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Study on mat-surface fabrication utilizing fixed-abrasive tool (Application to brittle material)

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Abstract Mat-surface is a surface with microscopic irregularities whose dimensions are close to the wavelengths of visible light (400-700 nanometers). The new method that utilizes fixed-abrasive tool to fabricate mat-surface without pre-masking and large scale back up facility, is proposed in our last report. The report clarifies that, mat-surface must be produced with fixed-abrasive process, If the relative motion between tool and work in grinding process can be realized as that in blasting.
In the reports, however, materials of workpieces which are ductile, such as steel and aluminium alloy, were selected. These materials are relatively easy to be indented. Therefore, in order to develop a new application of the proposed method, the method is applied to brittle material such as glass, it is investigated whether mat-surface can be obtained.

1. Introduction
In surface finishing process, surface without any reflex of light is often required. The surface is called “Mat surface” [1]. It is defined as a surface with microscopic irregularities whose dimensions are close to the wavelengths of visible light (400-700 nanometers).

In common industrial techniques, mat-surface is produced by using chemical etching, electrical or laser abrasion, loose abrasive lapping, or shot blasting. These conventional processes, however, demand pre-masking of workpiece and relatively large scale back up facility.

Therefore, in order to fabricate mat-surface without pre-masking and large scale back up facility, New method which is utilizing fixed-abrasive was proposed in our previous study [2-8].

Figure 1 shows the developed tool. It has two small diamond wheels. The wheels are fixed to the tool body thorough axles. Figure 2 illustrates how to use the tool and how the tool generates mat surface. In use of the developed tool, it is not pushed onto the work surface with high pressure like knurling but just touched on the surface. Although it seems like knurling process, our studies was clarified so far that pressure of the tool in the process is lighter than that in knurling [2].
Figure 1. Driven-type mat-surface-fabrication tool [2].

Figure 2. Illustration of Mat-surface generation with developed tool

(a) Before
(b) After

Figure 3. Surface observation of workpiece with microscope [2].

Figure 3 (a), (b) shows the photographs of the surface of aluminum workpiece before, after the work processed with mat-surface-fabrication tool, respectively. In figure 3 (a): the work surface before experiment, some regular marks which are generated by cutter of lath are observed. On the other hand, in Figure 3 (b): after processed with the developed tool, the cutter marks are disappeared, and mat-surface is generated. Also, the topography of the obtained mat-surface is measured then. Random dimples are clearly observed over processed surface. These results proved that the idea to produce mat-surface by applying fixed-abrasive is right, and that the developed tool feasible [2].

On the other hand, however, ductile materials such as steel and aluminum alloy, were used in the reports. These materials are relatively easy to be indented by means of plastic deformation. Meanwhile the developed tool has never been applied to brittle material yet. Thus, the purpose of this study is to investigate whether the developed tool can produce mat-surface on surface of brittle material such as glass.

2. Experiment

2.1. Difference in mat-surface fabrication about glass and metal

Soda lime glass is selected for material of workpiece in this experiment. Table 1 is comparison of mechanical property between soda lime glass and aluminium alloy #2017 which was used in our former reports. Aluminium alloy which has rich ductility is easy to be indented. After processing it with mat-surface-fabrication tool, many random dimples that the most range of the peak and the volley
is from 10 to 15 um, are produced on the surface, then the surface demonstrates mat. Meanwhile, hardness of glass is about five times harder than that of aluminium although Young’s modulus is almost the same, as shown in table 1. Surface of the grass is harder to be indented than that of aluminium. Cracks and Tips on glass surface are easier to be generated than that on aluminium surface because of the brittleness of glass. Therefore, the important key to obtain mat-surface on glass surface is to generate small tips without any generation of large cracks. This indicates that tool should be stroked on workpiece repeatedly as many as possible while relatively light weight is loading to tool.

Table 1. Mechanical properties of workpiece.

|                     | Soda lime glass | Aluminum alloy 2017 |
|---------------------|-----------------|---------------------|
| Young’s modulus (MPa) | 7.16×10^4     | 6.9×10^4            |
| Vickers hardness (N/mm²) | 5374          | 1029.4              |

2.2. Experimental set-up
Plate is selected as a workpiece in processing experiment of glass, although shaft is used in experiment of metal processing. Because plate shape is general on market and the surface accuracy and roughness is constant in quality. Because of the shape of workpiece, experiment employs numerical controlled milling machine: Yamazaki YZ-400MD.

Figure 4 shows the experimental set-ups. The tool of Figure 1 is installed on z-axis (vertical) of milling machine, and a glass plate is fixed with jig on vice. The tool is stroked x-axis direction (right and left in the figure) as feed. Also, the tool is free to move along z-axis direction, as shown in figure 5. Processing pressure can be changed by means of replacing weight on the tool from 6 to 12 N, as shown in the figure.

Experimental conditions are listed in Table 2. Three kinds of processing parameter, weight, feed rate, number of strokes are selected and varied to be investigated.

![Figure 4. Experimental set-up.](image-url)

![Figure 5. Illustration of how tool works.](image-url)
Table 2. Specifications of diamond wheel and experimental conditions.

| Tool specifications | Abrasive type | Diamond |
|---------------------|--------------|---------|
| Grain size          | (44um) #440  |         |
| Wheel diameter      | 20           |         |
| Work material       | Soda lime glass |       |
| Processing parameter| Weight [N]   | 6, 9, 12 |
|                     | Feed rate [m/min] | 1, 2, 3, 4, 6 |
|                     | Number of Strokes | 1, 5, 10, 15, 20, 50 |

3. Results and discussion

3.1. Surface observation

Figure 6. Obtained surface.

Figure 6 is the obtained surface after milling machine stroked a glass plate with the developed tool. To distinguish process or not process area, backside of glass plate is painted with black painting. Two lines that is shown as white line in the figure 6 can be observed. Magnified photo (a), (b) is the area of not-processed, processed area, respectively. In photo of (b), the surface seems to be covered with random dimples which is generated by means of not indentation but chipping.
Figure 7. Topography of obtained surface.

The topography of the obtained mat-surface is also measured with Zygo New View 7100, as shown in Figure 7. Random surface with no direction that is produced by chipping are clearly observed over the processed surface. This proves that the fixed abrasive tool can produce mat-surface not only ductile material such as metal, but also brittle material such as glass.

3.2 investigation into optimum number of strokes of tool move

Figure 8. Effect of frequency of strokes on surface roughness Ra in each feed rate.

![Graph showing effect of frequency of strokes on surface roughness Ra in each feed rate.](image)

Weight loaded on tool :12N

Figure 8 shows how frequency of strokes effects on surface roughness Ra of workpiece under the condition of weight:12N and different five feed-rates. In this figure, photographs of typical obtained surface in each stroke condition is also mapped. In the area from 1 to 5 strokes, chipping area is not generated so much on surface in figure 9 (a), thus Ra is small. In the area from 10 to 20 strokes,
chipping area is not still sufficiently yet to cover the glass surface evenly, and some lines such as scratches is also seen in photo (b). Thus, distribution of Ra is broad. This concludes that the difference of stability in each process is large. Meanwhile, in area of 50 strokes, photo (c) demonstrates mat-surface, distribution of Ra is narrow. The result shows effect of number of strokes is heavier than that of feed rate, at least over 20 strokes must be desired to obtain stable mat-surface.

3.3 investigation into optimum weight of on tool
Figure 9 shows that effect of weight on tool on surface roughness Ra after tool is stroked 20 times on a specimen. Ra is in proportion to weight in each feed rate condition, since contact pressure of grit must be in proportion to weight and larger chipping must be also generated. Therefore, it results that heavier weight on tool as possible is desirable within range not to brake glass.

![Figure 9. Effect of weight on tool on surface roughness Ra. Tool is stroked 20 times on a specimen](image)

4. Conclusion
In order to investigate whether the proposed mat-surface-fabrication tool can produce mat-surface on surface of brittle material, experiment that uses glass as workpiece is executed in this study. In fabrication experiment of mat-surface, successful result is obtained. The important keys to use the mat-surface-fabrication tool are obtained. The obtained results are following:

1. our developed mat-surface-fabrication method and tool are effective to fabricate mat-surface of not only ductile material but also brittle material, since mat-surface on glass is obtained
2. fabricated mat-surface on glass is consist of chipping. The mechanism is different from the mechanism of mat-surface fabrication on metal that is consist of indentation.
3. effect of frequency of strokes of tool is larger than that of feed rate. At least over 20 times strokes must be desired to obtain stable mat-surface.
4. it is desired that the weight loaded on tool is as heavy as possible within such the range that the tool cannot brake glass.

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