초 냉각 가공에서의 LN2 의 감찰 효과 연구

- Investigation of LN2 Lubrication Effect in Cryogenic Machining -

공구 마모에 의한 마찰 계수 이론적 전개
Part 2: Friction Coefficient related to Tool Wear with Mathematical Evaluation

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Abstract

In this paper some physical evidences indicate that reduced friction occurs in an cryogenic machining process, in which LN2 is applied to the selected cutting zone. LN2 also reduced the tool wear rate to a great extent and elongated the tool life up to four times compared to emulsion cooling.

Introduction

Generally, lubricants can be broadly defined as materials which are used for one or more of the following purposes: to reduce friction, to prevent wear, to prevent adhesion, to aid in distributing the load, to cool the moving elements, and to prevent corrosion [1]. LN2 is well known for its cooling power due to its cryogenic temperature. We would like to see how it will affect the friction in the cutting process and the tool wear. Unfortunately, many factors are involved in an actual cutting process, the friction on the tool-chip interface cannot be measured directly. Therefore we will rely on indirect evidence to support the claim of lubrication effect by LN2. Cutting forces may provide some clue, as friction force is playing a role in the cutting process. Tool wear is another, lower friction in the cutting process should result in less wear to the tool. Then the chip, the workpiece material after the machining process, has been subject to some deformation due to the friction in the cutting process, should have some residual trace indicating the level of friction it has been subjected to. It seems cutting forces, tool wear, and chip morphology can provide indirect physical evidences to verify that friction was reduced by LN2 in cryogenic machining when compared to dry cutting.

this paper will emphasize on the indirect physical evidence involved in actual cryogenic machining. Cutting forces will be measured, tool wear will be examined, and chip will be inspected during or after the machining tests.

Experiment Result and Discussion

One major purpose for using a lubricant in the metal cutting process is to reduce tool wear, and hence improve tool life. In a cryogenic cutting, LN2 achieves the tool life improvement by reducing the tool-chip interface temperature to enhance the tool resistance against various wear mechanisms and by producing a lubrication effect to reduce the friction on the tool-chip interface. Therefore a charting of the tool wear development in cryogenic cutting process can demonstrate the frictional behaviors properly.

Tool wear is generated in a cutting process in two distinct forms, namely, crater wear and flank wear. The crater wear occurs in a form of crater on the tool rake face, and results from the friction of the chip flowing along the tool face. The flank wear produces a wear land on the tool flank, and is formed by the rubbing action of the newly generated work surface.

Based on an international standard on tool wear and tool life testing[2], the crater wear and flank wear for turning operations can be represented by the maximum depth of the crater valley, *KT*, and by the maximum width of the flank wear land, or *VBmax*, respectively. In the current study, a dial indicator with a resolution of 0.0127 mm (or 0.0005 in) was applied to measure the crater wear by using a needlepoint tip to reach the deepest point of the crater valley. A tool microscope (from Kennametal Inc.) was used to measure the flank wear. A tool insert is considered to fail if either *KT* becomes greater than 0.136mm (rake failure) or *VBmax* greater than 0.610mm (flank failure), whichever comes first.

Figure 1 and 2 show the developments of the rake crater depth *KT* and flank wear width *VBmax* for cutting Ti-6Al-4V at a surface cutting speed of 1.5m/sec. The dry cutting undergoes a catastrophic jump with the rate of both the flank wear and crater wear at the later phase of the tool life span. This may be due to the intense tool-chip interface temperature produced in the dry cutting, which makes the titanium chip strongly adhesive and diffusive to the tool rake, leading to a rapid blunting of the tool edge. The blunted tool edge reduces the effective flank clearance angle, resulting in a flank-work contact of high normal stress and friction, therefore, an accelerated flank wear, as also observed in [3].

Yet for cryogenic cuttings of Ti-6Al-4V either with primary nozzle on or with 2 nozzles on , the rake crater depth *KT* and flank wear *VBmax* approach the tool failure criteria line *KT*=0.136mm or *VBmax*=0.610mm only gradually. It can also be found, from a comparison of the Figure 7 and 8, that the tool rake fails prior to the flank failure for dry cutting, while the cryogenic cuttings result in a very slow rate of the rake crater wear, leading to an considerably earlier flank failure than the tool rake. This is also true for cutting speeds of 1.0m/sec, 2.0m/sec and 2.5m/sec, as demonstrated by our cutting tests of full tool life charted in Figure 3.

The significantly reduced rate of rake crater wear for the cryogenic cuttings with primary nozzle on alone also serves as evidence of the LN2 lubrication effect by the LN2 jet on the tool rake. Since the extended tool life is determined by the reduced rate of the tool flank wear for cryogenic cutting, the application of an additional LN2 jet directly to the tool flank (i.e., 2 nozzles on) has also led to a significantly further improvement in the flank life, due to the enhancement of the cooling effect by the LN2 jet from the secondary nozzle.

For the dry cutting operations of AISI1008, the flank always fails prior to the tool rake, and for cryogenic cutting of this material no essential rake crater wear was observed. Therefore, the tool failure is determined exclusively by the tool flank wear. Figure 4 shows the development of the tool flank wear for cutting AISI1008 at a surface speed of 8m/sec. Although the work cooling results in a lower maximum temperature on both the tool rake and flank than the chip cooling, it produces a high rate of the flank wear than the latter. This may be due to the fact that the primary deformation zone is also cooled overly by the work cooling. Because of the strong temperature dependency of AISI1008 yielding strength, the overly cooled primary deformation zone makes the work more resistance to shearing, producing considerably increased cutting force, which corresponds to a larger normal and friction force on the tool flank. This considerably increased cutting force will partially cancel the cooling effect by LN2 on the tool flank, which enhances the tool toughness against the abrasive friction. The cryogenic cutting with primary nozzle on , although producing a higher temperature on both the tool rake and flank than the work cooling, leads to a significantly reduced rate of the flank wear. This may be because the lubrication effect by the primary LN2 jet on tool-chip interface tends to prevent an essential rake wear (either rake crater wear or rake edge wear), which helps to maintain a sharp cutting edge, reducing the friction of the newly cut workpiece surface against the tool flank.

Conclusion

From the observations made on tool wear development, which are critical behaviors in a cutting process and influenced by LN2, the following conclusions can be derived; Tool wear rate, which is determined partially by the friction on the tool face, has been reduced by a margin, which is dependent on the cooling approach. The application of a LN2 jet to the localized tool rake face is essential for reducing both tool rake and flank wear.

References

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[3]. Bartle, E.W., Carbon Dioxide Permits Improved Machining Time , Machinery (America), Vol. 59, 1954, p.157

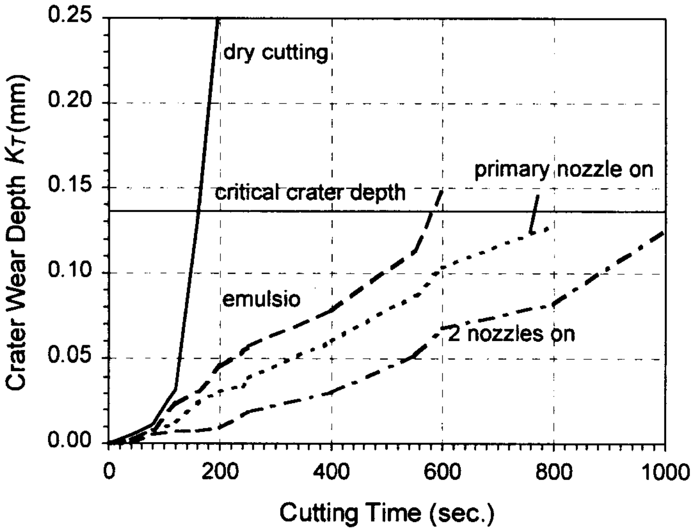

Figure 1 Crater Wear for Cutting Ti-6Al-4V at 1.5mm/s

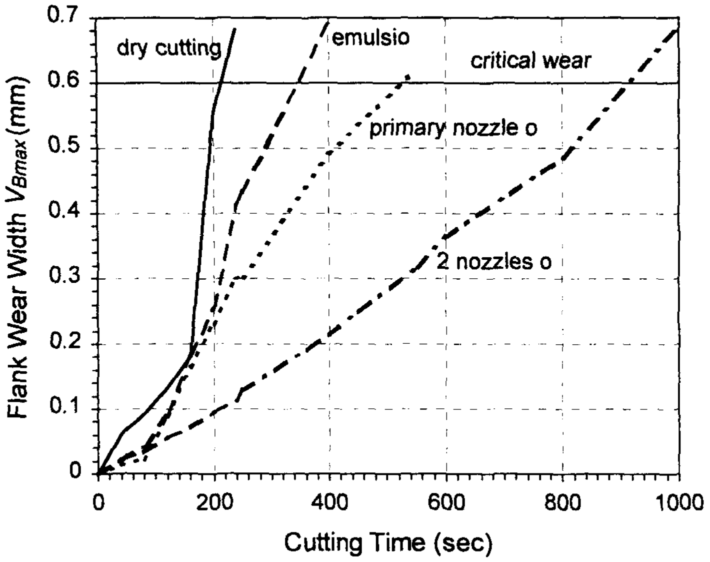

Figure 2 Flank Wear for Cutting Ti-6Al-4V at 1.5mm/s

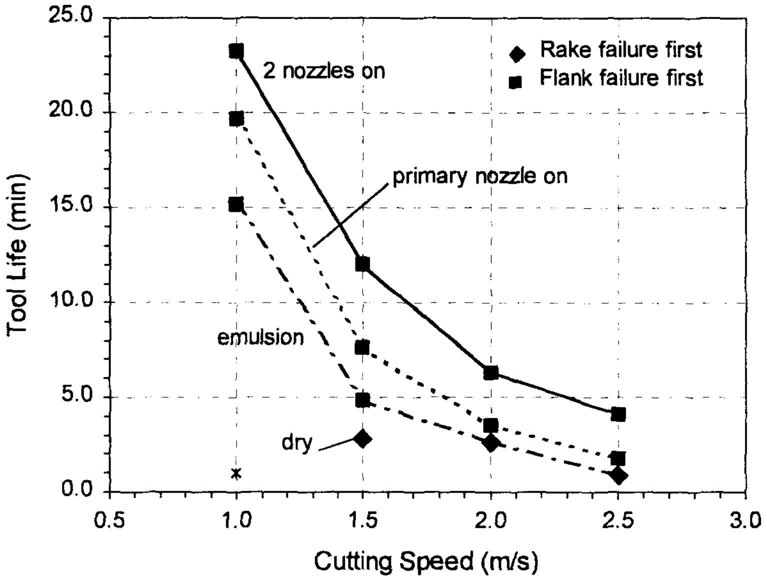

Figure 3 Tool Life for Cutting Ti-6Al-4V