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Application Note

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The Role of Cable Shrinkage in Passing

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1.0 Introduction

As the demand for optical connectors increases globally, so does the supply. Today, numerous suppliers offer a wide range of fiber optic products. This covers everything from basic components, to finished cable assemblies. One key element that end users have discovered in the recent years is that *not all connectors are equal*. The quality, reliability, and performance of optical components and cable assemblies are assured by not only selecting the best connectors; but by terminating those connectors onto high quality cabling, polishing and testing using the top-of-the-line equipment and following proper procedures. All these factors together help assure that the jumper assemblies meet or exceed the requirements of the relevant industry specifications. Especially the internationally recognized Telcordia GR-326 standard which outlines the Generic Requirements for Single-mode Optical Connectors and Jumper Assemblies, as well as others such as GR-1435, GR-3152, GR-3120 and AS5382.

These documents describe the testing criteria in the applicable environment. They also cover the importance of the physical parameters and how they relate to the performance of the jumper assemblies in such an environment. In addition, standards from IEC, TIA/EIA, ASTM, ISO, ITU, UL as well as other Telcordia General Requirement standards reference similar test procedures, test criteria, intermateability requirements, extended life testing, and more. When these standards are updated, they need to be reviewed to determine if a GR revision needs to be considered. The main purpose for GR documents is to determine if a connector or a connector assembly has the ability to perform in various operating conditions and to determine a long-term reliability.

The most common perception is that in order to pass the GR requirements you must have the best connectors, the best consumables, the best equipment, refined manufacturing practices and proper termination procedures. This is all true, however, what about the quality of the fiber optic cable itself?

If you were to examine the GR standards further, you will notice a paragraph that mentions cable constructions or “Cable Media Types”. The following excerpt is from GR-326:

> *R3-8 Cable Media Types*
> *The media on which connector plugs are mounted shall meet the criteria in either GR-409-CORE, Generic Requirements for Indoor Fiber Optic Cable, or GR-20-CORE, Generic Requirements for Optical Fiber and Optical Fiber Cable.*

And further:

> *Cable Media Types shall be defined as follows:*
> *• Type I Media: Reinforced jacketed cable of any diameter used as jumper cordage*
> *• Type II Media: Cable with a 900 µm buffer coating that may or may not be reinforced*

- *Type III Media: Connectors mounted on fiber with a 250 μm coating*

RATIONALE — The media types defined represent the different applications of optical jumpers used in typical telecommunications service provider environments. The different applications generate the need for different media types. However, even though the applications may be different, the media types must be compatible with the optical fiber cable requirements in the telecommunications applications. Therefore, it is necessary that optical jumpers use fiber cable, which meet the criteria in GR-409 or GR-20.

This highlights that not only high-quality connectors, equipment, and procedures must be in place, but also a cable that is compliant to the sited standards as well. This is especially apparent if you are dealing with a Type I Media. For Type II and Type III (900µm and 250µm fiber assemblies) the GR testing is less strict, because this type of the jumper cordage does not fall into GR-409 category that was written for reinforced jacketed cable types. Therefore, when testing to the GR standards it is important to understand Telcordia GR-409 and GR-20 cable standards.

GR-409 outlines the Generic Requirements for Indoor Fiber Optic Cable. This document sets forth proposed generic technical requirements and characteristics of single-mode and multimode optical fiber cables for indoor plant use. The requirements are based on National and International accepted industry standards and specifications. This document includes proposed functional design criteria, generic mechanical and optical performance requirements, and desired features. It specifies test methods for comparing the fiber, ribbon, or cable product against the stated generic requirements. The specified test methods are intended to provide a consistent and repeatable methodology that reflects the operational conditions for optical fiber, ribbon, and cable analysis. GR-409 requirements call out and reference a variety of National and International Standards in the main body of the document, as well as the sample size with a reference is made to GR-20 for most fiber and fiber ribbon specifications.

GR-20 outlines the Generic Requirements for Optical Fiber and Optical Fiber Cable. This document sets forth proposed generic requirements and characteristics of single-mode and multimode optical fibers, optical fiber ribbons, and optical fiber cables for Outside Plant (OSP) use. The requirements are also based on nationally and internationally accepted industry standards and specifications, also Telecommunications Service Providers' (TSPs) needs and deployment environments. This GR includes proposed functional design criteria, generic mechanical and optical performance requirements, desired features, and specifies test methods for comparing the fiber, ribbon, or cable product against the stated generic requirements. GR-20 is also intended to specify sampling criteria and test methodology information for Independent Testing Laboratories to provide consistent and repeatable results for optical fiber, ribbon, and cable test programs.

The above means that Telcordia GR-409 is the current standard of specifications for indoor fiber cables, while Telcordia GR-20 provides technical reference for outdoor cables. Some companies will have their own versions of cable requirement standards that reference GR-20 and GR-409 where they may also add additional qualifications that are typically more strict. Custom specification documentation dictates that the mechanical performance standard is agreed upon by the customer and the manufacturer. More recently, however, fiber improvements, particularly in developments of bend tolerant fibers, are challenging the industry to revisit the legacy test standards for fiber. With the increased performance, existing standards such as GR-409 and GR-20 may no longer be considered universally accepted criteria.

These standards try to address the fact that not all cable constructions are the same. Cables are typically designed in order to meet these standards, however, the variations within the standard allow compliant cables to perform very differently under environmental and mechanical stresses. Inherently controlling the cable shrinkage is one of the main challenges that cable manufacturers face. The following will highlight the details behind the manufacturing process of fiber optic cable.

A fiber optic cable typically includes a silica core/cladding 125 µm glass fiber with 250 µm coating, a buffer that surrounds the coating, a strength layer containing aramid yarn, and an outer jacket. An inner glass is surrounded by a UV cured acrylate coating deposited immediately upon the fiber glass draw. This UV cured acrylate is a first layer of defense for the silica glass and provides protection from moisture in the form of a hydroxide ion (OH^-) radicals which are prone to enter the glass surface microcracks making them wider and deeper. Microcracks are inherent to the glass itself and are the result of the manufacturing process and handling of the fiber. Fiber strength degrades with time due to fatigue resulting in crack growth accelerated by stresses and moisture. The fiber is typically shipped in 25km spools with a UV coating to a cable manufacturer. This 250 µm coated fiber is defined as Media Type III in the GR cables criteria. The cable manufacturer then extrudes the 600 µm or 900 µm buffer that functions to surround and protect the coated optical fibers further. This reduces the flaw formation and crack growth in the fiber. If no tight buffer is present, a water blocking gel serves as silica glass protection. The buffered fiber is defined as Media Type II in the GR documents. Strength members in the form of aramid yarn add mechanical strength to fiber optic cables to protect the internal optical fibers against stresses applied to the cables during installation and thereafter. Finally, an outer jacket is extruded to provide ultimate protection against damage caused by mechanical stresses such as crushing, abrasions, and other physical damage. Outer jackets also provide protection against chemical damage (e.g., ozone, alkali, acids). This now forms the Media Type I cable in the GR documents. However, one of the less obvious but very important roles for the outer jacket is to ensure that fiber inside are not bending in the event of severe environmental changes and exposures.

Fiber optic cables are designed for the optical fiber to have an excess length in relation to the cable outer jacket. Depending on the cable structure, this excess fiber length is 1% to 1.5%. That is why when measuring optical loss on a long length with an Optical Time Domain Reflectometer (OTDR) the actual cable length is less than the fiber by that amount. The fiber overlength protects the glass in the event of bending stress or tension on the cable. With both loads, the cable jacket expands in thickness due to bends or linearly due to tension. The excess fiber length protects the glass because the elongation of the cable construction does not immediately affect the fiber.

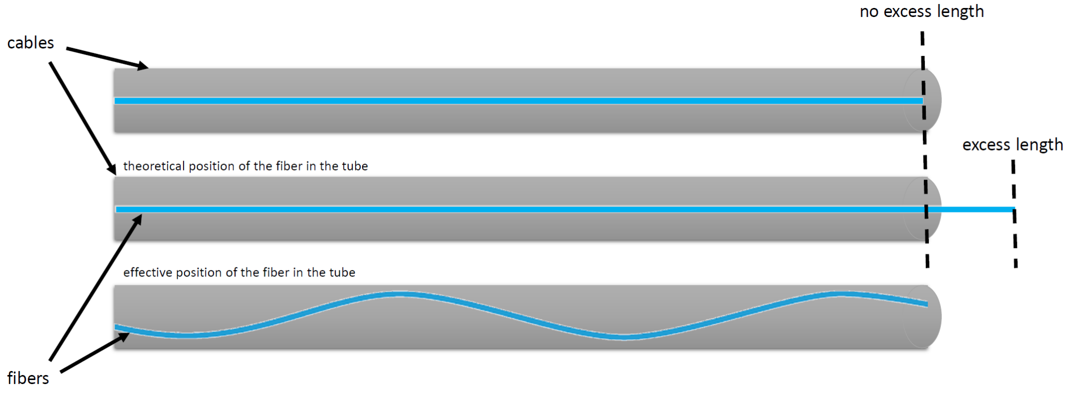

Figure 1 Fiber cable has extra fiber length by design

However, this fiber excess length also could play a negative role. The disadvantage of the designed fiber overlength is that it increases further with cable shrinkage and can lead to fiber bending.

2.0 Reversable cable shrinkage vs irreversible cable shrinkage.

It is well known that micro-bending of an optical fiber within a cable will negatively affect optical performance. Shrinkage of the outer jacket of a fiber optic cable can cause axial stress to be applied to the optical fiber, this causes micro-bending of the optical fiber. One cause of jacket shrinkage is thermal contraction with decreasing temperature. Another source of shrinkage is post-extrusion shrinkage. Shrinkage caused by thermal contraction is typically reversable (temporary shrinkage). Jacket shrinkage can also be permanent or irreversible within the same cable. Reversible shrinkage occurs at low temperatures. The temperature expansion coefficients of coated plastic materials are up 50 times higher than those of glass. When temperature cycles from +40°C to -5°C, the cable experiences a temperature-related shrinkage of approximately 0.5%. Typically, this is not noticeable since the excess length usually stays inside of the cable.

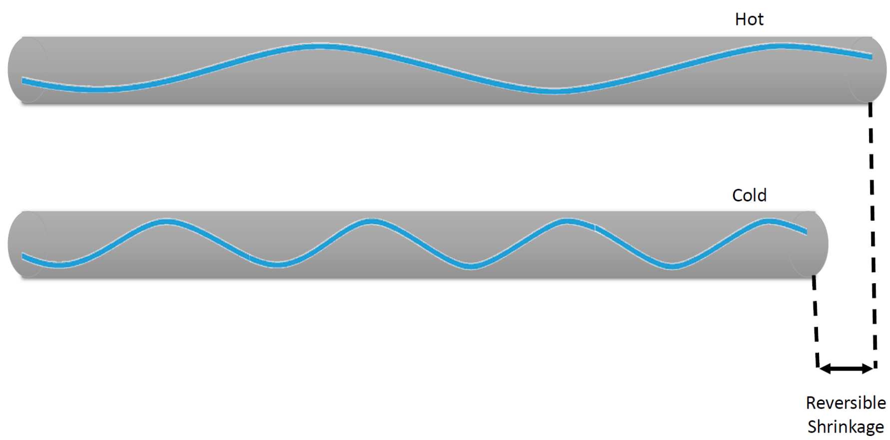

Figure 2 Reversable shrinkage is temporary

GR testing requires more severe temperature cycles from -40°C to +75°C. At lower temperatures the additional temperature-induced shrinkage of the cable construction becomes more noticeable. The jacket material, whether its PVC, PTFE or other elastomer types, contain plasticizers. A plasticizer is a substance that is added to a material to make it softer and more flexible. This is done to increase its plasticity and decrease its viscosity during the extrusion process. Any plasticizer at cold temperature stiffens and becomes hard. The increased hardness of plastics exerts greater pressure on the fiber. When this happens the fiber excess lengths can no longer be compensated inside of the cable. These effects are indicated in increased optical losses. In many cases cable shrinkage due to cooling is reversible because the original length is restored when the cable returns to the room temperature. The question is how severe was this reversable shrinkage.

The most detrimental flaw for the fiber inside of a cable construction is irreversible shrinkage. Plastics are amorphous materials which contain long polymer chain molecules positioned at random. During the manufacturing of a fiber optic cable, an optical fiber is passed through an extrusion die and molten plastic material is extruded around the exterior of the fiber. As the molten plastic exits the extrusion die, the plastic is elongated in the direction of flow and then passed through a cooling bath where the elongated shape of the plastic is set. This produces high shear forces, which makes the molecules to align in the longitudinal direction of the cable forming a spaghetti like structure. Before the molten plastic can change back to the amorphous state, it is cooled in the water bath right after the extrusion die. The orientation of the molecules in the longitudinal direction of the cable become frozen. If the plastic is not heated above a certain temperature (the Glass Transition Temperature [Tg] of the given polymer), a semi-crystalline spaghetti-like structure is retained. At temperatures above Tg, the polymer will begin to restructure back into the amorphous state. This causes the cable jacket to shrink. This shrinking process is considered irreversible. Various plastic materials have different glass transition temperatures ranging from 50°C to

100°C. This is the temperature when the most significant cable shrinkage (up to 5-8%) could occur. This is widely influenced by the combination of, extrusion process, recipe, and plastic materials used. This irreversible shrinkage is controlled by cable manufacturer's that guard their extrusion recipes and materials. This makes their processes proprietary manufacturer "know-how". The best cables in the market today exhibit shrinkage rates under 1% whereas lower quality cables can shrink up to 5-8%. SENKO has performed various GR-326 internal tests that have compared the performance of various connector types with various cables, as well as various furcation tubings in fanouts. It has been determined that the connectors that pass GR-326 on cables with relatively low shrinkage, could fail if terminated onto the high shrinkage cables due to fiber performance inside the cable.

3.0 Cable with Terminated Connectors

The cable jacket shrinkage is a significant problem in optical fiber connectorization when cable assemblies or patch cords are made. When a connector is terminated to the end of a fiber optic cable, a heat cure epoxy is often used to secure the ferrule onto the fiber.

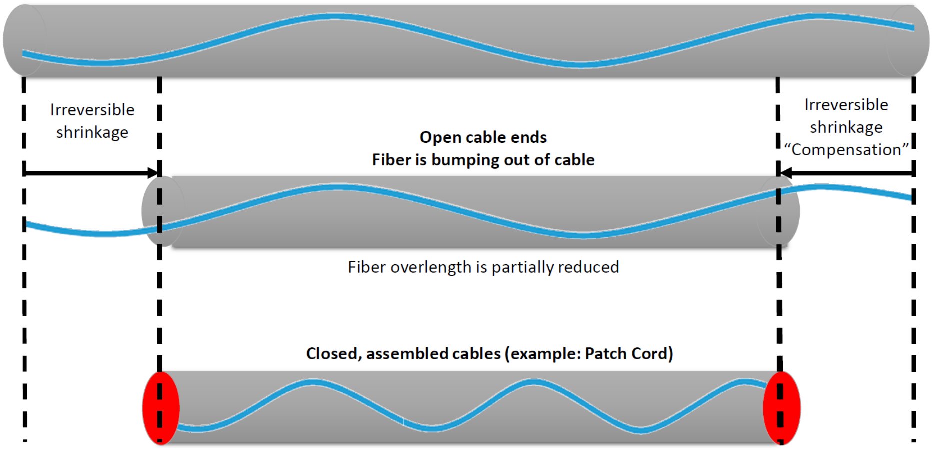

Figure 3 Cable could have excessively bended fiber during high shrinkage if the fiber locked with adhesive

When the cable is terminated on both sides', the attenuation increases due to the irreversible cable shrinkage. This is because both shrinkage types, reversible (temperature-induced cable shrinkage) and irreversible (structural cable shrinkage) stack together and the fiber overlength cannot be compensated anymore. Too much irreversible cable shrinkage leads to even higher attenuation throughout the duration of a temperature cycling test.

4.0 High shrinkage cable behavior.

With each high temperature cycle in the temperature cycling test, the cable continues to shrink. This carries from cycle to cycle resulting in increasing attenuation values at low temperatures.

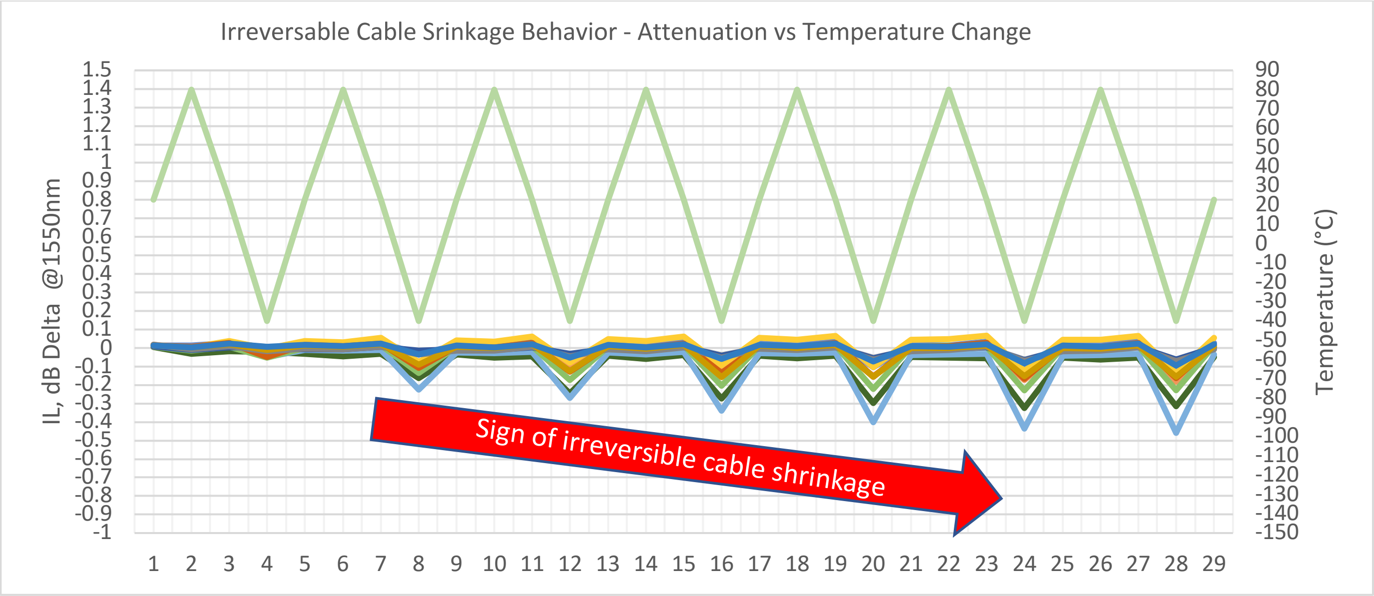

Figure 4 Optical loss during irreversable cable shrinkage increases with every cycle

5.0 Low shrinkage cable behavior.

Low shrinkage cables have low irreversible shrinkage at increased temperatures. In the temperature cycling test, the attenuation deviations are stable over the entire duration of the test.

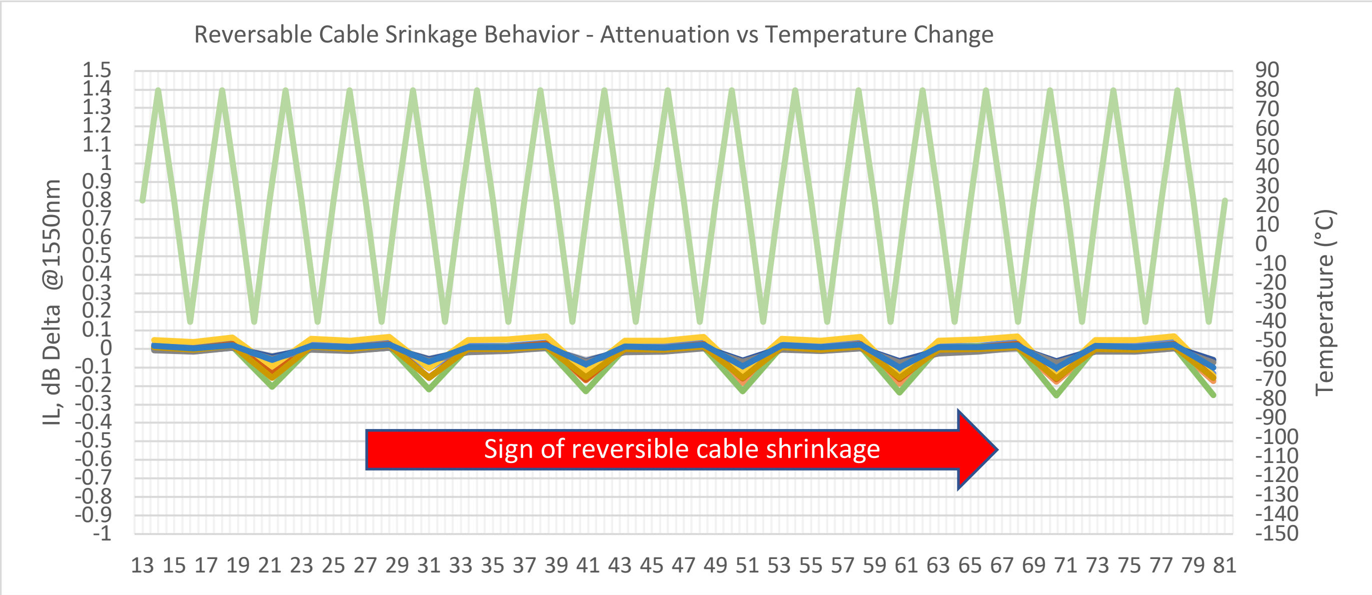

Figure 5 Optical loss during reversable cable shrinkage fluctueates the same with every cycle

6.0 What helps to minimize cable shrinkage effects?

In addition to using innovative cable extrusion methods another relevant improvement is the fiber's ability to bend in a smaller radius. The legacy fiber is governed by the ITU G.652D Standard. This fiber has a maximum allowable bend radius of 35mm. The new ITU G.657 Standard covers bend-insensitive single-mode fibers that are compatible with the original legacy fibers. The new standards for bend-insensitive single-mode fibers were introduced as follows:

- G.657.A1 (10 mm minimum bend radius)
- G.657.A2 (7.5 mm minimum bend radius)
- G.657.B2 (7.5 mm minimum bend radius)
- G.657.B3 (5 mm minimum bend radius)

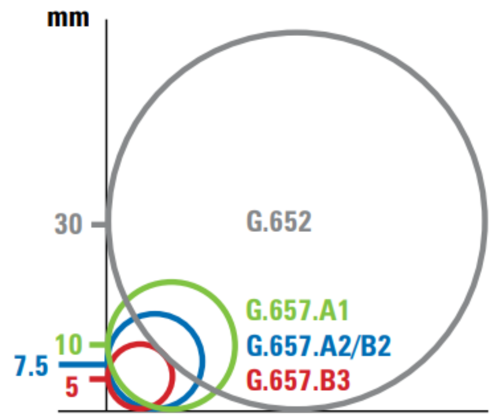

Figure 6 Critical bend radii is different based on fiber standard designation

Resistance to macro-bends and micro-bends in newer bend-insensitive fibers further helps the assembly's performance. In fiber optic transmissions, a macro-bend refers to a large visible bend in the optical fiber that can cause extrinsic attenuation and a reduction of optical power in the glass. Micro-bends are defined as nearly invisible imperfections in the optical fiber, usually created during the manufacturing process. These tiny imperfections can also cause a reduction in optical power, or increased attenuation. The bend-insensitive fibers have ability to reduce both effects.

Another tip to reduce fiber stress is to age the cable or furcation tubing in an oven prior to termination. Aging reduces the irreversible cable shrinkage explained earlier. Aging is typically performed as described in a Jacket Shrinkage Test procedure in another TIA document labelled FOTP-86. This test measures the shrinkage of a cable jacket due to exposure to temperature conditioning for a specified period of time. The samples are conditioned for two to four hours at 110 °C. As discussed previously this will have permanent irreversible shrinkage, which in this case is desired because it's prior to connectorization. This conditioning is a rapid contraction of the cable jackets molecular network, associated with disorientation in the amorphous phase, followed by a crystallization stage during which a molecular chain folding takes place.

7.0 Considerations for today's standards

The existing TIA and FOTP standards and test methods for optical fiber and cables are based on mechanical testing and attenuation changes, but they do not specify the cable design being tested. For example, if a reduced bend radius fiber is undergoing the same tests, its minimal sensitivity to micro-bending may allow it to pass the test while a micro-bend could still cause the fiber to stress over time. That means some cable designs could still be created with inherent failures in design, yet they could pass existing testing standards based solely on what is contained in GR-409 for tight buffered fibers.

Some uncertainty still applies with testing connectorized cables. GR-20 and GR-409 allow shrinkage of up to 5% and the newer ICEA-S-104-696 Standard for indoor/outdoor optical fiber cable also state that jacket shrinkage shall not exceed 5% when the jacket samples are tested in accordance with FOTP-86. The question becomes whether less than 5% shrinkage, as stated in this specification, is still an acceptable standard or benchmark. It could be too broad of a measurement based on the fact that new bend insensitive fibers will not show the same sensitivity.

What might work in loose tube multifiber cabling may not work in a duplex cable design that has tight buffered fibers with connector interfaces. The existing aging cycle in GR-20 and GR-409 was developed using high temperature only to detect changes in the jacket and buffering compounds, such as hardening, cracking or shrinkage over the aging process. Today, it should also consider whether those compounds will fail or not when testing a connectorized cable. To better predict a connectorized cable behavior possibly GR-20 and GR-409 should consider the thermal coefficient of linear expansion. This is the rate of expansion and contraction of a material over a given temperature profile. The rate of polymer change is typically an order of magnitude greater when compared to the fiber glass. These added criteria would better predict an attenuation in the cable when reduced bend radius fibers are used during cable shrinkage testing.

The behavior of loose-tube cable constructions with 250 µm fibers is different than the behavior of tight buffered cable constructions, which in turn is different than 72-fiber constructions, and so on. These existing standards should be reviewed and criteria might need to be added to specifically include the unique characteristics of reduced bend radius fibers and cable design types.

8.0 Conclusions

When conducting GR-326 type testing to ensure connectors performance, the quality and design of the cable construction needs to be carefully considered. The success of the cable assemblies passing this strenuous testing, depends heavily on the cable quality and type used. Even the most premium connector components will not hide the shortcomings of a poor cable construction that manifests in a form of excessive shrinkage during temperature cycling.

Throughout historical GR-326 data that SENKO performs routinely, there is a clear evidence that the cable quality is equally important as a connector quality. Ideal fiber optic cable design should have half the allowable cable shrinkage defined by GR-20 and GR-409 today. This is true especially for the cables designed for severe outdoor use that are intended to work with hardened IP fiber optic connectors. This is necessary to pass GR-3120 and GR-3152 requirements. With the increased environmental operating ranges of the cables, it is becoming a new normal that the thermal coefficient of linear expansion values need to be considered when choosing the cable to perform Telcordia GR qualification rounds.

As one example, the cable shrinkage challenge has been recognized by the Avionic industry when they adopted an SAE standard AS5382 called Fiber Optic Jacket Shrinkage Test for Aerospace Cable. This test requires SAE AS5382 § 5.6.7 to age 360mm samples of cable within 5-minutes of cutting it at 150°C +/- 3°C for 6 hours in an air circulating oven. The requirement is 2.3mm maximum shrinkage in a 360mm sample which translates to maximum shrinkage rate of 0.64%.

RFEFERENCES

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4. GR-3120-CORE Generic Requirements for Hardened Fiber Optic Connectors (HFOCs) and Hardened Fiber Optic Adapters (HFOAs)
5. GR-3152-CORE Generic Requirements for Hardened Multi-Fiber Optical Connectors (HMFOCs)
6. GR-1435-CORE Generic Requirements for Multi-Fiber Optical Connectors
7. FOTP-85
8. IEC 60794-1-2 Optical Fiber Cable Part 1-2: Basic Optical Cable Test Procedures
9. TIA/EIA-455-3A FOTP-3 Procedure to Measure Temperature Cycling Effects on Optical Fibers, Optical Cable, and Other Passive Fiber Optic Components
10. TIA/EIA-455-13A FOTP-13 Visual and Mechanical Inspection of Fibers Optic Components, Devices and Assemblies
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12. TIA/EIA-455-20A FOTP-20 Measurements of Change in Optical Transmittance
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14. AS5382 SAE Standard. Fiber Optic Jacket Shrinkage Test for Aerospace Cable
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16. Polymer Dimensional Changes in Optical Cables by Mateusz Lutomski and Barbara Gawdzik, Lublin University, October 2014

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