Cryogenic microshaping of viscoelastic polymer with single point diamond tool

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Abstract

Viscoelastic polymer, such as polydimethylsiloxane (PDMS), is extensively used as a substrate material of the micro fluidic chip. Generally, it is difficult to machine PDMS which performs adhesion and softness at the room temperature. However, applying the cryogenic machining which focuses on the glass transition phenomena of viscoelastic polymers, accurate cutting of PDMS becomes possible. In this study, in order to machine PDMS more efficiently and precisely, feasibility of cryogenic microshaping with non-rotational cutting tool was investigated experimentally.

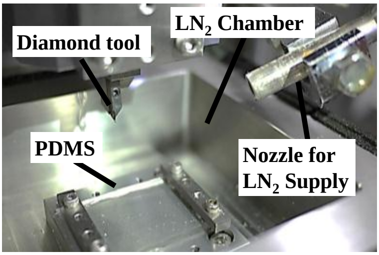
1. Introduction

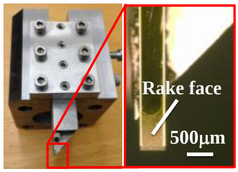
In general, micro channels on a micro fluidic chip made of PDMS are fabricated by the micromolding process. However, production process at the research phase of the micro fluidic chip is in desperate need of short-time process and small-quantity production with a wide shape-variety. In order to meet the demand, cryogenic micromachining method, which focuses on the glass transition phenomena of PDMS, was proposed [1]. In the recent past study, the cryogenic micro-milling process has been applied. However, highly efficient production is difficult because PDMS is torn when feed per tooth of milling tool is greater than sub-micro order [2]. In addition, cutter mark of milling tool remains on the machined surface occasionally and this leads to worse surface quality. In order to attain further highly efficient and precise cryogenic micromachining process, effectiveness of microshaping with non-rotational cutting tool was investigated. In this study, using a straight-nosed single point diamond tool, cryogenic microshaping tests of PDMS were carried out.

2. Cryogenic micromachining and experimental setup

It is difficult to machine viscoelastic polymer, such as PDMS, which is softness and adhesion at the room temperature. On the other hand, if PDMS is cooled under the glass transition temperature, it becomes hardness and small adhesion. Focusing on the glass transition phenomena, cryogenic micromachining has been proposed.

Figure 1 shows the experimental setup for the cryogenic microshaping test. In order to keep the glassy state during the cutting test, liquid nitrogen was constantly supplied from the pump into the liquid nitrogen chamber. This jig and no rotational straight-nosed single point diamond tool were set on the 3-axis vertical machining center (UVM450-C, Toshiba Machine), which was used in fabricating channels on PDMS.





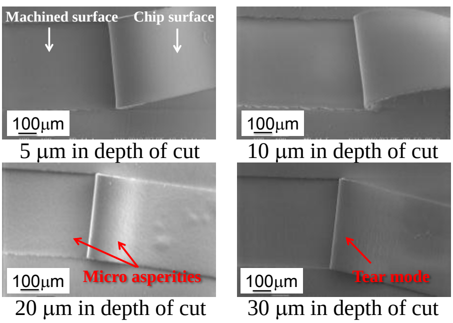
No rotational straight-nosed tool

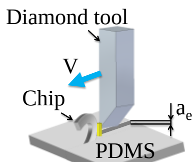
Tool	S.C.D
Tool width μm	500

Figure 1: Experimental setup for the cryogenic microshaping test

3. Effect of the depth of cut on surface quality

First of all, the effect of the depth of cut on surface quality was examined. In Figure 2 high quality machined surface without cutter mark was obtained when depth of cut was less than 10μm of cut.





Cutting condition

Workpiece: PDMS

Rake angle: -8 degree

Cutting speed V=50mm/min

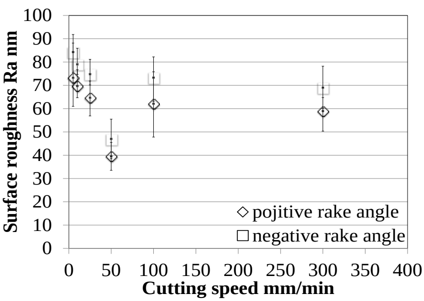
Depth of cut a_e=5, 10, 20, 30 μm

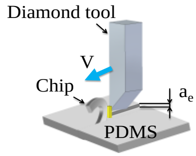
Figure 2: Observation of the machined surface and the chip surface

However, 20μm in depth of cut caused micro asperities on the machined surface and the chip surface. This is because a glassy state of PDMS could turn into adhesive state slightly at cutting point by the cutting heat in accordance with the increased cutting force and then, stick-slip at the flank face could be induced. In addition, when depth of cut was 30μm, the machined surface was torn because PDMS could be changed from glassy state to rubbery state by the increased cutting heat.

4. Effect of the rake angle and feed rate on surface quality

Using the non-rotational cutting tool with positive and negative rake angle, the effect of cutting speed on surface quality was investigated in view of the surface roughness. First of all, in terms of the relation between rake angle and surface quality, surface roughness in using positive rake tool was lower than in negative because cutting force based on the shear angle theory could be smaller. Next, with respect to the cutting speed, surface roughness was the lowest around 50mm/min in cutting speed. As a result, when cutting speed is 50mm/min, PDMS could keep the glassy state owing to reduction of the total cutting heat which depends on cutting force. On the other hand, if cutting speed was slower than 50mm/min, surface roughness increased again. In slower cutting speed, although cutting heat per unit time decreases, total cutting time gets longer and discharge of the chip becomes worse. Therefore, total cutting heat flowing in PDMS could increase and PDMS could not maintain the glassy state. Besides, when cutting speed was faster than 50mm/min, total cutting time was shorter. However cutting heat per unit time increased. This leads to higher total cutting heat and PDMS could be changed to rubbery state at the cutting point.





Cutting condition
Workpiece: PDMS
Rake angle: -8, 8 degree
Cutting speed V=5, 10, 25, 50, 100, 300mm/min
Depth of cut a_e=10 μm

Figure 3: The influence of rake angle and cutting speed on surface quality

5. Total cutting time

Table 1 shows the cutting conditions under which the lowest surface roughness could be produced in cryogenic micro-milling process and cryogenic non-rotational shaping. Using this conditions, total cutting time in micro grooves whose depth was 50μm and length was 20mm was calculated. As a result, compared with cryogenic micro-milling process, cryogenic non-rotational shaping could save the total cutting time by 58%.

Table 1 Comparison between micro-milling and No-rotational shaping

	Micro-milling process	No-rotational shaping
Cutting speed mm/min	4	50
Rotation speed min^{-1}	20000	Nothing
Ra nm	50	40
Total cutting time s	131	310

6. Conclusion

In order to enhance the efficiency and precision in cryogenic micromachining process, effectiveness of microshaping with non-rotational cutting tool was investigated. As a result, high quality machined surface without cutter mark was obtained if depth of cut was less than 10μm. In addition, positive rake angle tool using 50mm/min in cutting speed could produce the finest surface because of reduction of the total cutting heat. Furthermore, compared with cryogenic milling process in micro grooving, cryogenic non-rotational shaping could save the total cutting time by 58%. From the above, cryogenic microshaping could be one of the feasible methods to produce a micro fluidic chip made of PDMS efficiently and precisely.

References:

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