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Field-aging study shows strength of optical ground wire cable

The telecommunications industry has always relied on laboratory test results to ensure the long-term performance of optical fibers and cables in the field. Tests had to be developed to predict reliability because real-life installations were too recent to be considered long-term.

Now the industry is beginning to test field-aged cable. As we move toward a third decade of installed fiber optics, comparisons may be drawn between results of accelerated aging tests performed in laboratory environments and those of tests on fibers and cables that have spent years actually working under harsh field conditions.

Corning Inc. and Alcoa Fujikura Ltd. (AFL) recently conducted a joint study of a field-aged fiber-optic cable to determine whether aging in the field produces results different from those produced in laboratory environments. The subject of the study was a 3.7-km section of a 12-fiber optical ground wire (OPT-GW) cable manufactured by AFL. The cable was deployed in the field for nine years in southern Wisconsin, enduring some of the harshest conditions in the United States—temperature extremes, heavy ice loading, and high wind velocity.

Nine years in a harsh environment provides a severe field test of fiber-optic cable.

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Importance of lab testing

System owners and manufacturers have always valued the mechanical and optical reliability, as well as the "handleability," of optical fibers. For our purposes, a fiber's *mechanical reliability* refers to its inherent strength over time, which may define the mechanical resistance to failure and the life expectancy of a system. *Fiber handleability* relates to the ability of a system to be serviced. System owners must be able to strip cable, prepare and strip fiber ends, make new connections, re-route fibers, and perform general maintenance over many years of ever-changing conditions. *Optical reliability* refers to the system's ability to resist increased attenuation over time.

Until recently, these characteristics typically were studied using tests such as thermal aging, temperature cycle, and water soaks. In the field tests, performance of attributes such as attenuation, gas pressure tightness on the OPT-GW pipe, color permanence, strip force, and strength after mechanical stripping gives insight into the aging characteristics of the cable and fiber. These characteristics also may give insight into any reliability or handleability concerns, as well as possible correlation between laboratory and field-aging results. The purpose of the study was to analyze cable and fiber attributes and compare those findings to original cable and fiber performance characteristics and specifications.

The cable in this study is a tight-structure type OPT-GW design, introduced to the electric utility industry by AFL in 1985. OPT-GW cable serves two primary functions. Installed at the highest position of a high-voltage transmission line, the cable first serves as a lightning shield and a path to ground should a fault occur on the current-carrying phase conductors strung below. A static wire traditionally has provided this function. OPT-GW cable includes metallic components to provide the electrical path to ground.

Second, the cable contains optical fibers in its center, transmitting optical signals at high data rates over long distances. Utilities have been deploying optical-fiber networks over their rights-of-way to provide communications for many years. The use of OPT-GW has

Table 1. Extreme Weather in Southern Wisconsin (Jan. 1985 to Dec. 1995)

Min. temperature	–33°C	1/18/94
Max. temperature	39°C	8/16/88
Max. snowfall	44 cm	12/3/90
Max. sustained wind	46 km/hr	12/20/90
Max. wind gust	116 km/hr	7/7/91

Table 2. Strain History of Retrieved Optical Ground Wire

Condition	Duration (hr)	Stress (1% of RBS)	Strain (%)
Final EDS	78,840*	10.9	0.08
Ice and wind	72**	28.6	0.20
Low temperature	72**	16.7	0.12
Maximum wind gust (13 psf)	<1***	15.3	0.11
Minimum temperature (–27°C)	2-4***	17.3	0.12

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

EDS - Everyday stress
RBS - Rated breaking strength

proven to be very reliable due to its rugged construction and location high above ground, preventing accidental damage.

The design of the OPT-GW cable in this study is shown in Fig. 1. The nomenclature 56 mm^2/469 refers to the cross-sectional area of the stranded aluminum-clad steel wires (56 sq mm) and the outer diameter in thousandths of an inch (0.469 inch). Although this nomenclature involves both English and metric units, currently it is the industry standard method of identifying a particular OPT-GW design.

The cable includes a central strength member that is coated with a soft polymer jacket. Twelve singlemode 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 sheath is applied over the soft polymer matrix, forming the optical unit. Aramid yarn and heat-resistant tape are stranded over the unit's sheath before it is inserted into an aluminum pipe. While this cable design is first generation, the basic concepts are used in today's higher-fiber-count OPT-GW cable designs, which can reach hundreds of fibers.

The aluminum pipe provides a significant amount of the total electrical conductance of the cable. The yarn and tape provide a heat barrier under fault current conditions, when the temperature inside the cable can exceed 100°C for fractions of a second. The yarn also provides strain relief and a means of tying off the optical unit at each splice enclosure.

The cable construction is completed by 11 aluminum-clad steel wires stranded over the aluminum pipe. These wires provide not only the majority of the tensile strength of the cable but also more electric cable conductance.

All fibers in this study were standard Corning silica-clad singlemode coated with a mechanically strippable dual-layer acrylate coating system. Such fibers have been produced and deployed widely since the early 1980s. Six of the fibers were overcoated with a thin layer of solvent-based colored ink, while the remaining six were left uncolored.

The 12-fiber cable formed part of a fiber network located in southern Wisconsin. The cable was manufactured in January 1986 and installed during the first quarter of that year. The 3.7-km length of cable was installed on a 138kV high-voltage transmission line between Rock River and Darlington. The system ran continuously with no interruptions from its activation in 1986 until the owner de-installed the cable in 1995 and allowed the fiber and cable manufacturers to conduct aging/functionality testing.

Understanding the cable's environmental and stress history is critical to accurate interpretation of the de-installed cable's aging performance. Of particular interest is the climatological and in-service stress history of the cable.

Installed environment and weather patterns

Due to the low temperatures, high winds, and large amounts of frozen precipitation during the year, the southern Wisconsin area is considered a heavy loading area by the National Electrical Safety Code. During an average winter, cables may encounter maximum sustained winds over 40 km/hr, temperatures lower than –30°C, and radial ice loading of up to 1.3 cm. All of these conditions create extreme change and stress on the cable system.

Actual extremes during the nine-year time frame, as reported by the National Weather Bureau in Madison, WI, are summarized in Table 1. Figure 2 shows graphically the wind, temperature, and ice-loading parameters as quarterly extremes between January 1986 and December 1995. The figures show significant environmental change in this location.

The stress history for an installed cable comprises both the installed everyday stress (EDS) and the environmentally induced stress. The installed, or final, EDS of approximately 10.9% of the cable's rated breaking strength (RBS) was obtained from the original sag and tension tables used for the installation. Based on this data and the environmental information, it is possible to estimate the cable's additive strain history. Because the design of the OPT-GW cable uses tight structure construction, fiber strain is approximately equal to the cable strain. Given this relationship, a 1% cable strain can produce

56 mm^2/469 OPT-GW Cable Design

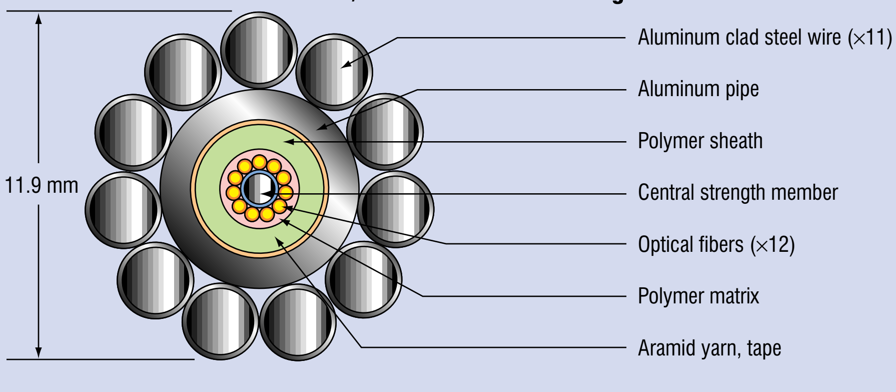

Fig. 1. This diagram depicts the 56 mm^2/469 optical ground wire used for the test. The nomenclature 56 mm^2/469 refers to the cross-sectional area of the stranded aluminum-clad steel wires (56 sq mm) and the outer diameter in thousandths of an inch (0.469 inch).

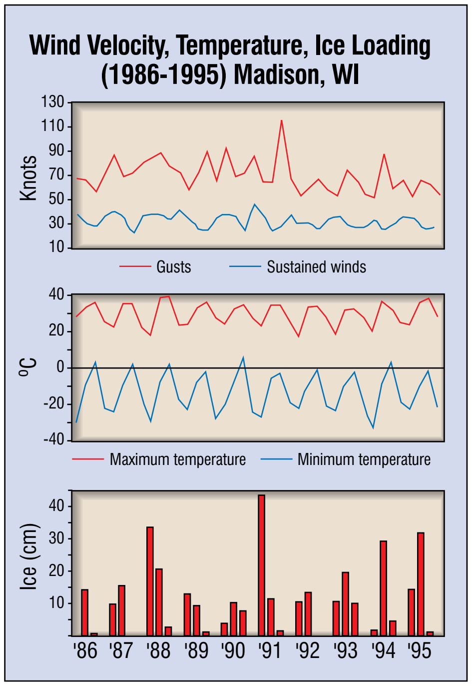

Fig. 2. These charts of the wind velocity, temperature, and ice loading in Wisconsin for the period 1986 to 1995 illustrate the harsh conditions endured by the cable.

approximately 100 kpsi of stress on the fibers.

The duration and magnitude of cable stress (percent of RBS) and fiber strain (percent) based on an average span length of 177 m are summarized in Table 2. As evident from the table and the information above, fibers inside the cable experienced a significant amount of strain and environmental change throughout their nine-year service. But none of this environmental change had any measurable impact on the cable or fibers.

Cable testing and results

To verify the condition of the retrieved cable and to assess handleability and reliability performance, AFL evaluated several critical cable/fiber performance attributes. The cable was visually inspected, attenuation performance and temperature dependence were measured, and the pipe gas pressure was checked to evaluate if any aging or deterioration of the cable and fibers was present.

Where possible, the findings were compared with those obtained before cable installation. Since some of the tests performed were not part of the original inspection nine years earlier, it was necessary to use typical data for cable and fibers of this vintage. The cable was inspected for signs of aging, corrosion, fatigue, deterioration, and damage. None were found.

All fibers were measured for *normalized attenuation* at both 1310 and 1550 nm. Measurements were made using a Photon Kinetics 6500 Single-Mode optical time-domain reflectometer in accordance with industry-recommended test procedures. The values were compared to both the original performance values and the original cable specification.

The attenuation results (Table 3) show a range of values at both 1310 (0.33 to 0.37 dB/km) and 1550 nm (0.22 to 0.26 dB/km). All values are consistent with the original 1985 specification requirements. These results illustrate the cable is still performing well, with no signs of attenuation increase due to aging or bending.

In a second cable/fiber performance test, the cable was *temperature cycled* from –40° to +85°C. Fibers were randomly spliced and concatenated together to form a continuous fiber path of approximately 23 km. Attenuation was monitored at 1550 nm during the entire test.

The cable was taken from room temperature to –40°C and held there for 24 hours, then taken from –40° to +85°C and held at that temperature for 24 hours. The same cycle (–40° to +85°C) was repeated before returning to room temperature. Attenuation changes at 1550 nm across the –40° to +85°C range on all cycles remained below 0.01 dB/km, and well below the original 0.20-dB/km cable specification. These results compare well to current OPT-GW temperature-dependence data.

The *gas pressure tightness test* verified the integrity of the aluminum pipe that contained the 12-fiber optical unit. Because the aluminum pipe hermetically isolates the fibers from the external environment, the pipe was tested for gas pressure tightness. This test was developed by AFL to verify pipe integrity after manufacture and can detect cracks and punctures down to micrometer sizes.

The test was performed by applying approximately 65 lb per sq. in. (psi) of inert gas pressure at one end of the cable, while monitoring the pressure at the opposite end. The air supply valve is left open until the pressure starts to increase at the other end. The pressure is allowed to equalize at both ends to approximately 40 psi. The pass/fail criterion requires that the equilibrium pressure at both ends be maintained for at least five hours. 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.

Fiber testing and results

After the cable evaluation was complete, fiber samples were carefully removed, shipped to Corning, and subjected to a variety of fiber evaluations. The 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 Fourier transform infrared (FT-IR) analysis. Testing was completed in accordance with industry-approved standards. Each fiber was examined for any signs of deterioration. Technicians testing the fiber indicated that the fibers appeared normal, and no deterioration was observed during handling and testing of each of the 12 fibers.

Table 3. Average Attenuation Results, OTDR length = 3734 m

Condition	1310 nm (dB/km)	1550 nm (dB/km)
Aged average	0.35	0.23
Range	0.33—0.37	0.22—0.26
Aged standard deviation	0.01	0.01
1985 requirement	≤0.50	≤0.40
1985 typical	0.37	0.26

Table 4. Average Fiber Strip Force Results

Sample	Mean Strip Force (N)	Standard Deviation (N)
Retrieved cable (uncolored)	4.08	0.62
Retrieved cable (colored)	4.13	0.29
10 yr archived, coat A	2.12	0.14
10 yr 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	

Color clarity and permanence were tested for each of the six colored fibers and given a Munsell Color System rating. The results were compared to today's wire and cable limits. All six colors were within the color tolerance and, more importantly, were distinguishable and continuous in color around the circumference and length of the fiber tested. Earlier published studies showed some issues with color cracking and flaking after laboratory aging. There was no evidence of this with the field-aged samples.

Strip force indicates a craftperson'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. Each result was then compared to a desired peak strip force of 1.3 to 8.7 N, as outlined in industry documentation. Results in Table 4 show the fiber strip force of the field-aged OPT-GW cable is similar not only to other fibers from the same 1985 to 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 requirement.

Fiber strength measurements were performed on 30 randomly selected fiber samples from the aged OPT-GW cable. The fibers were tested in tension at 2.5% strain/min rate with 0.5-m gauge lengths. Environmental conditions were 22.2°C and 50% RH. Testing was conducted on as-drawn silica-clad fiber of recent vintage for comparison. The results are summarized in Table 5. The field-aged fibers had a median strength of 665 kpsi (4.65 GN/sq m) while the as-drawn samples had a median strength of 666 kpsi (4.65 GN/sq m). Strength degradation was not observed with the aged samples.

Strength after mechanical strip (SAMS) testing was completed on the field-aged OPT-GW/fiber samples along with recent as-drawn fibers. SAMS testing was performed to assess the fiber's handleability and strength after mechanical coating strip. In this test, fiber is strength tested (0.5-m gauge length, 5% strain/min, in ambient conditions) using standard Instron equipment. The fiber's 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 fiber's coating. A summary of the results is shown in Table 5. The data show 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/sq m) compared to 161 kpsi (1.13 GN/sq m) for as-drawn fiber.

FT-IR spectroscopy analysis was performed on aged and un-aged coating samples. In this test, coating samples of the field-aged clear fiber—both the inner and outer primary coatings—were tested and compared to the same as-drawn coating system. Results showed a match between the field-aged spectra, both inner and outer primary, and the as-drawn coating spectra. This result indicates that the chemical structure of the field-aged sample is consistent to as-drawn fiber and, more importantly, that the field-aged coating appears to have all its as-drawn characteristics.

This study shows no indication of performance degradation of the OPT-GW cable or the fibers after nine years of service in southern Wisconsin. The cable performed well, and fiber reliability and handleability appear to be consistent with as-drawn and as-manufactured fiber and cable systems. Each characteristic tested either met or exceeded the original performance specification.

Other field studies conducted by Corning also show that normal-to-severe field aging of fiber-optic cabling systems has no impact on the functional or handling characteristics of the optical fibers. Furthermore, this result indicates that even under extreme environmental conditions—including documented cases of strong wind gust, heavy snow, and very low temperatures during a nine-year service life—this particular OPT-GW cable design provides excellent performance and fiber protection.

Table 5. Fiber Strength and Strength after Mechanical Strip (SAMS)

Sample	Strength		SAMS	
	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

Aging characteristics for installed optical-fiber cables are becoming better understood. While earlier studies may have warned of impending danger, it appears that the first installations are old enough to provide worthy field data. This data, combined with laboratory understanding, can give insight to the aging or long-term mechanical and optical reliability of optical fibers and cables.

As cables and fibers are deployed further into the networks, there is increased interest in understanding how networks perform in adverse environments. Based on these types of studies, system owners can be confident in the reliability and functionality of yesterday's, today's, and tomorrow's fiber-communications infrastructure.◆

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