

Corning® CPC® Protective Coating - An Overview

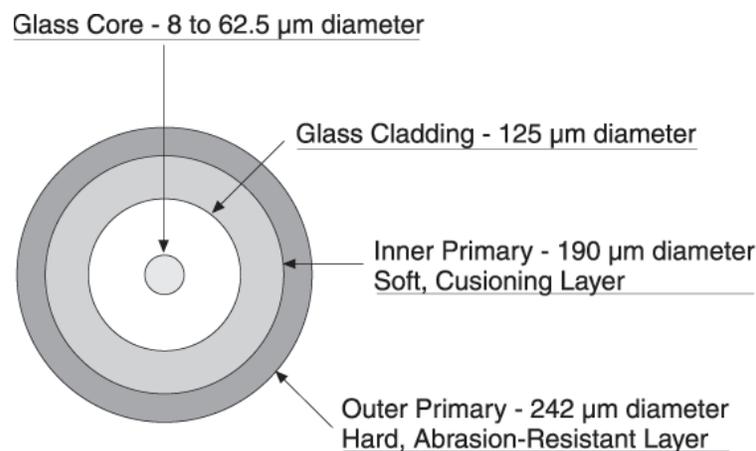
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The ability of an optical fiber to perform in the field is determined in no small measure by the quality of the coating that covers it. This paper describes some of the key physical attributes that such a coating will require, as well as tests used to help quantify them. Also described are common fiber coating tests that are used to predict product field performance.

Geometry

Optical fibers are typically produced with a polymeric coating in place to protect the glass surface. In current practice, a dual-layer coating system is used. The glass is coated with a primary (or inner primary) coating, which is usually a softer, rubbery material that cushions the glass from external mechanical loads. The primary coating is surrounded by a secondary (also referred to as outer primary) layer, which is a much stiffer material, meant to protect the fiber from abrasions and environmental exposure, as well as provide an acceptable surface for coloring. Both coatings are composed of complex mixtures of raw materials (monomers, oligomers, photoinitiators, additives). A typical cross section of an optical fiber is shown in Figure 1.



Schematic of a dual layer coating design

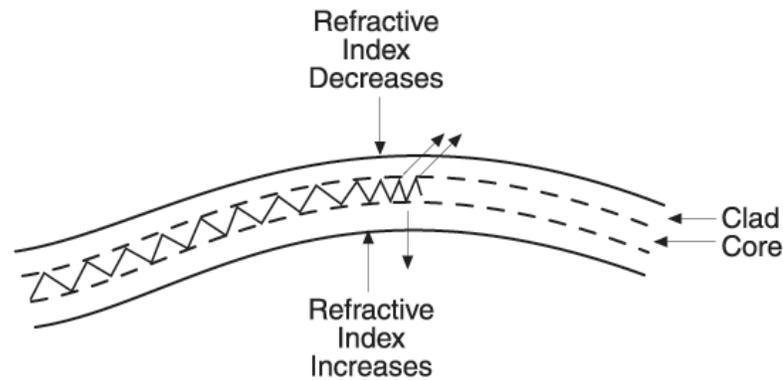
Figure 1

Corning's CPC® coatings are dual layer, or composite protective coatings. The primary and secondary coatings are applied sequentially in a liquid form as the glass fiber is drawn, and are sequentially cured by exposure to ultraviolet light sources.

Functions

Optical waveguide coatings serve two main functions: to protect the light-carrying ability of the glass fiber and to preserve the strength of the glass fiber. The coating composite structure performs the first of these functions by shielding it from mechanical loading. These mechanical forces can cause small deformations in the glass fiber light pathway, which may lead to a loss of light. More specifically, these deformations of the optical path cause the various propagation modes of the light to couple, if the deformations change rapidly enough along the fiber axis. Coupling to the cladding modes causes power to be lost from the guided modes in the core. These losses are termed "microbending" because the deformations are typically very small (tenths of a millimeter or less).

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Fiber microbending due to mechanical testing

Figure 2

Localized deformations responsible for microbending losses result from non-uniform externally applied forces, which could arise from irregularities of the cable or coating structure, winding the fiber on a spool under high tension or from thermally induced stresses. The latter deformations usually manifest themselves as an attenuation increase at lower temperature, and arise from the mismatch of the thermal expansion characteristics of the coating/glass composite. Microbending loss sensitivity can be minimized by both fiber and coating design. In the case of coatings, such factors as primary and secondary thickness and modulus, primary glass transition temperature, and overall coating concentricity play a fundamental role.

The second requirement of the coating composite is to preserve the strength of the glass fiber from either mechanical damage or stress corrosion (a phenomenon known to occur in glass). The reliability of optical fibers in factory or field environments depends upon the assurance that their strength is maintained over the entire length of the fiber. Although silica fibers have very high intrinsic strength, it is severely degraded by the presence of surface defects that act as stress concentrators.

Basic Characteristics

A variety of parameters are used to characterize the processing, performance and reliability of optical fiber coatings. The most significant include:

- *Modulus* quantifies the resistance of the coating to mechanical deformation. The two major types of moduli are Young's modulus – the resistance to uniaxial tension (being stretched), and shear modulus – the resistance to simple shear deformation (being twisted).
- *Elongation at break* is a measure of how much strain can be withstood by the coating before breaking.
- *Tensile strength* is a measure of stress when the sample breaks.
- *Glass transition temperature (T_g)* is frequently defined as the temperature below which a coating is brittle and above which it is flexible (although a more accurate definition is based on the fact that at glass transition temperature the coefficient of thermal expansion, or CTE, changes sharply). CTE, therefore, is another important characteristic of optical fiber coatings.
- *Water sensitivity* is defined as the amount of water absorbed by the coating, as well as the amount of materials extracted from the coating upon exposure.
- *Thermal Stability* is defined as % weight loss and % change in tensile properties of the coating sample.
- Other physical properties include *viscosity*, *density*, *refractive index* and *surface tension*.

The properties listed above are used to define the physical characteristics of a coating (be it either primary or secondary). As stated earlier, primary coatings are usually low modulus, rubbery materials that possess a low T_g (i.e. they are soft at low temperatures), have higher elongation prior to failure and require optical properties that help strip off stray modes from the glass optical fiber. The secondary coatings are generally quite stiff, high modulus materials. Since their job is to provide protection from mechanical abrasive forces, they are highly "cross-linked." This simply means that the polymer chains are tied together into a very strong, tightly woven structure. A further result of this tight three-dimensional structure is that it also imparts a strong resistance to chemical penetration and degradation of the coating.

These coating properties are closely correlated with properties of the optical fiber itself, such as microbending, pullout force, strength and fatigue, strippability, surface friction and color. An understanding of the coating characteristics is important in fully understanding the performance of the fiber in actual field applications.

Industry Trends

As fiber cable has been increasingly deployed, more demands have been placed on the coatings used. Some notable trends are:

- Improved microbend resistance
- Improved low temperature performance
- Improved ribbon strippability
- Improved environmental stability: solvent resistance, thermal stability, yellowing, water sensitivity
- Extension of technology to cable materials (UV curable inks and ribbon matrices)

As may be imagined, juggling such a large number of requirements proves challenging, and accounts for much of the effort that is required to develop and prove that a coating system is fit for use. As stated above, the trends above must be correlated to the physical characteristics of a coating pair, in order to meet the increasingly demanding requirements.

Since the introduction of the first commercially viable optical fiber, Corning has worked to continually improve the performance of its CPC coatings.

Fiber Coating Tests

All fiber coating tests are designed to characterize coating performance under the extreme conditions that a fiber may encounter in the field. Sometimes, extensive aging conditions under extreme environments are applied to ensure fiber performance for a 20-year service life or longer. The following section is a brief description of the more common tests to which a coated fiber is subjected:

Strip force test – The purpose of a strip force test is to characterize the force required to mechanically remove a fiber coating and the ensuing cleanliness of the fiber. Two internationally standardized tests procedures are most often used: IEC 60793-1-32, “*Measurement methods and test procedures - Coating strippability,*” and TIA/EIA 455-178A, “*Measurements of Strip Force for Mechanically Removing Coatings from Optical Fibers.*” The latter test procedure is commonly referred to as Fiber Optic Test Procedure (FOTP) 178. Application requirements are listed in the IEC 60793-2 series and TIA/EIA 492 series standards, and typically call for mean-peak strip force to be between 1.0 and 8.9 Newtons under a variety of environmental conditions. In actual use, however, when the mean-peak strip force reaches more than 4.5 Newtons, a craftsman will feel that the coating is hard to strip, thus setting a practical limit that is embedded within the specification. In addition, IEC requires the average strip force to be between 1.0 and 5.0 Newtons.

The ability to strip the coating is one of the most important properties, since it is the first step in preparing a fiber for connection, either by mechanical means or by fusion splicing. High strip forces can also potentially result in damage to the fiber. Since common specifications include both fiber with larger coating diameters (400 to 600 microns) and buffered fiber (900 microns in diameter), it is important to have a lower strip force to have a user-friendly fiber. The strip force of natural fiber is largely a product of the toughness of the secondary (or outer primary) coating, since the mechanism involves the coating buckling and breaking during stripping. It is important to note that the strip force test is not intended to measure the coating adhesion to glass – despite the fact that it is sometimes incorrectly used for this purpose. In order to correctly measure the adhesion of the coating to glass, the pullout test should be employed (see below).

Pullout test – This test is intended to characterize the coating adhesion between the inner primary coating and the glass fiber by pulling the glass fiber out of the coating. This test is designated as TIA/EIA PN-2746 (note that it does not carry an FOTP number), and is widely used by fiber manufacturers. The test result is recognized to include many non-adhesion components, such as coating friction and the shear strength of inner primary coating. The true coating adhesion to glass is complex and hard to measure. Acknowledging the complexity of the test results, Corning uses the pullout test as an indicator, rather than a true measurement, of coating adhesion.

Water soak test - This test is intended to characterize (but not measure the force of) the coating adhesion between the inner primary coating and the glass fiber under wet conditions. The fiber is soaked in water at various temperatures for periods of time up to 60 days, and inspected for micro-delaminations under a microscope at several time intervals. Typically micro-delaminations do not cause significant optical losses, nor does a total delamination of the coating from the glass, because in both cases only negligible amounts of point deformations are transmitted to the glass fiber, in turn only creating negligible sources of microbending. However, if enough micro-delaminations of an intermediate size occur when a fiber is soaked in water, significant optical losses may occur.

Corning also uses high temperature water soak conditions as an accelerated aging test in order to investigate the chemical adhesion between the coating and glass. The chemical adhesion between coating and glass includes the covalent bonding from the adhesion promoter in the coating and inter-molecular bonding from hydrogen bonds and van der Waals forces. Under severe conditions, the chemical adhesion can be weakened through an insertion of water molecules into the inter-molecular bonding, as well as the possible hydrolysis of the covalent bonds.

Solvent resistance – Two of the most important solvents an optical fiber may encounter in field are water and hydrocarbon-based fill compounds. As discussed above, if water transmits through a cable structure and into a fiber coating, the potential formation of micro-delaminations could deleteriously affect the fiber attenuation. Similar issues can arise from non-aqueous sources, such as cable fill compound. For example, in a loose tube cable design, a fill compound surrounds a fiber during its entire lifetime. Petroleum products, such as gasoline leaking from underground tanks, also pose a threat to fiber coating. The fill compound potentially can swell a coating and cause it to fall apart.

Water and hydrocarbons are located at the two extreme ends (hydrophobic and hydrophilic) of the spectrum of solubility parameters. The solubility parameter is an index used to determine the solvent compatibility with a polymeric material. If a coating behaves in a more hydrophobic manner, a fiber will perform very well under flood conditions, but potentially very poorly in hydrocarbon-based fill compounds. Most fiber coatings are formulated to be somewhere between the two extremes in order to have a good resistance to both types of solvents. The tests used to determine the water resistance are discussed in the previous section. The fill compound resistance is characterized by soaking a fiber in mineral oil – a generic, aggressive substitute for proprietary fill compounds – and monitoring the attenuation and dimensional changes of the fiber coating under accelerated conditions. Other solvent resistance tests used to measure the effects of short-term exposure to a variety of solvents are common in industry specifications.

Summary

This paper is only a brief overview of the complex science behind developing, testing and deploying high-quality composite protective coatings for optical fiber. Corning has been a leader in optical fiber for over 30 years, and has continually refined coating formulations to improve the performance and reliability of CPC coatings, while adapting to the unique and ever-changing requirements of the optical communications industry. Corning recognizes that choosing the right fiber for network applications is important, and selecting Corning fiber for installations not only ensures the highest quality glass, but also the industry's highest quality coating: Corning CPC coating.

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