Thermal Stability of the CPC® Fiber Coating Sytsem

WP4250
Issued: July 2010
Supersedes: July 2003
Authors: Arpita Mitra, Inna Kouzmina, Maritza Lopez

Introduction

Corning's enhanced, dual acrylate CPC® coating technology provides excellent protection to the optical fiber's glass surface while maintaining superior microbend and environmental performance as demonstrated in laboratory testing conditions ranging from -60°C to +85°C. This temperature range dates back to early optical fiber projects at the telephone operating companies and applies to the temperatures to which the majority of their cables might be exposed. However, Corning recognizes that there are applications for the optical fiber beyond the telecommunications industry that might expose the fibers to higher temperatures for limited periods of time, e.g. adhesive curing procedures in photonic devices, temperature sensing in geophysical applications, military applications, etc. Even though some of these applications exceed Corning products' operating temperature range, customers rely on Corning to understand the optical fiber performance and behavior when being exposed to extreme temperatures.

There are many variables to consider when predicting performance of optical fibers at extreme temperatures, such as duration of exposure, the media, and the stress the fiber will be subject to. Unfortunately, few technical papers have been published on the high temperature performance of typical UV-cured dual layer optical fiber coatings: Suzuki, et al. presented a paper in 1996 with the objective of determining the maximum temperature that could be used in accelerated aging tests in air of urethane-acrylate fiber coatings. For both evaluated attributes, the change in mechanical properties and in thermal yellowing, they concluded that they could use temperatures up to 120°C to predict what would happen at room temperature for long periods of time, but that 150°C was too hot. These authors concluded that a shift in mechanism of the chemical reaction that was happening occurred between 120°C and 150°C. By using infrared light to characterize the heated coatings, they also concluded that both the color change and the degradation in mechanical properties were associated with the thermal oxidation of the urethane segment in the coating. They did not provide the composition of the coatings they were testing other than to compare coatings containing aromatic and aliphatic urethanes, and the composition is expected to have an effect on the results. Frantz, et al. published a study looking at the effects of aging (thermal and other environments) on optical fibers with incompletely cured coatings, but they only exposed the fibers to temperatures up to 85°C. Murata, et al. reported on the thermal color change of fiber coatings and ribbons exposed to 120°C and concluded that the fiber colors would be discernible for more than 20 years at room temperature.

Corning Optical Fiber strives to provide the best possible technical support – before, during and after the sale. Hence, due to the lack of technical information readily available on this subject, Corning Optical Fiber performed an extensive study to respond to customers' questions about what to expect when exposing Corning optical fibers to elevated temperatures.

This white paper summarizes the results of such experimentation. Main chapters of discussion are attenuation response to aging, coating geometry changes and coating mechanical property changes due to heat exposure.

CORNING

[1] A. Suzuki, M. Ban, T. Hattori, N. Akasaka, and Y. Matsuda, Int'l. Wire and Cable Symposium Proceedings, 1996, p. 471-477.

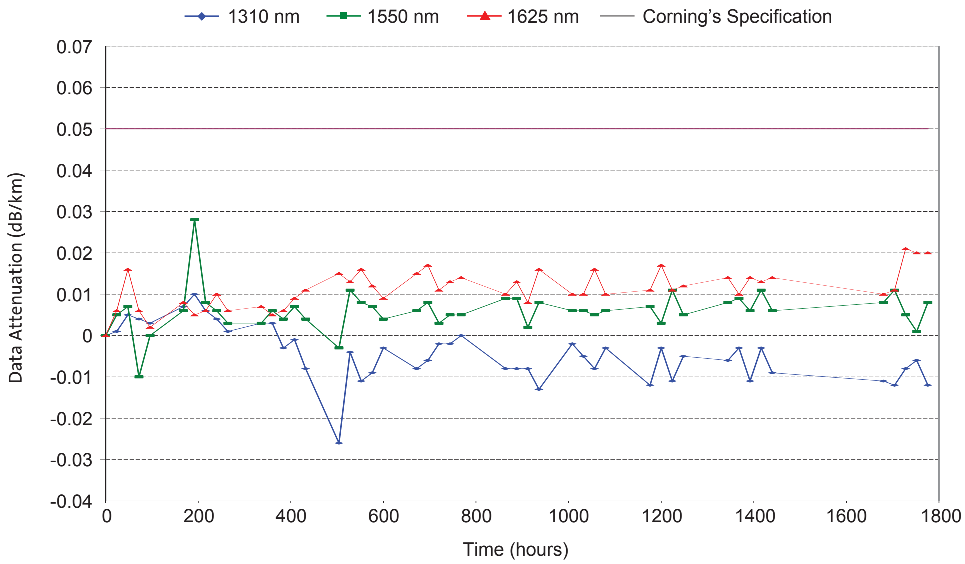
[2] R. A. Frantz, I. M. Plitz, H. H. Yuce, and O. S. Gebizlioglu, Int'l Wire and Cable Symposium Proceedings, 1992, p. 279-284.

[3] A. Murata, K. Kobayashi, K. Oohashi, S. Araki, and T. Maruoka, Int'l Wire and Cable Symposium Proceedings, 1995, p. 151-155.

Attenuation Changes at Higher Temperatures Exposure

Attenuation plays an important role in the fiber performance since its reduction enables longer reach of the optical signal. In order to understand the effect of high temperatures on attenuation, Corning wound one kilometer lengths of single-mode fibers into 9” diameter loose coils. These samples were later deployed in temperature chambers at different environmental conditions (85°C, 85°C/85%RH, 150°C, 200°C and 300°C) and the attenuation change was periodically monitored.

Figure 1 represents the performance of Corning fibers at 85°C, which is the upper limit of Corning’s fiber operating range. As shown in Figure 1, the attenuation change was always within the product specifications (≤0.05 dB/km at each wavelength) even when the exposure time exceeded the standard test procedure for heat aging (30 days or 720 hours).

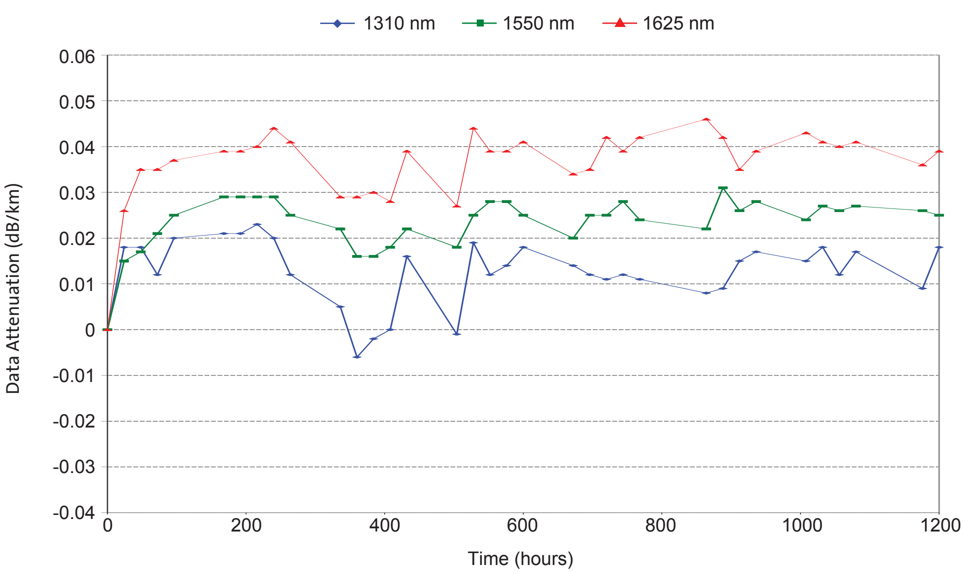


Attenuation Change for Fibers Exposed to 85°C

Figure 1

Attenuation spikes shown on Figure 1 are commonly due to measurement noise due to the short sample length that was employed.

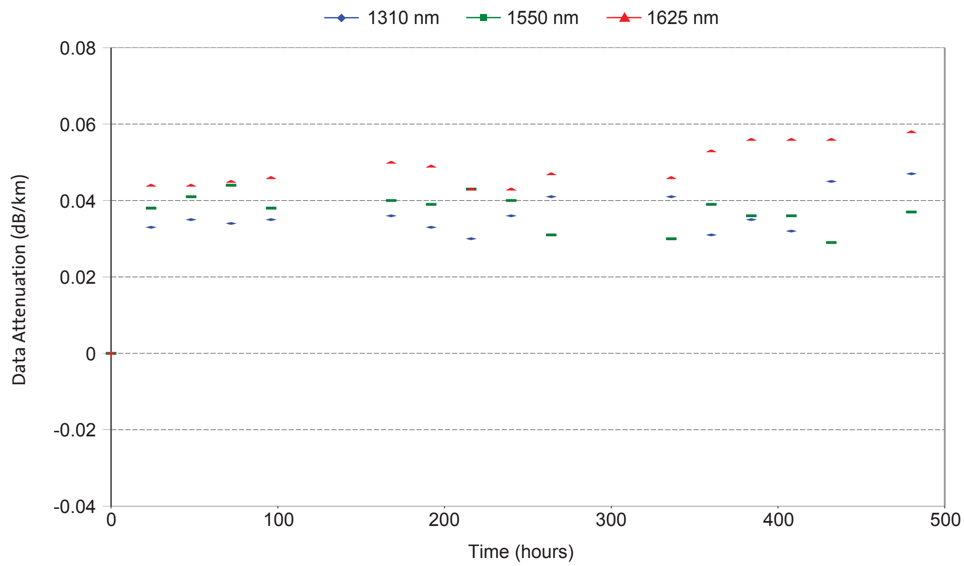
Figure 2 and Figure 3 show the performance of Corning single-mode fibers exposed to air at 150°C and 200°C respectively. Attenuation change increases with higher temperatures in comparison to the 85°C exposure; however data in Figure 2 does not show an effect on attenuation, as the increase is maintained under 0.05 dB/km for all wavelengths investigated (1310 nm, 1550 nm and 1625 nm) at 150°C. In the next section, we will see that fiber coating slowly starts oxidizing at this temperature, reducing the coating volume and mass.



Attenuation Change for Fibers Exposed to 150°C

Figure 2

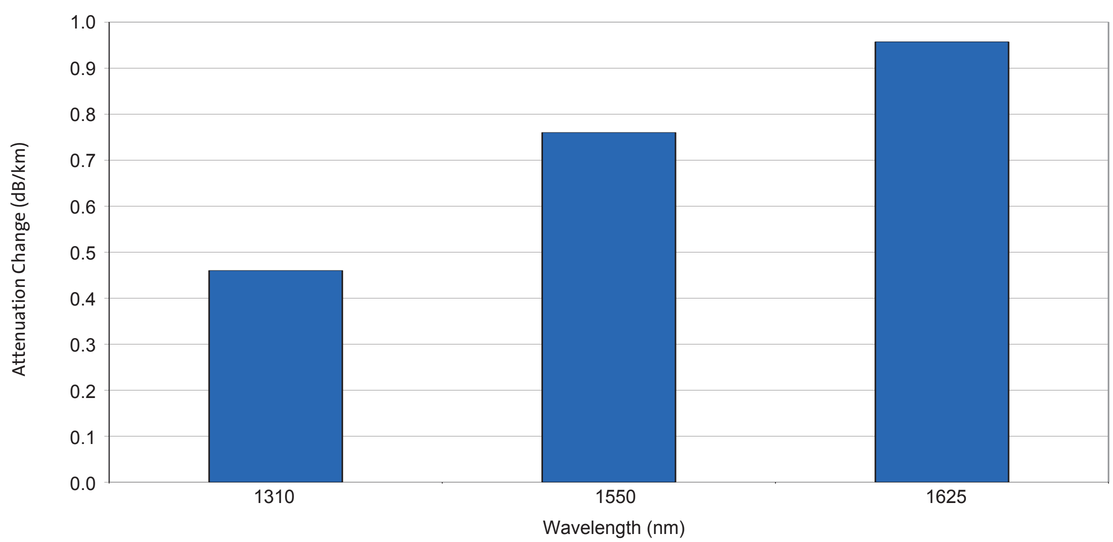
The similar increase in attenuation change is observed with fibers in air at 200°C. Figure 3 shows the attenuation change increasing, particularly after being exposed to air at 200°C for more than 300 hours.



Attenuation Change for Fibers Exposed to 200°C

Figure 3

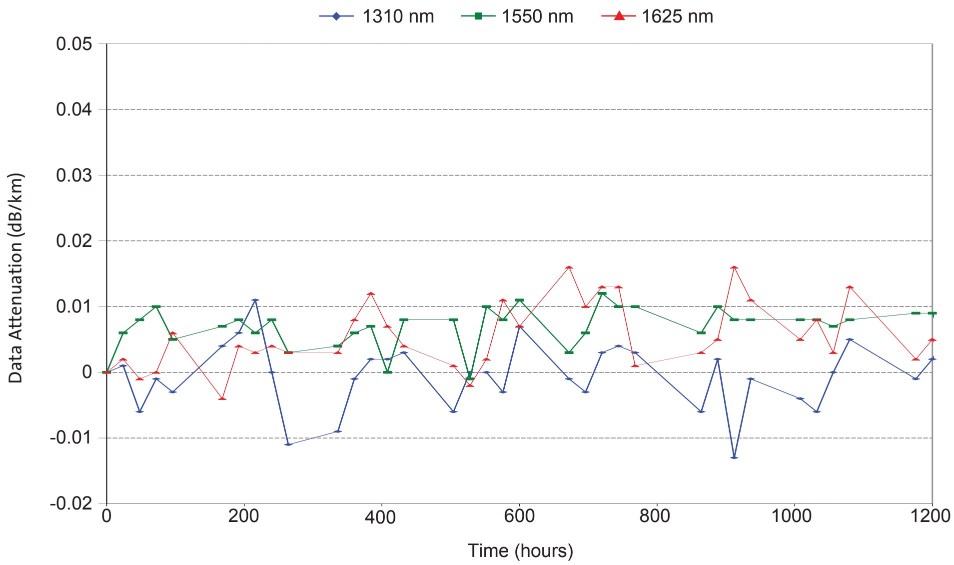
The final temperature the fibers were exposed to was 300°C. At this temperature, the fibers presented signs of microbending within the first 20 hours of exposure. As seen later in this report, there is a rapid oxidizing of the coating in air at this temperature as evidenced by its rapid decrease in outer diameter. Clearly, the fiber is only suitable for use at this temperature for very short periods of time. Figure 4 shows the attenuation change observed at different wavelengths when exposing Corning's fibers to 300°C for 18.5 hours in a loose coil configuration.



Attenuation Change for Fibers Exposed to Air at 300°C
(18.5 hours on loose coil configuation)

Figure 4

Fibers were then exposed to a hot and humid environment (85°C with 85% relative humidity) for 1,200 hours (i.e. 50 days). Figure 5 demonstrates that the optical fibers comfortably met Corning's ≤0.05 dB/km specification even after exposure to these conditions. Reader may notice Figure 5 similarities with Figure 1, Attenuation Change for Fibers Exposed to 85°C as expected.



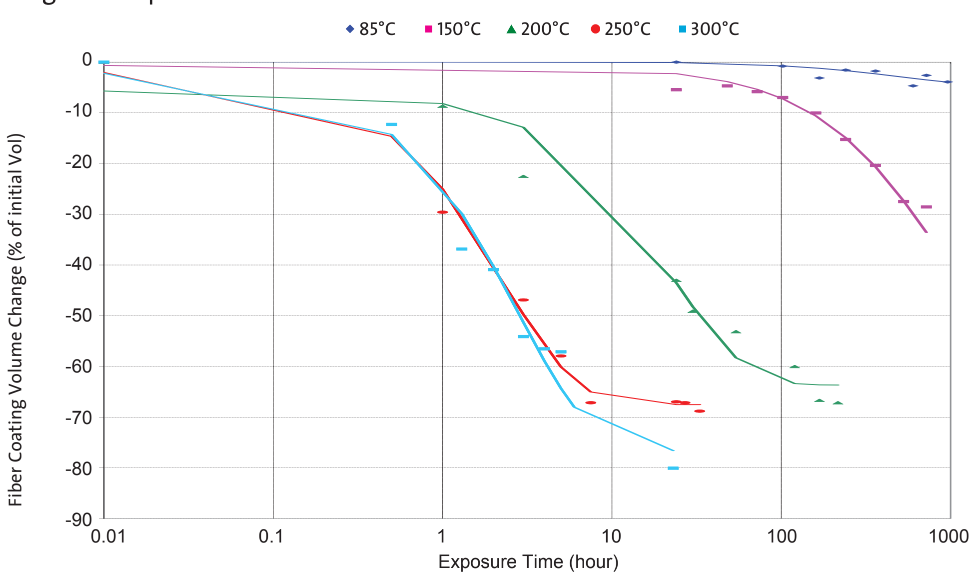
Attenuation Change for Fibers Exposed to Air at 85°C and 85% RH

Figure 5

The attenuation changes at higher temperatures given in this section are only for uncabled single-mode fibers, specifically fibers in a loose coil configuration. These results should be directionally indicative of what happens to fibers in cables exposed to higher temperatures, but the reader should bear in mind that the cable materials will also be exposed to the higher temperature. The cable materials may have different temperature ratings and may affect the attenuation results.

Changes in Coating Diameter on Exposure to Heat in Air

The urethane-acrylate polymers used in optical fiber coatings oxidize when heated in the presence of air. When coated optical fibers are heated in air (as the coating is oxidized), the volume and mass of coating decreases as the exposure time increases. Figure 6 below shows how the total coating volume (outer and inner primary combined) decreases with time upon exposure to higher temperatures.



Volume Change on Optical Fibers Exposed to Air at High Temperatures

Figure 6

Exposure of Corning's fibers to 85°C for a duration of 1000 hours (41 days) results in a slight loss of weight or volume. This negligible loss is expected and is accounted for by loss of absorbed water and volatile components, such as very small amounts of unreacted photoinitiator, stabilizers, monomers, and other materials not chemically bonded to the urethane-acrylate polymer network.

At higher temperatures, the oxidative degradation of the coating happens rapidly as seen by the progressive decreasing of coating volume. For temperatures of 150°C and above, the coating volume decreases steadily with exposure time. At 200°C, nearly a third of the coating volume is lost after 10 hours of exposure. At 300°C, most of the coating volume is lost within the first 24 hours of exposure.

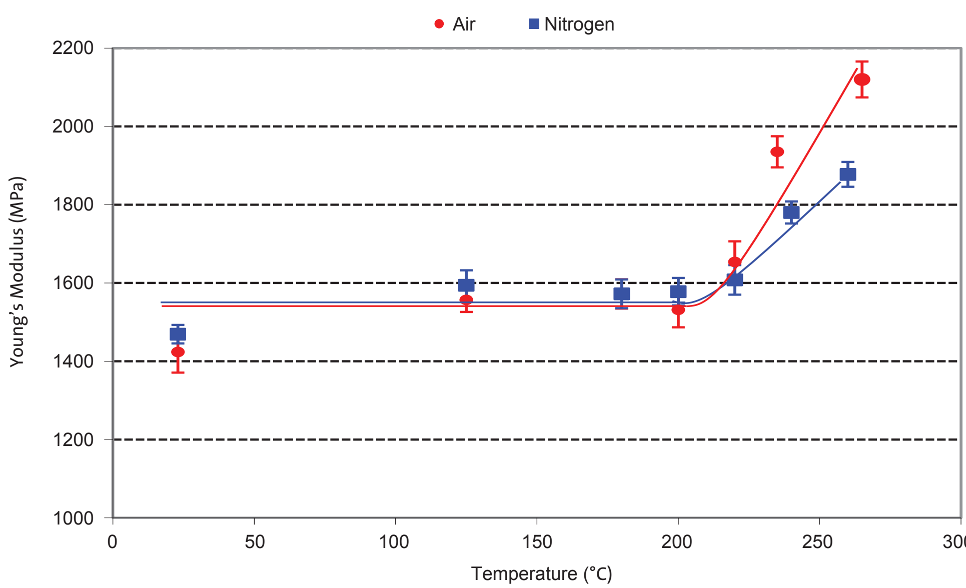
Coating Mechanical Property Changes with Heat Exposure

The mechanical properties of outer primary coating rods were evaluated after a 2.5 hour exposure to temperatures ranging from ambient to 265°C.

For cable designs or other applications where there is limited oxygen or air, Corning evaluated the coating's mechanical properties in a nitrogen atmosphere. Then all measurements were done in both air and nitrogen atmospheres.

Coating rods were made for this test by injecting liquid coating into Teflon® tubes of approximate 0.022 inches of internal diameter. The filled tubes were then cured with ultra violet light and the Teflon tubes were removed to expose the cured coating rods.

Figure 7 shows the change in Young's modulus of the outer primary coating rods after 2.5 hours of exposure to high temperatures in both air and nitrogen atmospheres. As seen in this figure, there is no appreciable change in Young's modulus until the temperature reaches the 200-220°C range. Once this temperature is surpassed, the modulus rises significantly for both air and nitrogen environments.

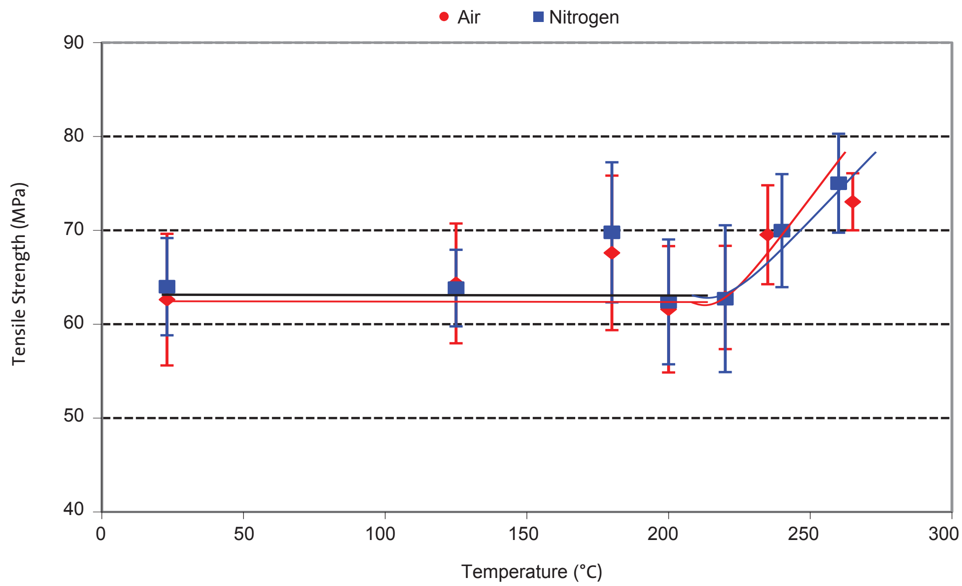


Young's Modulus of Outer Primary Coating Rods

Figure 7

Tensile strength and elongation at break were also evaluated on coating rods exposed to 2.5 hours at high temperatures in air and nitrogen. The tensile strength was observed to increase in both atmospheres when the temperature reached 220°C, while the elongation at break yielded a falloff when temperature exceeded 180°C, as shown respectively in Figure 8 and Figure 9.

Figure 8 shows the tensile strength of the outer primary coating rods after 2.5 hours exposure to high temperatures in both air and nitrogen media.

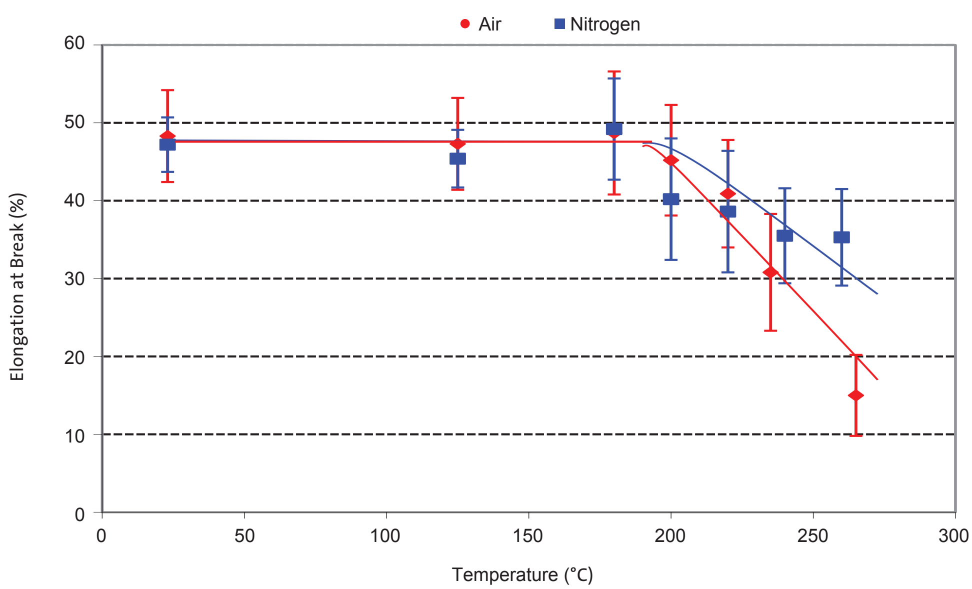


Tensile Strength of Outer Primary Coating Rods

Figure 8

The observation of increased tensile strength with reduced elongation at break was consistent with increased cross-linking occurring at temperatures of 200°C to 220°C and higher.

Figure 9 shows the elongation at break for the coating rods after being exposed for 2.5 hours to up to 300°C in air and nitrogen.



Elongation at Break for Coating Rods

Figure 9

Summary

The thermal stability of CPC® coated optical fibers has been comprehensively studied – in air for optical fibers and in air and nitrogen for coating rods. The reader should bear in mind that all this experimentation was conducted on bare fiber in loose coil deployment; different deployment conditions could affect the results.

As expected, the results show progressively more changes in the coating as the temperature increases and as the exposure times increase. Performance at 85°C heat exposure is within the Corning's specification, with minimal coating volume loss due to loss of volatiles that are not incorporated into the polymer coating network. Exposure to 150°C and 200°C in air results in very small attenuation increases but does result in the gradual loss of fiber coating volume. This work suggests that this coating system could handle 100 hours at 150°C, about 20 minutes at 200°C and about 5 minutes at 250°C. However, these are not operating ranges specified by Corning Optical Fiber. Exposure to longer time periods or higher temperatures would result in the loss of the coating properties to protect the optical fiber from mechanical and environmental conditions.

The evaluation of coating rods exposed for 2.5 hours to heat in air show no significant change in Young's modulus until the temperature reaches the 200 – 220°C range, followed by a significant increase at higher temperatures. Correspondingly, the tensile strength increases and the elongation at break decreases above 200°C, consistent with increased cross-linking. While similar results were observed on exposure of the coating rods to heat in nitrogen, the extent was lower compared to air atmosphere.

It is important to note that Corning's Specialty Fiber division manufactures optical fibers specially engineered to operate at extreme temperature conditions. For more information please contact your Corning sales representative.

Corning Incorporated
www.corning.com/opticalfiber

One Riverfront Plaza
Corning, New York
USA

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

WP4250