Study on Force Controlled Micro Grooving Using Burnishing Tools

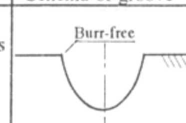
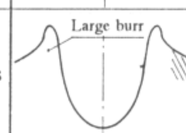
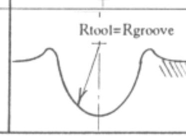
Masami Masuda, Yoshiharu Waki, Akihiro Inada, Atsushi Mutoh
Grad. Sch. of Sci. & Tech., Niigata University, 8050 Ikarashi 2-no-cho, Niigata 950-2181, Japan
Yukio Maeda
Prod. Eng. Res. Lab., Hitachi Ltd., 292 Yoshida-cho, Totsuka-ku, Yokohama 244-0817, Japan

1. Introduction

Functions of components are decided by a micro texture formed on their surfaces, which are characterized statistically and are difficult to understand the correlation with the surface functions, because the surfaces have a random micro texture produced by grinding or polishing process in general. This brings about a try and error iteration in R&D process of new products, or becomes occasionally a serious accident in the market. Therefore, it is essential that surfaces are characterized quantitatively in order to optimize surface functions in the field of optics, tribology, chemical action and so on. Therefore, normalized surfaces covered with such a uniform texture as the aggregate of a well-defined micro groove are useful for analyzing quantitatively the effect of a texture surface upon surface functions instead of a random micro texture surface.

In this paper, effects of grooving conditions upon groove geometry are discussed for the purpose of producing arbitrary micro grooves and their aggregate. Surfaces with micron or sub-micron grooves and textures covered with them are expected to use not only in the above-mentioned tentative texture but also in many other applications. Therefore, various kinds of grooves with sharp-edged shoulders, with large burrs on the shoulders or with an accurate bottom radius are required on specialized surfaces as shown in Table 1.

Table 1 Groove geometry and its feature

	Schema of groove	Feature & application
① Burr-free shoulders		* Most popular application * Unnecessity of burr removal process ·Micro dynamic bearing
② Large burr on both shoulders		* Large surface area ·Heat transfer ·Anchor effect for adhesion * Small contact area ·Preventing from sticking
③ Accurate bottom radius		* Normal design & appl. ·Lenticular sheet ·Riblet ·Micro guide way ·Oriented reflecter

2. Experimental procedure and conditions

2.1 Grooving machine

A grooving machine used for the experiments has a rotary table for chucking a circular workpiece and a sliding table for traversing a burnishing tool in a radial direction[1)2)]. The features of the machine are as follows;

1) The normal component of burnishing force can be controlled constant at accuracy of ± 0.1mN, since preventing from chucking errors or parallel errors of workpieces.
2) The machine can produce a texture pattern with the aggregate of a straight line, a circle line and /or sinusoidal line.

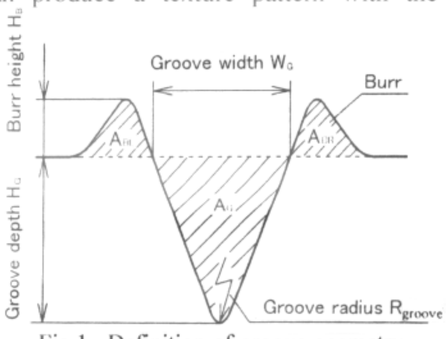


Fig.1 Definition of groove geometry

2.2 Grooving conditions

Grooving conditions are shown in Table 2. Coni-

Table 2 Grooving conditions

Forming equipment	Micro texturing machine
Tool	① Conical tool Single crystal diamond Top angle θ=143°, 170° Radius of sphere SR=7.5um, 43um
	② Keel-shaped tool Single crystal diamond Trans. radius R=0.2um,Top angle θ=150° Longitudinal radius R'=10mm
	③ Spherical tool Spphire Radius of sphere SR=10um
Workpiece	cf. Table 3
Normal load	W = 0.5-500mN
Rubbing speed	v = 3-120mm/min
Lubricant	① Dry
	② Wet (Nisseki, Spinox S4) Viscosity : 3.96cst/313K

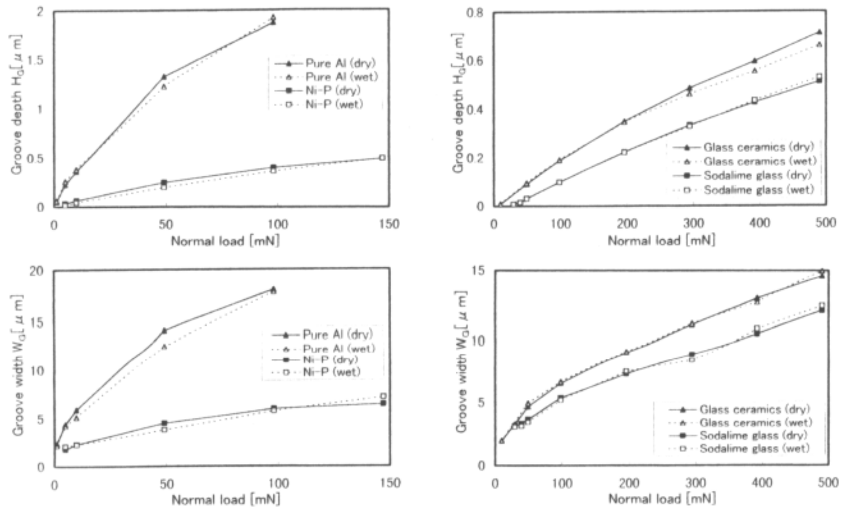
Table 3 Mechanical properties of work material

Work material	Vickers hardness	Density [mN/mm³]	Young's modulus [N/mm²]
Pure Al	60	25,100	70,600
Ni-P	500		119,600
Sodalime glass	680	24,400	71,500
Glass ceramics	610	23,500	96,800

cal, spherical and keel-shaped tools made of either single crystal diamond or sapphire are used for grooving. The keel-shaped tools have 10mm radius in a rubbing direction and 0.2μm radius in a transverse direction. Workpieces are made of pure Al, Ni-P, sodalime glass and glass ceramics, whose mechanical properties are shown in Table 3.

2.3 Measurement of groove geometry

It is significantly interested in the grooving process and grooving conditions if tool geometry would be copied on work surfaces with any accuracy. The parameters of grooving geometry as shown in Fig.1 are measured with SPM (TopoMetrix TMX-2000).



(a) Pure Al and Ni-P (b) Glass

Fig.2 Effect of normal load on groove depth and groove width

3. Grooving results and discussion

3.1 Groove geometry

Grooving tests on four kinds of work materials were carried out using a conical tool (θ=143°, SR=7.5μm). Fig.2 shows the effect of normal load on groove depth and groove width. The groove depth and groove width are approximately proportional to the square root of normal load. This behavior is similar to the fact in indenting tests. On the other hand, the groove depth and groove width except tool life seems to be not so sensitive to the lubricant.

3.2 Relation between groove depth and groove width

Fig.3 shows the correlation between groove depth and groove width. The groove width on sodalime glass and glass ceramics is 1.6 - 2.2 times larger than that on pure Al. Any cracks or chippings did not appear around grooves even at a maximum normal load of 490mN, according to SEM observation. As a result, sub-micron forming is possible on such brittle material as glass.

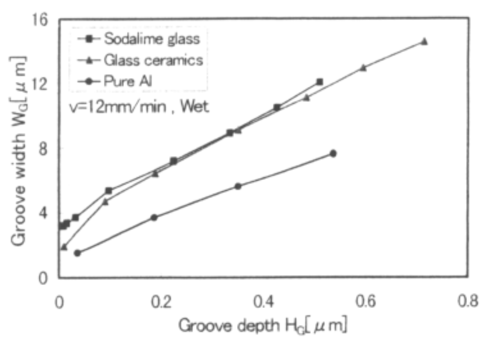


Fig.3 Relation between groove depth and groove width

3.3 Effect of Rubbing speed

Groove depth on sodalime glass grooving increases 60% with the decrease of a rubbing speed from 120 mm/min to 3 mm/min, although groove depth and groove width on pure Al fluctuate approx. ±10% in the same range of the rubbing speed as well as groove width on sodalime glass.

Forming accuracy can be investigated by "radial ratio" of a groove radius relative to a tool radius. Fig. 4 shows the correlation between groove depth and the radial ratio. In this figure, the radial ratio increases with the decrease of groove depth for sodalime glass or glass ceramics grooving, especially on wet grooving of glass.

On the other hand, tool geometry is copied more accurate on pure Al, because radial ratio indicates 1.1 - 1.8 at a groove depth less than 0.6um.

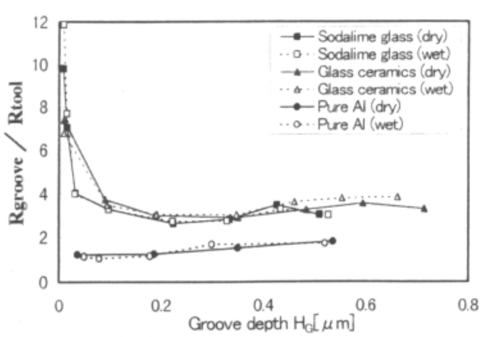


Fig.4 Relation between groove depth and radial ratio

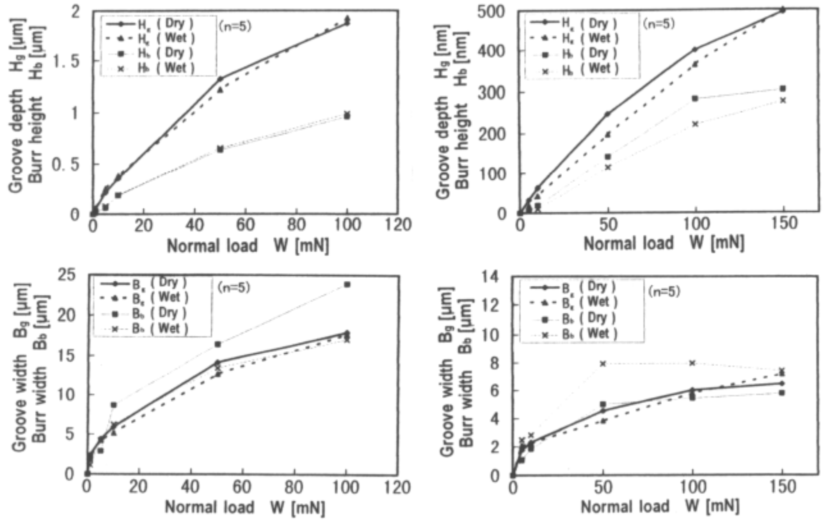
3.4 Burr height and burr width

Fig.5 shows the influence of normal load on burr height and burr width in pure Al and Ni-P grooving. According to the figure, groove depth and burr height in Ni-P grooving are relatively smaller and groove width and burr width are relatively larger in comparison with pure Al grooving. A good texture is achieved by pure Al grooving at a low normal load, when relatively large surface area, small contact area or large burr height is required. Although larger burr width and smaller burr height are obtained in wet Ni-P grooving than those in dry Ni-P grooving. The lubricant seems to affect delicately the burr width and burr height. The effect of lubricant has to be continued investigating.

3.5 Adjacent grooving

Only a micro groove is scarcely applied to actual products, but some aggregate of micro grooves is more useful in industry. Therefore, the interference between adjacent grooves has been investigated in the grooving process, using parameters as shown in Fig. 6.

The first and the second grooves were made in the similar way, except a rubbing direction in the second groove across the first groove at a small angle. Thus, the interference between adjacent groves can be made clear by profiles in a transverse direction at any groove pitch.



(a) Pure Al (b) Ni-P

Fig.5 Influence of normal load on groove geometry

Fig. 7 shows the symmetricity between adjacent grooves in wet grooving of pure Al. SR7.5μm conical tool and SR100μm sapphire tool are used in (a) and (b) respectively. A tool makes two grooves in the same rubbing direction in (a) and (b), but in the inverse rubbing direction each other in (c). Although the symmetricity between adjacent grooves seems to fluctuate considerably in this figure, some regularity is observed .

1) Maximum values of out-of-symmetry indicates at a larger groove pitch when the groove depth is larger.
2) This is because that the groove depth at the second grooving becomes smaller when a tool rubs on the burr formed further from the center of the first groove in the case of a large groove depth.
3) At an extremely large groove pitch, good symmetricity is obtained substantially, without any interference each other.
4) Symmetricity in opposite direction grooving (c) is analogous to that in same direction grooving (a), but the former has not so strong correlation with the latter. This means the burr indicates any orientation induced by the grooving.

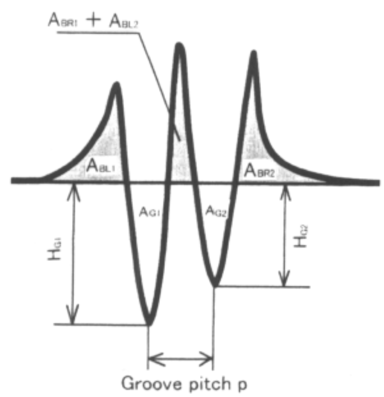
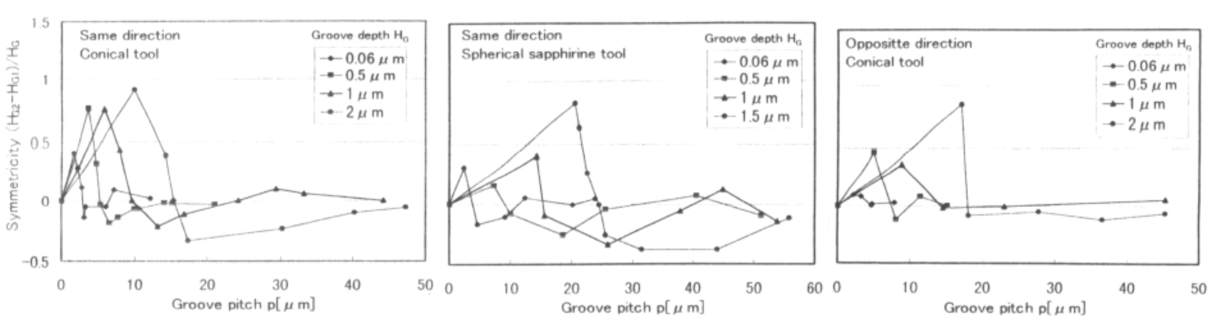


Fig.6 Definition of groove geometry in adjacent grooves



(a) Same direction with conical tool (b) Same direction with spherical sapphire tool (c) Opposite direction with conical tool

Fig.7 Influence of groove pitch on symmetricity

3.6 Examples of texture pattern with micro grooves

Various kinds of textures were made tentatively using the developed grooving process. Some examples are shown in the following ;

ex.1) Fig. 8 shows a texture covered with numerous short grooves. The work material is Al alloy, so the burrs are piled up at the ends of all grooves.

ex.2) Fig. 9 shows an example of a texture covered with cross grooves, pitches of which are 50μm and 18μm respectively. The workpiece was diamond turned to an undulation surface with 2um amplitude prior to micro grooving.

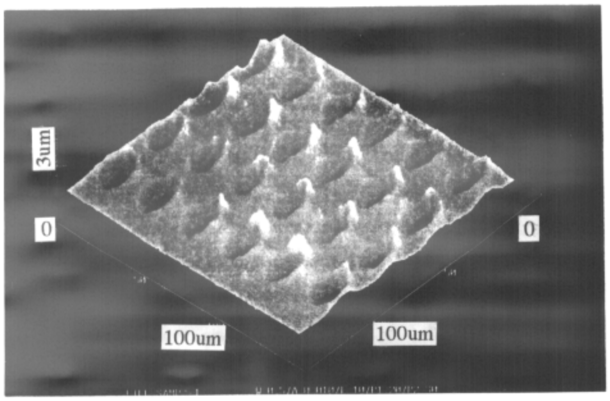


Fig.8 Texture with short grooves

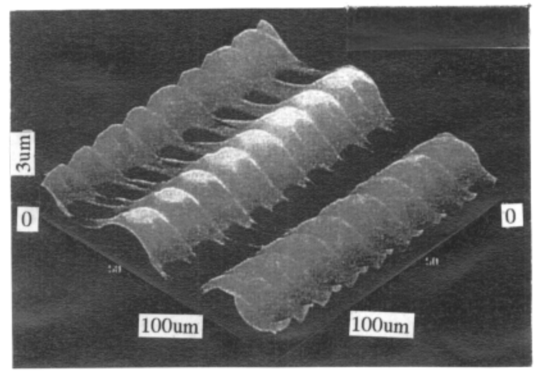


Fig.9 Texture with cross grooves

4. Conclusions

The groove geometry is discussed in sub-micron grooving processes for non-ferrous metals and brittle materials on a force controlled micro grooving machine with a burnishing tool made either of single crystal diamond or of sapphire.

1) For pure Al, the burr on the groove shoulders is inevitably large because of plastic flow from grooves, although the groove radius is copied relatively precise from the tool geometry.

2) The groove width on glass is 1.6 - 2.2 times larger and bottom radius of grooves is almost twice larger than those on pure Al, when grooves on glass are formed as deep as those on pure Al.

3) The burrs on groove shoulders force to decrease the groove depth at a closer pitch between adjacent grooves, because the actual volume to be removed in the following grooving pass increases on the burrs.

Acknowledgement

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References

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