Deterministic Design of "Engineered Tool" (A New Diamond Tool)

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1.Introduction

The present report demonstrates fly-cut experimental results for brittle materials cut using the Engineered Tool (a new diamond tool), and introduces the tool design of the Engineered Tool.

The reasons for developing the Engineered Tool and the experimental results for two kinds of Engineered Tool are obtained for fused silica and single-crystal Si as fundamental data in order to aid in the design of future Engineered Tool. The experimental results of shear (or ductile) mode grinding indicate two serious obstacles to the development of the Engineered Tool.

One obstacle is that the removal rate is limited by the wheel-to-workpiece contact area, which may cause heat generation. During the experiment, cracks caused by burning appeared on the ground surface, and shear mode grinding was impossible. The result indicated that a large contact area limits the induction of coolant and promotes high temperatures in the coolant zone where heat is generated. In some types of grinding geometry, a large contact area is difficult to avoid. Therefore, as suggested previously, an alternative is to excite the wheel at ultrasonic frequency, which also admits coolant between wheel and workpiece. The grinding force was found to be lower than that obtained with no vibration (conventional) grinding in shear mode [1]. Furthermore, exciting the wheel to induce a coolant in the contact zone was found to enable a two-fold increase in the removal rate.

The other obstacle is that the ground surface is scratched by various abrasive grits on the grinding wheel surface [2]. Therefore, it is very difficult to maintain a high-quality ground surface, because uniform grit size, form, density, and orientation are not possible when using the grinding wheel. Thus, the inadequacies of the grinding wheel clarified the need to develop a new diamond tool, which is called the Engineered Tool [3].

2. Engineered Tool

Engineered Tool has many small posts on a single crystal diamond surface (1,0,0). The diamond size is $2\times2\times1$ mm. In the example shown in ***Fig.1***, the posts were precisely machined to be 15 μm apart using an excimer laser. Each post size is 5×5 μm square, having a height of 10 μm height as shown in ***Fig.2***. This represents a very high density of active diamond of a constant and known spacing.

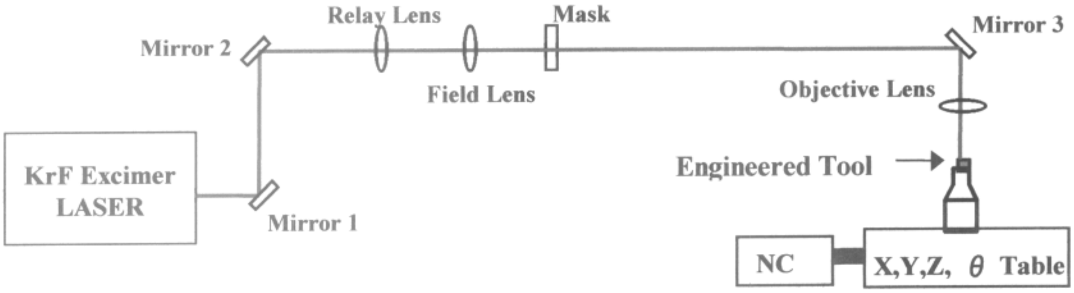

Fig.1 Manufacturing of ET using Excimer Laser

In addition, it is possible to align the diamond orientation can be aligned so as to provide uniform and minimal wear of the posts. The post size, form, and density of the Engineered Tool can be designed flexibly.

Clarification of the expected accuracy and the critical depth of cut of each material will allay a suitable tool to be designed for each material.

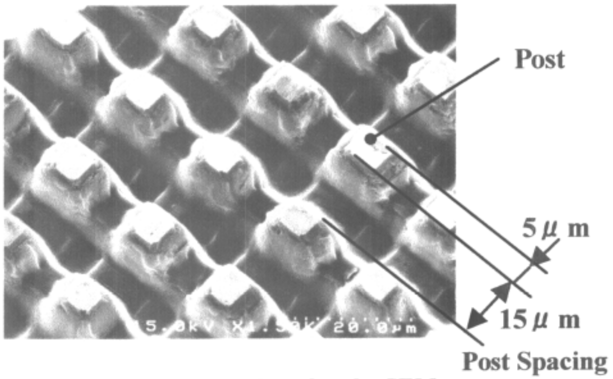

Fig.2 Engineered tool surface by SEM

3. Preparatory Experiment of Fly-Cut

A fly-cut experiment of single-crystal Si was performed using the Engineered Tool with ultrasonic vibration (*Fig.3*).

In this experiment, many individual cutting marks were examined using a laser microscope (*Fig.4, 5*) in order to measure the critical depth of cut. The critical depth of cut was found to be 0.21 μ m.

In addition, the post patterns were found to have been precisely copied on the workpiece surfaces in shear (or ductile) mode [4].

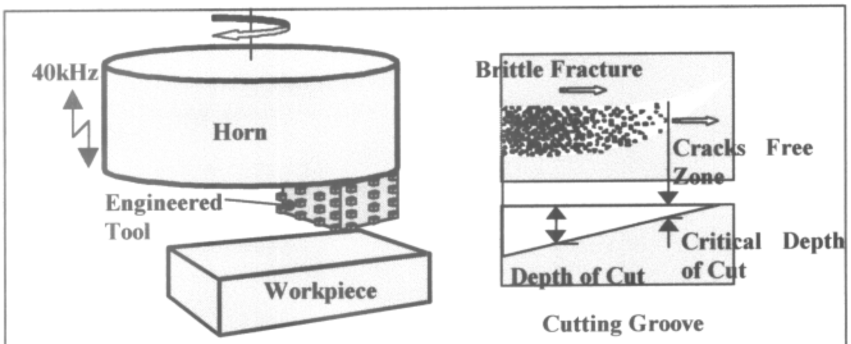

Fig.3 Schematic drawing Fly-cut experiment using Engineered

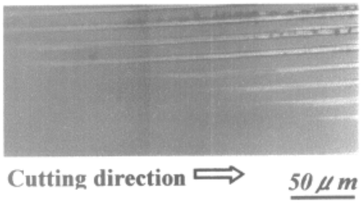

Fig.4 Photograph of cutting grooves using Engineered Tool

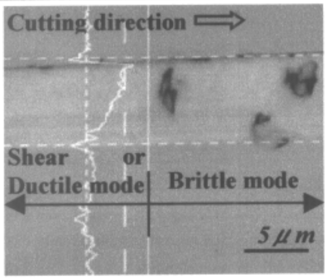

Fig.5 Transition boundary from shear (or ductile) mode to brittle

4. Deterministic Design of the Engineered Tool

Based on these results, design of the Engineered tool based on the expected accuracy and critical depth of cut, appears to be possible, because the successive active posts can be determined by distributed post patterns. The new design of the Engineered Tool is shown in ***Fig.6***, in which [dt] is the total depth of cut, or n times [dc]. Furthermore, the rake angle of this tool can be determined by the critical depth of cut [dc] (***Fig.7***).

Therefore, the new Engineered Tool will enable the removal rate of a brittle material to be increased n times in shear (or ductile) mode.

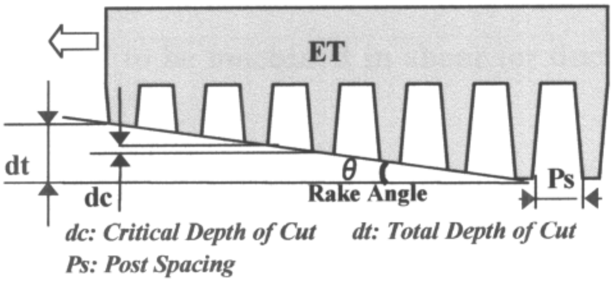

Fig.6 Deterministic design of Engineered tool

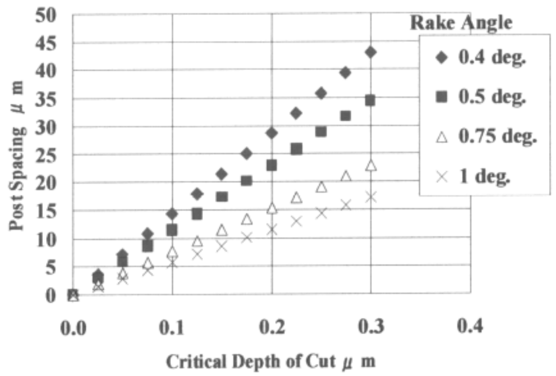

Fig.7 Post spacing versus critical depth of cut of the new Engineered tool

5. Fundamental Experiment of Fly-Cut using the New Engineered tool

The new Engineered tool was manufactured to the following specification rake angle; 0.4 degree, [dc]; ~0.1 μ m, [dt]; 8 μ m (***Fig.8***).

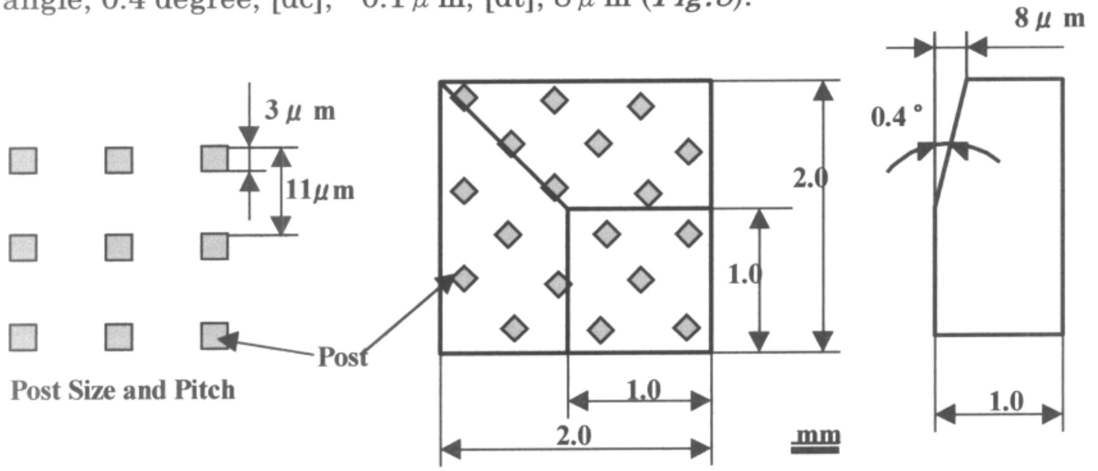

Fig.8 Schematic drawing of the new Engineered Tool

Using the new Engineered tool, single-crystal Si was cut in a fly-cut experiment. Then, a schematic drawing of the cutting mechanism is shown in ***Fig.9***.

As a result, single-crystal Si was found to be machined in shear (or ductile) mode (*Fig.10*), at 6 μm [dt], or about 30 times [dc].

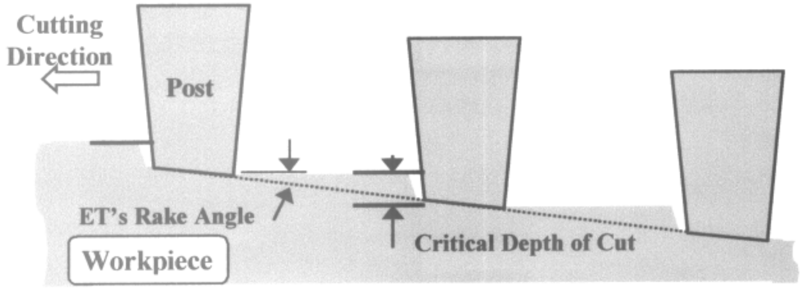

Fig.9 Schematic drawing of the cutting mechanism using the new Engineered Tool machining

6.Conclusions

(1) The Engineered Tool can be designed based on the expected accuracy and critical depth of cut.

(2) A new Engineered tool was manufactured to have the following specifications rake angle; 0.4 degree, [dc]; ~0.1 μm, [dt]; 8 μm.

(3) Using the new Engineered tool, Single-crystal Si was found to be machined in shear (or ductile) mode until 6 μm [dt], in this experiment.

These results indicate that the Engineered Tool is useful in high-precision machining of hard and brittle materials.

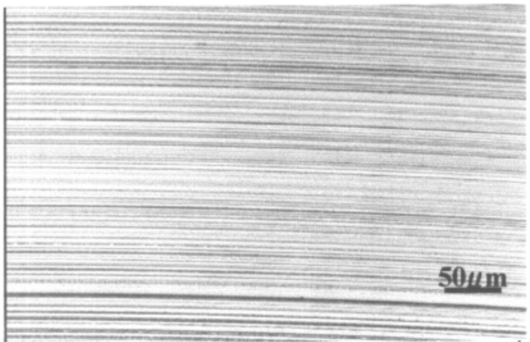

Fig.10 Shear (or ductile) mode surface of the single-crystal Si using the new Engineered Tool

Reference

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