Effect of Air-jet Assisted Little Quantity Lubrication on Surface Roughness of Aluminium Alloy 7050-T7451 in Milling Process

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Abstract. In order to solve the problems of cooling effect, lubrication effect and application cost in the existing green cutting technology, the method of air-jet assisted little quantity lubrication is put forward. Milling experiment of aluminium alloy 7050-T7451 is performed on the platform of established air-jet assisted little quantity lubrication system. The results show that: (1) air-jet assisted little quantity lubrication has a good cooling and lubrication effect, which can significantly reduce the surface roughness; (2) under the same other process conditions, the lubrication and cooling ability increased with the increase of cutting fluid flow rate, which results in the decrease of surface roughness; (3) when the flow rate of the cutting fluid reaches a certain threshold value, the effect of air-jet assisted little quantity lubrication on surface roughness is very close to that of wet cutting, and it has little effect on surface roughness by increasing cutting fluid flow rate.

1. Introduction
Green cutting is a hot research point in the field of green manufacturing, which has attracted many scholars to carry out relevant research. Common green cutting methods include: dry cutting, MQL cutting, cryogenic cutting, green wet cutting. However, almost all of the existing green cutting methods have their own shortcomings and limitations. The reason is mainly that the existing green cutting methods cannot have a well balance of cooling effect, lubrication effect and application cost. Dry cutting completely eliminates the negative impact of cutting fluid on worker and the environment, but it can be seen from the research literature that tool wear is the main concern in dry cutting research [1-4]. The reason is that due to the lack of cooling and lubrication effects of cutting fluid, tool durability and workpiece surface quality are affected. The cutting fluid flow rate of MQL is only 5-200mL/min, but due to its weakened cooling capacity, the application of MQL has been limited. In addition, other several green cutting methods show deficiency of cooling and lubricating ability or have high application cost [5-8].

Little quantity lubrication (LQL) is a type of cooling lubrication method between MQL and conventional wet cooling lubrication [9]. The cutting fluid flow rate of LQL is 50-500mL/min. The purpose of applying LQL is to decrease lubricant consumption as much as possible without decreasing tool durability and worsening workpiece surface quality. The results show that LQL can effectively extend tool life and improve the workpiece surface quality. However, it has been found in the research that cutting fluid can hardly reach the centre of cutting zone during high-speed cutting, thereby reducing the cooling and lubricating effect of the cutting fluid. In addition, due to the low jet speed of
the cutting fluid, chips may accumulate on the workpiece during the milling process, which may scratch the machined surface and impede cutting fluid reaching the cutting area. In order to solve the problems of LQL in the previous research, a new method of air-jet assisted LQL (AJLQL) is put forward in this research.

Surface roughness is an important feature to evaluate the surface quality of workpiece, which has an important influence on the operational performance and service life of workpiece. Under the same process conditions, reducing workpiece surface roughness is one of the main purpose of AJLQL. In this paper, a self-developed AJLQL system is used to research the effect of AJLQL on the surface roughness of aluminium alloy 7050-T7451 in milling process.

2. Establishment of AJLQL system

The principle of AJLQL is that a small amount of cutting fluid is atomized by compressed air, and atomized cutting fluid is injected into the cutting zone in very high speed. The cooling effect is mainly achieved by atomized cutting fluid through vaporization heat transfer and forced convection. The compressed air can also play cooling effect by forced convection. The lubrication effect is achieved by high-speed atomized cutting fluid. Cutting fluid flow rate of AJLQL is 50-500mL/min. As the cutting fluid flow rate of AJLQL is greater than that of MQL, it has a better performance in cooling and lubrication effects.

AJLQL system is shown in Figure 1. Compressed air is applied through an air filter, controlled by the solenoid valve. Cutting fluid and air are mixed in mixing valve and then flow into the atomizing nozzle. Cutting fluid is well metered through the peristaltic pump. If the cutting fluid level of cutting fluid tank is lower than the set level, the level alarm will beep. The system is equipped with cutting fluid filtration device and bubbling equipment. The cutting fluid is stirred evenly to avoid clogging. Compressed air pressure is in the range of 0.1-0.8MPa.

3. Experimental setup

The experimental setup is shown in Fig.2. The experimental work is performed on a TK855 vertical machining center. The workpiece material is aluminum alloy 7450-T7451 with size of 150 × 43 × 38, shown in Fig.3. Milling method is end milling. The tool path is along positive direction of x-axis. The cutter is a carbide two-tooth end mill with a diameter of 10 mm. The spindle speeds $n$ are 4000 rpm and 8000 rpm, the feed rates per tooth $f_z$ are 0.02 mm, 0.04 mm and 0.06 mm, the milling width $a_e$ is 10 mm, the milling depth $a_p$ is 4mm. Cutting fluid is emulsion with 10% mass percentage. Dry cutting (Cd), AJLQL cutting with cutting fluid flow rate of 50 mL/min (C50), AJLQL cutting with cutting fluid flow rate of 150 mL/min (C150), and wet cutting were carried out for each group of process parameter. The experimental design is shown in Table 1. In order to obtain reliable data, each experiment was repeated 3 times, and 3 test areas were selected at equal intervals on the cutting surface obtained in each experiment. The surface roughness was measured using a portable surface roughness meter TR300.
4. Results and analysis

4.1 Experimental results

216 data obtained through 24 tests are shown in Table 1. In order to analyse the surface roughness obtained under different cooling and lubrication conditions, 9 data obtained in each experiment was averaged. The results of the average surface roughness obtained under the six process conditions are shown in Fig. 4. It can be seen from Fig. 4 that among the four cooling and lubrication methods under different process conditions, the surface roughness of dry cutting is the largest, and the surface roughness values of C50 cutting, C150 cutting and wet cutting are smaller than those of dry cutting in turn. In addition, it can be found that the surface roughness obtained by C150 cutting and wet cutting is almost the same in addition to that of Fig. 4 (a), and even the surface roughness of wet cutting is larger than that of C150 cutting in Fig. 4 (b) and Fig. 4 (c). It can be seen from the calculation that the surface roughness obtained by C50 cutting, C150 cutting and wet cutting under the six process conditions is reduced by 7%, 15% and 17.7% respectively compared with dry cutting.

| n (rpm) | fz (mm/2) | Surface roughness Ra(μm) |
|---------|-----------|--------------------------|
|         | Dry cutting | C50 cutting | C150 cutting | Wet cutting |
| 4000    | 0.02       | 0.260 0.258 0.261 | 0.250 0.252 0.253 | 0.221 0.224 0.222 | 0.199 0.202 0.204 |
|         | 0.04       | 0.267 0.265 0.269 | 0.242 0.240 0.238 | 0.231 0.233 0.232 | 0.232 0.229 0.230 |
|         | 0.06       | 0.315 0.318 0.312 | 0.290 0.294 0.287 | 0.264 0.260 0.266 | 0.269 0.262 0.258 |
| 8000    | 0.02       | 0.261 0.263 0.259 | 0.238 0.245 0.241 | 0.221 0.219 0.216 | 0.218 0.220 0.225 |
|         | 0.06       | 0.324 0.324 0.321 | 0.297 0.297 0.294 | 0.277 0.272 0.271 | 0.266 0.264 0.264 |

Table 1 Experimental design and results
4.2 Experimental Analysis

The reasons for the above experimental results can be interpreted as such, due to lacking the cooling and lubrication function of lubricant in dry cutting, the workpiece and tool are in dry friction state, the friction force is large, so the surface roughness in dry cutting is the biggest. Because of the increase of cutting fluid injected into cutting area in C150 cutting compared with C50 cutting, cooling and lubrication effect increases. The increase of lubrication effect results in the decrease of surface roughness. The increase of cooling ability will reduce the plastic deformation of workpiece, which results in the reduction of the surface roughness value.

When the cutting fluid flow rate is up to 150mL/min, the flow rate of AJLQL is less than that of wet cutting. But because the compressed air and atomized cutting fluid are injected into cutting zone at a high speed, the quantity of cutting fluid injected into the cutting zone is almost the same as wet cutting. C150 cutting and wet cutting have similar lubrication effect. In cooling aspect, the formation of strong forced convection cooling of C150 cutting is to make up for the reduction of cutting fluid flow rate which may resulted in the reduction of cooling capacity. So, the cooling effect and lubrication effect of C150 cutting are similar to wet cutting, which results in the close surface roughness values. The significance of this phenomenon is that the satisfied cooling and lubrication effect can be achieved without increasing cutting fluid flow rate when the cutting fluid flow rate of AJLQL is up to a certain threshold.

5. Conclusions

The effects of AJLQL on the surface roughness of aluminium alloy 7050-T7451 milling are experimentally researched by using a self-developed AJLQL system. The results of four different cooling lubrication methods show that AJLQL can significantly reduce the surface roughness. The results are as follows:
(1) In the cutting process under AJLQL condition, with the increase of cutting fluid flow rate, the cooling and lubrication ability increases, which results in the decrease of surface roughness; 
(2) When the cutting fluid flow rate of AJLQL increases to a certain threshold, the surface roughness is very close to that of wet cutting, and the further increase of cutting fluid flow rate has little effect on the surface roughness.

In this paper, the experiment is carried out at conventional cutting speed. In the further research, we will focus on the impact of AJLQL on high speed machining.

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