting fluids with hexadecyl dimethyl ammonium bromide. (d). Cutting fluid with graphite solid lubricant; (e). Cutting fluid with molybdenum disulfide solid lubricant.

(2) Solid lubricant is not suitable for use as a lubricant of cutting fluid. The friction coefficient obtained by using cutting fluid with solid lubricant is generally large, which indicates that solid lubricant can not play its lubricating effect in this cutting fluid and is incompatible with this cutting fluid.

(3) Glycerol-acid supersliding agent and hexadecyl dimethyl ammonium bromide are suitable lubricants to be added to cutting fluid. When using the above two materials as lubricants, the friction coefficient curve is obviously lower than that of the basic cutting fluid, which has better cooling and lubricating effect. Glycerol, boric acid and hexadecyl dimethyl ammonium bromide are non-toxic and harmless, and are very suitable for the development of new environmentally friendly water-based cutting fluid.

(4) The analysis of tool wear shows that the tool wear is the most serious when the basic cutting fluid is used, followed by the cutting fluid with glycerol-acid super-sliding agent and the cutting fluid with hexadecyl dimethyl ammonium bromide. However, compared with the basic cutting fluid, the other two kinds of tool wear is lighter. Cutting fluids with glycerol-acid and hexadecyl dimethyl ammonium bromide have good anti-friction and anti-wear effects on cutting tools.

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