Verification of Optical Fiber and Cable Reliability

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Abstract

As environments are becoming increasingly harsh, the ability of optical fiber cable to withstand such environments is of the utmost importance to outside plant users. Laboratory accelerated aging environments have long been used as a measure to predict field performance of optical fiber and cables' ability to withstand harsh environments. However, there has been an issue in linking the laboratory environments with actual field exposure. To this end, actual field data from such a cable should provide real evidence of an optical fiber cable's ability to withstand these environments, thus providing the link between actual long-term reliability and laboratory tests.

In the present study, a 10 year-old field-aged cable was extracted from its deployed environment and tested to determine its resilience in withstanding mechanical and environmental conditions. In order to assess its resilience, a wide range of tests was performed on the aged cable and its components. The results of these tests were compared to test results obtained from unaged samples of the same era as well current data on the same design.

Surface roughness of the fiber was determined using an Atomic Force Microscope (AFM). Strength testing was conducted to verify failure probability. In addition, fiber strip force testing and Fourier Transform InfraRed (FTIR) analysis were conducted to determine the effect of aging on the coating materials.

Optical and material performances of the cable under mechanical stress were compared to historical test data on the single-armored, six-position, loose-tube cable design. These tests were performed in accordance to industry standard requirements. Testing results showed that there exists no significant degradation in the optical fiber cable's performance, which verifies laboratory testing and speaks to the true reliability of optical fiber cable.

Cable Design and History

The design is a single-armored, six-position cable (see Figure 1) which contains two live gel-filled 2.5/1.5 mm tubes with six fibers each, three soft fillers and one hard filler. The cable was manufactured in 1987 in compliance with Bellcore Specifications TR-TSY-000020, Issue 3 requirements. The fiber is Corning® SMF-28™ CPC3 standard single-mode optical fiber.

In 1987, the cable was installed in Oregon, at the base of the Cascade Mountain foothills, between the town of Medford and the Rogue River. The geography of the installation site indicates that it is a river valley surrounded by four mountain ranges. East of Medford are the Cascade Mountains with an elevation of 4,000(1219.5m) to 9,500 feet(2896m) and west of Medford are the Coast Range Mountains with an elevation of 3,500(921.1m) to 5,500 feet(1676.8m). North of Medford is the Umpqua Divide with elevations from 3,500(921.1m) to 5,500 feet(1676.8m) and south of Medford are the Siskiyous Mountains with elevations from 3,000(914.6m) to 7,600 feet(2317m).

The approximate mean annual temperature for Medford is 53°F(11.7°C) with recorded low temperatures of 0°F(-17°C) and high temperatures of 100°F(37°C). The mean annual precipitation averages 20.6-in(52.4 cm.) and average annual snowfall is 8.1 in (20.6cm). Because of it's geographical location, Medford is subjected to annual flooding and mudslides. A mudslide in 1997 was responsible for 200 feet

(61m) of this cable surfacing in a washout. The customer decided to reroute and replace the cable since the vicinity of a mudslide remains unstable for long periods. After rerouting the new cable, 86 feet of the 1987 cable was removed from a manhole and sent back to Pirelli Cable and Systems North America research facility for evaluation.

The 10-year-old field aged cable was an opportunity to benchmark and compare some of the mechanical, material and optical performances of a field-aged cable with original test results recorded on this 1987 cable design.

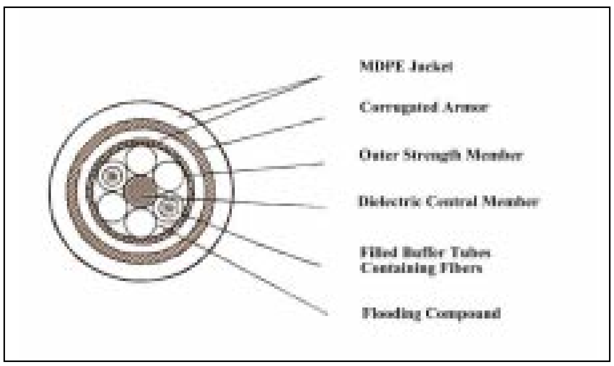

Figure 1. Loose-Tube Cable Structure

Cable Testing

Because only an 86 foot(26 meter) length of cable was available, it was necessary to limit the testing to the most significant areas of performance. Cable twist, flex, compression and impact, water penetration, compound flow, cable jacket shrinkage, tensile elongation of the outer jacket and fiber stripability were selected to be conducted at Pirelli's research facility. These tests would provide the information on cable performance after 10 years of field service and allow comparison with the original data acquired during the time of manufacture as well as with current requirements. Additional fiber tests were scheduled at Corning.

The cable was evaluated against the requirements of Bellcore specifications TR-TSY-000020 issue 3, GR-20-CORE issue 1, and the corresponding Electronic Industries Association (EIA-FOTP) test procedures with regard to mechanical and material performance.

Additional internal tests referred to as Product Capability Test (PCT) were performed upon completion of the tests, according to the requirements of the above Bellcore specifications. Cable performance in PCT provides important data by defining the capabilities of the cable design when tested beyond the requirements of the detailed specifications. It also provides valuable information when used to compare the field aged fiber optic cable performance with test data obtained for this design in the 1987 Initial Product Qualification.

PCT requirements are similar to Bellcore specifications with the exception that mechanical tests are more rigorous due to increased repetitions in the cable impact and cyclic flexing. Cable twist sample length was reduced from 4 meters to 2 meters. The PCT compressive strength test was performed with an increased load.

In the earlier Bellcore specification, the optical requirements for mechanical testing required measurements to be taken at the 1310 $\pm$ 20 nm wavelength for dispersion-unshifted single-mode fibers. The optical changes were based upon the total average change of at least four randomly chosen fibers. However, PCT and the current Bellcore specification require optical measurements at the 1550 nm wavelength and a minimum of 10 fibers for cables with six fibers per tube. Optical performance was monitored on all of the fibers in this twelve-fiber cable design.

The test setup required a minimum cable length of 18 meters with both cable ends stripped of the cable jacket for approximately 1 meter to expose the core components. The prepared length of the cable was placed through the mechanical test apparatus.

The 12 fibers were concatenated into a loop by fusion splicing. One end of the loop was fusion spliced to a 1000-meter pigtail connected to an Optical Time Domain Reflectometer (OTDR). The operational settings on the OTDR were based on 2 point dB loss with a 100 nanosecond pulse width. The horizontal and vertical scales were maximized in order to view all fibers under test on the OTDR display. Initial measurements before each test consisted of overall dB loss for the 12 fibers and individual measurements of each fiber. The fibers were identified by distance markers on the OTDR as shown in Figure 2.

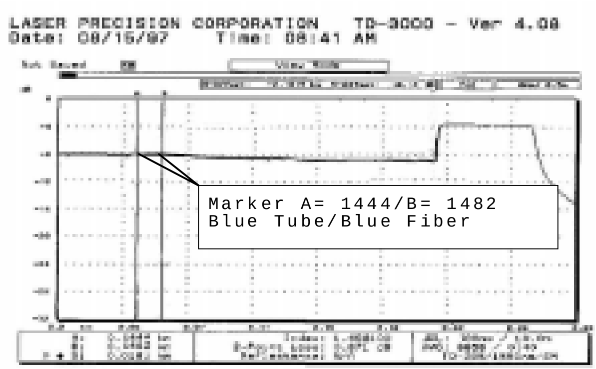

Figure 2: OTDR trace of fiber distance marking

The mechanical tests were performed according to the Bellcore specification followed by the PCTs. PCTs were performed in areas adjacent to the original test sites.

The cable was dissected upon completion of all tests to determine presence of mechanical damage. Examination of the jacket and armor was made under 10-x magnification at each test site.

The mechanical requirements of TR-TSY-000020, Issue 3, and GR-20-CORE, Issue 1 are shown in Table 1. Table 2 lists the mechanical test results obtained on the cable sample and Table 3 displays PCT requirements along with the performance of the test cable compared to these criteria. In both cases, the results show no evidence of deterioration in cable performance.

Based on the test results, there is no degradation in the optical or mechanical performance of the cable. The cable passed all the requirements of both Bellcore specifications (past and present) in Impact Resistance, Compressive Strength, Cable Twist, and Cyclic Flexing. The PCT results are comparable to data collected on similar cable designs.

Material Samples

All samples were conditioned according to the requirements of the Bellcore specification(s) and the EIA/TIA FOTP. The optional preconditioning cycle in compound flow allowed by the earlier Bellcore specification was omitted.

The summary of material requirements and results shown in Tables 4 and 5 also confirm that no cable degradation occurred.

An additional test was performed on the PBT buffer tubes due to concerns on the aging performance of this material. There is no apparent degradation of the PBT buffer tubes according to the comparison of the unaged and field aged test results in Table 6.

Fiber Testing and Results

While some of the cable was allocated for cable testing, a smaller section was reserved for fiber testing. Fiber samples were removed and subjected to a battery of fiber tests. The results from the field-aged fiber were compared to the appropriate recently manufactured fiber characteristics, and in accordance with relevant industry requirements. Fiber testing included strip force, atomic force microscopy, FTIR (Fourier Transform Infra-Red) analysis, dynamic fatigue, and strength testing.

Strip Force Testing

Strip force measurements give an indication of the fiber handler's ability to remove protective coating from the glass portion of the fiber without incurring damage. Strip force testing was conducted in accordance to FOTP-178 and EIA/TIA-455-178 "Measurements of Strip Force Required for Mechanical Removing Coatings from Optical Fibers." For this test, a total of 10 samples of each available fiber were tested for peak strip force (Newtons) and compared to a desired peak strip force range of 1.3N to 8.7N as outlined in Bellcore Document GR-20, issue 1.

Strip force testing results are summarized in Table 7. The aforementioned information shows that fibers dissected from the field-aged cable are comparable in strip force to those that were manufactured during the same time-period, but not cabled. The mean peak strip force average for both field-aged fibers is 3.09N.

Dynamic Fatigue and Strength Testing

Dynamic fatigue and strength testing were conducted to determine the effect of field aging on inherent fiber strength characteristics. Several samples were tested after having been pre-conditioned in a 23°C, 50% R.H. experimental environment. Due to the amount of fiber available, the samples were distributed equally among the four strain rates (0.025%, 0.25%, 2.5%, 25%) resulting in four fiber samples per strain rate.

Table 7 shows the results of the strength testing conducted on the fiber from the field-aged cable.

Figure 3 compares the Weibull distributions of the samples for aged and non-aged fiber at the 2.5%/min strain rate. The field-aged fibers had median strengths comparable to non-aged samples at the associated strain rates.

Figure 4 shows the results of dynamic fatigue testing. The results show that for dynamic fatigue, the field-aged fiber meets the proposed, GR-20 issue 2, Bellcore criteria of $n_d \geq 18$ with a n_d=19.4. Thus, testing has shown that no significant degradation in strength or dynamic fatigue characteristics has occurred to the tested fibers due to 10 years of environmental field aging.

Atomic Force Microscopy

Atomic force microscopy has been shown to be a useful technique for examining extremely small surfaces. For this reason, AFM testing was conducted to confirm the effect of field aging on the fiber.

AFM testing results are shown in Table 7 and three-dimensional images are provided in Figures 5 and 6. Results show that surface roughness values for the field-aged fiber bear a close resemblance to fiber of the same vintage that has been archived and fiber that was recently manufactured.

Based on this data, it can be deduced that the field-aging conditions did not seriously affect the surface roughness of the fiber.

Fourier Transform Infrared (FTIR)

FTIR scans of ink, inner primary and outer primary coatings were conducted to determine the effect of field aging on the chemical compositions of the aforementioned materials. The data shows that for both field-aged ink and coating samples, close matches were found with existing, known materials. The results show that the field-aged fiber has the same chemical characteristics as recently manufactured fiber with the same vintage CPC3 coating.

Summary and Conclusion

After significant aging in the field, the ability of this optical fiber cable to withstand harsh environmental conditions and remain in excellent condition was tested. As a result of the battery of testing that was conducted on this particular cable, it can be concluded that the reliability of optical fiber cables is such that reliability and lifetime models created to predict in-field service are more than suitable to accurately predict fiber and cable reliability. Optical and mechanical testing was conducted on both fiber and cable to verify performance after field aging. All testing indicates no degradation in fiber/cable performance. Thus, the reliability of optical fiber/cable has been verified.

Table 1: Bellcore Specifications Mechanical Test Requirements

	TR-20, Is. 3 Test Setup	GR-20, Is. 1 Test Setup
Impact Resistance	6.0 kg load 25x 150 mm drop distance	4.0 kg load 25x 150 mm drop distance
Compressive Strength	440 kg for 10 minutes	300 kg for 10 minutes
Cable Twist	4 m length 10 cycles of ± 180° twist	2 m length 10 cycles of ± 180° twist
Cable Cyclic Flexing	25 cycles on mandrel 20 x cable OD	25 cycles on mandrel 20 x cable OD

Table 2: Mechanical Test Results

Test	TR-20, Is 3 Specification	GR-20 Is. 1, Specification
Impact Resistance	Pass/ 0.05 dB @ both wavelengths	Pass/ 0.00 dB @ 1550 nm
Compressive Strength	Pass/ 0.05 dB @ both wavelengths	Pass/ 0.00 dB @ 1550 nm
Cable Twist	Pass/ 0.00 dB @ both wavelengths	Pass/ 0.00 dB @ 1550 nm
Cable Cyclic Flexing	Pass/ 0.00 dB @ both wavelengths	Pass/ 0.00 dB @ 1550 nm

No splits or cracks in cable sheath or armor under 10x magnification found at any of the test sites.

Table 3: Product Capability Test Requirements and Test Results

Test	Test Setup	Results
Impact Resistance	6.0 kg load increase # 30% 150 mm drop distance	Pass/ 0.02 dB @ 1550 nm
Compressive Strength	Increase load 30% for 10 minutes	Pass/ 0.05dB @ 1550 nm
Cable Twist	2 m. length 10 cycles of ± 180° twist	Pass/ 0.00 dB @ 1550 nm
Cable Cyclic Flexing	Increase cycles 30% on mandrel 20 x cable OD.	Pass/ 0.00 dB @ 1550 nm

No splits or cracks in cable sheath or armor under 10x magnification found at any of the test sites.

Table 4: TR-TSY-000020, Issue 3 Material Test Requirements

Test	Requirements
Water Penetration	No leaks in 1 meter sample for 4 hours
Compound Flow	No drips after 24 hours @ 65°C
Jacket Shrinkage	Shrinkage < 5% each specimen
Jacket Tensile Elongation	Min. yield strength = 11.0 MPa , Elongation %= 400
Fiber Strippability	Remove 50 mm of coating ≤ 13.4 N force.

Table 5: TR-TSY-000020, Issue 3 Material Test Results

Test	Results
Water Penetration	No leaks in 1 meter sample for 12 hours
Compound Flow	No drips after 24 hours @ 65°C
Jacket Shrinkage	Shrinkage < 4% each specimen
Jacket Tensile Elongation	Min. yield strength = 13.5 MPa, Elongation %.> 500
Fiber Strippability	Remove 50 mm of coating ≤ 3.4 N force.

Table 6: Internal Material Test Result Comparison

Test	1987 Test Results	1998 Test Results
Buffer Tube Tensile (PBT)	Unaged=5800 psi 250% Elong @ break	Aged = 6900 psi 325% Elong @ break

Table 7: Fiber Test Result Summary

	Field-Aged Fiber	Archived or Recently Manufactured Fiber
Peak Strip Force	3.09 N	3.18 N**
Median Strength	677 kpsi	649 kpsi*
Surface Roughness	.29 nm	.12-.49 nm*,**

* Archived, **Recently Manufactured

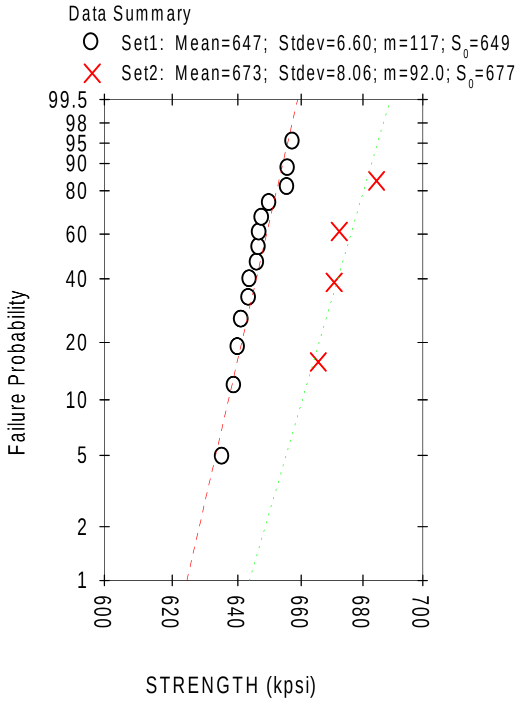

Figure 3: Comparison of field-aged fiber (Set 2) strength to non field-aged fiber (Set 1) strength.

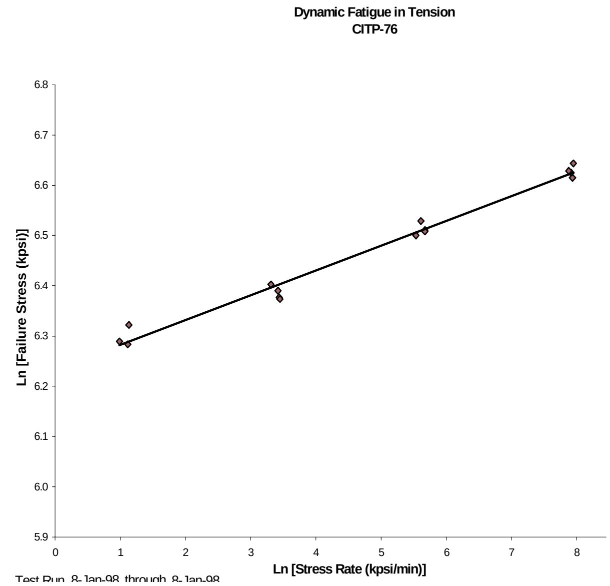

Figure 4: Dynamic Fatigue Data at each of the four strain rates (25, 2.5, 0.25, 0.025%/min)

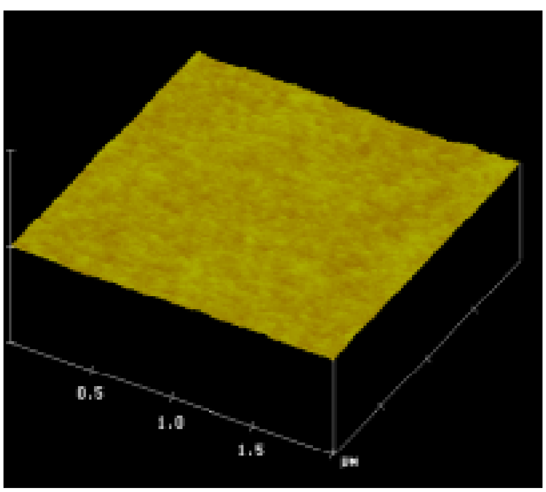

Figure 5: AFM scan for recently manufactured fiber with surface roughness of 0.12nm

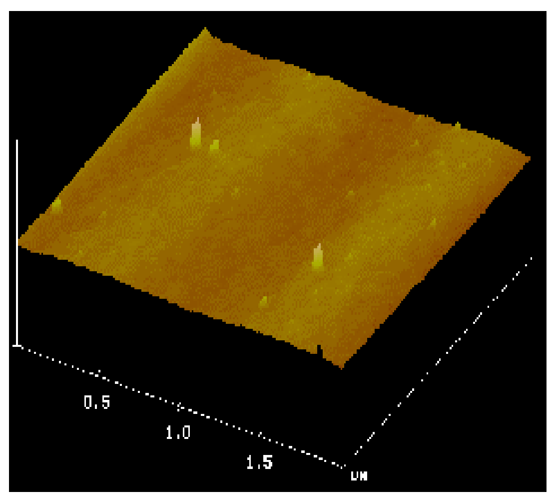

Figure 6: AFM scan of field-aged fiber with surface roughness of 0.29nm

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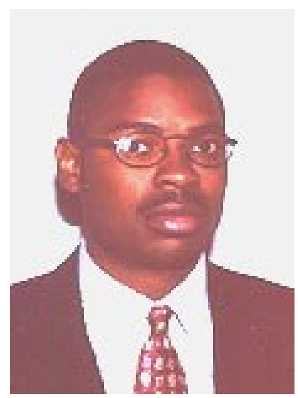

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