초 냉각 가공에서의 LN2 의 감찰 효과 연구
- Investigation of LN2 Lubrication Effect in Cryogenic Machining -

절삭 칩 미세 구조에 관한 나이트로젠 감찰
Part 3: Nitrogen Lubrication Mechanism related to Chip Microstructures

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Abstract

Machinability improvement by the use of liquid nitrogen in cryogenic machining has been reported in various studies. This has been mostly attributed to the cooling effect of liquid nitrogen. However, No study has been found in discussion on whether liquid nitrogen possesses lubrication effect in cryogenic cutting. This paper presents lubrication mechanism related to chip microstructure. The friction reduction was further reflected in larger shear angle and less secondary deformation in the chip microstructures.

Introduction

The improved tool life in cryogenic machining has been mostly attributed to the cooling effect of LN2 because lower temperature reduces hot softening of the tool and enhances the tool hardness for wear resistance. Yet no investigation have been attempted to reveal the possibility of lubrication effect by LN2 in metal cutting processes and to maximize the lubrication effect to a full extent in the tool life improvement.

Since LN2 is so different in nature from conventional cutting fluids, a new vision must be used to introduce the lubrication effect of LN2 to cryogenic machining. In order to make LN2 effective as a lubricant, an adequate design for applying LN2 to metal cutting has to be developed. An economical cryogenic machining process developed by Hong [1] has a unique way of delivering LN2 to the tool-chip interface. Through a specially designed nozzle, this process provides a possibility to achieve the LN2 lubrication effect. However, there is a need to collect evidences to prove the existence of lubrication in cryogenic machining.

Experiment Results and Discussion

In a cutting process, the chip is formed by removal of a material layer from the workpiece. This chip forming process includes two steps. (1).The formation of the chip starts in an area called primary deformation zone, which extends from the tool cutting edge to the junction between the surfaces of the chip and workpiece, and is characterized by a heavy shear deformation. (2).The chip slides on the tool rake face with a high normal load, undergoing a heavy friction by the tool rake face and resulting in a secondary deformation beneath the chip face which is in contact with the tool rake face. The heavy shearing in the primary deformation zone and the heavy friction in the secondary deformation zone will change the morphology of the chip grains tremendously. The primary deformation produces distinguishable parallel slip lines of the deformed material grain throughout the chip thickness while the secondary deformation leads to a further bending of the slip lines in a shallow layer of the chip, which is adjacent to the tool face. Therefore, a microscopic inspection on the chip structure provides an approach to tracing into the tool-chip friction. Obviously, the larger the friction on the tool-chip is, the thicker is the zone that is influenced by the friction. Furthermore, the friction on the chip also damps the chip flow on the tool face and therefore tends to increase the slip line angle[2]. These facts justify an evaluation of the tool-chip friction based on the slip line angle of the chip body and on the thickness of the secondary deformation zone. Since both the primary and the secondary deformations are plastic in nature, it suffices to perform the microscopic inspection on the chip samples that are collected after the cutting process.

In this study, the metallurgic micrograph technique has been used to inspect the microscopic features of the chip samples. In order to obtain a high quality metallurgical micrograph that reflects the chip microstructure clearly and accurately, the chip face influenced by the tool-chip friction was perpendicularly oriented to the viewing surface. For this purpose, the chip was encased firstly in an epoxy resin at room temperature to obtain two-dimensional rectangle faces. After the chip-embedded resin was cured fully, it was hot-mounted in a ruling model with Bakelite powder under a pressure of 4200PSI and a temperature of 150o for about 20 minutes.

The pre-treatment process of the specimen consisted of a four-stage manual grinding with the series of water-lubricated papers. The direction of grinding was rotated by 90o with each change of the abrasive paper grade so that the removal of the previous grinding scratches was well guaranteed. Excessive grinding at any grade of abrasive paper was avoided because it can cause a subsurface deformation that would leads to significant artifacts and not be eliminated by succeeding grades of abrasive paper. The grinded specimen was then polished by using an aluminum slurry with a 0.3-micron grain size in water on medium-nap cloth and by using a BUEHLER polishing machine at low speed. This eliminated an extra stress layers on the specimen surface so that a scratch-free surface was obtained. In order to achieve a clear specimen surface, a water polishing without any other abrasives media was added was performed, which lasted 3 to 5 minutes.

The specimen was etched using a Nital solution (4ml HNO3, 100ml ethanol) for 30 to 50 seconds at room temperature. With this chemical treatment, the sharpness and the contrast of the microstructure morphology were found to be in high resolution even under 1000X magnification. A metallurgical microscope was used to photograph the specimens microstructure under a bright-field illumination with a green color filter.

Figure 1(a) and (b) show the chip microstructures (with a magnification 200X) for a dry cutting and cryogenic cutting of AISI1008 at a cutting speed of 6m/s, respectively. The cryogenic cutting was performed by cooling the tool rake (primary nozzle on). The slip lines that occur at the shearing plane can be seen clearly throughout the chip thickness for both the dry and cryogenic cuttings. For the dry cutting, the grain structure is deformed severely, compared to the cryogenic cutting. The slip line angles for the cryogenic cooling is approximately 48o, smaller than that for the dry cutting (57o). Correspondingly, the reduced slip line angle for the cryogenic cutting leads to a reduced thickness of the chip body. More importantly, it can be seen that the cryogenic cutting results in a reduced thickness of the secondary deformation zone.

Figure 2(a) and (b) show the chip microstructures for a dry and a cryogenic cutting of Ti-6Al-4V at a cutting speed of 1.5m/s, respectively. The cuttings were performed with a feed of 0.25 mm (0.01 in.) and a cutting depth of 1.27 mm (0.05 in.). For the cryogenic cutting, LN2 was applied to both the tool rake and flank (2 nozzles on). The slip line angle for the cryogenic cutting is 37o, lower than 54o for the dry cutting. The significantly reduced slip line angle has decreased the chip thickness in the cryogenic cutting. The thickness of the secondary deformation zone for the dry and cryogenic cutting is 34 *m* and 17 *m*, respectively.

The reduced slip line angle, chip thickness and secondary deformation in cryogenic cutting of these two materials served as a evidence of the reduced friction on the tool-chip interface, implying a lubrication effect of LN2 in cryogenic machining which is expected by applying LN2 in fine jets of high pressure to the localized tool faces.

Conclusion

From the observations made on chip microsructure, which are critical behaviors in a cutting process and influenced by LN2, the following conclusions can be derived;

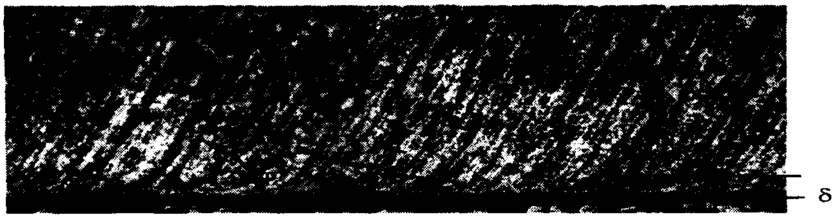
(1). The thickness of the chip body and the secondary deformation zone, the slip line angle, which are influenced mainly by the friction on the chip by the tool face, can be reduced distinguishably in a cryogenic cutting, compared to a dry cutting.

(2). The reduced friction on the tool-chip interface in cryogenic cutting, as demonstrated by these experimental observations, may serve as an indicator of the lubrication effect of LN2 in the cryogenic machining, which uses the cooling approach proposed in this paper.

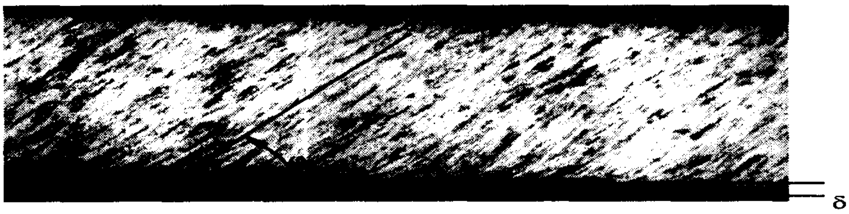
Reference

[1]. Hong, Shane and Ding, Yucheng, Cooling Approaches and Cutting Temperatures in Cryogenic Machining of Ti-6Al-4V , Int. J. of Machine Tools and Manufacture, Vol. 41/10, June 2001, pp 1417-1437.

[2]. ANSI/ASME B94.55M-1985, Tool Life Testing with Single-Point Turning Tools, sponsored and published by ASME.



(a) Dry cutting



(b) Cryogenic cutting

Figure 1 Chip Microstructure for Cutting AISI1008 at 6m/s

(a) Dry cutting

(b) Cryogenic cutting

Figure 2 Chip Microstructure for Cutting Ti-6Al-4V at 1.5m/s