Experimental Analysis of Milling Aluminum Alloy with Oil-Less Lubrication of Nano-Fluid

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Abstract. The nano-fluid added with nano-particles in the easily degradable vegetable oil base ensures that the contact angle of the aluminum alloy 7075 under the vegetable oil base is slightly improved, and the lubrication performance is further strengthened, the cutting force is reduced, the surface quality is improved, and the roughness is reduced. When milling the aluminum alloy 7075, the lubrication performance effect of the nano-fluid is evaluated. Taking aviation aluminum 7075 as workpiece. The contact angle, cutting force, surface roughness and SEM appearance of the workpiece were evaluated under four lubrication conditions: dry processing, emulsion pouring, micro lubrication of cottonseed oil and cottonseed oil-based + 0.5% Al₂O₃ nano-particles. The experimental results show that the contact angle of nano-fluid to aluminum alloy 7075 is slightly larger than that of vegetable oil, but with the addition of nano-particles, the chips roll from sliding, making the surface morphology of the machined surface good, the cutting force minimum, the roughness minimum, indicating that the nano-fluid lubrication and antifriction performance is good.

Keywords: Nano-Fluids, Contact Angle, Oil-Less Lubrication, Milling, Aeronautical Aluminium

1. Introduction
With the application of aluminum alloy materials more and more widely, people gradually use the
methods of heat treatment and adding alloy elements to strengthen pure aluminum and get a series of aluminum alloys. Aluminum alloy not only keeps the advantages of light weight of pure aluminum, but also has high strength. It has high strength and toughness of aviation aluminum alloy with tensile strength over 600MPa. Therefore, lubrication and antifriction of milling aluminum alloy has become an important development direction. In modern cutting lubrication, from pouring, dry processing to micro lubrication, on the basis of micro lubrication, a proper amount of nano-particles are added to the degradable base oil to prepare nano-fluid, which is then mixed with high-pressure gas and atomized by the nozzle in the form of small droplets to the cutting area [1]. Based on the above theory, nano-fluid oil-less lubrication cutting is a new efficient, environmental friendly, clean and low carbon lubrication method. A mixture of nano-fluids and compressed gases injected into the cutting zone, with a focus on the role of nano-fluids in lubrication, friction reduction and antiwear. When milling high strength aluminum alloy, the lubrication in milling area is insufficient and the cutting tool failure is too fast [2,3].

Professor Ai Xing [2,4] of Shandong University and others have carried out experimental, theoretical and numerical simulation research on the failure mechanism and tool life of high-speed cutting of aviation aluminum alloy 7050-T7451. It is found that felted wearing, diffusion wear and oxidation wear are the main failure mechanisms of high-speed milling tools. He Ning, Li Liang, Su Yu, [5,6] et al, of Nanjing University of Aeronautics and Astronautics mainly carried out research on systematic low temperature oil-less lubrication milling of aeronautical materials. The performance parameters (jet parameters and fluid concentration) of Al6061-T6 milled by SiO2 nano-fluid micro lubrication were organized to study by Sayuti, a Malaysian scholar [7]. Iran scholar Rahmati's research team and others [8,12] used MoS2 nano-fluid oil-less lubrication to mill aviation aluminum alloy AL6061-T6. Li Changhe, Yang Lei, Zhang Yanbin[9-11], Basic research on lubrication mechanism and application of MQL cutting fluid based on vegetable oil.

In this paper, the milling process and contact angle test of aviation aluminum alloy 7075 under different lubrication modes were conducted, and the milling lubrication performance of aluminum alloy 7075 under nano-fluid micro lubrication was compared and analyzed.

### 2. Experimental Equipment and Scheme

#### 2.1. Experimental Equipment

**Table 1.** Experimental equipment

| Serial Number | Device Name                          | Specification and Type | Quantity | Remarks                  |
|---------------|--------------------------------------|------------------------|----------|--------------------------|
| 1             | Dema processing center               | ML1060B                | 1        | Machining center          |
|               | Trace lubrication system             |                        |          |                          |
| 2             | Dynamometer + charge amplifier       | JR-YDCL-05B            | 1        | Micro lubrication Laboratory |
| 3             | Stylus surface roughness meter       | SH6C                   | 1        | Micro lubrication Laboratory |
| 4             | Scanning electron microscope         | DV2TLV                 | 1        | Materials Laboratory     |
| 5             | contact angle instrument             | JGW-360A               | 1        | Micro lubrication         |
2.2. Experimental Materials

Table 2. Experimental materials

| Serial Number | Name          | Specification and Type | Quantity | Remarks                     |
|---------------|---------------|------------------------|----------|-----------------------------|
| 1             | Cutting tool  | Ø20 arbor              | 1        | Machining center            |
| 2             | Blade         | APKT1135PDER           | 4        | Micro lubrication Laboratory|
| 3             | Aluminum alloy 7075 | 40×30×30              | 1        | Micro lubrication Laboratory|
| 4             | Cottonseed oil | First order            | 500ml    | Micro lubrication Laboratory|
| 5             | Al2O3 nano-particles | 70nm                 | 20g      | Micro lubrication Laboratory|
| 6             | Cutting fluid | 2%                     |          | Machining center            |

2.3. Experimental Scheme

In the experiment, dry processing, traditional emulsion, Al2O3 nano-particles + cottonseed oil and pure cottonseed oil were used to mill aviation aluminum alloy 7075. The mass fraction ratio of nano-particles and cottonseed oil was 0.5%.

Table 3. Experimental Parameters

| Milling parameters     | Value       |
|------------------------|-------------|
| Milling mode           | Face-milling|
| Milling rotational speed $W_s$ (r/min) | 2200 |
| Feed rate $V_f$ (mm/min)    | 500       |
| Back cutting depth $a_p$ (mm) | 0.4     |
| Side cutting depth $a_e$ (mm) | 10       |
| Trace lubrication flow rate (mL/h) | 50     |
| Trace lubrication nozzle distance (mm) | 30    |
| Trace lubrication nozzle elevation angle (°) | 50 |
| Trace lubrication nozzle incident angle (°) | 35   |
| Trace lubrication air pressure (MPa) | 0.4   |

Verify the lubrication performance of aviation aluminum alloy 7075 under the same milling mode with different lubricants, and analyze the experimental data from the surface quality and integrity.

3. Analysis and Discussion of Experimental Results

3.1. Influence of Different Lubricants on Wettability of Aluminum Alloy 7075 Contact Angle

Milling lubricant has an effect on wettability of contact angle of aviation aluminum alloy 7075. The
smaller the contact angle is, the easier the liquid is to wet the solid and form an oil film on the surface of wetted parts. As shown in Fig.1, the measurement results of contact angle of different lubricants on the surface of aluminum alloy show that cottonseed oil has a smaller contact angle on the surface of aluminum alloy than traditional lubricant emulsion and has a better wettability, which is conducive to the formation of oil film and improve lubricity.

![Image of contact angle measurement](image)

**Figure 1.** Wetted contact angle of different lubricants on aluminum alloy materials

3.2. *Analysis of Milling Force for Milling Aluminum Alloy 7075 with Different Lubricants*

Under the same machining parameters, the cutting force of milling aluminum alloy changes, which shows the lubrication performance and effect of different lubricants. It affects the wear of cutting tools and the surface quality. The force condition of milling aluminum alloy under four different lubrication modes is shown in Fig.2. Compared with the force condition in X, y and Z directions, the dry machining cutting force under no lubrication is significantly larger, while the force under micro lubrication of cottonseed oil and nano-fluid is smaller, and the force with nano-particle lubricant is the smallest. It is analyzed that adding nano-particles in cutting can change chip removal from sliding mode to rolling mode, further increase lubricity and reduce friction.

3.3. *Analysis of Milling Surface and Chip Surface Morphology of Aluminum Alloy 7075 under the Milling of Different Lubrication Methods*

When milling the surface of aluminum alloy 7075 under different lubrication modes, the different lubrication modes will affect the surface quality of the workpiece, which is caused by the influence of the machining tool mark and built up edge. The tool mark formed by dry milling is larger, the aluminum alloy chip build-up of casting milling is harder, the tool mark of cottonseed oil lubrication and nano-particle lubrication is smaller, which also shows that the lubricant with smaller contact angle has better lubricity.

3.4 *Milling Surface Roughness of 7075 Aluminum Alloy with Different Lubrication Methods*

The surface roughness of aluminum alloy 7075 workpiece milled by different lubrication methods is measured by the stylus surface roughness measuring instrument, as shown in Fig.4, and the surface profile of aluminum alloy 7075Ra0.1724µm> for dry milling is measured, and Ra0.1647µm> for pouring milling is measured, and Ra0.1443µm> for cottonseed oil micro lubrication milling is measured, and Ra0.1316µm for Al2O3 nano-particles + cottonseed oil micro lubrication milling is shown in Fig.5. These data show that the micro lubrication of nano-particles improves the surface...
quality of workpieces.

![Image](image1.png)

**Figure 2.** Force condition of milling aluminum alloy 7075 under different lubrication modes

![Image](image2.png)

**Figure 3.** SEM of cutting surface of milling aluminum alloy 7075 under different lubrication methods

(a) Dry processing  
(b) Micro lubrication of cottonseed oil  
(c) Cast-resin type  
(d) Micro lubrication of Al2O3 nano-particles

(× 200)
Empirical Conclusions

The milling process of 7075 aluminum alloy specimen under four different lubrication methods was carried out. The experimental results are as follows:

1. The order of contact angle was: emulsion > cottonseed oil + Al₂O₃ nano-particles > cottonseed oil;
2. The order of milling force F (x) is: dry machining > pouring > micro lubrication of cottonseed oil > micro lubrication of cottonseed oil + Al₂O₃ nano-particles;
3. The order of surface roughness was: dry processing > pouring > micro lubrication of cottonseed oil > micro lubrication of cottonseed oil + Al₂O₃ nano-particles;

The results show that nano-fluid micro lubrication has better lubrication and antifriction properties in cutting aluminum alloy 7075.

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