Which of the material properties dominates surface roughness of diamond turned plastics

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1. Introduction

Plastics are very useful materials as their specific gravity is small and as we can design and adjust desirable property of the material to some extent. If you intend to use the plastics to micro parts or fine parts, high accuracy or small surface roughness is needed. To attain these, diamond turning is a possible candidate by economical or engineering point of view. But there are a lot of kinds of plastics and it is thought that attainable surface roughness depends on the kind of plastics. That sort of application has already been popular in optical fields. For example, material of eyeglasses has changed from glass to plastics. Contact lenses are plastics machined with diamond turning. Much more applications of changing from metal or other to plastics are expected. However machinability, especially micro-machinability of the plastics has not been revealed yet, though most plastics are so softer than metals or ceramics

This study is concerned with the question that which of the material property of plastics have effect to the attainable surface roughness.

2. Experiments

This study was performed experimentally. Table 1 shows experimental conditions. Cutting tests with round nose diamond tool were conducted. We used the apparatus of fly cutting method. Five kinds of plastics were evaluated. Those were, polycarbonates (PC), polystyrene (PS), polymethylmethacrylate (PMMA), polyamide 6 (PA) and high-density polyethylene (HDPE). In the cutting tests both a new (sharp) tool and an old (dull) tool were used, and both feed rate and depth of cut were altered. ZYGO New View 100, an optical surface profiler, evaluated the surface

Table 1 Experimental condition

Material	Polycarbonates, PC Polystyrene, PS Polymethylmethacrylate, PMMA Polyamide6, PA High density polyethylene, HDPE
Tool	Single crystalline diamond (Nose radius=5mm) Sharp tool / Worn tool
Depth of cut	2--40 μm
Feed rate	2--80 μm/rev
Cutting speed	600m/min
Cutting method	Fly cutting
Coolant	Nothing / Dry air

roughness and an optical microscope observed the surface.

From the experimental result for diamond turned plastics, the depth of cut did not affect their surface roughness. On the contrary, it was proven that the feed rate influenced for the surface roughness, especially in PS as shown in Fig.1. It is clear, because the theoretical roughness is defined by nose radius of tool and the feed rate.

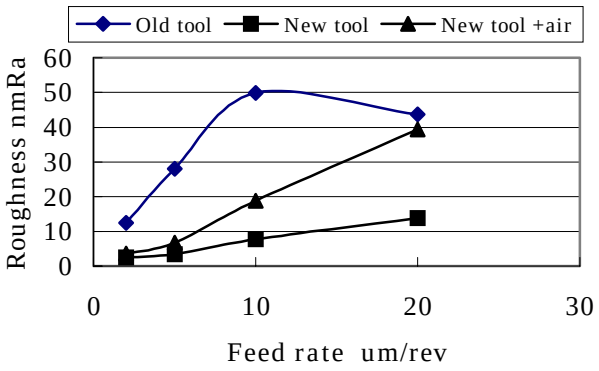

Fig.1 Influence of feed rate to surface roughness in diamond turning of PS

3. The factor that seems to affect the surface roughness.

Next four is mentioned as the factor, which seems to affect the surface roughness in ultra-precision cutting of the plastics.

(a) Condition of tool edge

It is good the result which there are no chipping and abrasion at the edge of the tool in order to prove from the experimental result. As the plastic is fundamentally a soft material, and it can be easily influenced by condition of the tool edge, it seems to obtain the good surface roughness by carrying out the cutting by choosing thing of which the condition of the edge is good as much as possible.

(b) Feed rate

As mentioned above, small feed rate tends to get good surface. Though actual roughness values are more than that of theoretical ones, it happened that smaller the feed rate is more smooth the surface becomes. However once it becomes too small as 2 μm/rev, the surface cannot improve at all.

(c) Tensile strength

Generally speaking tensile strength of a material is a primary factor of the surface roughness at metal cutting, because the yield shearing stress is correlated to the tensile strength. When the tensile strength is high, it is thought that the surface roughness on a machined surface is bad because large shear stress is needed to remove the material.

Fig.2 shows the relation between the tensile strength of each material and the surface roughness on same experimental conditions. Since it becomes the right riser almost, it is proven that there is to some extent correlation between the tensile strength and the surface roughness on the graph, if HDPE is removed in this figure. Though HDPE was cut from the reason that tensile strength was small in this study, experimental result is different from expected one.

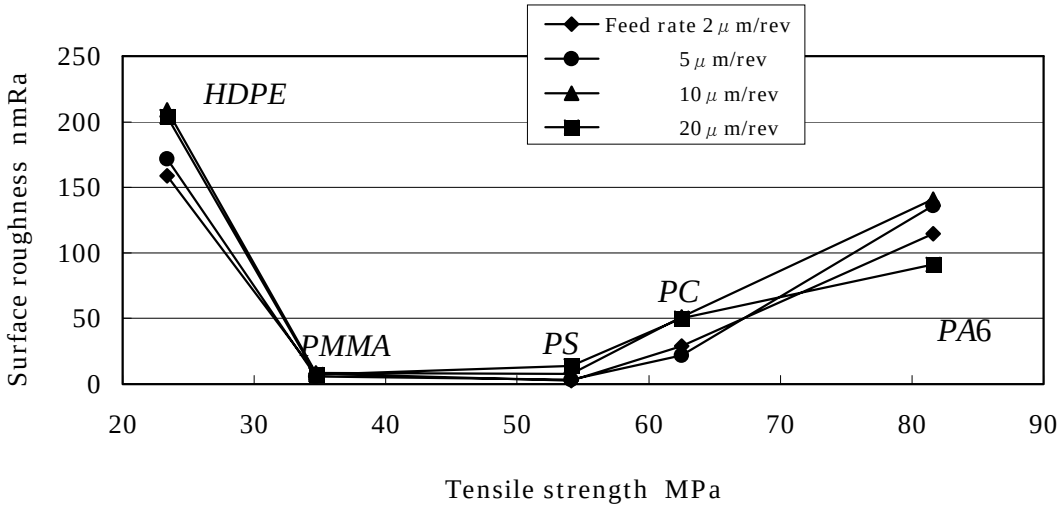

Fig.2 Relation between tensile strength and surface roughness of plastics

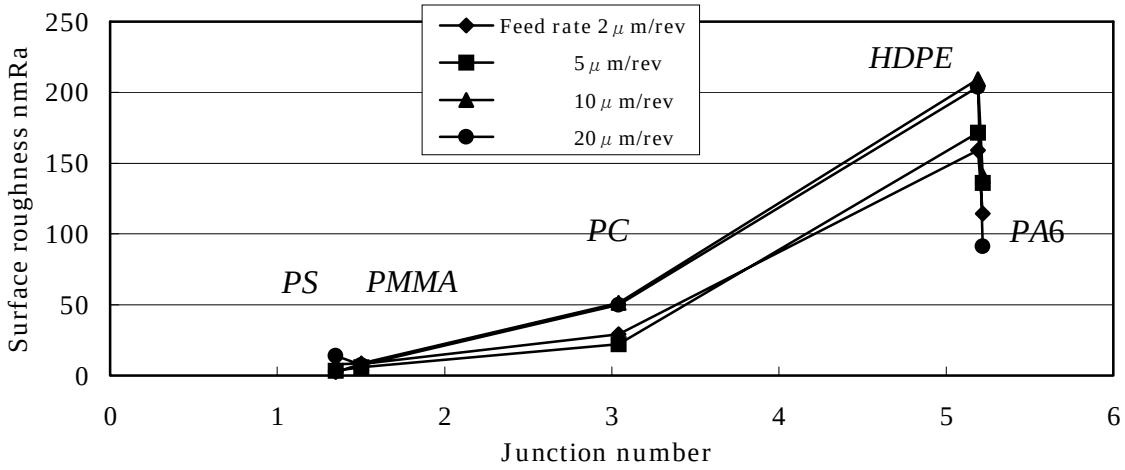

Fig.3 Relation between junction number and surface roughness of plastics

(d) Degree of crystallization (Junction number)

Fig.3 shows the relation between junction number of the materials and the surface roughness. The graph shows the tendency that is almost fixed with the right riser, and the relationship between the junction numbers seems to influence it than the relationship between tensile strength and surface roughness of machined surface.

The junction number is defined to a number of molecular chain per unit cross section in a material. The number is related to degree of crystallization, which is a proportion of crystallized parts in the material. Actually at PS, PMMA or PVC (polyvinyl chloride) it all consists of the amorphous region and PC slightly has the crystal region, and PA, PP (polypropylene), PE and so on

have much more regions. It is considered that this fact agrees with the experimental result and that the degree of crystallization affects the surface roughness.

4. Discussion

The plastic is the giant molecule structurally cohering in secondary coupling force based on van der Waals force among molecular chains as an essential point unlike the metal. The microscopic mechanism of the plastic destruction was considered as follows.

(1) It becomes an unequal distribution from the viewpoint of the molecular level, when it applied even in on the macroscopically uniform external force. The force works to not only interatomic coupling in molecular chain but also the secondary coupling.

(2) Extended coupling is cut off, when the external force is increased. Though the coupling of the circumference shoulders the loss to some extent, the cutting similarly continues.

(3) A micro crack is generated after the cutting of the coupling is accumulated. Such micro cracks arise in here and there on the workpiece. The micro crack becomes macroscopic crack by accumulating or combining.

(4) With cutting the secondary coupling where the resistance is less than the first coupling, the macroscopic crack grows and brings about the last destruction.

On this sequence, the destruction of plastic is mainly upon the secondary coupling part, and a part of destruction of the primary coupling seems to contribute less.

5. Conclusion

The derived conclusions from this study are as follows.

(1) Degree of crystallization of the material shows a good correlation to the generated surface roughness. As the junction number is a scale of the degree of crystallization, if the junction number is low, the surface roughness of the diamond turned one is expected to good surface.

(2) In four materials except HDPE good correlation between the tensile strength and the surface roughness is shown. HDPE's surface roughness is the worst during five kinds of plastics though the tensile strength of that is the lowest.

(3) Good surface roughness is obtained by using a good conditioned, that is new and sharp tool.

(4) Lower the feed rate is, better the surface roughness is. The feed rate is more effective to the surface roughness than the depth of cut.

(5) Polystyrene is the most sensitive to effect of the factors to the surface roughness. The best result within our experiments of 2.3nmRa (average roughness) was obtained using new tool, 5μm feed rate and 2μm depth of cut.

(6) The experimental factors are not susceptive when PMMA is machined. The surface roughness is roughly good. You can get a good surface steadily when using PMMA.