Fracture Strength Measurement of Miniature Internal Thread in Glass

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1. Outline

In tour laboratory, we have been studying the fabrication of miniature internal threads on glass slides. Glass is a typical brittle material, thus it is difficult to machine. Laser processing is one of the methods to process glass, and it is used for cutting and drilling through holes. However, it is difficult to fabricate holes other than simple straight holes, such as internal threads.

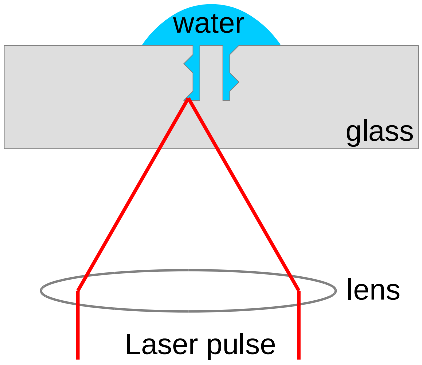

Figure 1: Sheme of fabricating miniature internal thread in glass using water-assisted laser processing.

Thus, we used a technique called "in-liquid ablation" or "liquid-assisted laser processing". In this technique, the solid material to be processed is brought into contact with a liquid, water in this case, and laser pulses are focused near the interface between the solid and liquid (Fig. 1). By this method, we were able to fabricate an S0.5 internal thread. [1]

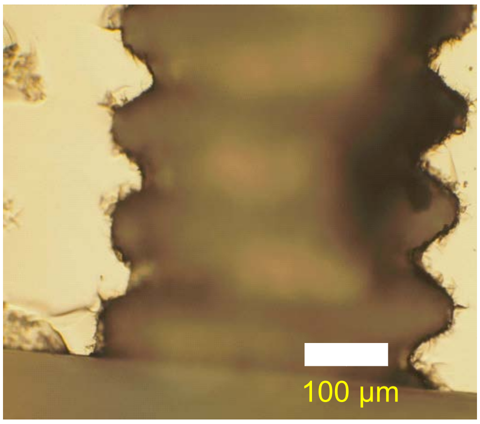

Figure 2: Cross section of an internal thread fabricated in a glass slide.

However, when the fabricated screw was broken and its cross section was examined, cracks were observed as shown in Fig. 2. We expected that the strength of the internal thread would be degraded because of the cracks. Therefore, in this study, we inserted a male screw and pulled on it to measure the strength of the fracture around the internal thread and the removal of the male screw. In addition, we attempted to improve the strength by heat treatment.

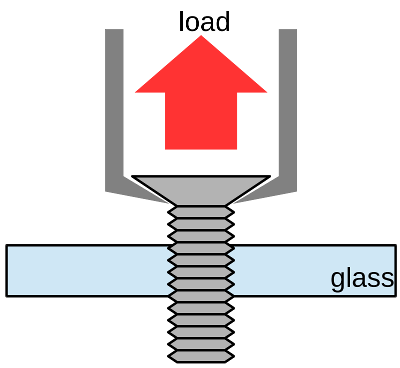

Figure 3: Scheme of measurement of fracture strength.

2. Results

We inserted a commercially available S0.5 male screw into the S0.5 internal thread on glass slide. Then, we attached a hook to the head of the male screw, and pulled the male screw to measure the strength at which the glass slide was fractured (Fig. 3). The hook was attached to the eDPU-50N load cell and pulled up using the EMX-1000 N test stand (Fig. 4). The tensile speed was set at 10 mm/min.

Example of the results is shown in Fig. 5. This figure shows the data for three samples (three glass slides) without heat treatment. Three data are overlaid. As seen, the load increased gradually with time and then decreased rapidly after the maximum. There were also cases where smaller local maxima were observed around the maximum value (red and green lines). We interpreted this data as follows: sometimes growth and fracture of small cracks due to the load did not result in the fracture of whole thread structure; fracture of whole thread structure occurred when larger load was applied. The average value of the maximum load in these three trials was about 17 N.

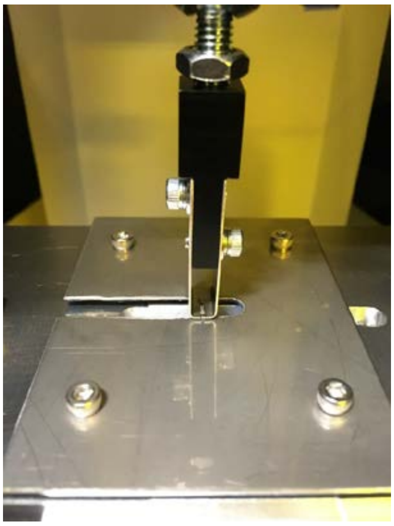

Figure 4: Photograph of fracture strength measurement device.

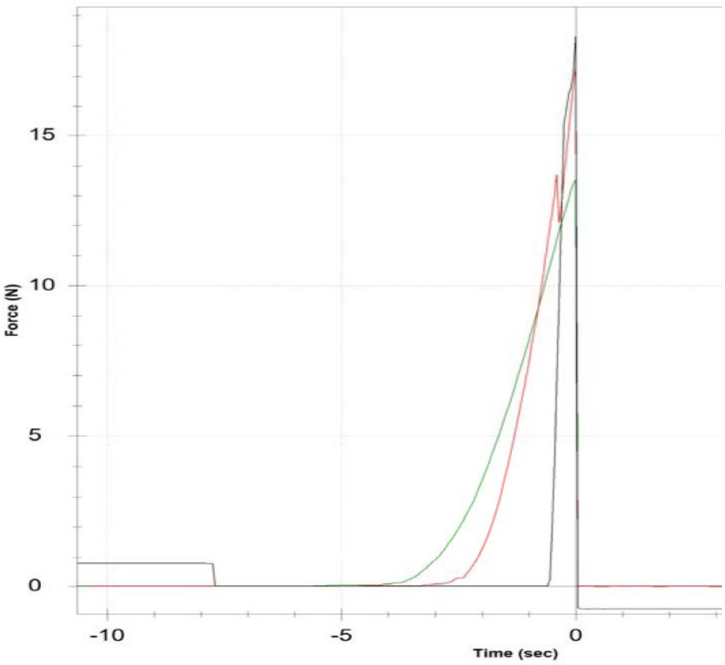

Figure 5: Example of results of fracture test (sample without heat treatment).

Samples after heat treatment were measured in the same way. Heat treatment was carried out in an electric furnace with an air atmosphere. The sample was kept at 570 °C or 620 °C for about 30 minutes. When the sample was treated at 630°C, the internal thread was deformed and no longer functioned as thread, thus 620°C seems to be the upper limit temperature. After heat treatment at 570 °C, the strength was almost the same as that without heat treatment. After heat treatment at 620 °C, the average value of the maximum load became about 27 N, indicating an improvement in strength. In addition, a decrease in cracks was observed in the cross section. However, a calculation with a simple model indicated that the value of 27 N corresponds to the maximum tensile stress in the glass about 1.3 MPa,[2] which is more than an order of magnitude smaller than the general strength of glass (50 to 100 MPa), so there is still room for improvement.

3. Progress with the Introduction of Force Test Stand

In this study, the EMX-1000N force test stand (IMADA Co., Ltd.) was used to apply the load for fracture. In the past, the load was applied using a primitive method of hanging a bucket of water (Fig. 6). By introducing the force test stand, the load can now be varied continuously and stably. In addition, the phenomenon of multi-step fracture, which was not expected before, was found for the first time by using this device.

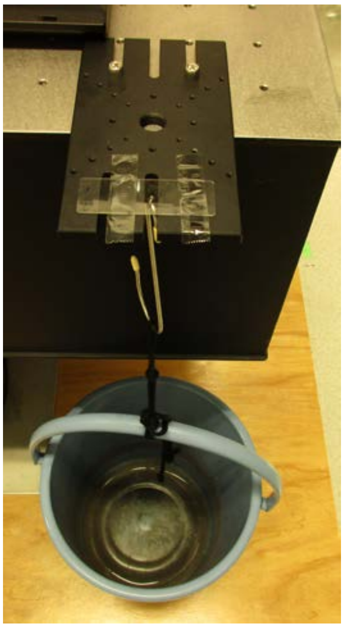

Figure 6: load application method before introducing force test stand.

4. Future development

We are currently working on the development of a new processing method to prevent cracks, rather than reducing cracks by heat treatment. This has not yet been realized, but when it is, we hope to measure the fracture strength.

5. Acknowledgements

We would like to appreciate IMADA Co., Ltd. for providing us with equipment such as Force Test Stand, Force Gauge, and Load Cell.

Many students contributed to this research are also acknowledged. The results shown in this report are mainly obtained by Mr. Ryosuke Yaekashiwa.

References

[1] H. Degawa, N. Urano, and S. Matsuo, “Laser Fabrication of Miniature Internal Thread in Glass Substrate,” *Micromachines*, vol. 8, no. 2, p. 48, Feb. 2017, doi: 10.3390/mi8020048.

[2] R. Murakami, H. Nakagawa, and S. Matsuo, “Water-Assisted Laser Drilling for Miniature Internal Thread in Glass and Evaluation of its Strength,” *J. Laser Micro Nanoeng.*, vol. 12, no. 3, pp. 203–206, 2017, doi: 10.2961/jlmn.2017.03.0005.