Strengthening Glass by Polymeric Coatings

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Glass is an intrinsically strong material. However, due to the presence of defects, practical strength of glass articles is significantly lower than the theoretic strength (e.g., by about two orders of magnitude) [1]. An effective method of strengthening glass is highly desirable for making stronger, safer, lighter, or cheaper glass products.

Strengthening of glass is traditionally achieved using techniques like thermal tempering and ion exchange. Both approaches create compressive stress on the glass surface for strengthening. However, the tendency to create surface distortion in the tempering process, the very slow rates of ion exchange, and the significant energy costs involved in both approaches require new ways of strengthening glass. Applying a coating to glass surfaces or edges has become more attractive for glass strengthening due to the fact that it is easier to implement and has the capability to render other properties to the coated surface.

There are two types of coating technologies to strengthen glass. One is surface-strengthening, where a coating is applied to the surface of glass articles to fill and cure surface flaws created during production process. Examples include containers, light bulbs, etc. The other is edge-strengthening, where a coating is applied to glass edges to fill and cure flaws created during

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scribing or cutting of glass. Examples include window glass, displays, hard-drive disks, lenses, mirrors, etc. Whereas the surface-strengthening has the advantage of covering every flaw on a glass surface, edge-strengthening has the advantage of saving raw materials by only coating the regions where the concentration of flaws is extremely high.

Several types of coating systems have been reported in literature, including sol-gel coatings [2-3], epoxy coatings [4], and acrylate coatings [5]. They all show significant increase of glass strength. It is intriguing that even though the moduli of these coatings vary by as much as two orders of magnitude, their strengthening effects are similar. This phenomenon has driven researchers to examine strengthening mechanisms in detail.

Different theories have been hypothesized in glass strengthening. Fabes & Uhlmann proposed that filling-in and partial healing of surface flaws are the major mechanisms of strengthening glass with sol-gel coatings [2]. Hand *et al.* [6] proposed that closure stress arising from the thermal expansion mismatch of the coating within cracks accounts for the observed strengthening.

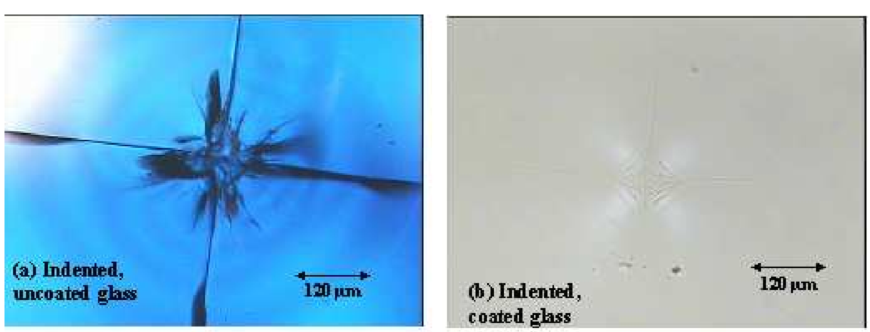

Figure 1. Optical microscope images of indented glass before and after coating.

In this work, the effects of using polymeric coatings on edge-strengthening and surface strengthening were examined. The coatings provided significant increase of the glass strength at the low end and at the mean value of strength distribution. The coatings were found to cover the flaw zone and partially fill in the cracks (Figure 1). Different surface treatments led to different levels of strengthening, indicating the importance of coating adhesion. The coating's thermal and mechanical properties affected the extent of strengthening. A coating formulation with a higher glass transition temperature tended to provide a better strengthening effect, indicating the importance of closure stress within cracks generated during film curing process (Figure 2). The results indicate that strengthening is realized by three factors, i.e. flaw filling, good adhesion, and closure stress.

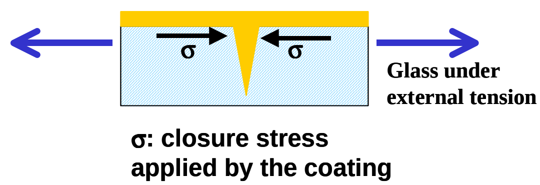

Figure 2. Closure stress generated by the coating to strengthen glass under external tension.

To develop strengthening coatings for commercial applications, wet adhesion of the coatings is critical for success due to requirements on environmental weathering in humid conditions or cleaning procedures. This has been a challenging task because of poor adhesion of most polymers on glass. Blister formation, delamination, and cracking have occurred in long-term immersion test. It was found out that the wet adhesion of a coating generally dropped as the coating became harder or the glass transition temperature of the coatings increased. This trend is opposite to the trend of how glass transition temperature affects strengthening.

Overall, it remains challenging to develop a coating that can both strengthen glass and exhibit outstanding wet adhesion.

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