The Mechanical Reliability of Corning® Optical Fiber in Bending
White Paper

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Introduction

Optical fiber often finds itself in the situation where it is coiled in a tight space, routed through a package or bent as it connects devices together. Each of these situations can place tight bends on the fiber. Furthermore, the trend in the industry is to make components, connections, etc. ever smaller. Tight bends can place high levels of stress on the fiber, posing a possible reliability risk. This paper will examine the effects of bending on the reliability of Corning fiber and give some guidance for fitting fiber into small places.

In order to calculate the reliability risk of bending fiber in tight configurations, a reliability model is needed. Corning uses a Multi-Region Power Law Model for such reliability predictions. The details regarding the experimental and theoretical justification of our reliability model have been published elsewhere.[1,2]

Corning has also published a paper entitled *Mechanical Reliability: Applied Stress Design Guidelines.*[3] This publication defines the allowable safe-stress values that can be applied to optical fiber to minimize the risk of mechanical failure. These safe-stress values are based on the proof stress and fatigue theory of how flaws grow in glass over time.[4] Proof testing is a processing step which eliminates flaws below a given strength. If the applied stress remains below some fraction of the proof stress, flaws will not grow to failure over the duration of the stress event. The prime example of this is the 1/5 rule, which states that one should not exceed a stress of 1/5 of the proof stress to insure long-term reliability of the fiber. For 100 kpsi proof tested fiber, this would be 20 kpsi or a corresponding bend radius value of 32 mm.

The above Guidelines were developed for long-haul fiber applications, where thousands of kilometers of fibers are deployed. For these long lengths, it is necessary to design around the proof stress level. However, for fibers in short-length applications, where the lengths tend to be in meters instead of kilometers, one can exceed the safe-stress guidelines with minimal reliability risk. This is because the probability of encountering flaws near the proof stress level is low for these short-length applications. Therefore, one can expose the fiber to tighter bends in short-length applications with limited risk.

It is important to remember that the recommendations regarding tight bends in this analysis are for mechanical reliability reasons only. Optical performance may be affected by bending to small radii.

Strength Testing

To determine the bend radius for some acceptable level of risk, one must first measure the fiber's strength distribution. Proof testing eliminates the largest or weakest flaws. Flaws that survive proof testing occur infrequently and long lengths of fiber must be measured in order to find them. The strength distribution is measured at Corning by sequentially stressing 20-meter sections of fiber to a load of 350 kpsi (2.4 GPa) in an automated fashion.[5] The strength of any flaw weaker than 350 kpsi is recorded and those that survive this strength test are usually too strong to be of concern. Complete details on the development of a fiber strength distribution in this manner can be found on Corning's website.[6] Depending on the fiber type, strength distributions are established using hundreds or even thousands of kilometers of fiber. The appropriate strength distribution is then used as input into the reliability model to estimate the reliability of the fiber.

Corning Fiber Bend Analysis

Using the strength distribution for Corning's SMF-28® fiber, reliability estimates were made for a variety of bend radii, fiber lengths under bend and proof stress levels. Prior to making reliability determinations, certain assumptions must be made regarding the operating conditions, length and expected lifetime of the fiber. The following assumptions were made for this analysis:

- The fiber length under bend has no additional tension or torsion associated with it
- Short-term bend duration defined as ≤ 1 minute (assembly)
- Long-term bend duration defined as 20 to 40 years
- 125 micron cladding diameter fiber
- Fiber has not been mechanically damaged during post-proof test handling
  - This is a critical assumption as most premature fiber breaks can be attributed to handling induced damage

Tables 1 and 2 below give the long-term allowable bend radius for a range of fiber lengths and failure probability levels ranging from common terrestrial applications ($F=1e^{-4}$) to submarine ($F=1e^{-6}$). Table 1 is for fiber proof tested at 100 kpsi and Table 2 is for fiber proof tested at 200 kpsi.

Allowable Bend Radius Values for 100 kpsi Proof Tested SMF-28® Fiber for Given Failure Probability Levels (20 - 40 year lifetime).
Table 1

(100 kpsi Fiber)	**Allowable Bend Radius**		
Fiber Length	**$F = 1e^{-6}$** (1 ppm)	**$F = 1e^{-5}$** (10 ppm)	**$F = 1e^{-4}$** (100 ppm)
1 m	16 mm	10 mm	6 mm
10 m	26 mm	17 mm	10 mm
100 m	29 mm	27 mm	17 mm

Allowable Bend Radius Values for 200 kpsi Proof Tested SMF-28® Fiber for Given Failure Probability Levels (20 - 40 year lifetime).
Table 2

(200 kpsi Fiber)	**Allowable Bend Radius**		
Fiber Length	**$F = 1e^{-6}$** (1 ppm)	**$F = 1e^{-5}$** (10 ppm)	**$F = 1e^{-4}$** (100 ppm)
1 m	11 mm	8 mm	5 mm
10 m	12 mm	10 mm	8 mm
100 m	15 mm	13 mm	10 mm

There are several observations that can be gleaned from these tables:

1. When short lengths of fiber are used the allowable bend radius can be significantly lower than the recommended 32 mm bend radius for long-length applications.
2. The longer the length in bending the larger the allowable bend radius. For example, in Table 1 a 1 meter length of fiber at a failure probability of 1 in 10,000 ($F=1e^{-4}$) can be bent to 6 mm whereas a 100 meter length should be bent to no tighter than 17 mm.
3. The allowable bend radius at a 100 kpsi proof stress is quite small and will suffice in most cases. However, 200 kpsi proof testing allows one to employ a tighter bend radius when needed.

One can also incorporate the effect of time or bend duration on the allowable bend radius. This is important because often times fiber is temporarily bent in order to perform a measurement, route the fiber through a package, etc. Table 3 below shows that for short-term handling events, the fiber can be bent somewhat tighter.

The Effect of Bend Duration on the Allowable Bend Radius Values for 100 kpsi Proof Tested SMF-28® Fiber.
A failure probability of $F=10^{-4}$ was used.
Table 3

(100 kpsi Fiber)	**Allowable Bend Radius**	
Fiber Length	**Short-Term Bend**	**Long-Term Bend**
1 m	3 mm	6 mm
10 m	5 mm	10 mm
100 m	8 mm	17 mm

The short-term allowable bend radius is about half the long-term allowable bend radius.

Other Considerations

Single bend in the fiber: There are situations where one would like to place a single bend in the fiber. In this case one will be dealing with the high-strength region of the distribution where the glass is basically flawless. If one were to use the bend parameters given in the tables above, the risk of failure would be less. If a smaller bend radius is desired, give Corning a call as there are other technical considerations one must make.

Splices and terminations: The above bending guidelines do not apply to any situation where the polymer coating has been removed. Splices and terminations should be proof tested. The maximum stress in bending should be no greater than $1/5^{th}$ the proof stress. To convert bend radius to stress, see our calculator at: http://www.corning.com/opticalfiber/products__services/technical__papers/.

Tension, bending and torsion: There are cases when the fiber is permanently subjected to some combination of bending, tension, and/or torsion. In such a case, it is best to call Corning and allow us to help determine if the configuration is a safe one.

Summary

It is often necessary to place optical fiber in situations where it will experience tight bends over a relatively short length. It is possible for the resulting stress level to exceed recommended applied stress guidelines established for long-length applications. In the case of long fiber lengths one designs around the proof stress level, but for short lengths it is highly unlikely that a proof stress level flaw will be located in the short length of fiber under bend. To quantify the reliability risk for short fiber lengths in bending, strength testing of many kilometers of fiber was performed and used in conjunction with Corning's reliability model. This modeling was carried out for a variety of fiber lengths in bending, risk levels, proof test levels and bend durations. For short fiber lengths, one is allowed to subject the fiber in considerably smaller bends. This should be useful for those pressing for smaller packages and deployment configurations.

The bend recommendations listed in this paper do not provide a guarantee that the fiber will not fail. They are based on the knowledge of the strength distribution of Corning fiber as it leaves our manufacturing facilities, and do not include any degradation to the strength distribution from subsequent handling or other damage sources. For additional information, please refer to a separate white paper regarding the proper handling of optical fiber.[7] In addition, the customer should recognize that there are numerous applications for these fibers, therefore optical loss and power levels should also be considered when the fiber is deployed in tight bend configurations.

Please visit Corning's web site for more information and papers on mechanical reliability at http://www.corning.com/opticalfiber/products_services/technical_papers/.

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