Crack initiation tendency of aluminoborosilicate glasses suitable for chemical strengthening

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Relationship between crack initiation tendency of glass before chemical strengthening and fracture strength of the glass after chemical strengthening was investigated. Aluminoborosilicate (ALBS) glass, which has the lowest crack formation probability before chemical strengthening, shows more stable fracture behavior after chemical strengthening. In order to understand relation between crack initiation tendency before strengthening and glass structure, Raman spectra of various silicate glasses were measured. It is found that glasses exhibiting higher crack resistance have high concentration of Q^3 and Q^4 units.
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Introduction

Due to safety concerns, glass with reliable strength is still one of the fascinating materials for industries. One approach to obtain such mechanically reliable glass is to prevent crack propagation in glass under a stress. Chemical strengthening is one of the most common practical methods to prevent crack propagation in glass. Although the chemical strengthening process is an effective way to overcome brittleness of glass, all industrial glasses face potential damage during processing and handling before strengthening. Thus, glasses with higher crack resistance (lower crack formation probability) are highly desirable. We reported that ALBS (aluminoborosilicate) glass is one of the better compositions for chemical strengthening, because ALBS before strengthening shows higher crack resistance and because ALBS after strengthening shows a lower CT (central tension) and a narrower strength distribution[1)]. In this study, some mechanical properties of ALBS before and after chemical strengthening are evaluated and relationship between less-brittleness and fracture behavior after strengthening is discussed. In addition, structural characteristics of less-brittle glass are investigated using Raman spectroscopy.

Experimental

Crack formation probability before strengthening was determined at each indentation load using a Vickers hardness tester. Four kinds of glass compositions: soda-lime silicate (SLS), aluminosilicate (ALS-1, ALS-2), and ALBS glasses were used for the evaluation. After strengthening, the compressive stress on the surface (CS), the depth of the compressive stress layer (DOL), and CT of these glasses were measured using a surface stress meter with results shown in Table I. Some fracture tests (Four-point bending, ring on ring etc.) were performed for these glasses after strengthening. In addition, Raman spectra of various silicate glasses including ALBS were measured in order to discuss relation between crack resistance before strengthening and glass structure. The glass compositions were

Table I. Compressive layer properties of glasses after ion-exchanging (410 ˚C, 8 h)

Name	CS (MPa)	DOL (µm)	CT (MPa)
ALBS	765	41	51
ALS-1a	840	39	53
ALS-1b[a]	844	55	79
ALS-2	775	50	65
SLS	609	12	11

a: The ion exchange condition is 410 ˚C, 4 h.

prepared by replacing of SiO_2 in the base glass composition (ALBS) with other oxides (Al_2O_3, B_2O_3, Na_2O, K_2O, or MgO). They were named as “Series A”, “Series B”, “Series N”, “Series K”, and “Series M”, respectively.

Results and Discussion

As shown in Fig. 1, ALBS shows higher crack resistance among these glasses. In Table I, CS and DOL of ALBS are less than those of ALS glasses. However, ALBS after strengthening shows a narrower strength distribution as shown in Fig. 2. It is considered that such a narrower strength distribution results from damage tolerance of ALBS before strengthening. For practical use, strength stability and minimum strength are quite important, rather than maximum or averaged strength, because glass failure is a statistical property. Therefore, less-brittle behavior before strengthening is an important factor to design the glass suitable for chemical strengthening.

In order to get an insight into a relation between crack resistance before strengthening and glass structure, Raman spectra of various silicate glasses were measured. After deconvolution of the Raman peak assigned to Si-O stretching vibration, the concentration of structural units of Si, or Q^n, was estimated.

As shown in Fig. 3., crack formation probability shows a sharp decrease at the ratio $(Q^3+Q^4)/(Q^2+Q^3+Q^4)$ of ca. 0.7. Limbach *et al.*[2] suggest that the connectivity of network forming ions is one factor to control crack initiation behavior. The relation in Fig. 3 also supports their suggestion. Although the network may be also affected by the coordination number of Al or B in glass, it can be concluded that glasses exhibiting higher crack resistance have higher concentration of Q^3 and Q^4 units.

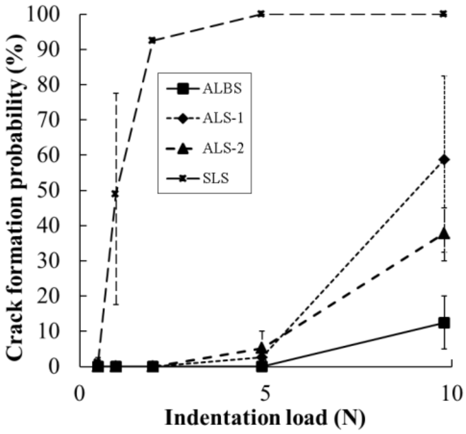

Fig. 1. Crack formation probability of each glass in air before chemical strengthening.

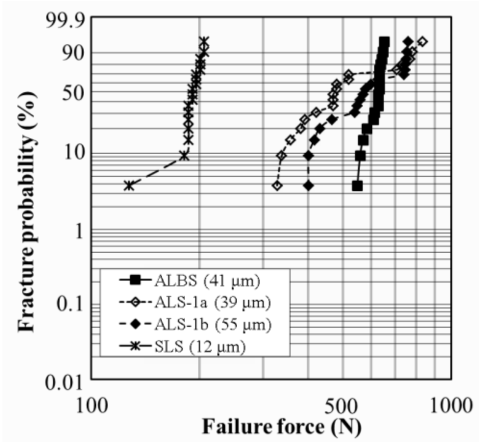

Fig. 2. Four-point bending strength after ion-exchanging for pre-damaged glasses with 9.8 N Vickers indentation; DOLs are shown in parentheses.

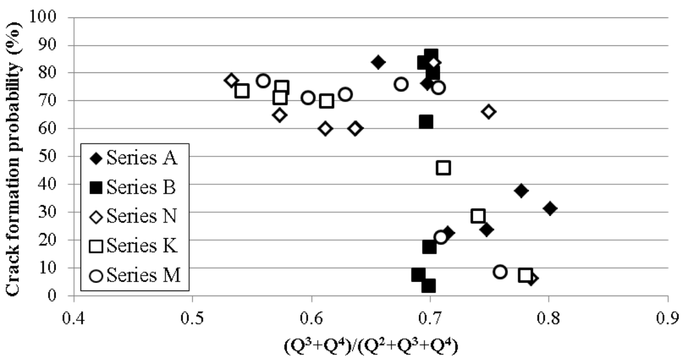

Fig. 3. Relationship between crack formation probability at 1.96 N in water and $(Q^3+Q^4)/(Q^2+Q^3+Q^4)$.

References:

1) H. Morozumi *et al.*, *Int. J. Appl. Glass Sci.*, **6**, 64-71, (2015).

2) R. Limbach *et al.*, *J. Non-Cryst. Solids*, **417-418**, 15-27 (2015).