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Better Coating through Chemistry:

Research in Optical Fiber Coatings

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When considering optical fiber, there is a significant amount of attention paid — and rightly so — to the glass core and cladding responsible for carrying light signals down the length of the fiber. But the ability of an optical fiber to perform this function in a network is determined, in no small measure, by the quality of the coating that covers it.

Optical fiber coatings have been an area of considerable focus virtually from the moment that Corning scientists proved, more than 30 years ago, that glass fiber was a viable medium for communications. After all, for optical transmission to be truly practicable and to compete with the incumbent copper technology of the day, these fibers would have to perform just as well outside of the lab in rigorous conditions.

In the past three decades, optical fiber coating has come a long way. What was once a simple one-layer glazing, intended perhaps only to provide the fiber with a certain level of protection against scratches and scuffs, has become a robust dual-layered coating designed not only to ensure the long-term reliability and light-carrying ability of the glass, but also to make it easy to cable and install.

To create coatings this dynamic demands a molecular-level understanding of the glass and the coating materials, and expertise in photo chemistry and kinetics. Beyond this fundamental chemical knowledge, the development of advanced coatings calls for an appreciation for a fiber's use, as different applications may put unique constraints on the fiber in the field, and, just as importantly, the requirements of the cablers and installers who will work with the fiber.

The Basics of Coating

Optical fiber coatings today are designed to serve two primary roles: to protect the light-carrying ability of the glass fiber and to preserve its strength. While some of the first coatings in the history of optical fiber were a single layer of protective material, dual-layer coatings are the industry norm today, as researchers discovered early on that they offered improved performance for the fiber.

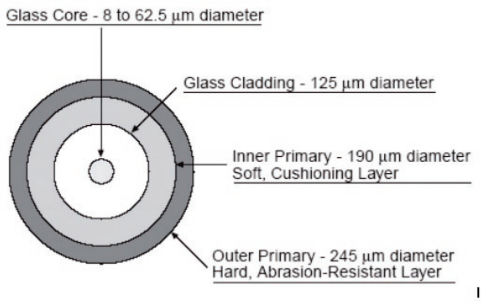

Figure 1: A schematic of Corning's dual-layer acrylate coating design. Acrylate coating chemistry is generally best suited to the stringent coating requirements of optical fiber.

In these composite coatings, a primary — sometimes also called an inner primary — coating, which is usually a softer, rubbery material, is applied directly to the glass fiber. A secondary, or outer primary, layer of much stiffer material is then applied over the inner primary coating, surrounding it (Figure 1). This firm outer layer, like early single-layer coatings, protects the fiber from abrasion and basic environmental exposure (moisture, dirt, etc.), and also provides a satisfactory surface for coloring the fiber if desired. The more elastic inner layer serves essentially as a cushion for the glass it surrounds, which absorbs the majority of external mechanical stresses placed on the cabled fiber and even adds an additional level of environmental protection.

A freshly drawn silica fiber with a flawless surface is extraordinarily strong, but can be susceptible to surface defects, such as nicks, abrasions or punctures, which might not affect the transmission of the light itself, but could significantly erode the strength and reliability of the fiber in the field over time. The outer coating serves as a shell to preserve the glass strength. Were this the only protection the fiber needed, a single-layer coating would do the job quite well.

But the inner coating's shock absorber-like function is particularly crucial because mechanical stresses that are not absorbed and are transferred to the glass can cause small deformations in the light pathway within the fiber. Specifically, these deformations of the path can cause the propagating modes of light to couple, which results in attenuation, or signal loss. This mechanism of loss is called "microbending" because the deformations are typically very small, tenths of a millimeter or less. Microbending is typically caused by non-uniform forces applied externally to the fiber, and can be triggered by irregularities in the cable, or by winding the fiber on a spool under high tension.

Fortunately, microbend sensitivity can be minimized both through the design of the fiber itself as well as by the use of dual-layer coating. For coatings, insensitivity to microbend can be improved in a number of ways, including chemical control — developing coating materials that are resistant to tension, twist or temperature — as well as geometric control — managing the thickness of the individual coating layers and the overall concentricity of the coating itself.

Beyond all this, these composite coatings must meet other requirements for practical use, including how the coating adheres to the glass, its chemical stability and durability over time and its ability to be easily processed and integrated into the fiber manufacturing process, just to name a few. And that brings us to the intricacies of coating research.

MONOMERS, POLYMERS AND COATING

At Corning's Sullivan Park research facility, the Corning Optical Fiber coating development group has evaluated many hundreds of optical fiber coating profiles, including both inner and outer primaries, in the past seven years.

According to team manager Ed Fewkes, while Corning has had a team assigned to work with fiber coatings since the early days of optical fiber commercialization, the group has shifted its focus in the last decade to highly specialized research into coating chemistry. The result, Fewkes adds, is a coating team with expertise and knowledge on par with the world's top academic research institutions.

"We recognized that to create a superior coating, one that delivers to the high standards of Corning fiber, you must really get into the chemistry of the coating," Fewkes said. "We're talking about a fundamental understanding of how molecules behave. What's critical is that we are continually learning more, and that knowledge delivers continual improvement in the coating. The more you do, the more arrows are in your quiver to solve coating challenges."

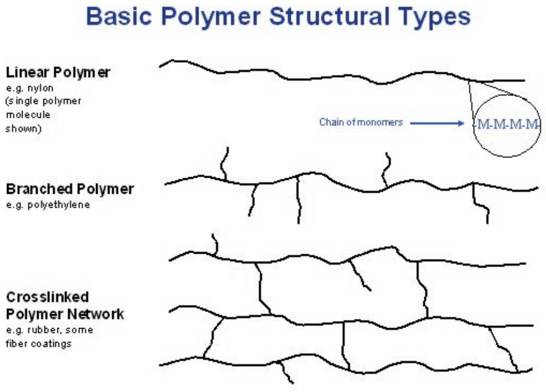

FIGURE 2: The combination of monomers (molecules) can affect the structural property of the polymer, creating diverse compound types with unique attributes. Linking multiple polymers into crosslinked polymer networks provides even more diversity. Almost like weaving threads, the resulting crosslinked polymer network might be very stiff or very elastic, depending on which polymers are linked and how they are linked.

At their most basic level, coatings are an interconnected series of polymers. A polymer is a synthetic or naturally occurring compound, usually with a high molecular weight, created by linking simple monomers (molecules) into very large and long chains. Change the composition of monomers and/or change the polymer's molecular weight, and you change the attributes of the polymer, such as its stiffness, heat resistance and stability.

These diverse polymer structures can become recognizable materials in and of themselves, such as nylon. But polymers can also be linked linearly to create different, more complex compounds: crosslinked polymer networks (Figure 2). Like molecules within a polymer, a virtually infinite combination of polymers can be linked to create these more complex structures and, with similar diversity, produce the resulting attributes of the polymer network.

Corning researchers have proven that crosslinked polymer network structures are best suited to optical fiber coatings. Interconnected polymers are environmentally robust, as they generally do not dissolve in solvents or water, show increased resistance to abrasion and can be designed to be highly elastic or highly stiff, as desired. And the diversity of crosslinked polymer compounds adds another level of versatility to designing coating materials to address specific attributes, such as mechanical or thermal properties.

A Careful Balancing Act

While polymer compounds offer seemingly infinite possibilities for coating materials, these are tempered by practicality. An optical fiber and its coating have a lot in common: the immutable laws of physics allow only so much flexibility in the profile design of a fiber, as changing one fiber attribute inevitably has an impact on one (or more) other attributes. (For example, generally speaking, lowering the slope of a non-zero dispersion-shifted fiber also decreases its effective area, which will reduce its power-handling capability.)

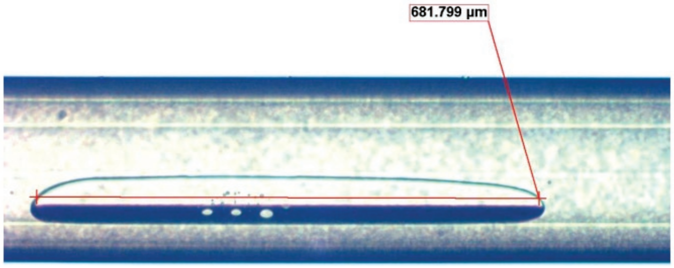

Figure 3: A non-uniform adhesion (NUA), creating small pockets between the glass and the inner primary coating.

Similarly, the laws of chemistry demand a series of tradeoffs: increasing the thermal resistance of a crosslinked polymer network might, for example, result in decreased elasticity with mechanical loading. Adhesion is another important area of balance: the coating should adhere reliably to the glass in order to effectively perform its role as protector. Low adherence can result in gaps between the glass and the inner primary coating (see Figure 3). On the other hand, a coating that adheres too well to the fiber requires a much higher strip force and can become difficult to strip and splice in the field.

So creating an ideal fiber-optic coating is a careful balancing act of attributes; Fewkes estimates there are at least 50 material properties that his team considers when developing and evaluating potential coating types. There is a certain amount of flexibility in prioritizing which attributes are most critical, depending on the fiber's function within the network — a flexibility afforded by these complex polymer compounds.

For example, the coating of a specialty fiber used in a laser application would put a higher priority on its heat tolerance and its resistance to abrasion from general handling, but given its short length and high transmitting power, might have less need for microbending tolerance. In this case, a single layer of a stiff, highly thermal-resistant coating may be the best fit for this fiber.

However, a submarine fiber, deployed in rigorous undersea conditions, handled very rarely (perhaps never again) after installation and required to transmit reliably for decades, would likely have very different coating requirements, with high insensitivity to microbending, good splicing performance and long-term stability within the cable being at the top of the list. In fact, those attributes are crucial for virtually any transmission fiber, from ocean to desktop, making those high focus areas for Fewkes' group.

“The quest for the ‘holy grail’ of coating — the ideal coating — has changed over the years, from a coating that is infinitely stiff to one that is infinitely elastic, or one that is entirely resistant to temperature,” said Fewkes. “But in our view, the real holy grail of coating is one that balances all of the requirements for the fiber in the short- and long-term. A superior coating provides the best possible performance during the fiber's manufacturing, cabling and installation, for the lowest cost and for the longest period.”