Optical Fiber Strength, Fatigue and Handleability After Aging in a Cable

Anurag Dwivedi, G. Scott Glaesemann

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Introduction

Handleability of optical fiber pertains to the ability to strip, clean, cleave, terminate, and connectorize short lengths of fiber during installation of re-entry. The combined bending and tensile stress applied to short fiber lengths during termination or splicing can be on the order of 200 to 300 kpsi (1.4-2.1GPa).[2] For example, it is believed that applied stresses on this order can be generated during stripping and that the peak strip force is simply a reflection of this. Therefore, in addition to such external factors as damage from the stripping tool and stripping technique, the fiber brings two key handleability properties; namely, fiber strength and peak strip force. Sufficient strength over short lengths ensure survival of the handling even and a peak strip force within established limits keeps the applied stress below the fiber strength during stripping.

Strength testing and peak strip force testing are two ways in which the handleability of cabled fiber can be assessed. These tests can be performed on as-drawn or a-cabled fibers to examine handling during installation. To determine the handleability of fiber for eventual re-entry one would clearly prefer to rest fiber in the aged sate. Whereas there is an abundance of strength date on short fiber lengths after laboratory aging, there are only a few publications that examine the strength of fiber in the field aged state.[3,4] The purpose of this study is to examine the handleability of fiber aged in a cable and to reflect on the significance of the results as they pertain to handleability of fibers during cable repair.

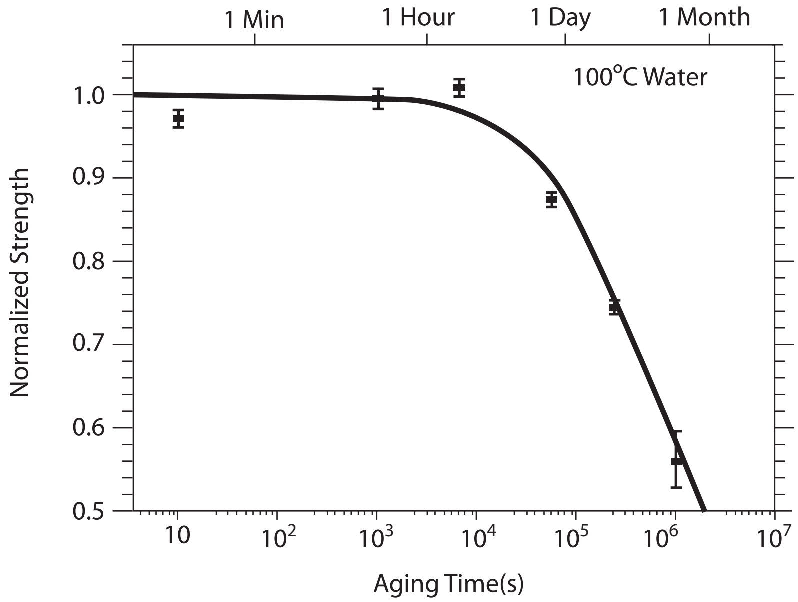
Aging of pristine optical fiber surfaces is a process whereby extreme temperature and humidity conditions in the lab oratory may introduce microscopic flaws on the surface of optical fiber. The introduction of these flaws in known to reduce fiber strength of short lengths from near intrinsic levels. For, example, Figure 1 shows a dramatic decrease in fiber strength, as measured in 2-pt bending, as a function of time in 100°C water.[5] Like the data in Figure 1, nearly all aging studies have been performed on short lengths of optical fiber in the as-drawn condition an in unrealistic aging environments. Consequently, some have suggested that aging is a life-limiting phenomenon for installed optical fiber.[6,7,8]

However, for most fiber application, one can show that the flaws of greatest strength related reliability risk are not those on pristine fiber surfaces. Rather, it is the flaws near the proof stress that pose the greatest risk.[9] Thus, the aging of relatively large flaws receives the bulk of our handleability concern. The aging and fatigue of relatively large flaws in optical fiber has been addressed in a recent publication.[10]

Due to the susceptibility of the silica optical glass fiber to sub critical crack growth, cabled are designed to minimize the applied tensile stress on the fiber. To the authors' knowledge, no field failure has been attributed to strength degradation from fiber fatigue. The effect of either coatings or the cable components during aging on the fatigue resistance of silica fiber is also studied in the present work by testing the dynamic fatigue of cable-aged fibers.

CORNING

Fiber Strength After Aging in 100°C Water (ref. 5)
Figure 1

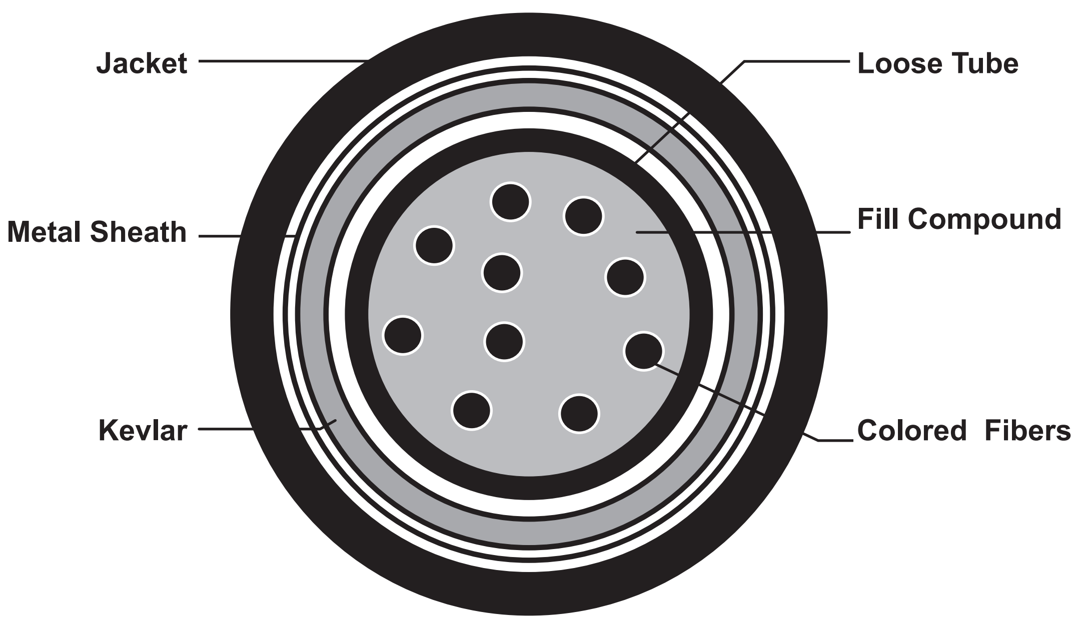


The Cable Design

A schematic of the design of cable used in the present study is shown in Figure 2. The fibers in the cable consisted of nine standard silica-clad fibers and one commercial titania-doped-silica-clad fiber. All fibers were coated with dual layer acrylate coating and an overcoating of a then layer of solvent based colored ink.

These fibers are contained with a buffer tube filled with fill compound. Kevlar strength members flooded with a water blocking compound are arranged around the buffer tube. This assembly is enclosed within a steel armor which is not hermetically sealed. Finally, an outer polyethylene jacket surrounds all the components. The basic components surrounding the fiber are labeled in Figure 2.

Schematic of the Cable Design
Figure 2



Aging Conditions

The deliberate aging tests preformed on this cable are given below.

Accelerated aging:

- ≈15 days at 70°C during Temperature Cycling
- 7 days at 80°C Heat Soak
- 5 weeks at 80° and 94% RH Heat/Moisture Aging

Storage: The cable was stored on a wooden reel and left outside the building from August 20, 1990 until December 3, 1992. There was no thermal wrap covering the cable. The combined effect of laboratory aging and natural environment was severe enough that the original cable reel disintegrated and the cable had to be transferred onto another reel before testing.

Experimental Testing

In this study we focus primarily on fibers from the outermost wrap of the original reel since this portion of the cable was directly exposed to the aging environment.

Removing fibers from the cable:

Approximately two meters of cable was cut from the cable reel and fibers were carefully pulled out without touching the prospective gauge length portion of the fibers. The filling compound was removed from individual fibers by soaking a Kimwipe cloth with D-Gel and carefully sliding the fiber through the cloth. After cleaning, fibers were hung vertically by attaching their ends to the double-sided sticking tape mounted on the wall. All specimens were prepared in a controlled environment of 45% RH and 23°C.

Strength Testing:

Strength testing was performed on a universal testing machine. The gauge length was 0.5 meters and the cross head speed was 500 m/min which corresponds to a strain rate of approximately 70%/min. Fibers were attached to the testing machine by wrapping fiber a minimum of two lines around 2" diameter seamless Tygon tubing capstans as either end of the gauge length. The fiber is finally held in place by securing he ends under an elastomeric band. The test environment was maintained at 45% RH and 23°C. Approximately 15 specimens were tested for each color.

Strip Force Testing:

Strip force testing was performed using the industry accepted TIA test method FOTP-178.[11] Peak strip force results were obtained using a data acquisition rate of 5 Hz. The effect of coloring ink on peak strip force was studied. Also, the peak strip force was measured as a function of preconditioning time in ambient environment.

Dynamic Fatigue Testing:

In addition to examining fiber handleability, it is convenient to perform fatigue testing as well. Specimens were removed from the cable, cleaned, and stored in ambient conditions for two months. All specimens were preconditioned in the test environments of 100% RH and 23°C before testing. Fibers were tested using four strain rated ranging from 25%/min. to 0.025%/min. Fifteen specimens per rate were tested for silica-clad fibers, whereas, only five specimens per strain rate were used for the titania-doped-silica clad fiber.

It is important to note that the functional implications from fatigue results obtained on short fiber lengths tested at fast rates has been questioned. Fatigue tests longer lengths using slower stressing rates provide more functional n parameter since the fatigue of the largest flaw under static loading condition controls the mechanical reliability of fibers in the field installed cables. In the present study, however, tests were performed on shorter lengths dues to the difficulty in removing long length fibers from the cable. For this reason, the fatigue results of short length cable aged fibers from this study are compared with those obtained on drawn fibers.

Results and Discussion

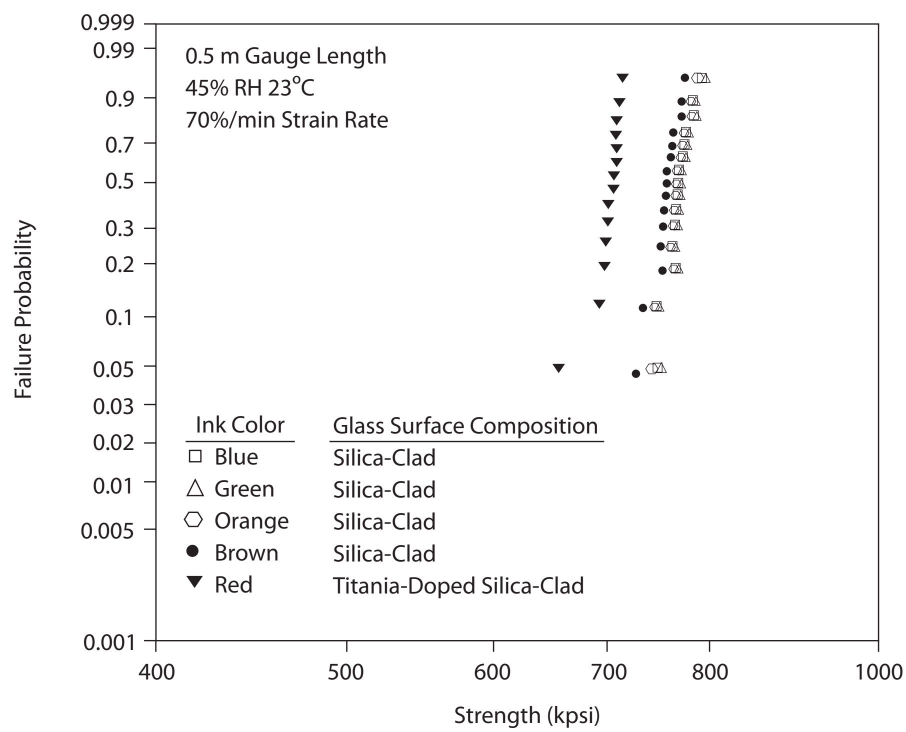
The Aging Environment:
Though accelerated aging is convenient for commercial purpose, it is recognized that models translating experimental results from accelerated aging studies to actual in-service environment results are limited. Without a predictive model for translating accelerated test environments to equivalent in-service environment, one can either wait 10 to 20 years and test actual field installed cables or choose accelerated tests that are far worse than expected for the in-service environment. The first option requires an unacceptable amount of patience for cable developers while the latter, used for this study, runs the risk of being too conservative.

Strength Experiments:
Several specimens were tested for strength immediately after preconditioning in 23°C/455RH for one week. The strength values are shown in Figure 3 and Table 1 for fibers of different color. The results indicate that there is little dependence of strength on ink color. More importantly, the measured silica-clad fiber strength distribution with a median value of 775 kpsi (5.35 GPa) is the same as the as-drawn fiber strength distribution for this fiber shown in Figure 4. Similarly, the strength of the aged titania-doped-silica-clad fiber of 715 kpsi (4.93 GPa) is typical for this fiber in the as-drawn condition.[12] It is concluded that the aging of this cable has not degraded the strength distribution of the fibers contained within. The strength of these fibers is sufficient for common field handling scenarios during cable repair even after the severe aging.

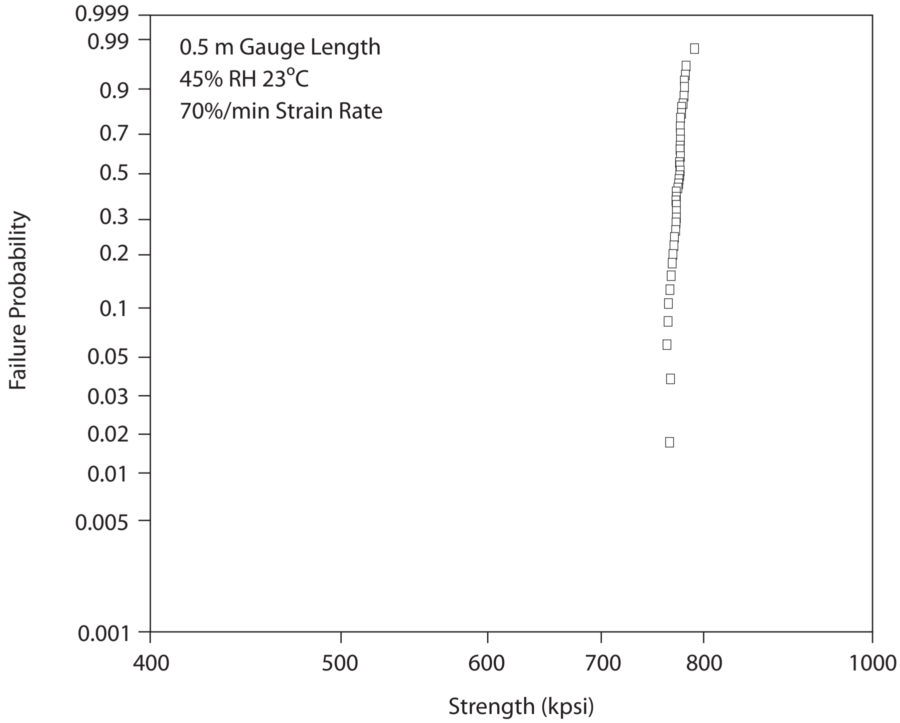
Fiber Strength and Fatique after Aging in Cable
Table 1

Fiber Type	Color	Mean Strength kpsi (GPa)	Weibull Slope m	Fatigue Susceptibility Parameter (n_d)
Silica-clad	Blue	783 (5.40)	63	23
Silica-clad	Green	791 (5.46)	73	
Silica-clad	Orange	782 (5.39)	54	
Silica-clad	Brown	767 (5.29)	62	
Titania-doped Silica-clad	Red	712 (4.91)	47	27

Strength Distribution of Fibers Removed from Cable
Figure 3



Typical Strength Distribution of As-Drawn Silica-Clad Fibers
Figure 4



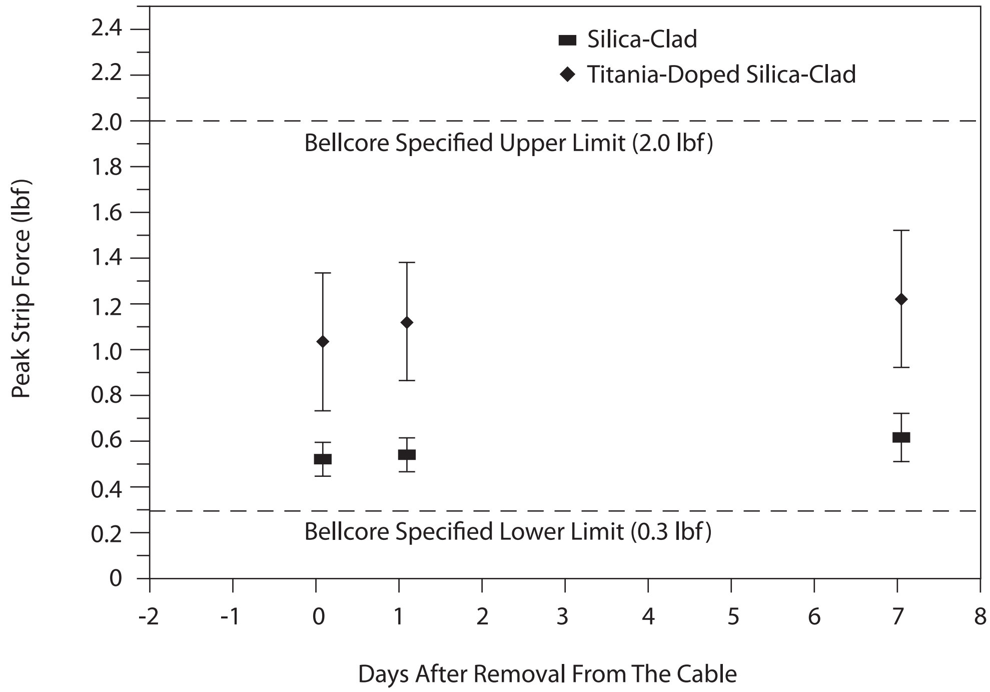
Strip Force Experiments:
Strip force measurements were performed on each of the colored silica-clad fibers immediately after removal from the cable. The strip force results of aged colored fibers are summarized in Table 2 where the standard deviation for five test specimens is reported. The results show that there is little or no dependence of strip force on ink and there the peak strip force is approximately .053 lbf for silica-clad fibers. Furthermore, the strip force values for aged silica-clad and titania-doped-silica-clad fibers (Table 2) are typical as-drawn values of the respective fiber/coating systems.

Fiber Peak Strip Force after Aging in Cable
Table 2

Fiber Type	Color	Mean Strip Force, lbf (N)	Typical Strip Force of As-Drawn Fibers, lbf (N)
Silica-clad	Blue	0.55 ± 0.07 (2.45 ± 0.31)	0.55 ± 0.04 (2.45 ± 0.18)
Silica-clad	Green	0.54 ± 0.10 (2.40 ± 0.45)	
Silica-clad	Orange	0.50 ± 0.05 (2.22 ± 0.22)	
Silica-clad	Brown	0.54 ± 0.08 (2.40 ± 0.36)	
Titania-doped Silica-clad	Red	1.05 ± 0.29 (4.67 ± 1.29)	1.05 ± 0.15 (4.67 ± 0.68)

To better understand the effect of time after removal from the cable on the handleability of the fiber, peak strip force was measured as a function of the drying time after removal from the cable. A total of 20 specimens were stored in laboratory ambient conditions of 23°C and relative humidity ranging from 25 from 35%. The results from this testing are summarized in Figure 5 and show a small increase in peak strip force their for both fiber types. This increase is believed to be due to the removal of residual moisture from the coatings. All fibers shown strip force appropriate for good handleability of the fibers.

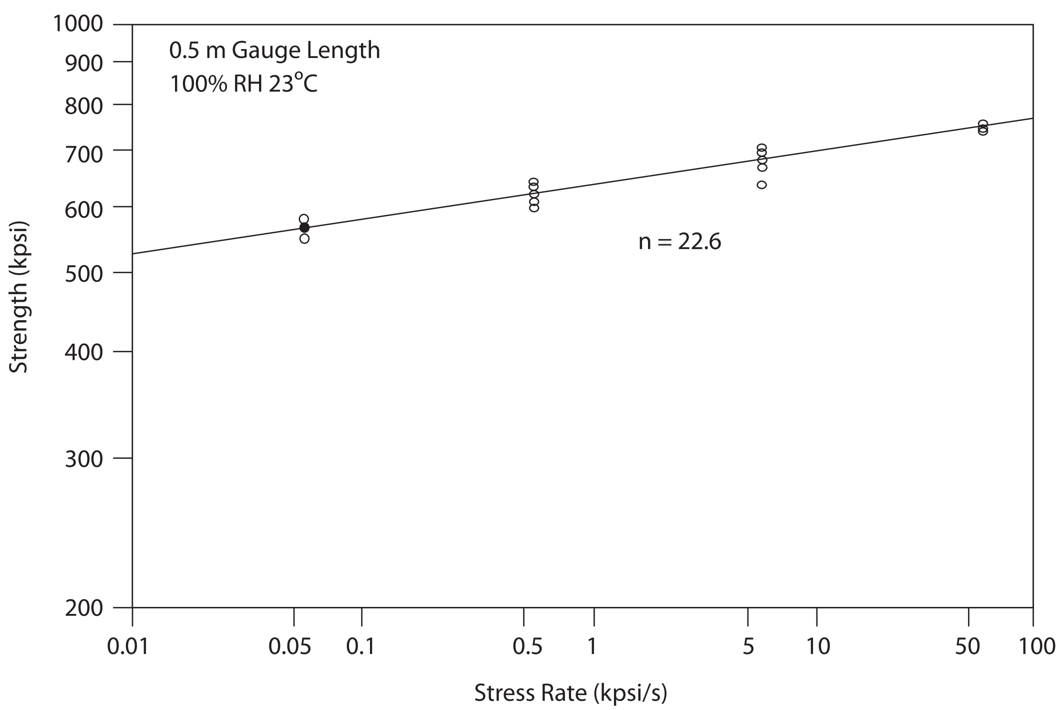
Peak Strip Force as a Function of Drying Time
Figure 5



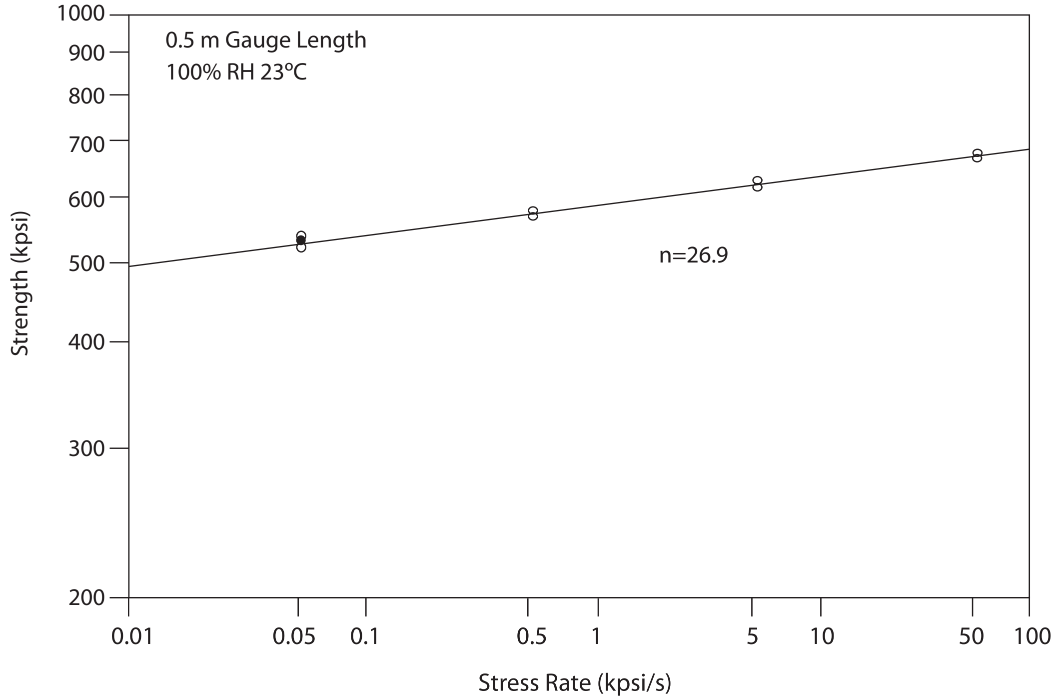
Dynamic Fatigue of Aged Fibers:

Dynamic fatigue testing of these fibers did not yield any unusual results. The n value for silica-clad fibers and titania-doped-silica-clad fibers was measured to be 22.6 and 26.9, respectively. The dynamic fatigue plots are given in Figures 6 and 7 respectively. Dynamic fatigue of aged fibers is not statistically different from that of as-received fibers tested in the same manner. This indicated that the fatigue behavior of the fibers was not degraded by aging in the cable.

Dynamic Fatigue of Silica-Clad Fibers
Figure 6



Dynamic Fatigue of Titania-Doped-Silica-Clad Fibers
Figure 7



Summary

Severe aging of a fiber-optic cable did not degrade the handleability or fatigue behavior of the fibers contained within it. The peak strip force of aged fibers is the same as the typical peak strip force of un-aged fibers and is considered appropriate for handleability. In addition, the strength of fibers aged in fill compound and other cable components because no strength degradation was observed after severe cable aging.

This work also suggests that the cable components do what they are designed to, which is protect the fiber even in events such as severe aging. This suggestion is also supported by the recent work published by Haslov where strength and static fatigue resistance of fiber is found to be better in cable environment than in un-cabled form. In conclusion, the cable-aged fibers are handleable for cable repair and the aged coating and cable components did not create an environment where accelerated fatigue or aging of the fibers occurred.

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    Instron Corp., Canton Ma.

Corning Incorporated
www.corning.com/opticalfiber

One Riverfront Plaza
Corning, New York
USA

Phone: (607)248-2000
Email: cofic@corning.com