Experimental study on a new type of cutting fluid based on hexadecyl dimethyl-ammonium bromide

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Abstract. The theory of superlubricity brings a new idea and direction to solve the problem of wear and tear of high-speed cutting tools. According to the superlubricity theory, a new type of cutting fluid based on hexadecyl dimethyl-ammonium bromide was developed by combining superlubricity agent and cutting fluid. Furthermore, taking the cutting of titanium alloy as the object, high speed cutting tests of the new type of cutting fluid were carried out. Finally, a large number of comparative analyses were carried out based on the experimental results. The research shows that the new type of cutting fluid has better cooling and lubrication effect, and can play a good role in reducing friction of cutting tool and improving surface quality of workpiece. The optimum concentration range of hexadecyl dimethyl-ammonium bromide is 2%-4%.

1. Introduction
During the process of metal cutting, the tool used will gradually wear out, and the machining surface quality will deteriorate, and the dimension error will exceed the reasonable range, resulting in a huge waste, greatly reducing the productivity and increasing the processing cost[1-2]. High quality cutting fluid can play the role of cooling, lubrication, rust prevention and cleaning[3]. The friction reduction effect of cutting fluid can reduce the above situation. However, the traditional cutting fluid has poor friction reduction effect. At present, a new superlubricity theory appears, in which the friction coefficient is 0.001 or lower. Superlubricity theory is one of the advanced scientific theories with broad application prospects in the field of tribology for more than 20 years. The emergence and development of superlubricity theory brings new ideas and directions to the problem of rapid wear of high-speed cutting tools for machining materials[4-6]. Based on the superlubricity theory, this paper innovatively combined superlubricity agent and cutting fluid to develop a new type of cutting fluid, in which the hexadecyl dimethyl-ammonium bromide was used, providing a theoretical basis and technical support for effectively solving the problem of rapid tool wear.

2. 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. Hexadecyl dimethyl-ammonium bromide (cetyl dimethylammonium bromide) superlubricity agent was introduced into the cutting fluid.

The test 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 was adopted, and the type ydx-iii9702 piezoelectric milling dynamometer was used. The four cutting speeds selected in the test
are 600r/min, 1100r/min, 1600r/min and 2100r/min respectively. The feeding speed was selected as 300mm/min.

The cutting process and measuring process were as shown in Fig. 1 and Fig. 2.

3. Test results analysis

3.1 Analysis of cutting force and friction coefficient

Fig. 3 shows the change of cutting force with the cutting fluid introduced with hexadecyl dimethyl-ammonium bromide at the cutting speed of 1100r/min. It has been pointed out that when some materials shear at high speed, the molecular state will change, thus greatly reducing the friction coefficient, and even reaching the state of superslip, which can be seen in cetyl dimethyl ammonium bromide. In this paper, hexadecyl dimethyl-ammonium bromide is added to the cutting fluid as a lubricant to study the cooling and lubrication effect of the cutting fluid at four different speeds.

When the cutting speeds were 600r/min, 1100r/min, 1600r/min and 2100r/min, the cutting forces and friction coefficients are shown in Table 1:
Table 1. Cutting force and friction coefficient during cutting process

|       | 600r/min | 1100r/min | 1600r/min | 2100r/min |
|-------|----------|-----------|-----------|-----------|
| F_X N | 247.7    | 160.1     | 128.4     | 170.7     |
| F_Y N | 364.2    | 239.4     | 247.2     | 283.4     |
| µ     | 0.973    | 0.958     | 0.766     | 0.871     |

It can be seen from the table when using such cutting fluid, large friction coefficient will appear at a lower speed. The friction coefficient is 0.97 and 0.96 at the cutting speeds of 600r/min and 1100r/min. When the speed continues to increase, the friction coefficient decreases relatively greatly. At 1600r/min, the friction coefficient is 0.78. When the velocity continues to increase, the friction coefficient increases somewhat, and at 2100r/min, the friction coefficient is 0.87.

In addition, the test results show that using cetyl dimethyl ammonium bromide as a lubricant, considering the factors such as artifacts, cutting tool and cutting speed at the same time to consider the molecular state, so the friction coefficient show irregular state, but the average value are smaller, explain hexadecyl dimethyl-ammonium bromide according to certain proportion to join the cutting fluid, have a good cooling and lubricating effect, anti-friction of cutting tool and workpiece surface quality can play a good role.

3.2 Tool wear analysis

The tool used in this test is a tungsten-cobalt cemented carbide tool. The wear condition of the three cutting edges of the tool tip, back cutting face and main cutting edge was observed. Tool wear with cetyl dimethyl ammonium bromide cutting fluid is shown in Fig. 4:

Figure 4. Tool wear with cetyl dimethyl-ammonium bromide cutting fluid

As can be seen from FIG. 4, 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.

The degree of wear of cemented carbide cutting tool directly affects the machining surface quality of the workpiece, and even affects the dimensional accuracy, increasing the processing cost. Therefore, it is of great significance to reduce the wear and prolong the service life of the tool as far as possible. The cutting fluid with hexadecyl dimethylammonium bromide superslip agent developed in this experiment has a good effect on cutting tool friction reduction.
4. The optimal formulation of a new cutting fluid

In this paper, hexadecyl dimethyl-ammonium bromide was selected as the lubricant to be added into the cutting fluid. Add to the cutting fluid in the test of hexadecyl dimethyl-ammonium bromide concentration of 2%, for the sake of hexadecyl dimethyl ammonium bromide, the best content, a comprehensive analysis of its physical and chemical properties in the design of other ratio of cutting fluid, to set the concentration gradient of 1%, the research in the basic additive proportion of 2.5% sodium carbonate, 15% triethanolamine, dimethyl silicone oil, 2% and 5% under the condition of invariable polyethylene glycol (peg). The properties of the four cutting fluids with the addition of 1% hexadecyl dimethylammonium bromide, 2% hexadecyl dimethylammonium bromide, 3% hexadecyl dimethylammonium bromide and 4% hexadecyl dimethylammonium bromide were studied respectively. Number the four cutting fluids was as shown in Table 2.

| No. | Sodium carbonate | triethanolamine | Methyl silicone oil | Polyethylene glycol (peg) | Cetyl dimethyl ammonium bromide |
|-----|------------------|-----------------|--------------------|--------------------------|--------------------------------|
| No.1| 2.5              | 15              | 2                  | 5                        | 1                              |
| No.2| 2.5              | 15              | 2                  | 5                        | 2                              |
| No.3| 2.5              | 15              | 2                  | 5                        | 3                              |
| No.4| 2.5              | 15              | 2                  | 5                        | 4                              |

Similarly, according to the above cutting parameters, the changes of three milling forces are recorded, and then the friction coefficient of the cutting fluid is obtained. Its change curve is shown in Fig. 5:

![Figure 5. Friction coefficient curves of different concentrations](image)

According to the change curve of friction coefficient, when the concentration of cetyl dimethyl ammonium bromide is low, the friction coefficient is large and the lubrication effect is not good. When the concentration is increased to 2%, the friction coefficient is 0.766, which is considered to be in a good lubrication state. When the concentration continues to increase, the friction coefficient shows a trend of slightly decreasing and then slightly increasing.

In this test, hexadecyl dimethyl-ammonium bromide adsorbs on a layer of lubrication film between the workpiece and the tool to achieve the effect of lubricating friction pair. When the concentration of lubricant was too low, it can not reach the lubrication effect in the cutting process, and the lubrication film formed was not smooth enough, so its anti-friction effect was not obvious enough. After increasing the concentration of lubricant molecules, the friction coefficient was significantly reduced,
indicating that the lubricant molecules had a good lubrication effect at this time. Comparing the friction coefficient of No. 3 and No. 4 cutting fluid, it was found that when the concentration rises to large, the friction coefficient rises slightly, but it was basically the same. It was suggested that the lubricant molecules reach saturation at this concentration.

Based on the above analysis, the optimal concentration range of cetyl dimethyl ammonium bromide was 2%-4%.

5. Conclusion
(1) Based on the superlubricity theory, a new type of cutting fluid which hexadecyl dimethyl-ammonium bromide was developed.
(2) High-speed cutting test was constructed, and the cutting force and friction coefficient under four cutting speeds were obtained. The test results show that the friction coefficient of new type of cutting fluid starts to decrease when the cutting speed reaches a certain value. The cutting fluid with cetyl dimethyl-ammonium bromide has better friction reduction effect.
(3) Optimal formula of the new type of cutting fluid was further studied. The results showed that the optimal concentration range of cetyl dimethyl ammonium bromide was: 2%-4%.
(4) The paper innovatively combines the superlubricity agent and base solution to develop a new type of cutting fluid with excellent friction reduction and anti-wear performance, which will provide a theoretical guidance for the design of new cutting fluid.

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