Overcoming Slow Crack Growth in Window Materials

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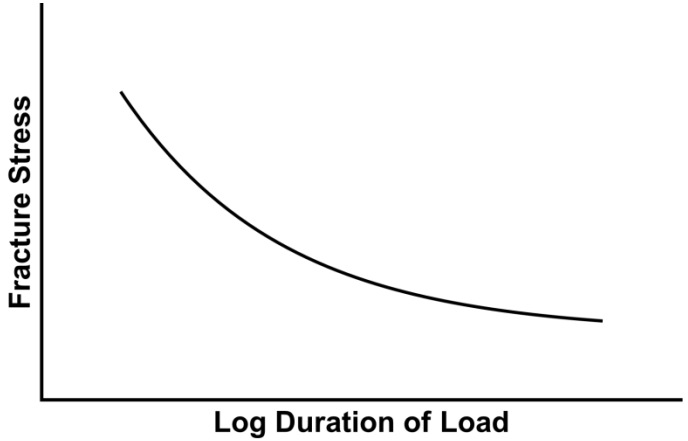
Delayed Failure

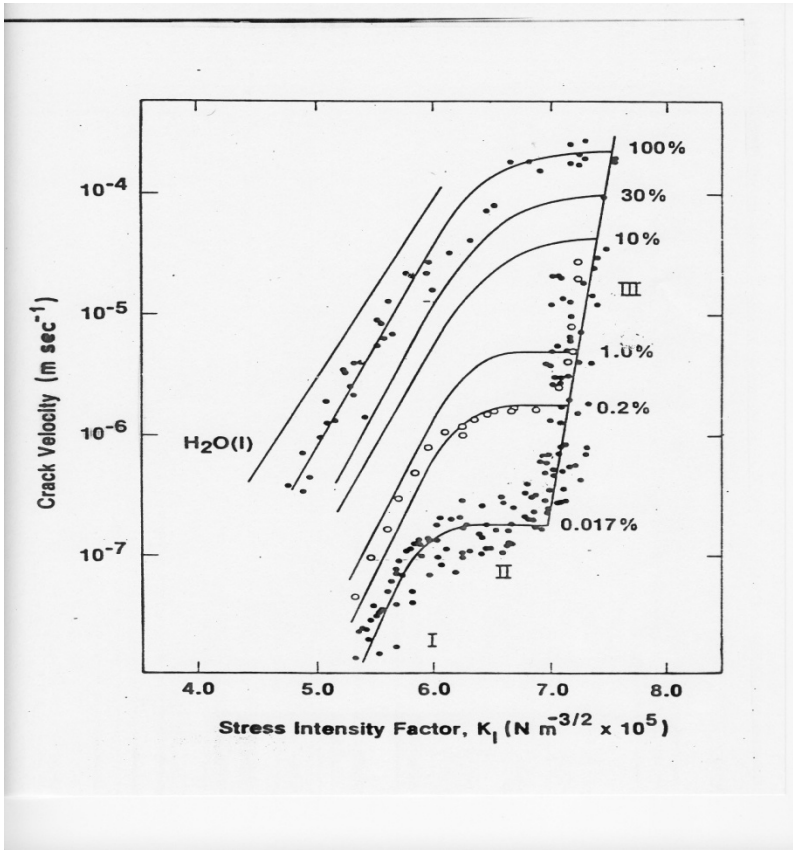


- **Perhaps even more than strength, slow crack growth leading to ultimate failure is a limiting factor in the use of glass as a structural material.**

First Direct Measurement of Crack Growth

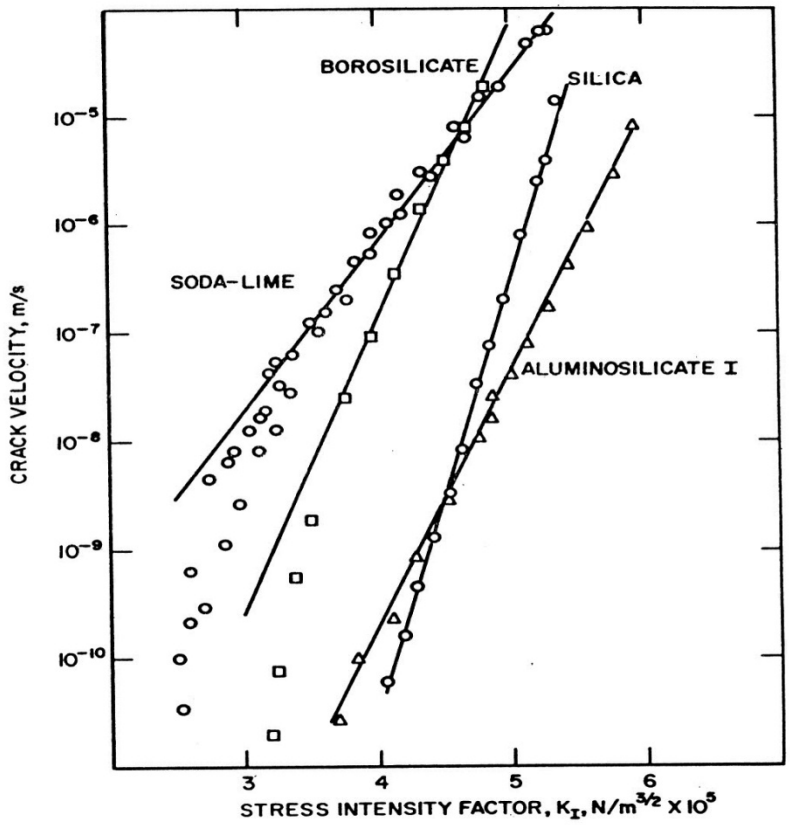
(Wiederhorn, J.Am.Cer.Soc., 50 407 (1967))

- **Double-cantilever-beam tests**
- **Soda-lime glass tested in N_2 gas of different relative humidity**
- **Observed 3 crack growth regimes, each controlled by a different mechanism**



Glass Composition Effects

(Wiederhorn, J.Am.Ceram.Soc. 53 543 (1970)



The slope of the V-K_I curve, N, is a measure of the glass's resistance to crack growth.

We have no way to predict the effect of glass composition on N.

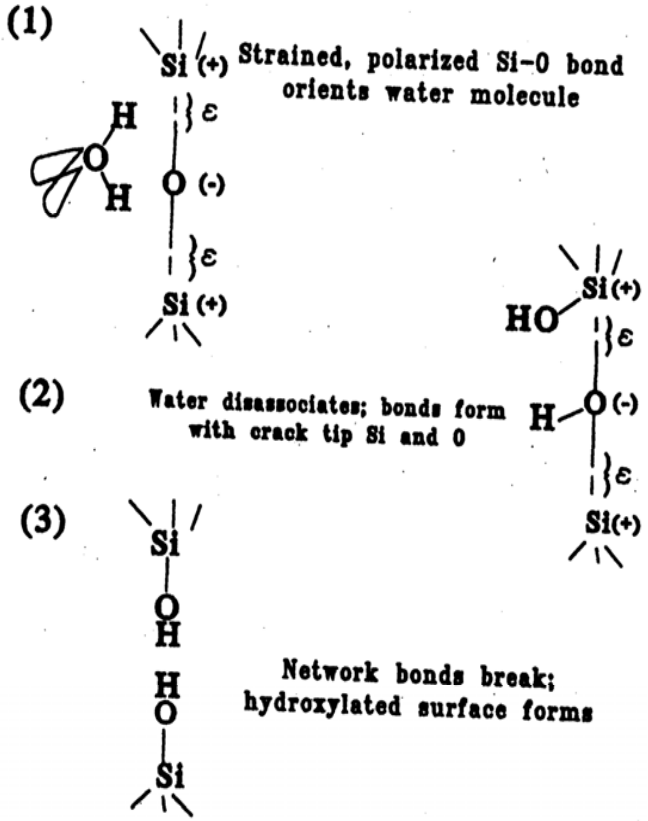
Why water?

Water is the primary cause of crack growth for glasses under stress, but what is it about water that is important, and what other chemistries might behave similarly?

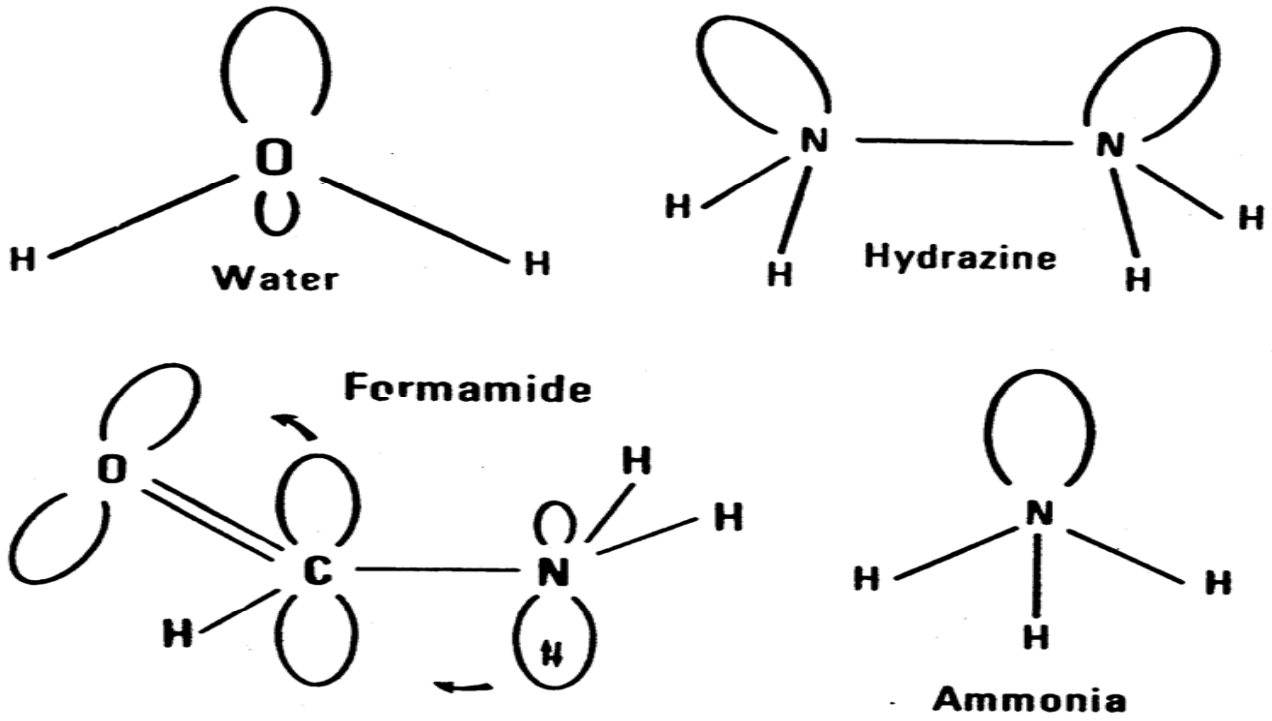
Molecular Mechanism

(Michalske and Freiman J.Am.Cer.Soc. 66 288 (1983)

- **Water donates "lone-pair" electrons and protons**
- **No corrosion products**
- **No change in crack tip shape**
- **Mechanism termed "dissociative chemisorption"**



Some Molecules That Cause Crack Growth



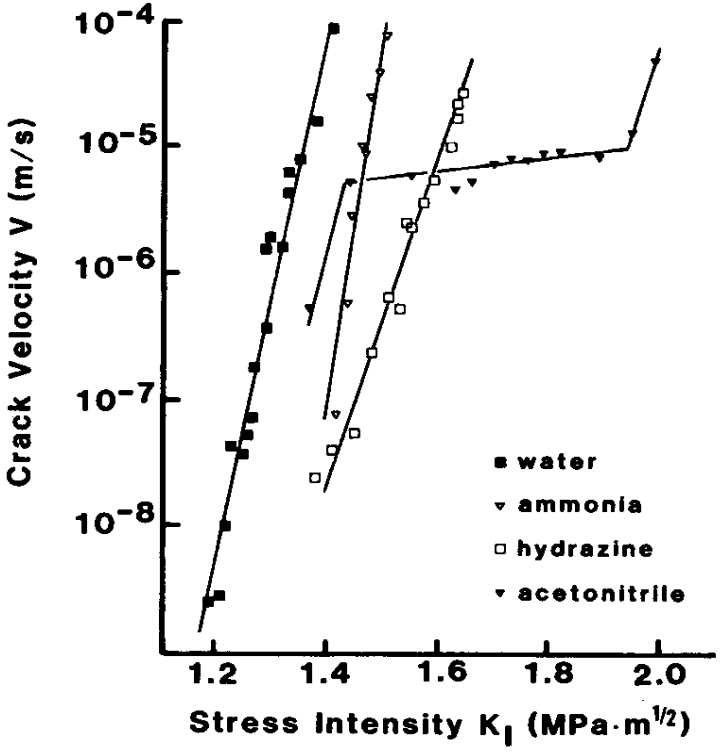
It isn’t just glasses that are susceptible to environmentally enhanced crack growth in water and etc.

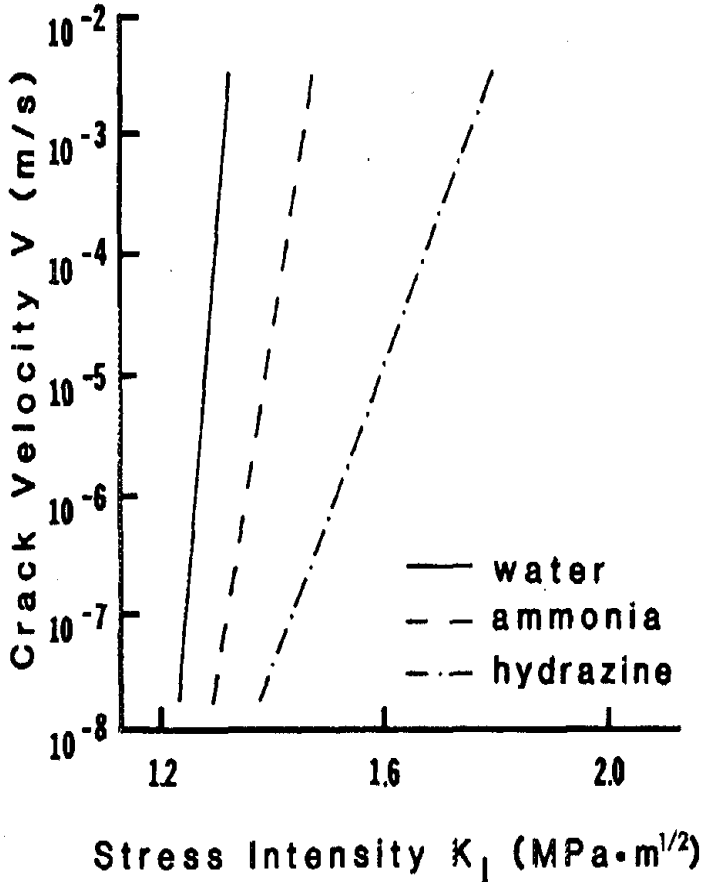
Almost all brittle materials behave in this way.

Sapphire Behaves Like Silica

(but not exactly)

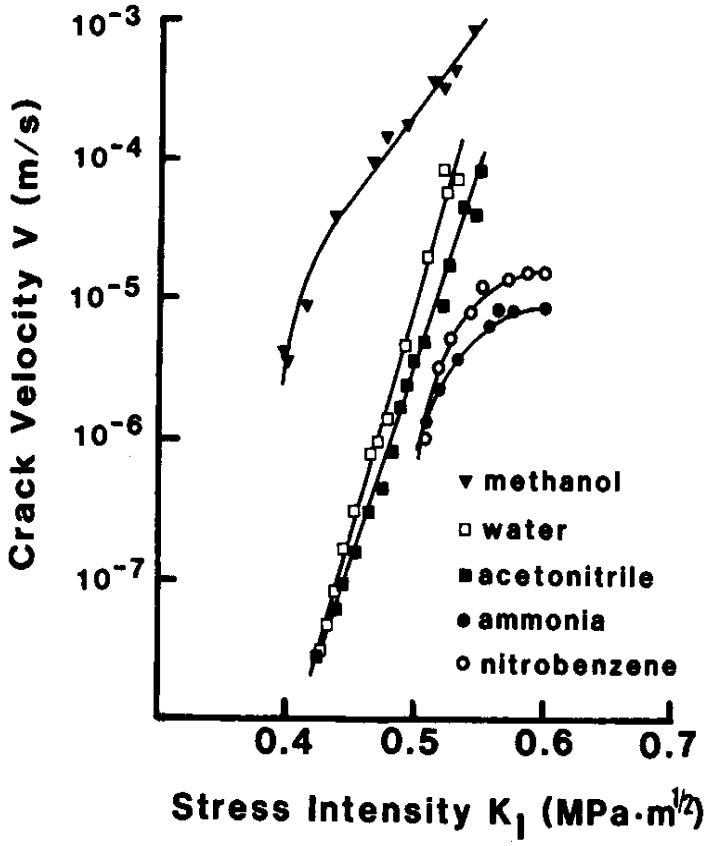
(Michalske, Bunker, Freiman, J.Am.Cer.Soc. 69 1986)

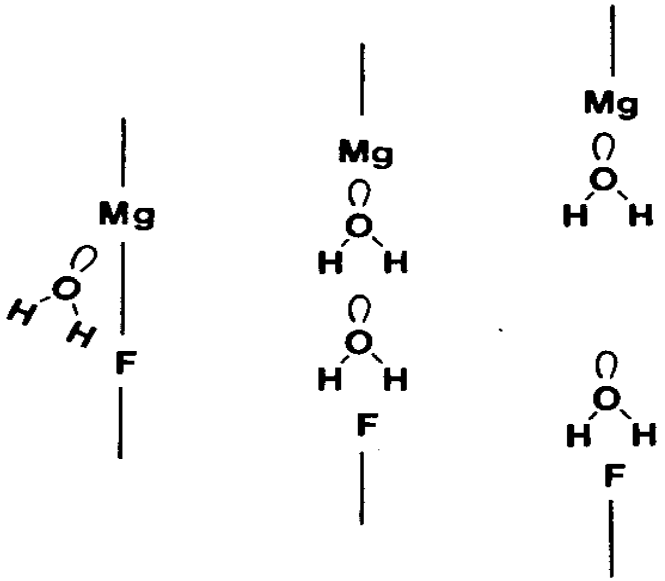




MgF_2 Is Different: Electrostatics Control

(Michalske, Bunker, Freiman, J.Am.Cer.Soc. 69 1986)





Silicon

- **No environmentally enhanced crack growth has been documented in bulk silicon crystals.**

- **Strain does not cause charge separation in purely covalent materials, so there is no tendency to react with a water molecule.**

Is there a way to reduce the sensitivity of glass (and other ceramics) to crack growth?

While still retaining transparency?

A recent paper suggests help with the slow crack growth problem.

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Nanostructured Ceramic Oxides with a Slow Crack Growth Resistance Close to Covalent Materials

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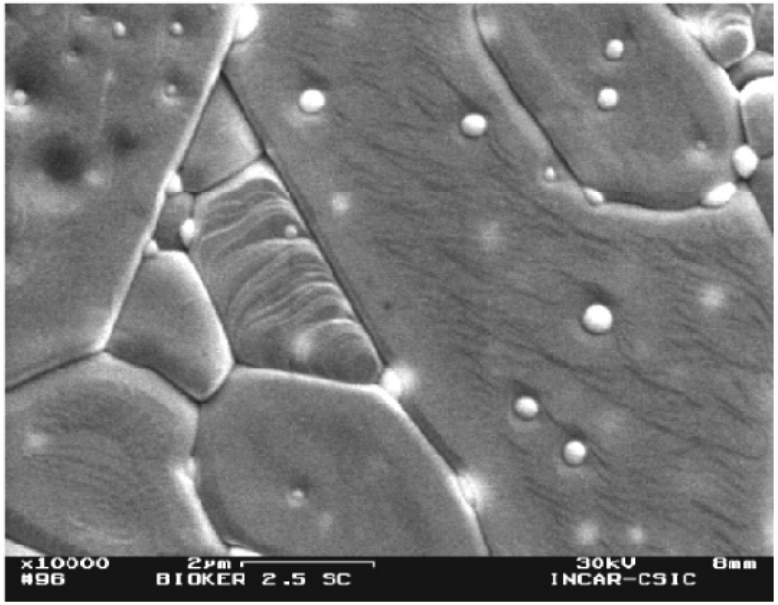
ABSTRACT

Oxide ceramics are sensitive to slow crack growth because adsorption of water can take place at the crack tip, leading to a strong decrease of the surface energy in humid (or air) conditions. This is a major drawback concerning demanding, long-term applications such as orthopaedic implants. Here we show that a specific nanostructuration of ceramic oxides can lead to a crack resistance never reached before, similar to that of covalent ceramics.

1.7 vol% ZrO_2 Particles were added to alumina

(b)



D_{50} ~150 nm

V- KI curve was shifted to a higher KI, and had a steeper slope indicating greater resistance to crack growth.

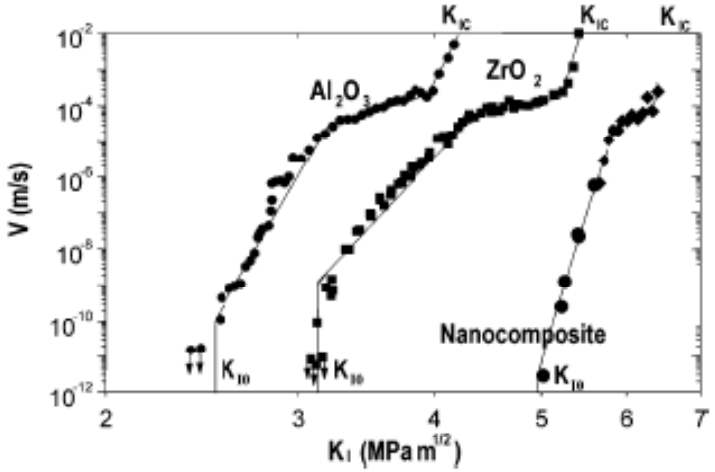


Figure 4. V–K_I curve of the present nanostructured composite, compared with standard alumina and zirconia.

How to Maintain Transparency

- **Must avoid scattering losses:**
  - **Small particle sizes, <150nm**
  - **Small volume fraction, <2%**
  - **Good match in refractive indices**

- **These conditions can be met for a wide variety of matrix-particle combinations.**

Summary

- Loss of strength with time under load is a problem in the design and use of glasses and other brittle materials.
- Suggest that the addition of very small percentages of second phase particles can reduce the susceptibility of a brittle material to moisture enhanced crack growth.
- Also suggest that the transparency of a material can be largely retained through the correct selection of materials and particle sizes.
- A provisional patent application has been submitted.