Dependence of fiber strength on time, temperature and relative humidity

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The most critical variable effecting the strength of silica lightguides is the availability of water to the fiber surface. At very low temperatures (T < 77°K) and at high vacuum ($p_{H_2O} < 10^{-7}$ torr) the thermodynamic activity of water is so low that mechanical failure of the fiber occurs by the direct breaking of Si-O-Si bonds. In this case very high strength (~ 12-14 GPa) and very slight time dependence (n = $\dfrac{d \ln t}{d \ln \sigma}$ ≈ 150) are expected.[1] Also an activation energy comparable to the SiO bond energy is observed (~ 100 kcals/mol). On the other hand, under normal conditions (T ~ 0–100°C and normal relative humidity), the strength and time dependence are controlled by the combination of stress and the reactivity of water with the fiber surface: $SiO_2 + H_2O$ = SiOH HOSi. In this case the time dependence of strength is very much greater (n ~ 20) and the activation energy is approximately 30 kcal/mol.[2] Because of this rather extreme time dependence, the short time tensile strength (say t_f = 10 secs) is only about 5.5 GPa and will be reduced again by a factor of ≈ 2 (to ≈ 2.8 GPa) in about one week. A subject which continues to be discussed and studied is the proper analytical description of this time dependence. In this regard, Bubel and Matthewson[3] have studied the behavior of several proposed models for time dependence. They find that the differences in predicted lifetimes from the models differs significantly. In particular they suggest that the universal use of the optimistic power law is not appropriate.

The detailed response to the activity of water at constant temperature is unknown. It has been suggested that both the relative humidity dependence of the strength and the failure time are power functions. However as in the case of the time dependence of strength, the exact relationships are difficult to determine unequivocally. On the other hand, certainly a qualitative description of these behaviors can be gained from equations of the following types.[4]

(1) $\sigma \sim p_{H_2O}^{\beta}$

(2) $t_f \sim (RH^{\beta})^{n-1}$

β ~ −0.1 at high relative humidities n ~ 20 (>10%), and -0.05 at low.

As can be seen from the above, while a qualitative understanding of the time, temperature and water vapor pressure dependence of strength has been achieved, a more quantitative understanding is required in order to develop a model which will allow predictions to be made.

The understanding of either the behavior of uncoated silica or silica with a given coating is, unfortunately not enough. It is clear that coating changes produce enormous

changes in the above behavior and thus a detailed understanding of the chemistry of the coating will also be necessary.

REFERENCES

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