RELIABILITY EVALUATION OF FIBER COATING ANOMALIES

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Abstract: Dual-coated optical fibers provide easier stripping and less sensitivity to micro-bending. Despite a record of success in the field, dual-coated fibers can still pose a challenge within the manufacturing environment since they are susceptible to developing physical anomalies during processing and fiber-handling. Although these anomalies are believed to be benign, there are very few published reports on reliability assessments.

We have investigated the effect that the presence of two types of anomalies has on the long-term reliability of fiber under a variety of conditions. The results are consistent with the favorable field experience to date, but also highlight the need for meticulous fiber-handling and diligent inspection techniques.

1. BACKGROUND

The earliest undersea optical fiber systems used fiber with a robust single coating for glass fiber protection. Shortcomings in the use of these coatings in the terrestrial marketplace led fiber manufacturers to develop a dual-coated protection layer. The dual coating design is optimized for fiber stripping and micro-bending. The inner primary coating is soft and rubbery with a low glass transition temperature (Tg). The outer coating is much harder and its main function is to protect fibers from external environmental and mechanical aggression.

Tyco Telecommunications has used dual-coated (UV Acrylate) fibers since the late 1990s. Compared to single-coated fibers, dual-coated fibers are easier to strip and less sensitive to micro-bending. Despite the successful field record of dual-coated fibers in terrestrial applications, the presence of coating anomalies raises concern for the use of dual-coated fibers in submarine applications.

The most prevalent anomaly is delamination between the inner primary coating and the glass fiber. Others such as compression artifacts and surface contaminations are also observed under certain circumstances.

2. FIBER COATING ANOMALIES

During submarine fiber subsystem manufacturing, the following anomalies in the fiber coating are most often encountered:

a) Delaminations

b) Compression artifacts involving the inner primary coating

c) Surface contaminations by adhesives or other materials used in manufacture

d) Cracks, nicks, surface abrasion or compression involving the outer coating

The most prevalent anomaly is delamination, which is the result of low adhesion at inner primary coating and the glass fiber interface. Delaminations are usually caused by fiber handling and so can occur at any point in the manufacturing process while the fiber is exposed to the manufacturing environment.

The size of the delamination is dependent on the manner in which it is created. The length can vary from less than 1 mm to about 1 to 25 centimeters, while the circumferential width can extend from a few percent to the entire circumference.

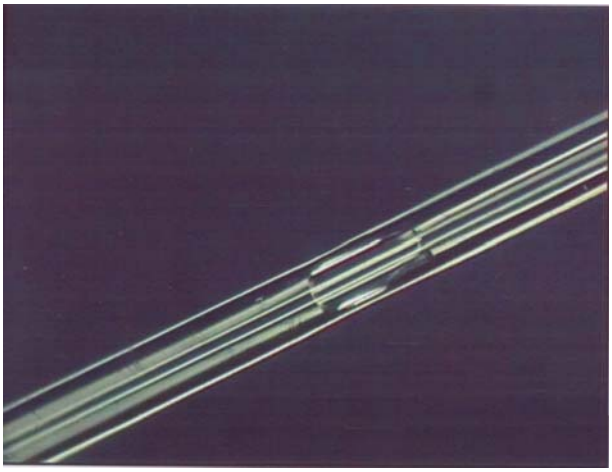
Compression artifacts involving the inner primary coating are also observed on dual coated fibers. Compression artifacts occur when a short length of coating material is crushed under pressure or lateral load and the coating is not able to recover to its original homogenous state. They appear as small round spots in the coating with a diameter ranging from sub-micron to about a few tens of microns. These anomalies can be caused by non-uniform compression and expansion of the coating material during handling or by uniform pressurization during manufacture.

Delaminations and compression artifacts are generally believed to have little impact on fiber reliability. There are two issues that need to be addressed. First, it is often difficult to distinguish delaminations and compression artifacts from surface contamination or even from cracks and nicks. These latter anomalies are cause for rejection. Therefore engineering time is often needed to distinguish among the anomalies and to determine the disposition of the product exhibiting them.

Second, it is unclear if delaminations and compression artifacts, although benign themselves, might evolve into more serious defects when subjected to fiber handling such as cleaning, clamping, or winding . We address this issue in the next section.

3. RELIABILITY ASSESSMENT - DELAMINATIONS

To assess their reliability impact, delaminations were intentionally created on 2 groups of fiber samples from different fiber manufacturers. The delaminations created were 1 to 5 mm in length with an uncontrolled circumferential coverage from 25% to full coverage. Figure 1 shows some delamination examples.



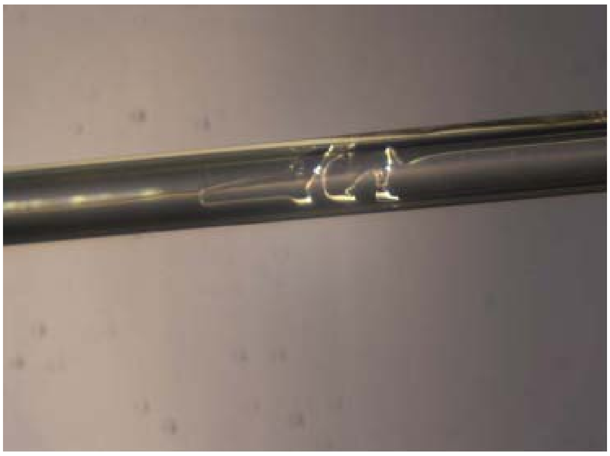


Figure 1: Coating Delamination

One set of samples was immersed in water for 3 days at room temperature to provide the worst-case fiber strength degradation for the case of a cracked coating. All fibers delaminations were visually inspected and the fibers were then pulled to destruction.

The strength data were plotted on a Weibull probability plot and compared with the data from two control samples. As shown in Figure 2, the samples with delaminations did not show measurable degradation compared to the two control samples which had no delaminations.

Additional samples were prepared to evaluate the evolution of delaminations under repeated fiber handling routines such as taping, wiping, coiling, coloring and splicing. The strength of these samples also did not show any degradation after handling followed by 5 days of water immersion.

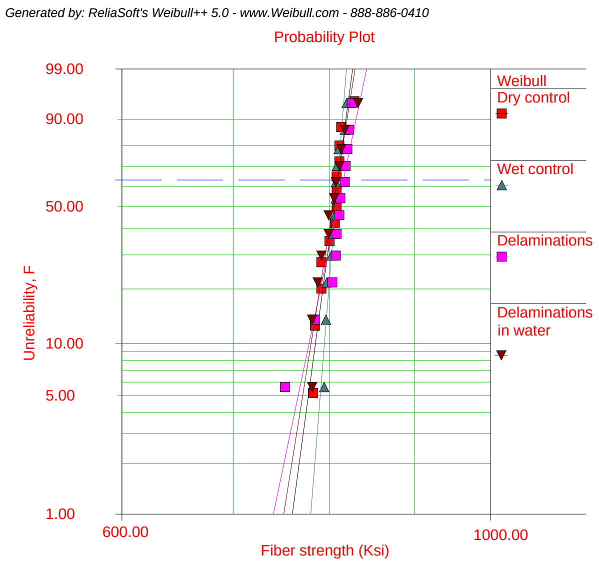


Figure 2: Weibull Probability Plots of Fiber Strength Data

These results give us confidence that the reliability impact of delaminations is very minimal for the short period of handling exposure that occurs in an undersea manufacturing environment.

4. RELIABILITY ASSESSMENT – COMPRESSION ARTIFACTS

Compression artifacts are not usually observed on fibers subjected to normal handling like stripping, clamping and wiping. Instead, they are observed on some dual-coated fibers after pressurization. Typical compression artifacts are shown in Figure 3. The randomly distributed but still isolated spots suggest the coating material is microscopically non-homogenous.

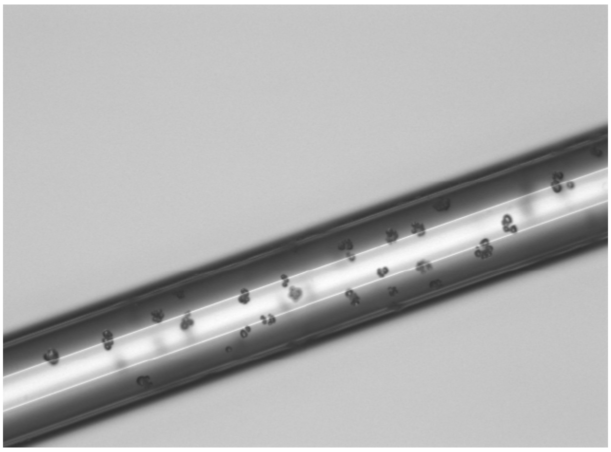


Figure 3 Compression Artifacts on Fiber Coating

In order to investigate whether compression artifacts develop into more serious defects during fiber handling, fibers with compression artifacts were subjected to repeated fiber handling routines. These included,

a) Cleaned with methanol and Texwipe® wipers.

b) Marked with colored pen and cleaned again.

c) Clamped on splicing machines, specifically on a marked section containing compression artifacts

d) Coiled around a mandrel, fiber loops slid up and down, and then uncoiled

e) Wound on a fiber storage wheel.

The fibers were visually inspected before and after handling and then subjected to an 85°C/85% RH environment for one week. No observable evolution of the compression artifacts was found. The fibers were then pulled to destruction and their strengths were compared to controlled group of fibers. No fiber strength degradation was observed.

5. VARIATION IN TENDENCY TO DEVELOP ANOMALIES

Although fiber coating properties such as modulus of elasticity, glass transition temperature Tg, adhesion to glass, strip-ability, elongation, water/solvent resistance have been well known for decades, we find that the ranges of the above parameters vary significantly among fiber suppliers. Consequently, fiber coating behavior varies from one supplier to another.

An example of this variability can be seen in the pull-out force, tested and measured per TIA/EIA PN-2746. The values of pull-out range from under 0.8 lbf/cm to 2 lbf/cm**.** We have found that low pull-out forces, implying lower adhesion of the primary coating to the glass fiber, correlates with the propensity of the coating to develop delaminations.

The conclusions we draw in the previous section are applicable to fiber from two suppliers, representing both ends of this range.

6. CONCLUSIONS

Both delaminations and compression artifacts are observed on dual-coated fibers. Due to a wide range of coating characterizations, some dual-coated fibers are more prone to develop these anomalies than others.

The investigations presented in this paper demonstrate that delaminations and compression artifacts have minimal impact on fiber reliability within a period of time and handling typical of the manufacturing environment for high reliability undersea telecom subsystems.

To differentiate delaminations and compression artifacts from other more detrimental coating defects such as surface contaminations, nicks, or cracks can be difficult and requires specific operator training and engineering time. Therefore, it is more desirable for our purposes to have a design of fiber coating which will satisfy stripping and micro-bending requirements while retaining sufficient resistance to delaminations, compression artifacts and other coating anomalies.figures