The Study on Applied Status Stability of Water-Based Cutting Fluids at Numerical Control Machining of Aviation Aluminum Alloy

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Abstract: When water-based cutting fluid is used in aviation aluminum alloy NC machining, soap precipitation and emulsification often occur due to its poor stability. It can cause the metal plate or equipment parts to scale or block the cutting fluid pipeline and filter system, which seriously affects the service life of the cutting fluid and the normal use of the equipment. At present, there is a lack of suitable evaluation standard for the stability of application state of water-based cutting fluid. In this paper, through the analysis of the state stability of four kinds of water-based cutting fluids, the state stability evaluation test is formulated. The hard water stability test and emulsion stability test are carried out for two kinds of semi synthetic cutting fluid and two kinds of fully synthetic cutting fluid. The test results show that this evaluation test can effectively evaluate the state stability performance of aviation aluminum alloy cutting fluid, and provide guidance for the optimization and management of cutting fluid in numerical control machining.

1. Preface
Water-based cutting fluid is widely used in high-speed NC machining of aviation aluminum alloy because of its good thermal conductivity[1]. The commonly used water-based cutting fluids include emulsion, semi synthetic cutting fluid and total synthetic cutting fluid. Among them, emulsion is gradually replaced by semi synthetic cutting fluid and total synthetic cutting fluid due to its poor environmental performance. At present, semi synthetic cutting fluid and total synthetic cutting fluid not only have all the properties of emulsion, but also meet or exceed the standard requirements of emulsion in lubrication, cooling and rust prevention[2]. It has become the main type of cutting fluid in high speed NC machining of aviation aluminum alloy. However, due to the quality problems or management problems of cutting fluid itself[3], soap precipitation and emulsification often occur in water-based cutting fluid used in CNC equipment. On the one hand, these two phenomena will cause serious harm to the health of the equipment and affect the normal use of the equipment. On the other hand, it is difficult to solve these two problems from the technical level. In order to avoid this kind of phenomenon, the hard water stability and emulsion stability of water-based cutting fluid must be in high level. In addition, effective measures should be taken to increase the service life of cutting fluid [4].
2. The danger and prevention of applied status instability of water-based cutting fluids

The metal salts that can increase the hardness of water will gradually accumulate during the use of water-based cutting fluid. And many additives react with calcium and magnesium salts in the working fluid, these complexes of calcium and magnesium are usually insoluble in water[5]. So it will be separated from the working fluid. This phenomenon is called soaping of water-based cutting fluid.

After the soaping phenomenon, the precipitation pollutes device and knife tool on one hand, which is hard to get rid of dirt on the surface of device and knife tools and influence the sensibility of device sensor; on the other hand, the precipitation, small chips and impurities agglomerate, blocking the pipeline of cutting fluids, filtering system and cold hole inside the knife tools to seriously influence the usage of device [6]. The good-quality cutting fluids reach above 1000ppm in the hardness of working liquid and then still keep the stable status.

The coordinate lubrication unit of most of numerical control devices has not the function of oil recovery at present. It is hard to avoid the lubrication being mixed into cutting liquid, especially the open device. The high resistance of emulsion of cutting liquid can make the obvious level between cutting liquid and lubrication, and then separate the lubrication from cutting liquid through oil skimmer and filtering paper to make sure the cutting liquid in a good condition. If it is in a poor condition for cutting liquid, it happens that the liquidation mixing into the cutting liquid will have the direct emulsion reaction with cutting liquid, which leads to difficult separation of oil and liquid and turns poor in the liquidity and cleaning ability, secondly, the functional additive of the liquid is separated, which leads to the lowered cutting liquid performance, especially it will even turn into the state of paste when it is serious, which leads to the blockage of numeric control device and damages due to over-loading pumps. It is hard to separate again that existence of emulsion isolates the contact of low layer liquid and air to provide the favorite condition for growth of anaerobic bacteria, making the liquid easier to corrupt and stink.

The hard water stability should be considered during the development of cutting liquid formulation. On one hand, it should be reduced to use the soap of fatty acid potassium and sulfonate in the formulation as much as possible, on the other hand, it can be added the hard water stabilizer to improve the hard water stability of cutting liquid in order to enhance the hard water stability of cutting liquid. Meanwhile, the formulation system of synthetic cutting liquid must keep the balance of HLB to make sure that the cutting liquid will not have the cloudy or stratified phenomenon. The emulsor can lower the boundary tension between oil and water. The lipophilic group and the lipophilic composition of the surfactant molecules at the interface are separately absorbed in the oil phase and water phase to arrange the interface membrane, preventing from the combination of emulsion particles and promoting the stability of cutting liquid. The stable investigation of current national standards of GB T6144-2013 and JB T7453-2010 for cutting liquid is only for the stability when storing, which is not involved in the stability of cutting liquid in the practical application. This essay designs and makes the stability testing of two groups, including hard water stability and emulsion stability testing in order to investigate the stability performance of cutting liquid in the practical application.

3. Testing design

3.1. Hard water stability testing

The configured hardness with magnesium sulfate, calcium acetate and distilled water is respectively hard water of 600 PPM, 800 PPM, 1000 PPM, 1200 PPM and 1400 PPM. The four kinds of cutting liquids, among which two are full synthetic and two are semi-synthetic are to use five kinds of hard water and four kinds of cutting fluids to prepare for 6% diluent and use 400PPM tap water to prepare for 6% diluent for comparison (as shown in figure 3). The appearance changes of diluent are observed as above. The main preparations are shown in the Table 1:
### Table 1: Preparation of hard water stability test

| Material name       | Model / Description | Quantity |
|---------------------|---------------------|----------|
| Cutting fluid-A     | Total synthesis     | 6*6ml    |
| Cutting fluid-B     | Total synthesis     | 6*6ml    |
| Cutting fluid-C     | Semi synthesis      | 6*6ml    |
| Cutting fluid-D     | Semi synthesis      | 6*6ml    |
| Tap water           | 400PPM              | 4*94ml   |
| Hard water-1        | 600PPM              | 4*94ml   |
| Hard water-2        | 800PPM              | 4*94ml   |
| Hard water-3        | 1000PPM             | 4*94ml   |
| Hard water-4        | 1200PPM             | 4*94ml   |
| Hard water-5        | 1400PPM             | 4*94ml   |
| Measuring cup       | 200ml               | 20       |

### 3.2 Emulsification stability testing

Four kinds of cutting fluids are prepared, of which two are total synthetic and two are semi synthetic. The measuring cylinder with the size of 300ml is adopted in order to realize the comparison of quantitative resistance to emulsion circumstances and processing environment. The lubricants with the viscosity level of 68 usually used on the production site are utilized in order to be suitable for the actual processing situation better. Considering that the cutting liquids are in the process of disturbance during the processing, we use a piece of disturbance bar to disturb oil and liquid to simulate processed state. Take four brands of cutting liquids to separately formulate the 6% diluent (shown as figure 1) and take four 300ml measuring cylinders to respectively fill into 100ml above diluent and add 100ml lubricants with the viscosity level of 68 to measuring cylinder (shown as figure 2). After stirring the four kinds of cutting liquids for 1 minute, and standing still for 5 minutes, 30 minutes, 1 hour and 12 hours, we observe the changes the oil and cutting liquid interface of measuring cylinder. The main preparations are shown in the Table 2.

### Table 2: Preparation for emulsion stability test

| Material name       | Model / Description | Quantity |
|---------------------|---------------------|----------|
| Cutting fluid-A     | Total synthesis     | 6*6ml    |
| Cutting fluid-B     | Total synthesis     | 6*6ml    |
| Cutting fluid-C     | Semi synthesis      | 6*6ml    |
| Cutting fluid-D     | Semi synthesis      | 6*6ml    |
| MIX stick           | Plastic             | 4        |
| Lubricating oil     | 68#                 | 400ml    |
| Measuring cylinder  | 300ml               | 4        |

![Figure 1: Prepare 6% diluent](image-url)
4. Testing result

4.1. Hard water stability testing
The hard water stability testing result is shown as Figure.3-8. It can be seen that the cutting liquids A, B, C, D are diluted with hard water for hardness of 400PPM, which is at the normal state. When water hardness is promoted to 600PPM, all the synthetic cutting liquid A will have slight turbidity. With the gradual rising of water hardness, the cutting liquid becomes more and more turbid. When water hardness rises to 1400PPM, the diluent becomes milky white, and the white saponification appears while it gradually becomes turbid; All the synthetic cutting liquids B have no stable changes rising from 400PPM to 1400PPM in water hardness and the small amount of saponification begin to precipitate in the liquid after the semi-cutting liquid D rises to 1000PPM in the hardness. With the gradual enhancement of water hardness, the amount of saponification are increasing gradually and the color gradually turns to milky white.
4.2. The testing result of emulsification stability

The semi-synthetic cutting liquid D has the largest volume of oil phase when we are standing still for 5 minutes after stirring, which reaches 124ml. The semi-synthetic cutting liquid C has the smallest volume of oil phase, which is only 102ml; When standing still for 30 minutes, there is no obvious changes of the four kinds of cutting liquids in the state of measuring cylinder; when standing still for 1 hour, there is an obvious emulsified layer of synthetic cutting liquid A with 6ml of volume, the volume of oil phase for synthetic cutting liquid B will reduce 10ml and the other two kinds of cutting liquids have no obvious changes; After standing still for 12 hours, the emulsified layer of synthetic cutting liquid A will increase to 8ml, the oil phase volume of synthetic cutting liquid B will reduce to 102ml. The semi-synthetic cutting liquid C has no obvious changes, and the oil phase volume of semi-synthetic cutting liquid D will reduce to 102ml and has emulsified layer of 2ml.

As shown in figure 9 is for the state of standing still for 5 minutes after stirring at the same time. The oil volume is shown as figure 3.
Figure. 9 Let stand for 5 minutes after stirring

Table 3 Fluid volume change

| Cutting fluid model | Oil layer volume | Volume of emulsion layer |
|---------------------|------------------|--------------------------|
| A                   | 110ml            | 0                        |
| B                   | 116ml            | 0                        |
| C                   | 102ml            | 0                        |
| D                   | 124ml            | 0                        |

As shown in figure 10 is the state of standing still for 30 minutes after stirring at the same time. The oil volume is shown as Figure 4.

Figure. 10 Let stand for 30 minutes after stirring

Table 4 Fluid volume change

| Cutting fluid model | Oil layer volume | Volume of emulsion layer |
|---------------------|------------------|--------------------------|
| A                   | 110ml            | 0                        |
| B                   | 116ml            | 0                        |
| C                   | 102ml            | 0                        |
| D                   | 124ml            | 0                        |

As shown in figure 11 is the state of standing still for 1 hour after stirring at the same time. The oil volume is shown as figure 5.

Figure. 11 Let stand for 1 hour after stirring
Table 5 Fluid volume change

| Cutting fluid model | Oil layer volume | Volume of emulsion layer |
|---------------------|------------------|--------------------------|
| A                   | 100ml            | 6ml                      |
| B                   | 106ml            | 0ml                      |
| C                   | 102ml            | 0ml                      |
| D                   | 124ml            | 0ml                      |

As shown in Figure.12 is the state of standing still for 12 hours after stirring at the same time. The oil volume is shown as figure 6.

![Figure 12](image)

Figure.12 Let stand for 12 hours after stirring

Table.6 Fluid volume change

| Cutting fluid model | Oil layer volume | Volume of emulsion layer |
|---------------------|------------------|--------------------------|
| A                   | 98ml             | 8ml                      |
| B                   | 102ml            | 0ml                      |
| C                   | 102ml            | 0ml                      |
| D                   | 102ml            | 2ml                      |

5.Conclusion

1) The testing result shows that the synthetic cutting liquid of different model of brands has larger difference in the hard water stability. When the cutting liquid of poor hard water stability reaches 600ppm, the liquid state will have obvious changes of state. With the gradual increase of water hardness, the state will be no more stable. The synthetic liquid of good hard water stability reaches 1400ppm and then still can keep the stable state.

2) The cutting liquid and guide rail oil form mixture of oil and liquid after stirring within the short time. The cutting liquid with a good stability of emulsion can be effective in inhibiting this phenomenon and make oil and liquid not have the reaction of emulsion. The mixture of oil and liquid will gradually separate after we are standing still for a long time but can not separate completely because the little amount of cutting liquid will be absorbed by oil. The cutting liquid with poor stability of emulsion will have an obvious emulsified layer within the short time after stirring.

3) The applied stability testing of synthetic cutting liquid can evaluate the normal keeping ability of cutting liquid in the practical application.

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