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Selective Stress Relaxation of Chemically Strengthened Glass for Mechanical Cutting by Reverse Ion-exchange using Electrochemical Discharge (ECD) Processing

Jonghwan Kim[1], Seong-Gu Kang[1] and Jihong Hwang[1,#]
1 Department of Mechanical Information Engineering, Seoul National University of Science and Technology, 232 Gongreung-ro, Nowong-gu, Seoul, Korea, 139-743
Corresponding Author / Email: hwangjh@seoultech.ac.kr, TEL: +81-2-970-6396

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Glass can be chemically strengthened by replacing small Na+ ions present on the surface of unstrengthened glass with large K+ ions. Through this process, relatively high compressive stress is generated on the surface while tensile stress is generated inside the glass for counterbalance. Consequently, it is difficult to cut the glass mechanically using the conventional methods such as scribing or grinding once it is strengthened. This limits its wider use for various applications other than display covers. To overcome this difficulty, a novel method for selectively exchanging the K+ ions present on the surface with Na+ ions was developed in this study. This was enabled by immersing the strengthened glass in the electrolyte of sodium hydroxide (NaOH) aqueous solution right below an electrode and generating heat locally by electrochemical-discharge (ECD) sparking. This provides the environment required for the reverse ion-exchange. The ECD system employed a blade-shaped tool electrode rather than a pencil-shaped electrode to reduce the processing time, and equipped with a diamond grinding wheel for mechanically cutting the glass after ECD processing. The preliminary work showed that it is possible to reversely exchange the ions and then cut the glass successfully by grinding even though the treatment is conducted on only one side of the glass without turning it over. For future work, it is necessary to optimize the process conditions for the reverse ion-exchange, which would allow for efficiently cutting chemically strengthened glass just before its use for various applications.

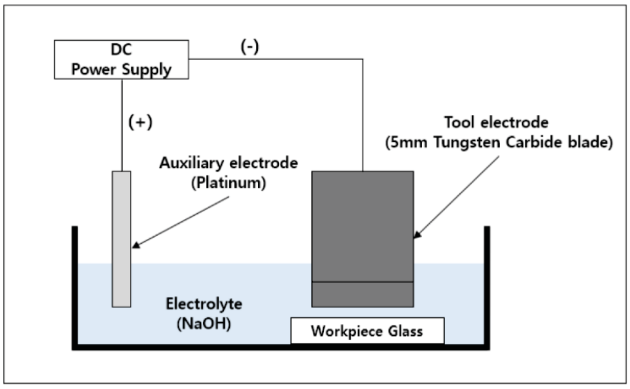
1. Introduction

Chemically strengthened glass is difficult to cut with the conventional mechanical method due to the presence of the compressive stress generated on the surface of glass by an ion exchange process. This results in inefficiency in mass production of glass displays because glass should be cut before strengthening and then strengthened individually. In this regard, this study probed the possibility of selective stress relaxation of chemically strengthened glass using electro-chemical discharge (ECD) processing with a purpose of cutting it by the conventional mechanical method. In this case, the ECD processing was applied because the spark generated and the electrolyte used in the ECD processing meet the requirements for selective reverse ion exchange - localized heat energy and alkali content salt. The results obtained through preliminary experiments showed that ion exchange could be made reversely and selectively on the surface of chemically strengthened glass and compressive stress could be relaxed. This enabled the cutting to be made using the conventional mechanical method.

2. Experiments

2.1 ECD System

Fig. 1 shows a schematic diagram of the ECD system used for this study. To construct this system, a blade-shaped tool electrode



made of tungsten carbide (cathode) was placed right above glass workpiece. The glass workpiece was immerged in a bath filled with sodium hydroxide aqueous solution (NaOH 32wt%) electrolyte along with an auxiliary electrode made of platinum (anode). The bath was mounted on a three-axis stage with a travel range of ±50mm of the x and y axes (horizontal directions) and ±15mm of z-axis (vertical direction). The glass material was Corning 2317 (Gorilla Glass 3, Corning, NY), and the workpiece size was 10mm×10mm×0.5mm (thickness). It has a layer on its surface with the compressive residual stress amounting to 700MPa, whose depth is around 40μm. A DC power (68V, 600-800mA) was supplied to the electrodes to generate sparks required for the reverse ion-exchange between the blade-shaped tool electrode and the glass workpiece. A grinding wheel was attached to the ECD system along with the blade-shaped tool electrode as shown in Fig. 2 to cut off the glass workpiece after the reverse ion-exchange by the ECD processing was completed.

Fig. 1 ECD system

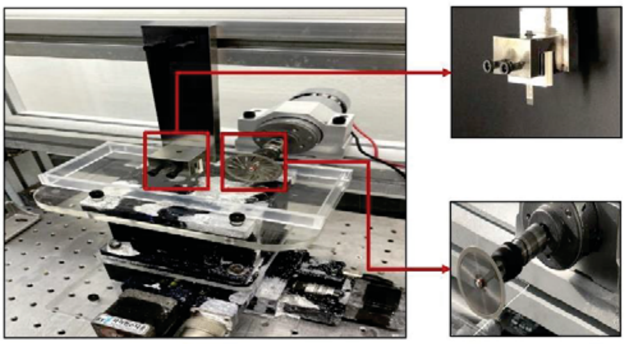


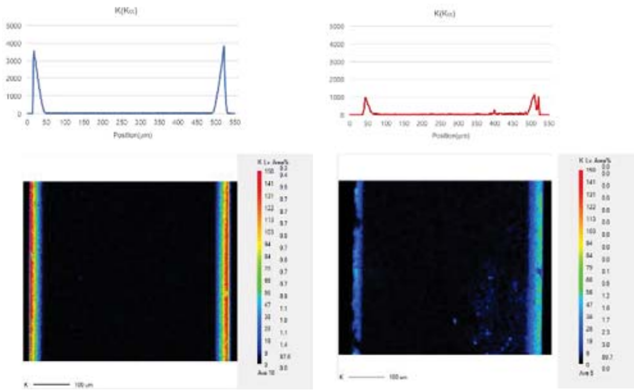
Fig. 2 Grinding wheel attached to the ECD system along with the blade tool electrode

2.2 Element Analysis

To obtain the evidence of the reverse ion-exchange by the ECD processing, a field emission electron probe microanalyzer (FE-EPMA) was employed because it allows for the quantitative and qualitative evaluation of an element at a certain point, along a line or over an area by scanning for known composition. The graphs in Fig. 3 show the analysis results of cross-sectional line and area made for the glasses before and after ECD processing, respectively. The cross-section for the ECD processed glass could be obtained by cutting it using the grinding wheel attached to the ECD system along the line placed right below the blade-shape tool electrode during the process. In these graphs, it is clear that the content of K+ ion is the highest at the surface and decreases to 0 at the depth around 50μm for the glass on which the ECD processing was made. This is contrasted to the result made for the ECD processed glass, in which the content of K+ ion drops significantly on the surface and remains almost negligible inside the glass. It is believed that this change would have allowed for the ECD processed glass to be cut successfully by mechanical grinding.

3. Conclusions

This preliminary work showed that it is possible to selectively exchange the K+ ions present on the surface of chemically strengthened glass with Na+ ions included in the sodium hydroxide aqueous solution electrolyte by the ECD processing. This enabled mechanical cutting of chemically strengthened glass to be made successfully. For future work, it is necessary to optimize the process conditions for the reverse ion-exchange, which would allow for efficiently cutting chemically strengthened glass just before the use for various applications.



(a) (b)

Fig. 3 Element analysis results of cross-sectional line and area made for the glasses (a) before and (b) after ECD processing was performed respectively

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