

MICRO-MACHINABILITY OF PLASTICS

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1. Introduction

Plastics are very useful material as their specific gravity are small and as we can design and adjust desirable mechanical, optical or chemical property of the material to some extent. When you intend to use the plastics to micro parts or fine parts, high accuracy or small surface roughness is needed. Usually plastic parts are made by some molding technology like an injection molding. However the technology has some difficulty to attain preciseness because of shrinking during cooling process. Thus in order to get a ultra-precise plastic parts you should apply a machining process, for example diamond turning or grinding, with a very small working unit (bit size). But there are a lot of kinds of plastics and it is thought that attainable working unit depends on the kind of plastics. This study is concerned with the question that which of the material property of plastics have effect to the micro-machinability of plastic materials.

2. Experimental procedure

The study was performed experimentally. Cutting tests with round nose diamond tool were conducted. We used the apparatus of fly cutting method of cutting speed 600m/min. Seven kinds of thermoplastics were evaluated. Those were polycarbonates (PC), polystyrene (PS), polymethylmethacrylate (PMMA), polyamide 6 (PA), high-density polyethylene (HDPE), polypropylene (PP) and polyvinyl chloride (PVC). ZYGO New View 100, an optical surface profiler, evaluated the surface roughness. The surface of each machined material is observed by optical microscope. The chips generated during machining are observed by scanning electron microscope.

3. Experimental results & Discussions

3.1. The effect on the surface roughness

During cutting experiments feed per revolution was changed with 2,5,10,20 $\mu\text{m}/\text{rev}$, though cutting depth was made to be 5 μm . An optical three-dimensional surface profiler evaluated the surface roughness in each material. In figure 1 the relationship between feed per revolution and surface roughness are shown. It is understood the value of the surface roughness greatly differs by the sample. In amorphous plastics like PMMA, PP or HDPE, the surface roughness is rather good and becomes worse with the increase in feed per revolution. It is a same tendency that the surface roughness is

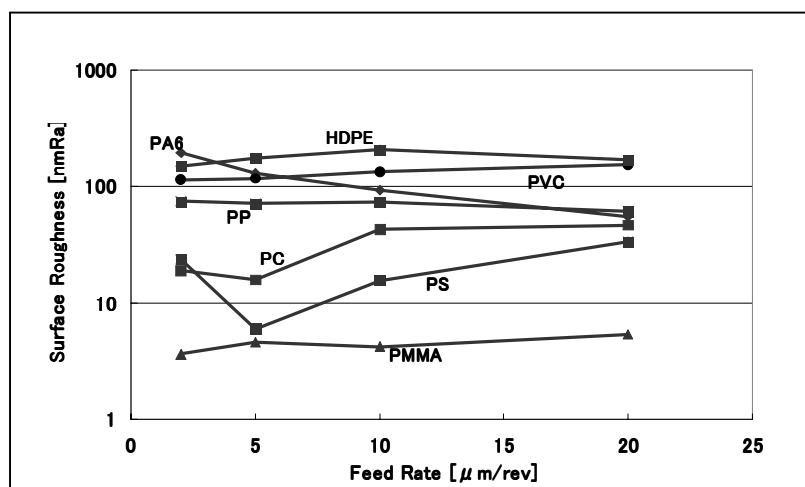


Fig.1 Effect of feed rate in several plastics

proportional to the square of feed per revolution in the equation of the theoretical aspect roughness. In partial crystallinity plastic as PS, PC, PVC and PA6, the surface roughness is bad and it does not change even if feed per revolution is changed.

3.2 The effect of the physical property.

The correlation of physical property of each material and surface roughness measurement result was examined. Following parameters showed the correlation.

(1) Compressive strength

Figure 2 shows the correlation between the surface roughness and the compressive strength of each material. There is generally a tendency of the right dropping. It shows an excellent linear correlation when the feed rate is 10 or 20 $\mu\text{m}/\text{rev}$. As the comparatively large feed generates the wider compressed area, the effect appears resistant.

(2) Tensile strength

There is generally a tendency of the right dropping as well as the case of compressive strength in the tensile strength. Similarly, it rode in the straight line, as feed per revolution was bigger. However, the dispersion from the linear regression is bigger than the case of the compressive strength. The action of the compression seems to be generally bigger than the tension.

(3) Glass transition temperature

Figure 3 shows the correlation between the surface roughness and the glass transition temperature. It became generally a figure of the right dropping as well as above-mentioned compressive strength and tensile strength. Especially, the good linearity in 5 or 10 $\mu\text{m}/\text{rev}$ it gets get. It is said that the molecular thermal motion becomes popular, when the temperature generally rises on the plastic, and the binding power of the intermolecular weakens and when degree of resistance for the external force lowers. This is thought to be a reason for the experimental result.

(4) Combination number

The combination number is the quantity which shows first combination number per unit cross section. Figure 4 shows the correlation between the surface roughness and the combination number. It became generally a figure of the

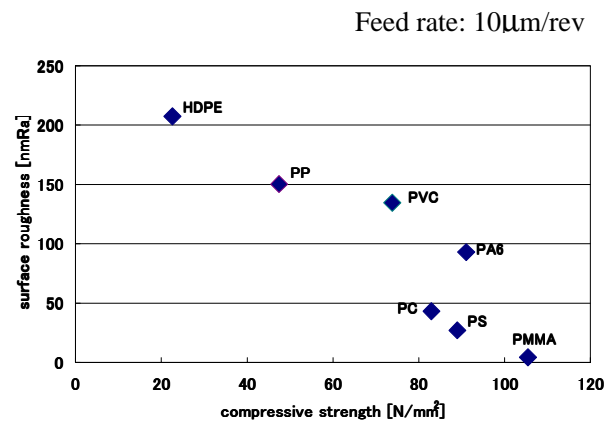
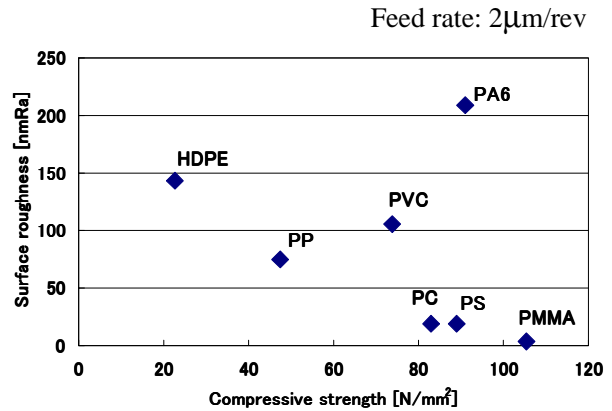


Fig.2 Effect of compressive strength

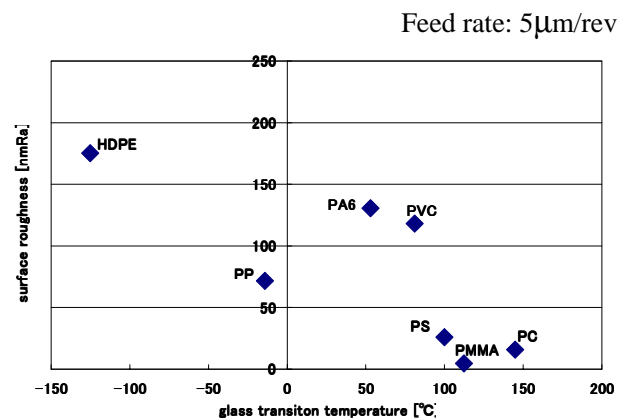


Fig.3 Effect of glass transition temperature

right riser. The good linearity in 2 or 5 $\mu\text{m}/\text{rev}$ it gets get. Feed per revolution shows that the combination number influences surface roughness in small case resistant. The surface roughness seems to improve, because molecular chain cut off in the cutting is few, if the combination number is little.

3.3 The effect of a heat in the cutting.

It is considered that physical property changes such as the softening in the cutting by temperature rise give large effect in the plastic cutting work result. Then, the effect of the cooling was examined

3.3.1 The effect of a heat in the polypropylene

The result of the cutting in both without there being the air-cooling at 2 $\mu\text{m}/\text{rev}$ feed per revolution is shown in figures 5. The horizontal axis of the figure is the combination number. That the effect of the air-cooling remarkably appeared was only the polypropylene. It seems to be because that the thermal conductivity of the polypropylene is the lowest within the sample that used by the experiment influences. Though with that the thermal conductivity is low, generated heat is locally easy to remain the cutting plane during the process; it seems to be able to positively release a heat by making the air-cooling to be this

3.3.2 Unique features of the polyvinylchlorid surface

In the cutting of the polyvinyl chloride, it was examined in detail, because the dispersion of the surface roughness in the sample in-plane was big. Figure 6 shows the results. The machined

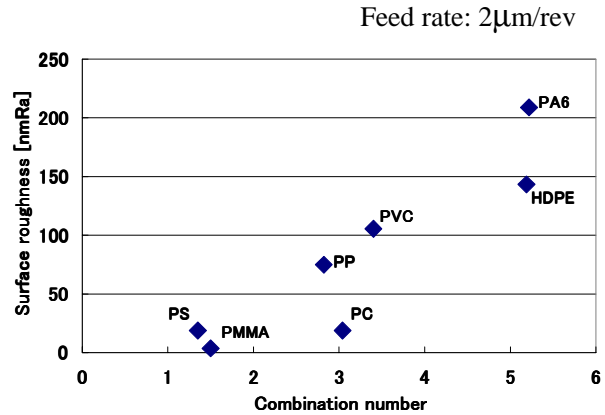


Fig.4 Effect of combination number

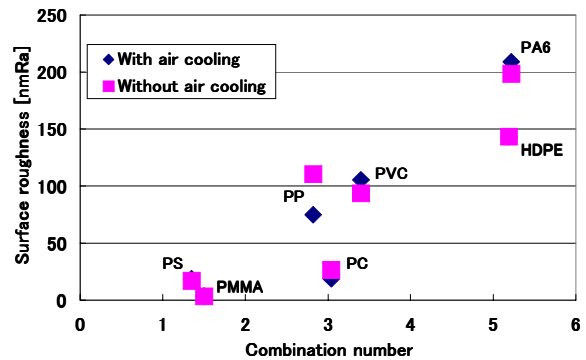


Fig.5 Effect of air-cooling

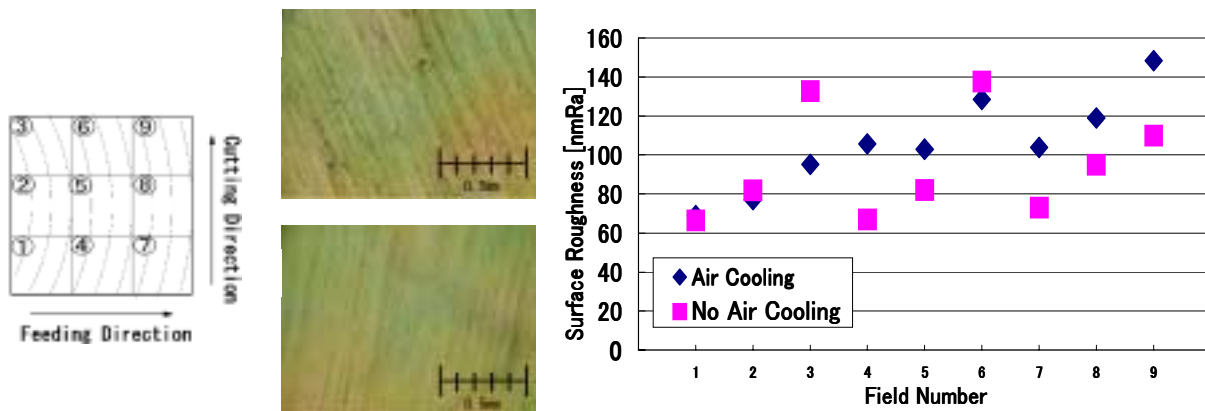


Fig.6 Close-up pictures and surface roughness of PVC at nine divided fields

surface is divided 3x3. The number 1 to 9 indicates the each area. As you can see on the pictures in Fig.6, the surface in the first part of cutting locus (No.1) is smoother than that in the last part (No.3).

The graph shows the surface roughness values of each area. No.1,4 and 7 machined without air-cooling show the almost same surface roughness. No.2,5 and 8, or 3,6 and 9 are similar respectively. Though it is not proven that this phenomenon is occurred by thermal effect, the phenomenon like generation and erasure of the built-up edge seems to occur. That this phenomenon did not carry out the air-cooling remarkably appeared. It became a result of right riser that generally continued, when the air-cooling was carried out. This physical property seems to influence, because the polyvinyl chloride is the sample in which thermo-stable temperature and deformation temperature are the lowest in handled sample.

3.4 The observation of the chip.

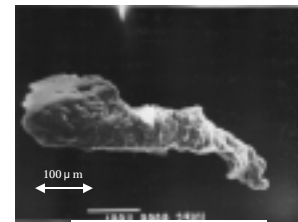
The cutting was carried out under 5 μ m cutting depth and 10 μ m/rev feed, with air-cooling. During the process chips were collected. The chips were observed by a scanning electron microscope.

Table 1 Summary of chip observations

HDPE	The width is wide, and the thickness is thinly uniform.
PA6	It has width, thickness, and it shrinks along the length direction.
PP	It is also filtered that it comes too, and the tip thickly and gradually thin.
PVC	It is similar to the PP.
PC	2 types result with linear and one similar to the PP.
PMMA	It is very thin, and it shrinks along the length direction.
PS	The thickness is constant in PC and similar shape



HDPE



PVC

4. Conclusion.

The derived conclusions from this study are as follows.

- (1) Surface roughness of each material is very different from each other under the same cutting conditions. Those of HDPE, PVC or PA6 are several tens bigger than that of PMMA.
- (2) Feeding speed has no effect to the attained surface roughness on the materials that generate bad surface like HDPE, PVC, PA6 or PP.
- (3) Junction number, compressed strength, tensile strength and glass transition temperature of each material have some effect to attained surface roughness. Junction number is a number of cross-linking per unit volume and a scale of the degree of crystallization.
- (4) It seems that chips have received some heating effect during cutting process. Degree of the effect depends on the material.
- (5) Air cooling or water mist cooling during cutting process is effective to only PP. Heat conductivity of PP is the least of the seven materials.
- (6) Surface of PVC after cutting process is not uniform. Surface roughness is varying to more than 50% on the surface. It also seems that heating affects the process.