Mechanical and Optical Functionality
Of Field-Aged Optical Ground Wire Cable

Mark L. Lundergan
Corning Incorporated
Corning, NY 14830

Bernd D. Zimmermann
Alcoa Fujikura Ltd.
Spartanburg, SC 29304

Bill Waterman
MRC Telecommunications
Brookfield, WI

Abstract:

An optical fiber's mechanical and optical properties, after many years of exposure to extreme operating conditions, are important descriptors for long-term fiber and cable reliability. A joint study was recently conducted on a field-aged composite optical ground wire (OPT-GW) cable containing conventional silica-clad single-mode fibers with 250 μm acrylate coating. In the study, fibers from a 3.7 km length of 12-fiber OPT-GW cable were extracted and tested for several critical cable and fiber attributes. The results showed that the environment had no impact on the optical fiber cable's performance, functionality and reliability.

Introduction:

The reliability and handleability of optical fiber and OPT-GW fiber-optic cable are important long-term performance characteristics meaningful to both system owners and the manufacturers of those systems. By definition, reliability is successive and positive testing results for a particular performance attribute over time. For fiber it could be measured inherent strength over time, an attribute that may define the mechanical resistance to failure; an important reliability descriptor. Reliability measures also are important because they may define the life expectancy of a system.

Handleability, on the other hand, relates to the serviceability of a system. Being able to service the system, strip cable, prepare and strip fiber, make new connections, re-route fibers and general maintenance over many years of ever-changing conditions are all important to the system owners and give flexibility, value and performance to the system.

In 1993, Bellcore published findings indicating that 1/3 of all telecommunication outages are caused by fiber optic cable failures due to accidental digups [1]. The study stated concerns for system failures, reliability and handleability issues, all due to fiber strength and coating degradation. To the authors' knowledge, there have been no field failures due to fiber aging or material degradation. Furthermore, in the examination of other field studies [2][3][4] along with this study, it was found that normal to severe field-aging of fiber optic-cable systems has had no impact on reliability and handling performance.

The purpose of this study was to analyze field-aged cable and fiber attributes and compare those attributes to original cable and fiber specifications and performance characteristics. Attributes and characteristics such as attenuation, gas pressure tightness, color permanence, fiber strip force and strength after mechanical stripping give insight into the aging properties of cable and fiber, and may indicate any reliability or handleability concerns. Also, the data collected allows further comparison of laboratory-generated and the field-generated results.

As we move towards the third decade of installed fiber optics, opportunities to evaluate field-aged cable and fibers are becoming more important in our understanding of long-term reliability. These studies are increasing our comfort with the survivability, handleability and re-entry performance of optical fibers and cables in the field.

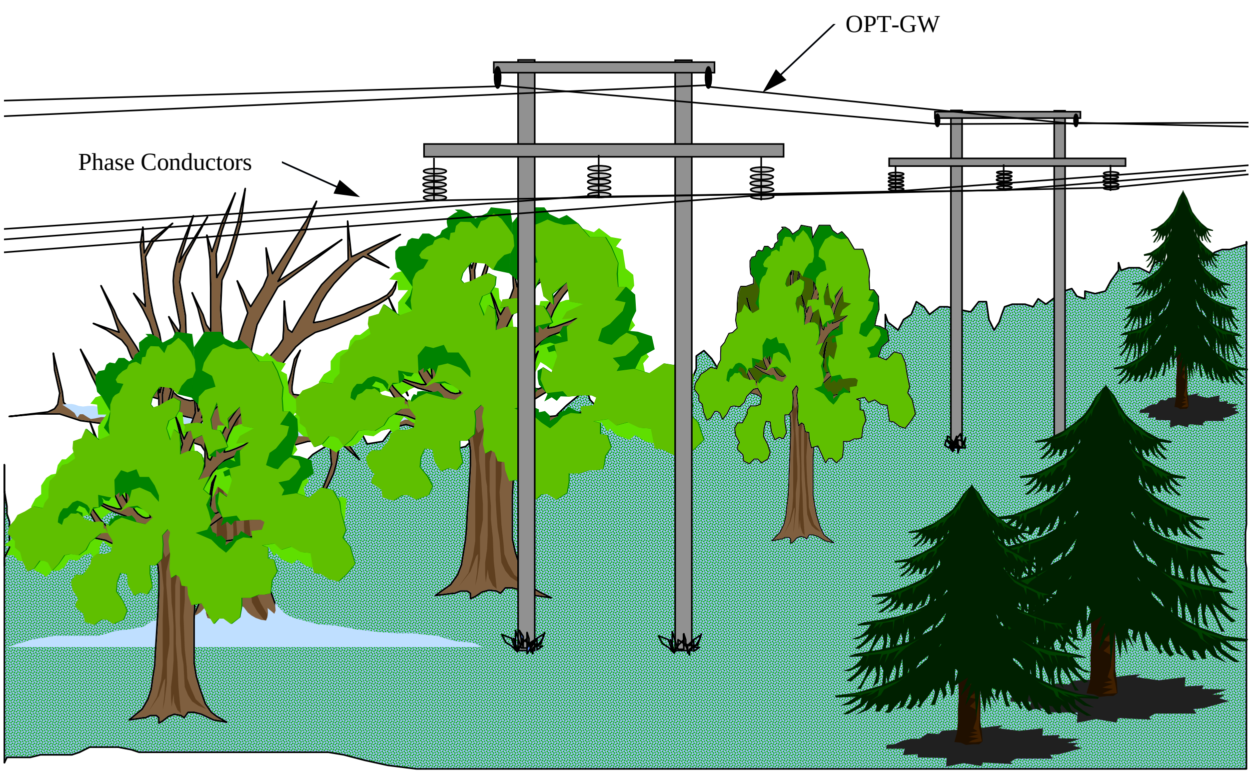

Figure 1: Typical OPT-GW Installation

Cable Design:

The cable in this study is a tight structure type optical ground wire (OPT-GW) design introduced to the electric utility industry in 1985. OPT-GW cable serves two primary functions:

1 - Installed at the highest position of a high voltage transmission line (Figure 1), the cable serves as a lightning shield and ground fault for the current-carrying phase conductors strung below. This function traditionally has been provided by a static wire. OPT-GW cable includes metallic components to provide the electrical path to ground.

2 - The cable contains optical fibers in its center, transmitting optical signals at high data rates over long distances. A primary advantage of an OPT-GW cable over a buried fiber optic cable is its reliability. This is due to the rugged construction and placement high above ground level, minimizing the potential for accidental damage. Another advantage, is use of the electric utility's right-of-way.

The design of the OPT-GW cable in this study is shown in Figure 2. The nomenclature $56mm^2/469$ refers to the cross-sectional area of the stranded aluminum-clad steel wires ($56mm^2$) and the outer diameter in thousandths of an inch (0.469"). Although this nomenclature involves both English and metric units, currently it is the standard method of identifying a particular OPT-GW design in the industry.

The OPT-GW cable supplied to the customer in 1986 includes a steel central strength member which is coated with a soft polymer jacket. A total of 12 single-mode optical fibers are helically stranded around the coated central strength member, and embedded in a soft polymer matrix which couples the fibers to the central strength member. A dual layer sheath is applied over the soft polymer matrix, forming the optical unit. Aramid yarn and heat resistant tape are stranded over the sheath of the optical unit before it is inserted into an aluminum pipe. The aluminum pipe provides a significant amount of the total conductance of the cable. The yarn and tape provide a heat barrier to the optical unit under fault current conditions when the temperature inside the cable can exceed 100 °C for fractions of a second. The yarn also provides a means to tie off and strain-relieve the optical unit at each splice enclosure. The cable construction is completed by stranding 11 aluminum clad steel wires over the aluminum pipe. These wires not only provide the majority of the tensile strength of the cable, but also provide most of the cable's conductance.

All of the fibers in this study were standard silica-clad single-mode fiber coated with a mechanically strippable dual layer acrylate coating system. Such fibers have been produced widely since the mid 80s. Six of the fibers were overcoated with a thin layer of solvent based colored ink and the remaining six were left uncolored.

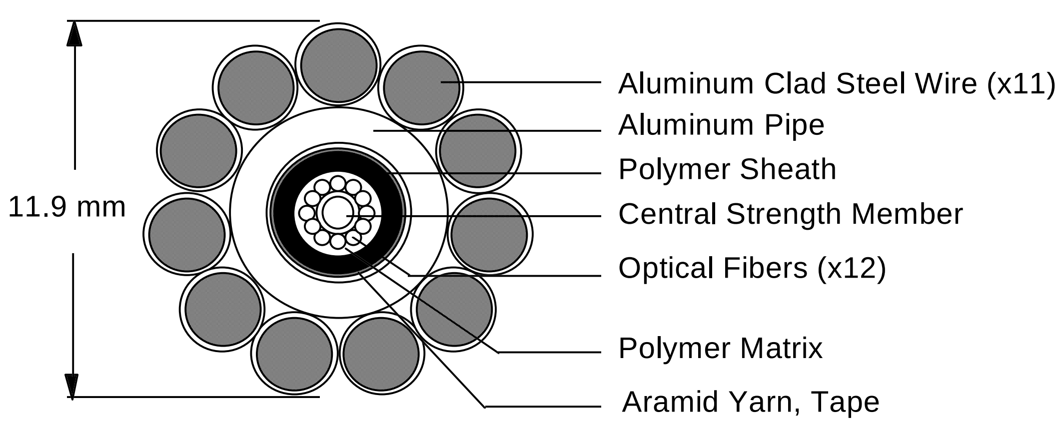

Figure 2 - 56mm^2 / 469 Opti al Groundwire Cable

Cable Installation Background:

The 12-fiber OPT-GW cable formed part of a fiber network located in the southern part of Wisconsin. The cable was manufactured in January 1986 and installed during the first quarter of 1986. The approximately 3.7 km of cable (reel A-021) was installed on a 138 kV high voltage transmission line of the WPL Rock River-to-Darlington route. The system was activated that same year.

After nine years of functional operation, the owner of the system de-installed the cable in 1995, and allowed the cable manufacturer and fiber supplier to conduct the reliability verification tests described in this paper. To accurately evaluate the aging performance of the de-installed OPT-GW cable, it is critical to understand the environment and stress history in which the cable had been operating for more than nine years. Of particular interest is the climatological and in-service stress history of the cable.

Weather and Stress History

Due to the low temperatures, high winds and amount of frozen precipitation during the year, the southern Wisconsin area is considered to be a heavy loading area by the National Electrical Standards Committee (NESC). During an average winter, the cable may encounter maximum sustained winds of up to 64 km/h, temperatures as low as -29°C, and radial ice loading of up to 1.3 cm.

Actual extremes, as reported by the National Weather Bureau [5] in Madison, Wisconsin during the nine-year time frame are summarized in Table 1. Figures 3, 4 and 5 show graphs of these five parameters as quarterly extremes from January, 1986 through December, 1995.

Based on the information above, and a final everyday stress (EDS) of approximately 10.9% of the cable's rated breaking strength (RBS) obtained from the sag and tension tables used for the installation, it is possible to estimate the cable's strain history. Since the design of the OPT-GW cable utilizes a tight structure construction, fiber strain is approximately equal to the cable strain. The duration and magnitudes of the cable stress (% of RBS) and fiber strain (%) based on an average span length of 177 meters are summarized in Table 2. As is evident from this table, the fibers inside the OPT-GW have experienced a significant amount of strain throughout the nine years.

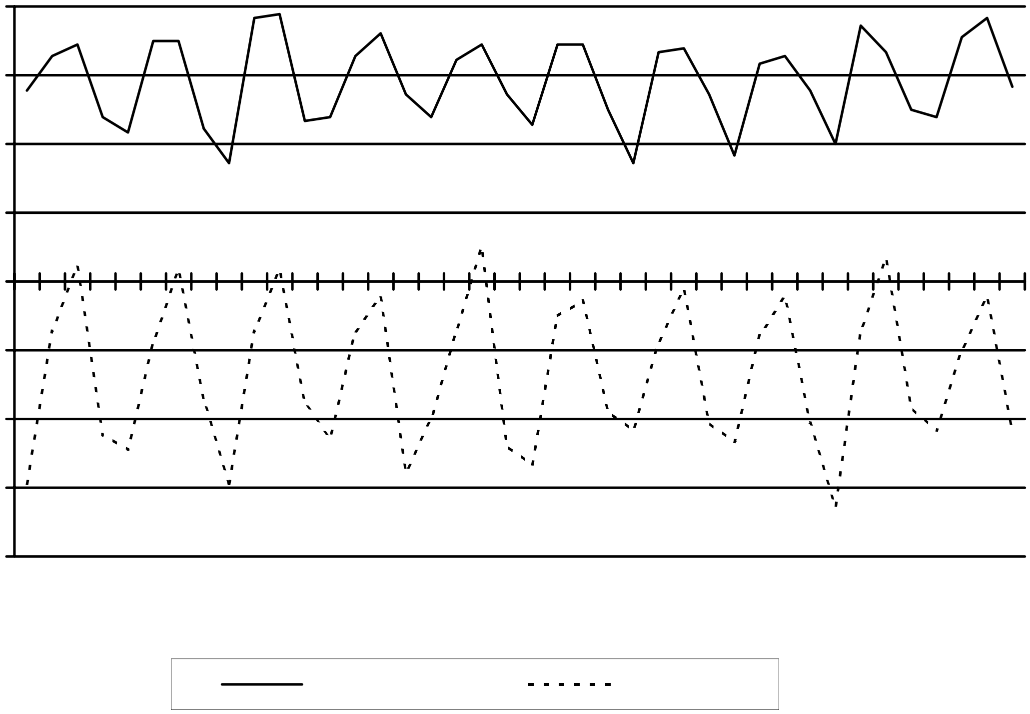

Figure 3: Temperature (1986 - 1995) Madison, WI

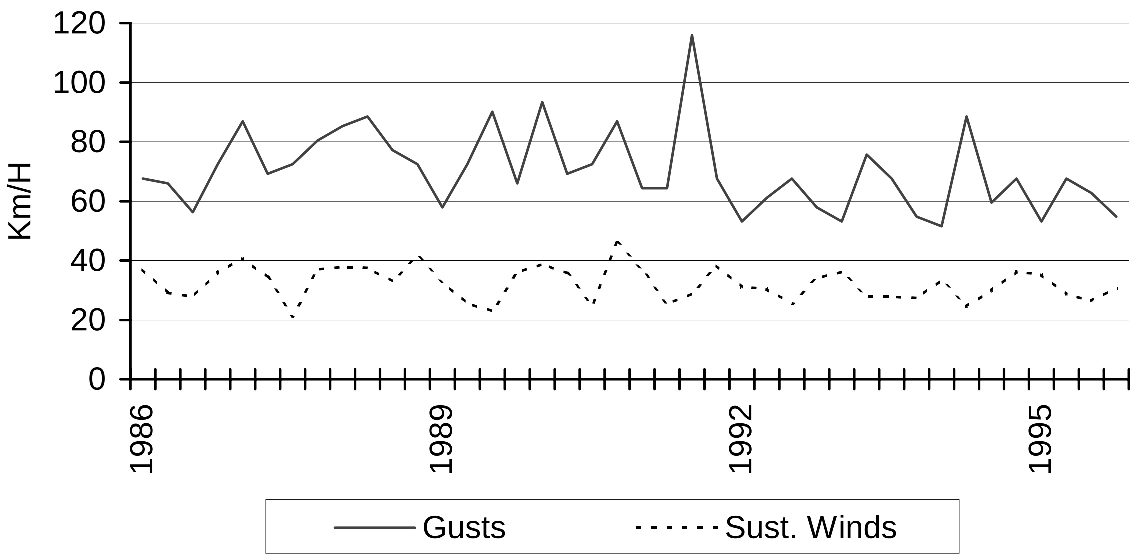

Figure 4: Wind Velocity (1986 - 1995) Madison, WI

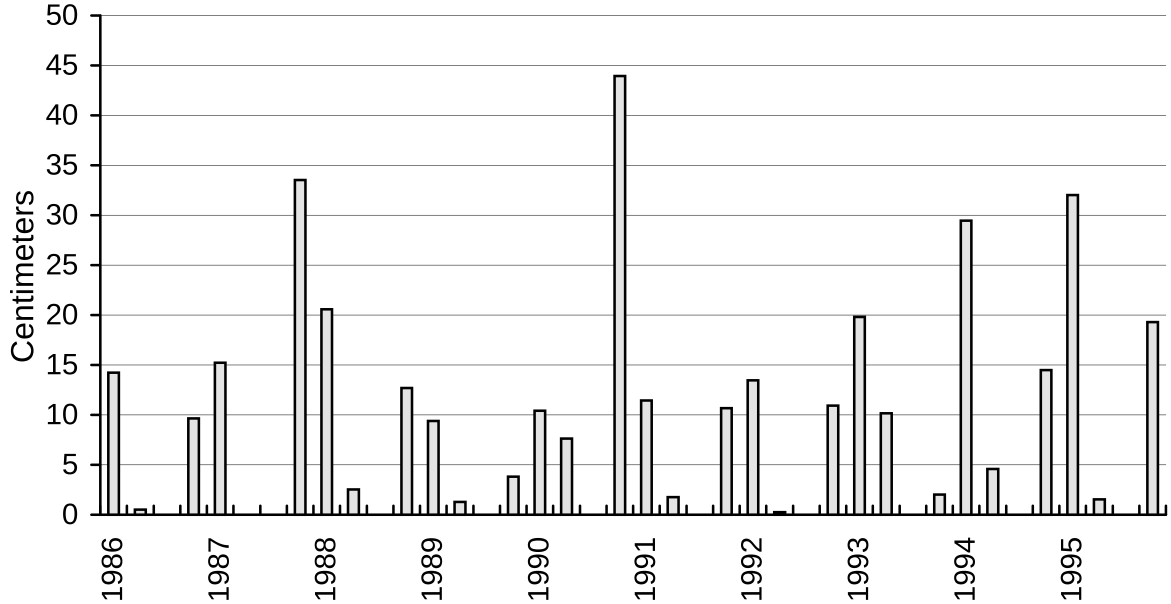

Figure 5: Snowfall (1986 - 1995) Madison, WI

Table 1: Extreme Weather Conditions
January 1985 - December 1995
National Climate Date Center

Minimum Temperature	-33°C	January 18, 1994
Maximum Temperature	39°C	August 16, 1988
Maximum Snow Fall	44 cm	December 3, 1990
Max Sustained Wind	46 km/hr	December 20, 1990
Max Wind Gust	116 km/hr	July 7, 1991

Table 2: Strain History of Retrieved OPT-GW

Condition	Duration (hrs)	Stress (% of RBS)	Strain (%)
Final EDS	78,840 *	10.9	0.08
Ice and Wind	72 **	28.6	0.20
Low Temp	72 **	16.7	0.12
Max Wind Gust (13 psf)	< 1 ***	15.3	0.11
Min Temp (-27°C)	2 - 3 ***	17.3	0.12

* (24 hrs/day) x (365 days/yr) x (9 years) = 78,840 hrs
** (8 hrs/year) x (9 years) = 72 hrs
*** Actual conditions encountered on 7/7/91 and 1/18/94

Cable Testing and Results:

To verify the condition of the retrieved OPT-GW cable, and to assess the cable and fiber handleability and reliability performance after nine years of service, several critical cable/fiber performance attributes were evaluated. Visual observations were made, attenuation performance and temperature dependence were measured and pipe gas pressure was checked to evaluate any aging or deterioration of the OPT-GW cable and fiber.

The test measurements obtained then were compared with those obtained before cable installation. Since some of the tests performed were not originally part of the original inspection, it was necessary to use typical performance data for cable and fibers of this vintage for comparison. The cable was shipped to the cable manufacturer for evaluation and the first round of testing. The cable was inspected for obvious signs of aging, corrosion, fatigue, deterioration and other signs of damage. None were found.

Attenuation by OTDR

All fibers were measured for normalized 1310nm and 1550nm attenuation. Measurements were made using a Photon Kinetics 6500 Single-Mode OTDR in accordance with industry recommended test procedures. The values were compared to both the original performance values and the original cable specification. The results are summarized in Table 3.

Table 3 shows the attenuation results after nine years exposure. The results show a range of values at both 1310nm and 1550nm: 0.33 - 0.37 dB/km at 1310 nm and 0.22 - 0.26 dB/km at 1550 nm. All values are consistent with as manufactured values and the original 1985 specification requirements. This indicates that the cable still is performing well with no signs of attenuation increase due to aging.

Temperature Cycling

The second cable/fiber performance test consisted of temperature cycling the cable from -40°C to +85°C. The temperature cycle test was performed in accordance to a modified version of IEEE-P1138 Std (1994) [6]. Fibers were randomly spliced and concatenated together to form a continuous fiber path of approximately 23 km. Attenuation was monitored using an LED source and power meter operating at 1550 nm during the entire test.

The cable was taken from room temperature to -40°C, and held there for 24 hours. The cable then was taken from -40°C to +85°C, and held at that temperature for 24 hours. The same cycle (-40°C to +85°C) was repeated before returning to room temperature. Figure 6 shows the measured attenuation change (dB/km) versus the chamber temperature and time of test. Attenuation changes at 1550 nm across the -40°C to +85°C range remained below 0.01 dB/km, and well below the original 0.20 dB/km cable specification. This result also compares well to current OPT-GW temperature dependence data.

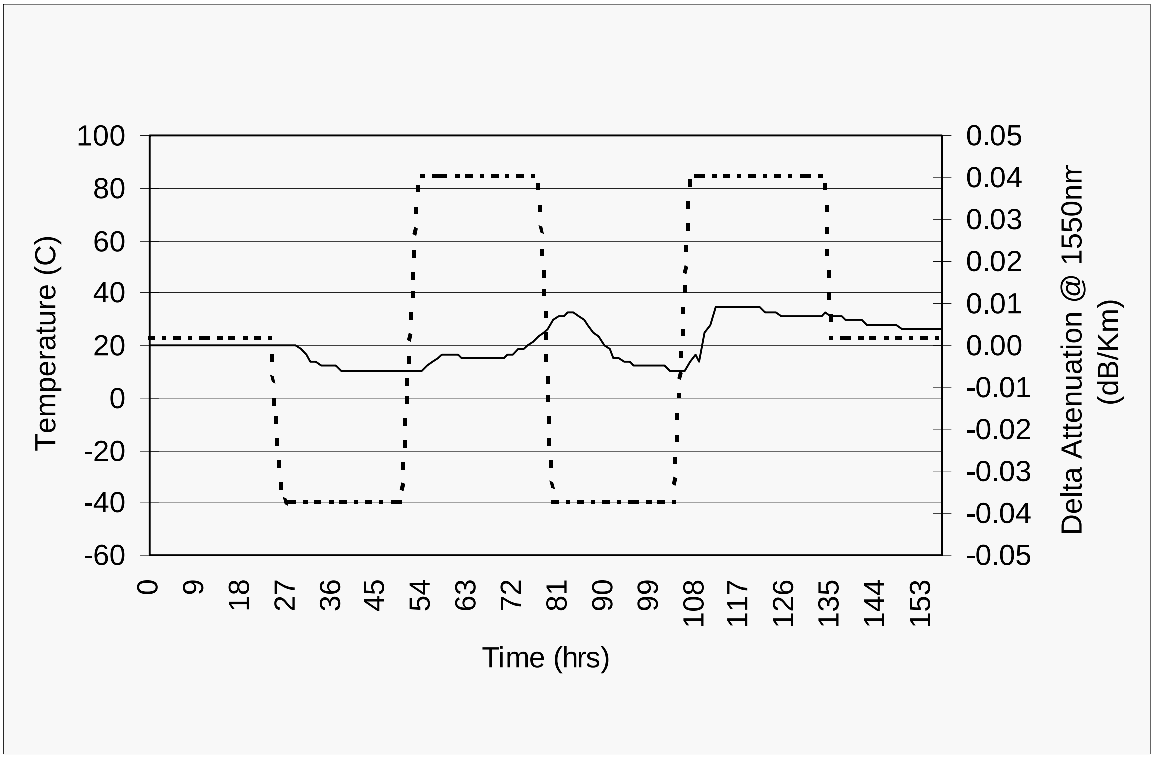

Figure 6: Temperature Dependence

Table 3 **OTDR Attenuation Results**

OTDR Length = 3734 m

Position	Color	1310 nm (dB/km)	1550 nm (dB/km)
1	Red	0.34	0.23
2	Clear	0.33	0.22
3	Blue	0.37	0.26
4	Clear	0.33	0.22
5	Green	0.35	0.25
6	Clear	0.35	0.24
7	Yellow	0.35	0.23
8	Clear	0.34	0.23
9	Brown	0.34	0.22
10	Clear	0.35	0.24
11	Black	0.36	0.24
12	Clear	0.33	0.24
1995	Average	0.345	0.234
	Std Dev	0.012	0.012
1985	Specification	≤ 0.50	≤ 0.40
1985	Average	0.37	0.26

Gas Pressure Tightness Test

This test verified the integrity of the aluminum pipe which contained the 12-fiber optical unit. Since the aluminum pipe hermetically isolates the optical fibers from the external environment, it was decided to test the pipe for gas pressure tightness. The gas pressure test was developed by cable manufacturer to verify pipe weld integrity after manufacture, and is documented as test condition OTP-3-10-081.

The test was performed by applying approximately 65 psi of gas pressure at one end of the cable (A), while monitoring the pressure at the opposite end (B). Figure 7 shows the test set-up. The valve at end A is left open until the pressure starts to increase at end B. The pressure then is allowed to equalize at both ends to approximately 40 psi. The pass/fail criteria requires that the equilibrium pressure at both ends is maintained for at least five hours.

The pressure results are shown in Figure 8. The field-aged cable maintained equilibrium pressure for the required five hour period. The results confirm that no pipe degradation (such as cracking or weld splitting) had occurred anywhere along the 3.7 km length after nine years of service.

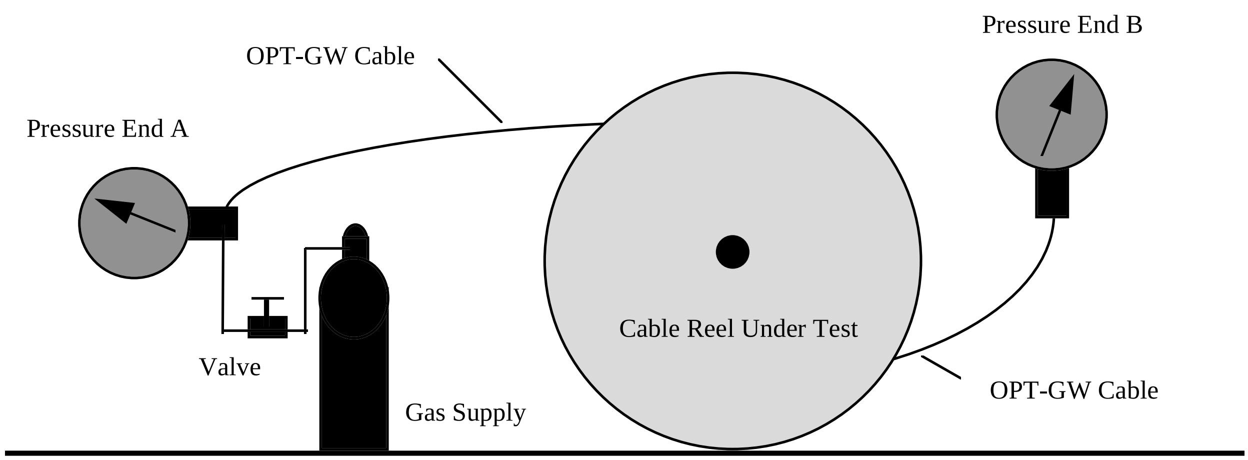

Figure 7: Gas Pressure Tightness Test

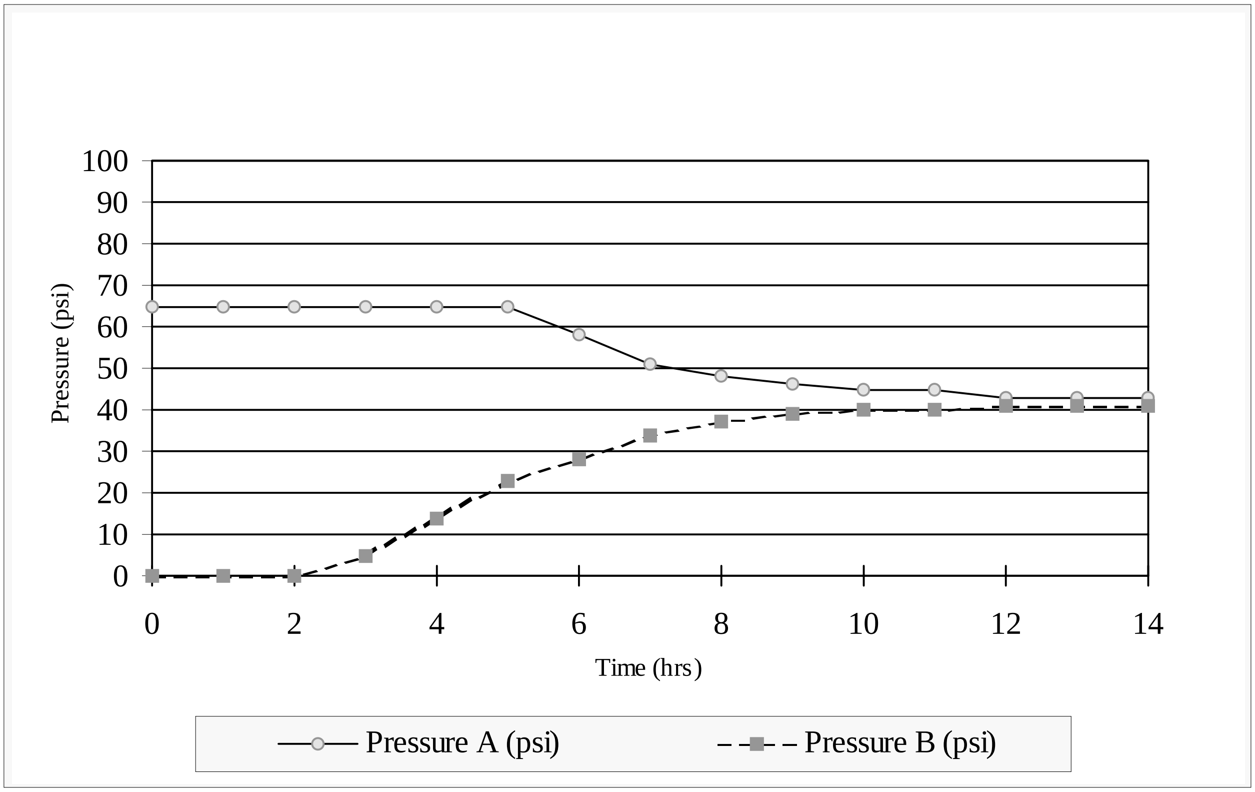

Figure 8: Gas Pressure Tightness Test

Fiber Testing and Results:

After the cable/fiber evaluation, fiber samples were carefully removed and subjected to a variety of fiber evaluations. The fiber results were compared to other fibers from the same era, industry requirements and as-drawn fibers. Testing included visual examination, color permanency, strip force, as-removed strength, strength after mechanical strip and FT-IR (Fourier Transform Infrared) analysis.

Each fiber was examined for any visual signs of abuse and deterioration. Technicians testing the fiber indicated that the fibers appeared normal and no issues were observed during the handling or testing of each of the 12 fibers. The technicians also indicated there was no obvious visual deterioration of either the colored or uncolored fibers.

Color Permanency

Color clarity and permanence were tested for each of the six colored fibers. Each fiber was tested using TIA/EIA- 359-A [7] and TIA/EIA-598-A [8] guidelines and each was given a Munsell Color System rating and compared to the required wire and cable limits. The ratings are listed in Table 4. All six colors were within the color tolerances outlined in the documentation and, more importantly, were clearly distinguishable and continuous in color around the circumference of the fiber.

Earlier published studies [9] show issues with color cracking and flaking after laboratory aging. There was no evidence of this with the field-aged samples.

Table 4: Munsell Color Values
(Hue Value/Chroma)

Color	Wire and Cable Limit	OPT-GW Cable
Red	10.5RP-5.5R 3-5/≥10	2.5R 3.5/12
Blue	7.5B-5PB 3-5.2/≥8	2.5PB 3.5/10
Green	9GY-5G 4-6/≥8	2.5G 4.5/12
Yellow	1.25Y-8.75Y ≥7.5/≥8	2.5Y 8.5/12
Brown	7.5R-7.5YR 2.5-4.5/4.5-8	10P 3.5/6
Black	N 0-2.3/0-0.5	N 1.5/0

Strip Force

Strip force testing was completed in accordance to test method EIA/TIA-455-178 "Measurements of Strip Force Required for Mechanical Removing Coatings From Optical Fibers" [10]. Strip force indicates a craftsman's ability to remove coating from the glass without undue fiber stress or breakage. In this test, 10 samples of each cable/fiber combination, both old and new, were tested for peak strip force (Newton) and compared to a desired peak strip force of 1.3 N to 8.7 N as outlined in Bellcore Document GR-20 [11].

A summary of the findings is listed in Table 5. The results show the fiber strip force for the field-aged OPT-GW cable was comparable to not only other fibers from the same 1985/1986 time frame (tested under the same conditions), but also to the newer generation OPT-GW/fiber combinations tested under the same conditions. All fibers met the Bellcore requirements.

Table 5: Fiber Strip Force Results

Sample	Mean Strip Force (N)	Std Dev (N)
Retrieved Cable (Uncolored)	4.08	0.62
Retrieved Cable (Colored)	4.13	0.29
10 year Archived, Coat A	2.12	0.14
10 year Archived, Coat B	3.16	0.33
New OPT-GW, Coat C	4.86	1.56
New OPT-GW, Coat B	2.89	0.29
Bellcore Requirement	1.3 - 8.7	

Fiber Strength

Fiber strength measurements were performed on 30 randomly selected fiber samples from the OPT-GW cable. The fibers were tested in tension at 2.5%/min rate with 50 cm gauge lengths. Environmental conditions were 22.2°C and 50% RH. Testing was also conducted on as-drawn silica-clad fiber of recent vintage. The results are summarized in Table 6. The field-aged fibers had a median strength of 665 kpsi (4.65 GN/m^2) while the current fiber samples had a median strength of 666 kpsi (4.65 GN/m^2). Strength degradation due to the phenomenon of zero-stress-aging was not observed.

Strength After Mechanical Strip Force

Strength after mechanical strip (SAMS) testing was completed on the field-aged OPT-GW/fiber samples along with recent as-drawn fibers. SAMS was performed to assess the fiber's handleability and strength after mechanical coating strip. In this test, fiber is strength tested (0.5m gauge length, 5%/min, in ambient conditions), using standard Instron equipment. Strength is tested after a 30 mm portion of the coating is mechanically removed from the center of the fiber. Standard "off-the-shelf" strippers are used to mechanically strip the acrylate coating.

A summary of the results is shown in Table 6. The data indicates that the aged cable/fiber samples are comparable to as-drawn fiber. For the retrieved samples the median SAMS was 156 kpsi (1.09 GN/m^2) compared to 161 kpsi (1.13 GN/m^2) for as-drawn fiber.

Table 6: Fiber Strength and Strength After Mechanical Strip

	As-Removed from Cable		Mechanically Stripped	
Sample	**Median Strength (kpsi)**	**Weibull Modulus, m**	**Median Strength (kpsi)**	**Weibull Modulus, m**
Retrieved Cable	665	> 90	156	3.3
Current Fiber Samples	666	> 90	161	2.4

FT-IR Testing

The final test performed was FT-IR spectroscopy. In this test, coating samples of the field-aged clear fiber, both inner and outer primary, were tested and compared to the same as-drawn coating system. Results show that the field-aged spectra, both inner and outer primary, and the as-drawn coating spectra match. These results would indicate that the chemical structure of the field-aged sample is consistent and comparable to as-drawn fiber and, more importantly, the field-aged coating appears to have all its as-drawn characteristics.

Discussion and Conclusion:

All indications are that the field-aged OPT-GW cable and fibers maintained their original performance; there is no indication that the fibers or cable have negatively aged over the nine years of harsh field-aging. Every attribute and characteristic checked, met or exceeded the original performance specification or met the performance of comparable as-manufactured fiber and cable.

There has been considerable debate over the phenomenon of "zero-stress-aging" where microscopic surface pits form on the fiber's glass surface when exposed to harsh laboratory environments like hot water for extended periods of time. These pits may lead to strength degradation and the perception of decreased reliability. There are few models that allow one to predict field aging behavior from laboratory aging behavior. However, as stated earlier, sufficient time has passed since the initial deployment of optical fiber cable to actually test the pervasiveness of this aging phenomenon. This study of actual in-service fiber, in addition to several others [2][3] demonstrates that such aging is not prevalent among cabled fibers.

In Summary, there is no indication from this study that the cable and fibers had experienced any degradation in performance since installation. The cable performed well, and fiber reliability and handleability seem to be consistent with as-drawn fiber characteristics. Furthermore, the results indicate that the particular OPT-GW cable design evaluated in this study provides excellent fiber protections under extreme environmental conditions. These conditions include documented cases of strong wind gust, heavy snow and very low temperatures during a nine year service life.

Acknowledgments:

At Corning Incorporated: The authors thank Dr. G. Scott Glaesemann, Dr. Anurag Dwivedi, P.T. Cruttenden, J.K. Cox and D.A. Clark for their technical advice, direction and experimental expertise.

At Alcoa Fujikura Ltd.: The authors wish to acknowledge Carol Campbell, Richard Turner, and David Reeve for assistance with data collection and cable testing.

References:

1. S.V. Lisle, "The History, Prevention and Impact of Fiber Optic Cable Failures," pp. 223-235, NFOEC 1993 Proceedings, June 14, 1993

2 A. Dwivedi, et al., "Optical Fiber Strength, Fatigue and Handleability After Aging in a Cable," pp. 727-734, IWCS Proceedings, 1994

3 J. Smith, et al., "Mechanical Behavior of Optical Fibers Removed From a Field-Aged Cable," pp. 848 -855, IWCS Proceedings, 1995

4 H. Yuce, et al., "Fiber Reliability Study of Field-Aged Optical Cables," pp. 705 - 711, IWCS Proceedings, 1992

5 National Climate Data Center, Federal Building, Ashville, North Carolina.

6 EIA/TIA Fiber Optic Test Procedure, 455-3A (IEEE-P1138 Std) 1994

7 EIA-359-A, EIA Standard Colors for Color Identification and Coding, 1984

8 EIA/TIA-598-A, Optical Fiber Cable Color Coding, 1994

9 A. Frantz, et al., "The Effects of Aging on the Discernibility of the Color Identification of Optical Fibers", pp 850 - 856, IWCS Proceedings, 1993

10 EIA/TIA Fiber Optic Test Procedure (FOTP-178)

11 Bellcore GR-20-CORE, Generic Requirements for Optical Fiber and Fiber Optic Cables, Issue 1, 1994