ROOM TEMPERATURE STRENGTH DEGRADATION OF OPTICAL FIBERS

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ABSTRACT

The strength degradation of lightguide fibers has been studied over a range of elevated temperatures and at room temperature. Using these data we show that accelerated testing can be used to predict ambient temperature behavior. An activation energy of ~90 $kJ.mol^{-1}$ describes the shift in corresponding times.

Keywords: Optical fibers, fused silica, strength, fatigue, aging, reliability.

2. INTRODUCTION

Since the initiation of mechanical studies on lightguide fibers, tests have characteristically been carried out at elevated temperatures (*e.g.* see Ref. 1). The purpose of such accelerated tests is to acquire degradation data in reasonable times. These tests are useful in differentiating between different fiber types, since in general the degradation of fibers provided by different manufacturers or by different processes will show different degradation rates at these elevated temperatures. In addition, it is important to understand the behavior of these fibers at ambient conditions. In this study we analyze data from four fibers in order to understand whether high temperature accelerated mechanical aging data can be simply transformed to predict room temperature behavior.

3. EXPERIMENTAL PROCEDURE

Polymer coated fiber from three sources were aged in distilled or deionized water at a range of temperatures. After the appropriate aging times the fiber was tested in two-point bending at a faceplate speed of 1000 $\mu m.s^{-1}$ in the same water but at room temperature. In the case of fiber aged for many years at room temperature, the bend test was performed using both coated fiber and fiber stripped of its coating by hot sulfuric acid, in order to avoid any effects from the partially disintegrated coating.

4. RESULTS AND DISCUSSION

The three polymer coated silica lightguide fibers, designated A, B and C, were aged in water at different temperatures. The two-point bending strengths measured at room temperature are shown in Figs. 1, 2 and 3, respectively. For fiber A (Fig. 1), aging was conducted at 100°C and 25°C. For the other two fibers, B

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and C (Figs. 2 and 3), aging was carried out at 80, 60 and 40°C. These data were fitted using an empirical model first proposed by France *et al.*:[2]

$$\frac{\sigma}{\sigma_0} = (1+\alpha t)^{-\beta} \tag{1}$$

where α and β are fit parameters. Temperature effects can be accounted for by assuming that α is Arrhenius:[3]

$$\alpha = \alpha_0 \exp(-E_a/RT), \tag{2}$$

where E_a is the activation energy, T is absolute temperature and R is the gas constant. The parameters, E_a, α_0 and β, are found by simultaneously fitting Eqs. (1) and (2) to the aging data at several temperatures.

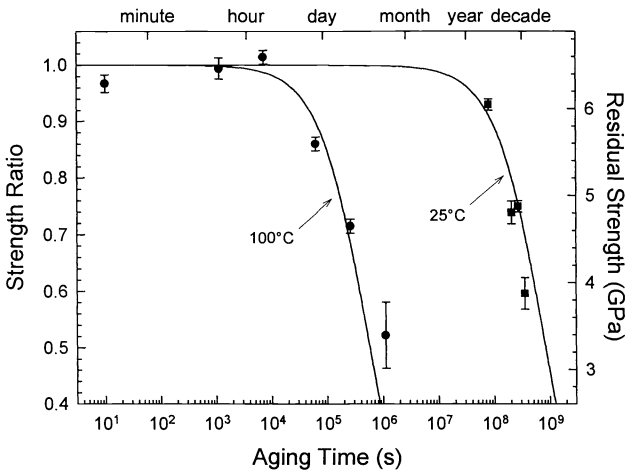

Fig. 1. Residual strength of fiber A after aging in distilled water.

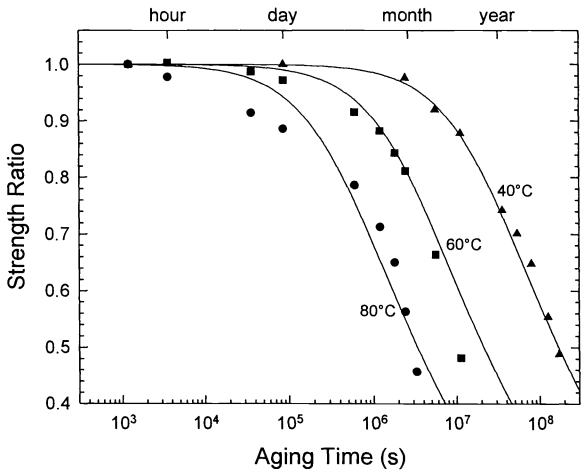

Fig. 2. Residual strength of fiber B after aging in deionized water.

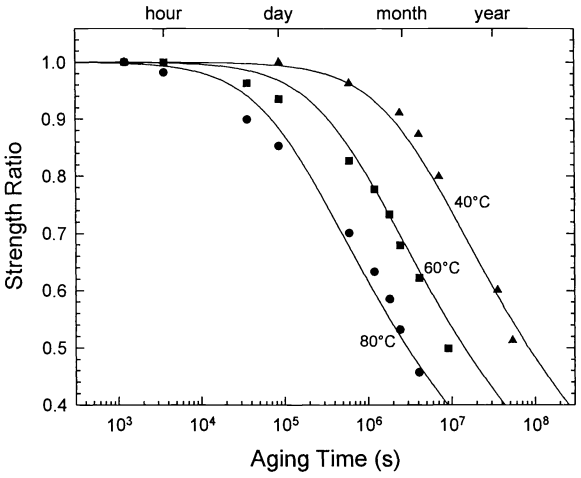

Fig. 3. Residual strength of fiber C after aging in deionized water.

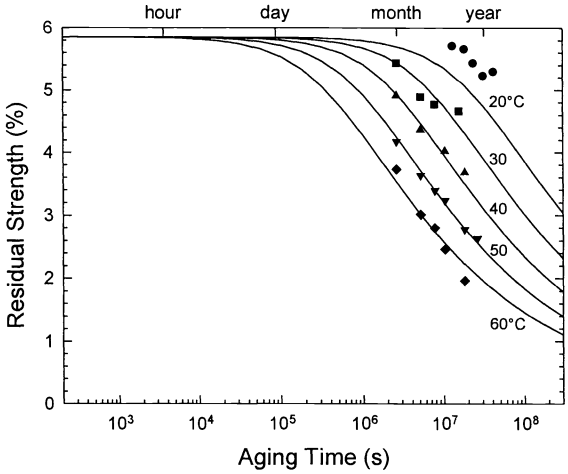

Fig. 4. Data of Griffioen[3] for residual strength (strain to failure) of fiber aged in water.

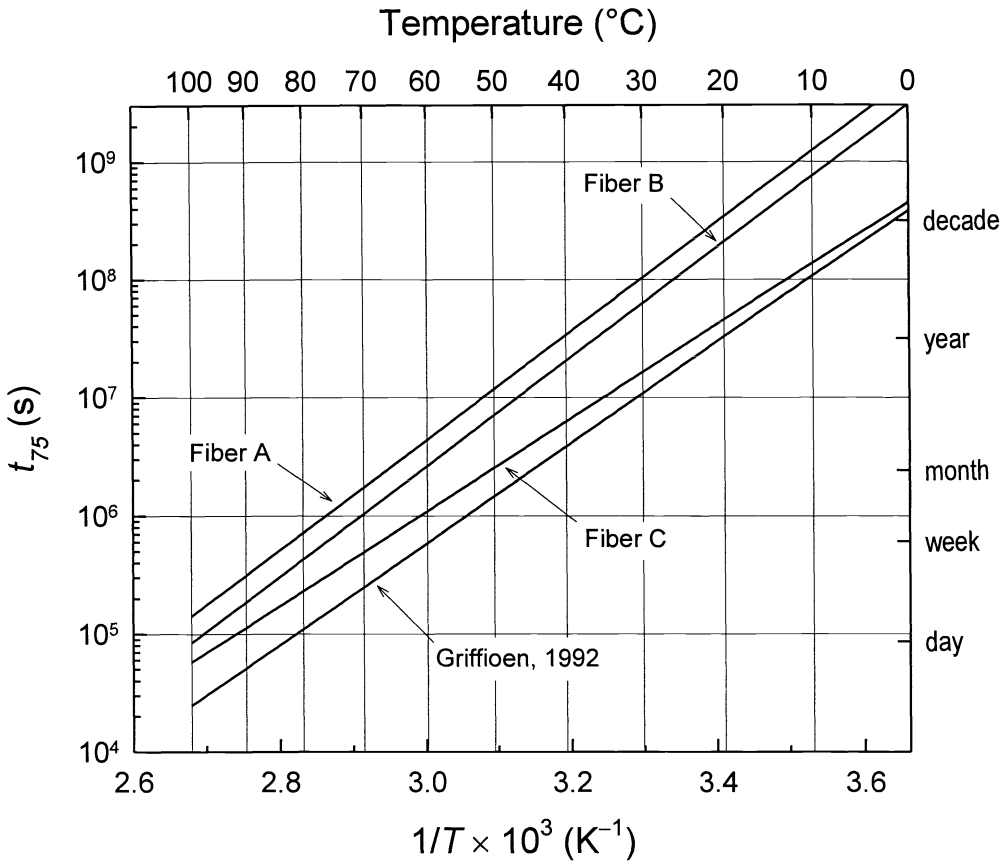

Fig. 5. Arrhenius plot of the values of the time for 25% strength reduction, t_{25}, from the fits to the data of Figs. 1 to 4.

The activation energies, E_a, determined for the three fibers (A, B and C) are 90 ± 7, 90 ± 7 and 77 ± 7 kJ.mol^{-1} respectively (95% confidence intervals). However, other forms of Eq. (1) have been tried and the values of the activation energies are insensitive to the form. The values of E_a are not unexpected, since the process being described is the reaction between silica and water which is known to be controlled by such an activation energy.[4] The important point to note is that the curves at different temperatures are similar in shape, but are merely shifted in time. The fact that the data for fiber A can be shifted from 100°C to 25°C without a shape change gives us confidence that the data for fibers B and C can also be shifted to 25°C without a change in shape using this equation. In addition, these data are very complete at each temperature.

As far as we are aware, the only other data on aging fused silica fibers at room temperature in water are those published by Griffioen,[3] which are shown in Fig. 4. These data fit Eqs. (1) and (2) reasonably well except at 20°C; the resulting activation energy is 83 ± 12 kJ.mol^{-1} and the fit is shown in Fig. 4. Compared to the data of Figs. 1 to 3, these data are not as extensive in aging time; most measurements are after the knee and do not show the general trends as clearly. The reason for the poor fit at 20°C is unclear.

Fig. 5 shows an Arrhenius plot of t_{25}, the time predicted from the fits to Eq. (1) at which 25% of the strength has been lost ($\sigma/\sigma_0 = 0.75$), for all four fibers discussed here. All four lines lie reasonably close to each other and values of t_{25} differ by little more than an order of magnitude throughout the temperature range of 0 to 100°C. It should be noted that more variability between different fibers has been observed elsewhere; Ritter *et al.*[1] have observed the onset of aging knees for different fibers under identical test conditions to range from 3 to 150 days at 80°C.

5. SUMMARY

We have shown that high temperature aging data can be shifted in time by means of an Arrhenius equation using an activation energy of ~90 $kJ.mol^{-1}$, which is typical of that found for reactions between silica and water. This information is extremely useful since it justifies estimating lifetimes at room temperature by extrapolating from data taken in shorter times under accelerated conditions.

6. REFERENCES

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