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Subcritical crack growth and lifetime prediction of chemically strengthened aluminosilicate glass

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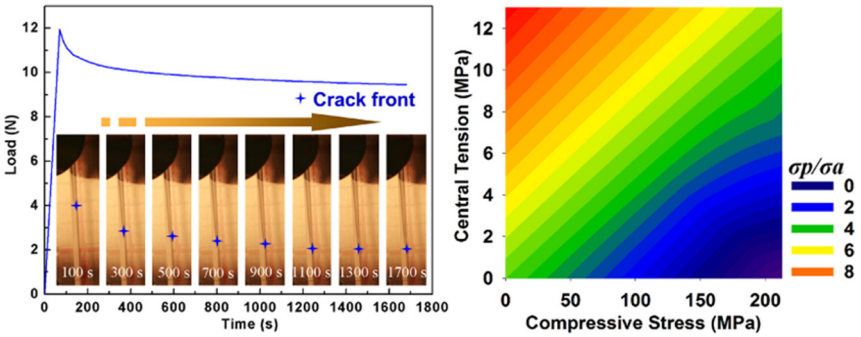
HIGHLIGHTS

- Subcritical crack growth of chemically strengthened glass was firstly investigated.
- An experimental evaluation procedure was developed based on the double torsion method.
- High CS and low CT can improve crack growth index and decrease susceptibility to fatigue.
- High CS and low CT for chemically strengthened glass have smaller proof test ratio.

GRAPHICAL ABSTRACT



The subcritical crack growth of chemically strengthened aluminosilicate glass in air and in water was firstly investigated using the double torsion (DT) technique. An experimental evaluation procedure has been developed based on the double torsion method. High CS and low CT for chemically strengthened glass show a smaller proof-test ratio, thereby indicating better survival characteristics.

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ABSTRACT

The effect of residual stress on subcritical crack growth in chemically strengthened aluminosilicate glass in air and water was firstly investigated using the double torsion (DT) technique. An experimental evaluation procedure was developed based on the DT method. The research demonstrates that high compressive stress (CS) and low central tension (CT) in chemically strengthened glass are beneficial in improving crack growth index and decreasing susceptibility to fatigue. Chemically strengthened glass with high CS and low CT exhibits a smaller proof-test ratio, which indicates better survival characteristics. The results are useful in designing the strength and optimizing the strengthening process by ion exchange to obtain a more robust glass with long service lifetime.

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1. Introduction

The evolution of glass defects depends not only on stress but also on physical and chemical interactions with environment. In fact, glass is subject to subcritical crack growth from mechanical defects, with the environment acting as a stress corrosion agent that triggers the evolution of mechanical defects until unstable fracture occurs even under constant external stresses that are well below the theoretical strength limit predicted by Griffith. This phenomenon is also known as static fatigue and has attracted considerable interest [1,2] .

Like most other corrosion, glass stress-corrosion is governed by a set of physical and chemical phenomena occurring at micro- and nanoscopic scale with the important parameters being the chemical composition of glass, presence of water or water vapor in the atmosphere [3,4], environment temperature, and acidity [5]. The most credited theory states that the phenomena occur from the rupture of silicon-oxygen bonds in the glass structure because of the presence of environmental water molecules in chemical reactions. Kinetic scales of these reactions involve absolute temperature, and the activation energy is provided by external stress.

Currently, several techniques have been used to observe the dynamics of subcritical crack growth during stress corrosion. These techniques include double cantilever beam technique [4], double cleavage-drilled compression method [6–8], and the double torsion (DT) method [9,10]. Among these methods, DT is the most widely used and reliable method for measuring subcritical crack growth curves (V–K_I) and failure prediction of glass, because the DT method has considerable stability of the four-point bending loading configuration. In addition, DT does not require difficult monitoring of crack length during testing.

Many studies have been conducted on crack evolution behavior of silicate glass [11–18]. However, to our knowledge, no data on subcritical crack growth of chemically strengthened glass exist [19,20]. The exchange of small alkali ions in silicate glass by larger ions from a molten salt bath below T_g produces a compressive stress (CS) in the order of 100–800 MPa on the glass surface, which results in glass strengthening. Compared with thermal tempering process, chemical strengthening is advantageous because the developed surface compression is usually much higher. Thus, no measurable geometric distortion generally occurs, and the method can be readily applied to relatively thin and complex geometry products, such as tubes [21–24]. The stress distribution around Griffith crack tips varies after chemical strengthening because of high CS on the glass surface, which may result in different subcritical crack growth behaviors. However, the effect of CS on subcritical crack growth in chemically strengthened glass remains unclear to date.

In this paper, the topic addressed is how CS affects subcritical crack growth with a focus on chemically strengthened aluminosilicate glass. We also aim to gain new insights into the mechanism of stress corrosion and static fatigue of chemically strengthened glass. Results illustrate that higher CS and lower central tension (CT) in chemically strengthened glass causes lower susceptibility to fatigue. Glasses with high CS and low CT have smaller proof-test ratios, thereby indicating better survival characteristics.

Table 1
Compressive stress, depth of stress layer, and central tension of chemically strengthened aluminosilicate glass before and after annealing.

Ion exchange temperature (°C)	Ion exchange time (h)	Before annealing			After annealing		
		CS (MPa)	DOL (μm)	CT (MPa)	CS (MPa)	DOL (μm)	CT (MPa)
420	1	704	21	9	124	67	5
420	3	667	41	16	175	80	9
420	12	540	92	31	213	108	13

2. Experimental procedure

The glass used in this work was 1.8 mm-thick aluminosilicate glass (Corning Gorilla 2318). According to the previous research [9], a variety of DT specimen geometries can be used. In this research, specimen and load geometry for precracking and load relaxation are illustrated in Fig. 1(b). The specimen was a thin plate with dimensions of 90 mm × 30 mm × 1.8 mm (L × W × d). All specimens contained a laser-machined notch of 10 mm in length and 0.15 mm in width. A single side groove with a width (W_g) of 2.0 mm and web thickness (d_n) of 0.9 mm was machined using a diamond wheel. Single side groove specimens were placed on the test fixture with the side groove on the compressive surface of the specimen. The specimen is best loaded and

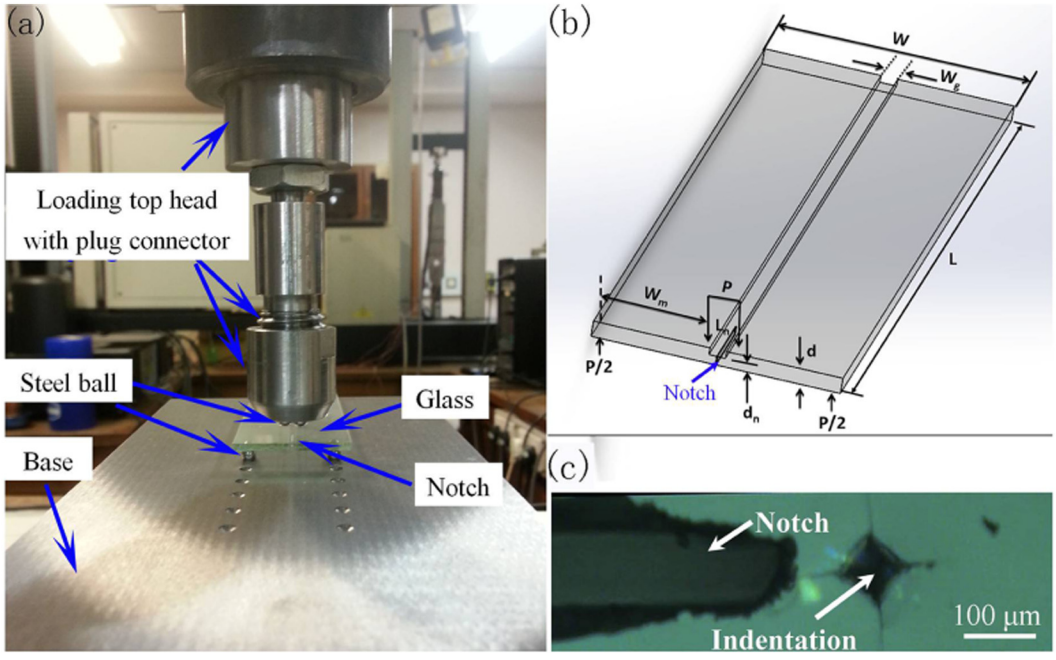

Fig. 1. (a) Experimental configuration for glass precracking and load relaxation. (b) Specimen and load geometry for precracking and load relaxation. (c) Typical image of indentation at the tip of the notch.