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Wiederhorn S M. Influence of water vapor on crack propagation in soda-lime glass.  
*J. Amer. Ceram. Soc.* 50:407-14, 1967.  
(National Bureau of Standards, Washington, DC)

Direct measurements of subcritical crack growth in soda-lime glass revealed a complicated relationship between the crack velocity, applied stress, and water vapor concentration in the environment. Experimental studies are discussed with reference to theories of delayed failure. [The *SC*® indicates that this paper has been cited in over 190 publications.]

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My studies on the effect of environment on glass fracture started with the well-known article by Jack Gilman,<sup>1</sup> who suggested that surface energies of solids could be determined by fracture experiments. By fracturing single crystals in a controlled manner, Gilman demonstrated that the surface energy could in fact be determined quantitatively by this technique. Being newly employed at the National Bureau of Standards (NBS), I was searching for an experiment on the mechanical behavior of solids that would fit into a program on ceramic science recently started at NBS. This method of characterizing fracture behavior of single crystals appealed to me, as it was new and dealt with a fundamental property of materials. Therefore, I designed equipment to duplicate Gilman's experimental technique. The equipment was built but never used, for while awaiting its construction, I had the idea that launched me into my investigations on the fracture of glass.

I realized that glass fracture could be studied if a method were devised to guide a crack along the midplane of a glass plate, so that double cantilever beam specimens of the type

used by Gilman could be made. If a scratch along the midplane of the slide would guide the crack, then the experiment was feasible. In my first experiment I scratched the midplane of a microscope slide with a diamond scribe and found to my delight that the scratch could be used both to introduce a crack and to guide it once introduced. Initial experiments on precracked microscope slides indicated that, at about one-half the load for immediate failure, cracks in glass moved in a slow and controllable manner. This observation was in apparent contradiction to the Griffith criterion for fracture, which predicted a critical stress for spontaneous failure.

After reviewing the literature on the strength and fracture of glass, I discovered the writings of R.J. Charles and W.B. Hillig<sup>2,3</sup> and realized that glass fracture was a kinetic process, wherein the reaction rate was controlled by the force applied to the glass and the amount of water vapor in the atmosphere. Crack growth could be described by reaction rate theory. Quantification of these ideas with experimental data on the growth of cracks in glass took about two years. My first two papers on this subject were published in the proceedings of two materials-science conferences.<sup>4,5</sup> The third and by far the more complete paper is the subject of this commentary.

The value of this study is based on its role in demonstrating the power of fracture-mechanics techniques for understanding crack growth in ceramic materials. The paper provided evidence for crack growth as an explanation of delayed failure in glass and established a natural bridge between earlier work on the strength of glass and subsequent work relating lifetime to crack growth behavior in ceramic materials. Since that time, a number of articles have been published on the subject of crack growth in glass<sup>6</sup> and the effects of environment on such growth. Many of these were either directly or indirectly influenced by this *Classic* paper.

1. Gilman J J. Direct measurements of surface energies of crystals. *J. Appl. Phys.* 31:2208-18, 1960. (Cited 285 times.)
2. Charles R J. A review of glass strength. (Burke J E, ed.) *Progress in ceramic science*. New York: Pergamon, 1961. Vol. 1. p. 1-38. (Cited 45 times.)
3. Hillig W B. Sources of weakness and the ultimate strength of brittle amorphous solids. (Mackenzie J D, ed.) *Modern aspects of the vitreous state*. Washington, DC: Butterworth, 1962. Vol. 2. p. 152-94. (Cited 25 times.)
4. Wiederhorn S M. Fracture surface energy of soda-lime glass. (Kriegel W W & Palmour H, eds.) *Materials science research*. New York: Plenum, 1966. Vol. 3. p. 503-28. (Cited 30 times.)
5. ———. Effects of environment on the fracture of glass. (Westwood A R C & Stoloff N S, eds.) *Environment-sensitive mechanical behavior of materials*. New York: Gordon and Breach, 1966. p. 293-317. (Cited 15 times.)
6. Freiman S W. Environmentally enhanced crack growth in glasses. (Kurkjian C R, ed.) *Strength of inorganic glass*. New York: Plenum, 1985. p. 197-217.

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