Chip Breakability in Turning of 7075 Aluminium Alloy with a High-Pressure Coolant Supply

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Abstract. Because of its extremely high strength to weight ratio, 7075 aluminum alloy is used for highly stressed structural parts including aircraft fittings, gears and shafts and various other commercial aircraft, aerospace and transportation equipment. In the case of cutting aluminum alloys, the chip breakability is the most important feature to ensure reliable operation in automated machining. In this study, in turning of 7075 aluminum alloy with a high-pressure coolant supply, the chip configurations, and the mass and thickness of chips were experimentally investigated. The following results were obtained:(1) In the case of a cutting speed of 5.0 m/s, a feed rate from 0.05 mm/rev to 0.50 mm/rev and a depth of cut from 0.1 mm to 3.0 mm, chips were not broken at a feed rate of 0.15 mm/rev or less with the conventional coolant supply. With a high-pressure coolant supply, the combination area of feed rate and depth of cut in which chips were broken was wider than that with the conventional coolant supply. With a high-pressure coolant supply, the combination area of feed rate and depth of cut in which chips were not broken was wider than that with the conventional coolant supply. With a high-pressure coolant supply at a coolant pressure of 7 MPa, there was a combination area of feed rate and depth of cut in which chips were not broken. However, chips were broken in all areas at a coolant pressure of 20 MPa.(2) In the case of both the high-pressure coolant supply, which has a coolant pressure of 7, 14 or 20 MPa, and the conventional coolant supply cutting method and the conventional coolant supply cutting method.

1. Introduction
Because of its extremely high strength to weight ratio [1], 7075 aluminum alloy is used for highly stressed structural parts including aircraft fittings, gears and shafts and various other commercial aircraft, aerospace and transportation equipment [2].

The machinability of metals is estimated by the cutting force, tool life, surface finish and chip shape. Due to the strength and hardness of aluminum alloys, the cutting force and tool life are relatively unproblematic, and the chip breakability is the most important feature to ensure reliable operation in automated machining [3].

One improvement in chip cracking is the use of free-cutting alloys. Conventionally, Pb is added to aluminum alloys to improve the chip breakability. However, due to the negative impact on the
environment, the addition of Pb has been banned in many countries. The addition of Si improves chip breaking performance [4]-[6], but when turning Si-added aluminum alloys with high speed steel tools, tool wear increases with the increase of Si contents [4]-[5], [7]-[8].

On the other hand, supplying coolant to the cutting area at high pressure improves chip breakability performance [9]-[11], and supplying high-pressure coolant to the cutting edge lowers the cutting temperature and reduces flank wear [12]. This method is also effective in reducing tool wear [9]-[11], [13].

Therefore, many studies on high-pressure coolant supply cutting of hard-to-cut materials such as hardened steel [14], titanium alloy [15]-[19], Inconel [12], [20], cemented carbide [21] have been conducted. However, there have been no reports on the effect of the coolant pressure on the chip breakability performance when aluminum alloys are turned with a high-pressure coolant supplied.

In this study, in turning of 7075 aluminum alloy with a high-pressure coolant supply, the chip configurations, the mass and thickness of chip were experimentally investigated.

2. Experimental procedures
The work material used was 7075 aluminium alloy. The chemical composition of the 7075 aluminium alloy is shown in Table 1. Table 2 shows the mechanical properties of the 7075 aluminium alloy.

The cutting material used was an un-coated ISO K10 cemented carbide, which is a commercially available insert. The configuration of the tool insert was ISO CNGG120408L-A3 (A3: groove-type parallel chip-breaker). The insert was attached to the tool holder DCLN L 2525M-12JCT (KYOCERA Cutting Tools, KYOCERA Corporation). In this case, the tool geometry was (-6, -6, 6, 5, -5, 0.8 mm).

| Table 1 Chemical composition of work piece (7075 aluminium alloy) |
|-----------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Si | Fe | Cu | Mn | Mg | Cr | Zn | Ti | Ti+Zr | Al |
| 0.09 | 0.22 | 1.6 | 0.03 | 2.7 | 0.20 | 5.8 | 0.01 | 0.01 | RE |

| Table 2 Mechanical properties of work piece (7075 aluminium alloy) |
|-----------------|-----|-----|-----|-----|
| Tensile strength [N/mm²] | Yield strength (0.2 % offset yield strength) [N/mm²] | Elongation [%] | Hardness [HV5] |
| 599 | 517 | 9.9 | 167 |

| Table 3 Cutting conditions |
|-----------------|-----|-----|---------------|
| Cutting speed | V=3.33, 5.00, 6.67 m/s |
| Feed rate | f=0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.40, 0.50 mm/rev |
| Depth of cut | ap=0.1, 0.2, 0.3, 0.5, 0.7, 1.0, 2.0, 3.0 mm |
| Cutting method | Dry cutting, Wet (Conventional coolant supply, High-pressure coolant supply) |
| Coolant | Water-soluble coolant (YUSHIROKE FGS650) |
| Coolant concentration dilution | 10 % ± 3 % |

Turning tests were carried out on a universal lathe (Type SL-25, DMG MORI COMPANY LIMITED) by adding a variable-speed drive. The driving power of this lathe was 11/15 kW and the maximum rotational speed was 3500 min⁻¹.

The high-pressure coolant was directed via three nozzles on the tool holder, namely, the coolant was injected at high pressure to both the rake face (one jet hole) and flank face (two jet holes) by nozzles “A” and “B” as shown Fig.1, respectively. The high-pressure coolant unit used was HIPRECO185-20 (TOKUPI Corporation). The maximum pressure was 20 MPa and the maximum pump water suction was 45 L/min.

Table 3 shows the cutting conditions. The coolant used was a water-soluble coolant (YUSHIROKE FGS650), and the coolant concentration dilution was 10% ± 3% as shown in Table 3.
The coolant supply system was a conventional coolant supply system, namely the coolant was supplied from an external nozzle, and was a high-pressure coolant supply system. In the case of a coolant pressure of 7, 14 and 20 MPa, the pump water suction was 13.5, 20.1 and 23.0 L/min, respectively.

The 7075 aluminium alloy was turned with a high-pressure coolant supplied under the cutting conditions shown in Table 3. The chip configurations were experimentally investigated.

![Figure 1. Method of injection of coolant](image)

### 3. Results and Discussion

Figure 2 shows the chip configurations in turning 7075 aluminum alloy at a cutting speed of 5.0 m/s, a depth of cut of 3.0 mm and workpiece diameters of 110.3 mm (feed rate 0.05 mm / rev) and 104.3 mm (feed rate 0.20 mm / rev). When the feed rate was 0.05 mm/rev, the chip was not broken short in the case of the conventional coolant supply.

On the other hand, the chip was broken short in the case of the high-pressure coolant supply (coolant pressure P=7, 14 and 20 MPa). When the feed rate was 0.20 mm / rev, the chip was broken short even in the case of the conventional coolant supply, however the length of chip with the conventional coolant supply was longer than that with a high-pressure coolant supply.

From the above, it was found that the high-pressure coolant supply method is effective for improving the chip breakage performance.

| Feed Rate (mm/rev) | Conventional | P=7 MPa | P=14 MPa | P=20 MPa |
|--------------------|--------------|---------|---------|---------|
| 0.05               | ![Image](image) | ![Image](image) | ![Image](image) | ![Image](image) |
| 0.20               | ![Image](image) | ![Image](image) | ![Image](image) | ![Image](image) |
P: coolant pressure with a high-pressure coolant supply, Conventional: conventional coolant supply, f: Feed rate.

**Figure 2. Chip configurations (Workpiece: 7075 aluminum alloy, Cutting speed: 5.0 m/s, Depth of cut: 3.0 mm, Diameter of workpiece D=110.3 mm (at feed rate f=0.05 mm/rev), D=104.3 mm (f=0.20 mm/rev)).**

Figure 3 shows the influence of the coolant pressure on the mass per chip in turning of 7075 aluminum alloy at a cutting speed of 5.0 m/s. In this figure, Fig. (a), (b), (c), (d), (e), (f), (g) and (h) shows a depth of cut of 3.0, 2.0, 1.0, 0.7, 0.5, 0.3, 0.2 and 0.1 mm, respectively. “P” is the coolant pressure with a high-pressure coolant supply, “ap” is the depth of cut and “Conventional” is the conventional coolant supply. If a short segment chip is not generated, the mass per chip is expressed as 3 g or more. Furthermore, the combination of depth of cut and feed rate used is a difficult cutting condition for breaking chips. That is, the cutting conditions used are the larger depth of cut and the lower feed rate, or the smaller depth of cut.

From this figure, it is clear that:

1. In the case of a depth of cut of 3.0 mm as shown in Fig. (a), the feed rate is below 0.25 mm/rev. In addition, the coolant pressure in the high-pressure coolant supply method is shown for three types of 7, 14, and 20 MPa. In the case of the high-pressure coolant supply, chips are broken at every feed rate. The mass per chip increases with the increase of the feed rate. Also, the higher the coolant pressure, the mass of chip becomes smaller. On the other hand, in the conventional coolant supply, chips are not broken at a feed rate of 0.15 mm/rev or less, so the mass of chip is large.

2. In the case of a depth of 2.0 mm or less, cutting experiments were carried up to a feed of 0.50 mm/rev. And, in the case of a high-pressure coolant supply, cutting experiments were carried at coolant pressures of 7 and 20 MPa. In the conventional coolant supply, chips are not broken at a lower feed rate. However, in the high-pressure coolant supply, the area, namely the combination of feed rate and depth of cut, where the chips are broken becomes wider.

3. When the coolant pressure P=7 MPa, the chips are not broken under the cutting conditions of a depth of cut of 0.5 mm and a feed rate of 0.05 mm/rev as shown in Fig. (e). Further, in the case of a depth of cut of 0.3 mm as shown in Fig. (f), the chips are not broken at some of the feed rates. On the other hand, when the coolant pressure P is 20 MPa, the chips are broken at all the depths of cut and feed rates.

From the above, in order to break the chips reliably, it is necessary to use the coolant pressure of 20 MPa.
Figure 3. Influence of coolant pressure on mass per chip in turning of 7075 aluminum alloy at a cutting speed of 5.0 m/s (Fig. (a), (b), (c), (d), (e), (f), (g) and (h) shows a depth of cut of 3.0, 2.0, 1.0, 0.7, 0.5, 0.3, 0.2 and 0.1 mm, respectively).

Figure 4 shows the influence of the coolant pressure on the thickness of chip in turning of 7075 aluminum alloy at a cutting speed of 5.0 m/s and a depth of cut of 3.0 mm. In the case of both the high-pressure coolant supply, which has a coolant pressure of 7, 14 or 20 MPa, and the conventional coolant supply, the thickness of chip increases with the increase of the depth of cut. And, the thickness of chip does not change depending on the cutting method, namely the high-pressure coolant supply cutting method and the conventional coolant supply cutting method).
P: coolant pressure with a high-pressure coolant supply, Conventional: conventional coolant supply.

**Fig. 4 Influence of coolant pressure on thickness of chip in turning of 7075 aluminum alloy at a cutting speed of 5.0 m/s and a depth of cut of 3.0 mm.**

Figure 5 shows the influence of the cutting speed on the thickness of chip in turning with the conventional and the high-pressure coolant supply. In the case of both the conventional and the high-pressure coolant supply, the thickness of chip decreases with the increase of the cutting speed. The reasons are as follows. As the cutting speed increases, the shear angle increases and the thickness of the chip decreases. This trend is similar to that explained by normal cutting theory. On the other hand, as compared with the case of the conventional and the high-pressure coolant supply, the chip is broken short in the case of the high-pressure coolant supply. However, the thickness of chip does not differ much. Based on these findings, it is considered that the increase of the coolant pressure does not significantly affect the shear angle.

From the above, it seems that the bending of chip caused by high-pressure fluid has a large influence on chip breakage in high-pressure coolant cutting [22].

**Figure 5. Influence of cutting speed on thickness of chip in turning of 7075 aluminum alloy at a cutting feed rate of 0.05 mm/rev and a depth of cut of 3.0 mm.**

**4. Conclusions**

In this study, in turning of 7075 aluminum alloy with a high-pressure coolant supply, the chip configurations, the mass of chip and the thickness of chip were experimentally investigated. The following results were obtained:

(1) In the case of a cutting speed of 5.0 m/s, a feed rate from 0.05 mm/rev to 0.50 mm/rev and a depth of cut from 0.1 mm to 3.0 mm, chips were not broken at a feed rate of 0.15 mm/rev or less in the conventional coolant supply.
In the high-pressure coolant supply, the combination area of feed rate and depth of cut that can be broken chip was wider than in the conventional coolant supply. In the high-pressure coolant supply at a coolant pressure of 7 MPa, there is a combination area of feed rate and depth of cut that can be not broken chip. However, chips were broken in all areas at a coolant pressure of 20 MPa.

(2) In the case of both the high-pressure coolant supply, which has a coolant pressure of 7, 14 or 20 MPa, and the conventional coolant supply, the thickness of chip increased with the increase of the depth of cut. And, the thickness of chip did not change depending on the cutting method, namely the high-pressure coolant supply cutting method and the conventional coolant supply cutting method.

(3) In the case of both the conventional and the high-pressure coolant supply, the thickness of chip decreased with the increase of the cutting speed.

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