Separating glass sheets via mechanically, selectively induced median cracks

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Glass cutting has always been difficult, resulting from the complexity of crack generation and its propagation mechanisms. The authors successfully demonstrate the selective median crack propagation in glass via mechanical scribing followed by initial crack formation. The median crack was propagated only backward toward the scribing direction from the initial crack. The critical outcome is that unfavorable cracks on the cut glass quality, such as radial or lateral cracks, were not generated. The crack propagation speed was ~1 μm/s order, and the depth was ~10 μm in the case of the scribing load of <1 N. The authors confirmed that the scribed glass by this method was breakable only backward direction. The crack propagation mechanism will also be discussed in the presentation.

1. Introduction

Controlled crack formation and propagation in glass is a critical process that can be applied to glass separation, while it is difficult to control. For example, when an indenter, a harder material than glass, is indented into a glass surface, median, lateral, and radial cracks form simultaneously [1, 2]. During the indentation, the glass's elastic and plastic deformation, densification, and shear flow occur, while the stress distribution also changes during the subsequent unloading process [3, 4]. In the scribing process for glass cutting, these phenomena are further complicated by the effects not only on the indentation direction of the tool but also on the scribing direction. To separate glass, median crack formation along the cutting line is essential. Practically, median cracks are formed by rolling a scribing wheel on the glass surface and are then separated by applying external stress [5]. However, cracks other than the above-mentioned median cracks remain on the glass edge after separation, and these cracks weaken the strength of the separated glass, particularly when tensile stress is applied to the glass edge.

The authors discovered a phenomenon in which only median cracks are formed and extended in glass by scanning a diamond tip. In this report, the authors discuss the median crack propagation phenomenon and applicability on separation of glass sheets.

2. Experimental

Fig. 1 shows the schematic of the initial crack formation and median crack propagation method [6]. A 500 μm thick alkali-free glass substrate (AF45, SCHOTT AG) was used as the sample. First, the glass

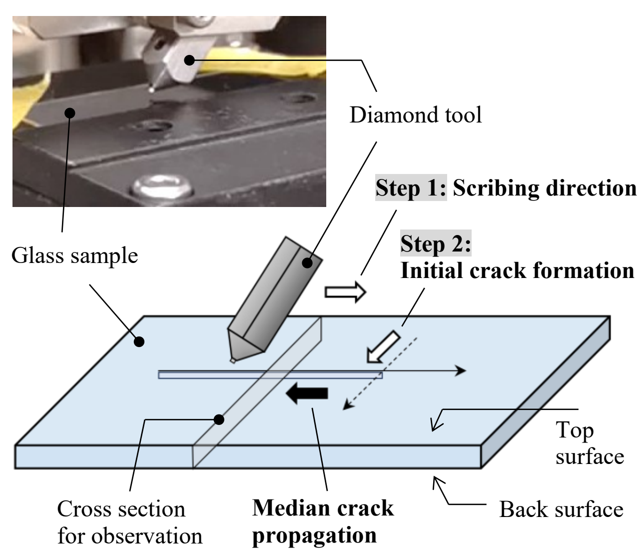

Fig. 1 Schematic of the initial crack creation and median crack propagation method.

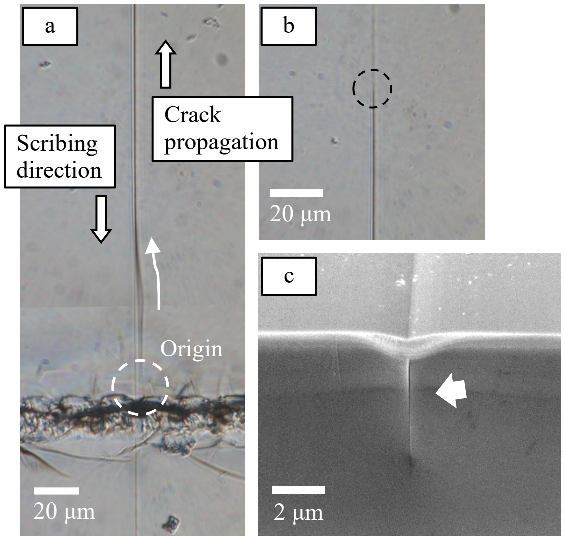

Fig. 2 Micrographs of propagated median cracks. Optical microscope images of a) median crack near crack origin, and b) median crack tip. c) SEM image of cross section.

was scribed using a diamond tool (SOLID-D, Mitsuboshi Diamond Industry Co., Ltd.). The diamond tool was connected to a linear servo guide via a pneumatic cylinder, and the scribing load was controlled in the range of 0.26-0.76 N in this experiment. Then, an initial crack was formed for median crack propagation. Scribing was performed using a scribing wheel (Micro-Penett, Mitsuboshi Diamond Industry Co., Ltd.) in the direction shown in Fig. 1 so that the first and second scribing lines are crossed each other. The processed glass was observed under an optical microscope (OPTIPHOT, Nikon Corp.) and a scanning electron microscope (JSM-IT200, JEOL Ltd.). The glass was further scribed from the back surface and broken to expose the cross-sectional surface in order to observe median cracks from the cross-sectional direction. The propagation speed of the median crack was measured by monitoring the position of the median crack tip with a camera.

3. Results and discussions

3.1 Median crack propagation and breakability of glass

Fig. 2 shows transmitted light images from an optical microscope near the initial crack (Fig. 2a) and at the tip of the median crack (Fig. 2b), and an electron microscope image of the median crack cross-section (Fig. 2c) when the scribing load was 0.3 N. The starting point of the median crack propagation is considered to be the radial crack caused by scribing for the initial crack formation. In the present experiment, the cracks initiated at a position slightly to the right of the centerline of the scribing area. Then, the crack propagated toward the centerline of the cut, in the opposite direction of the direction of scribing with the diamond tool. As shown in Fig. 2b, the tip of the median crack could be observed, which can be used to measure the propagation velocity. Furthermore, as shown by the arrows in Fig. 2c, it was confirmed that only median cracks were formed near the glass surface. On the glass surface, deformation with a depth of ~300 nm

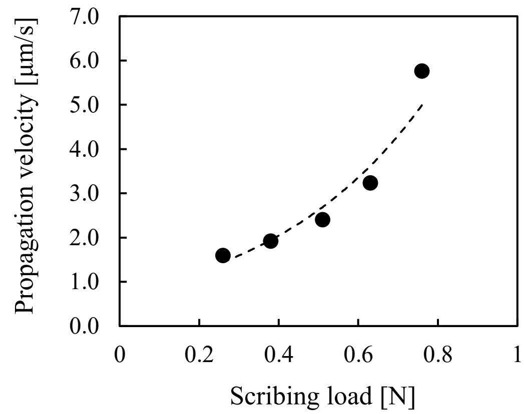

Fig. 3 Relationship between median crack propagation velocity and scribing load.

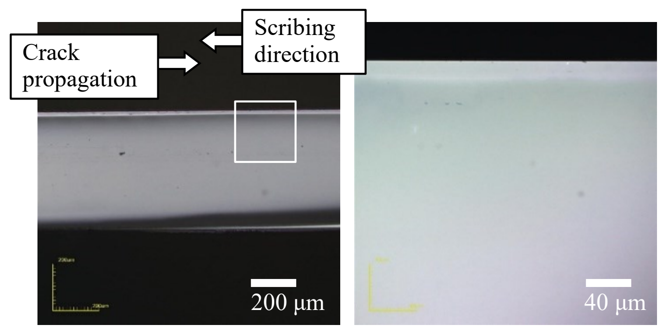

Fig. 4 Micrographs of the separated glass edge. The right image is a magnified view of glass edge near top surface (squared area in the left image).

was observed. There is a crack-free region between the glass surface and the top of the median crack (about 1–2 μm in depth), which is considered to be a plastic deformation region reported in indentation studies. The depth of the median cracks is ~10 μm considering the slanted angle for observation, although there is a possibility that the cracks may propagate in the depth direction when the glass is sectioned to expose the median crack. Fig. 3 shows the relationship between the scribing load using the diamond tool and the median crack propagation velocity. The measured crack propagation velocity was on the order of 1 μm/s and increased exponentially with the scribing load.

We also confirmed that the scribed glass was only breakable in the median crack propagation direction. Fig. 4 shows the micrographs of the separated glass edge. No defects were seen on the glass edge.

3.2 Discussion on crack propagation phenomenon

This crack propagation phenomenon is similar to the stress corrosion phenomenon driven by ambient humidity and the small stress reported by Wiederhorn [7]. Wiederhorn explained that the crack propagation velocity in stress corrosion phenomena increases exponentially with load applied in the crack opening direction. In another study, Marshall et al. [2] concluded that the tensile load in the crack opening direction after indentation is proportional to the load in the indentation direction. In this study, as shown in Fig. 5, if the same concept is applied, the crack propagation velocity has an exponential relationship to the load applied in the direction of crack opening. Based

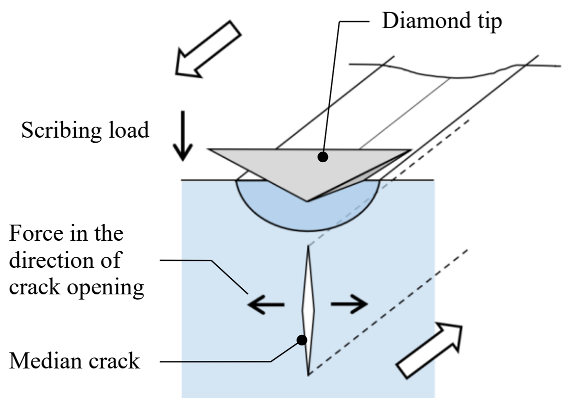

Fig. 5 Relationship between scribe load and tensile stress.

on these relationships, the crack growth in this study is considered to be similar to the stress corrosion phenomenon. In fact, when the humidity of the glass sample was increased by blowing on it, it was confirmed that the propagation velocity increased.

4. Conclusions

We investigated the phenomenon of median crack propagation in glass using a diamond tip. By scribing glass with a diamond tip and introducing initial cracks, median cracks could be extended near the surface. The median crack (~10 μm depth) was propagated in the opposite direction of the scribing, and the propagation velocity was on the order of 1 μm/s. The propagation velocity of the median cracks increased exponentially with load, and it was concluded that this phenomenon is similar to the stress corrosion phenomena reported in the past. The glass sample with the median crack was only breakable in the direction of crack propagation, and no defects can be seen in the sample.

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