Effect of optical fiber coating abrasion on aging behavior

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ABSTRACT

Optical fibers with different protective coatings were abraded then submerged in 50°C water for twenty-eight days. The strength of the abraded and control fibers exposed to zero-stress aging was tracked over time with tensile strength testing. Although the abrasion test represented a severe model of fiber handling, no appreciable strength degradation was detected on the fiber before or after zero-stress aging.

Keywords: optical fiber, reliability, harsh environments, abrasion, aging, fatigue, specialty fiber

1. INTRODUCTION

Optical fibers are typically covered with protective coatings which are designed primarily to maintain the strength of the glass fiber during installation and operation. For most applications, the fiber would be protected with multiple layers of coating, along with strength members and additional jackets or buffers. For example, a typical telecommunications cable has an array of fibers coated with primary and secondary acrylate coatings which are then wrapped in Kevlar and jacketed with a high-temperature polymer. Thus, the cable is designed to withstand the rigors of installation and protect the glass fiber from the destructive effects of the environment.

However, for many specialty fiber applications, it is either impractical or impossible to provide this level of protection. For example, in geophysical applications where temperatures can reach 300°C, most thermoplastic polymers would not withstand the elevated temperature. In aerospace designs where space is a premium, fibers are often placed under tight bends while exposed to aggressive heat and vibration conditions. Also, medical applications demand extremely high reliability in a fiber designed to travel (for example) through an artery. For these and many other applications, a small fiber design often necessitates a thin layer of coating for protection.

For fibers with only one or two layers of coating, abrasion becomes a critical concern as a failure mode. During the fiber draw process, a fiber will pass over several rollers and pulleys each of which can scratch the coating; this process is compounded if the fiber goes through additional prooftesting and respooling steps. Another issue is the unpredictable nature of handling by end-users. Operators “in the field” may pull fibers through conduits or other structures without regard for the condition of the fiber’s coating.

Although the handleability of optical fibers with regard to abrasion resistance should be an area of concern for reliability, the topic has received scant attention. This may be in part due to the absence of a standard for determining a fiber’s durability under abrasive conditions. In 1993, Oishi et al. tried to address this issue by proposing an abrasion test where a fiber passed over a sandpaper-covered roller while under tension.[1] The study suggested that a particle size twice the size of the secondary coating thickness is necessary to break the fiber. This was followed in 1998 by a paper by Wissuchek et al. demonstrating methods to determine a fiber’s resistance to mechanical damage.[2] In the abrasion test, a hollow tube of coating was bombarded with abrasive grit and then measured for strength. Finally, in 2003, Glaesemann and Clark presented a puncture resistance test that also found a correlation between a fiber’s mechanical reliability and the secondary acrylate coating thickness.[3]

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While the potential fracture of the fiber during handling is a concern, another critical issue is how coating abrasion may affect the aging characteristics of a fiber. That is, a rougher coating surface will have a greater surface area which may increase the diffusion rate of moisture through the coating. Furthermore, a damaged coating may be more susceptible to delamination allowing for greater water mobility at the glass-coating interface. These conditions can accelerate fiber fatigue and reduce the expected lifetime of a fiber.[4,5,6] Although the topic of fiber aging has been widely covered, the reported behavior may not adequately represent the "real life" conditions of a fiber roughly handled and deployed.

2. EXPERIMENTAL

Four fiber samples were prepared for this test:

- Acrylate X - 125µm glass / 195µm primary / 245µm secondary
- Acrylate Y - 125µm glass / 195µm primary / 245µm secondary
- Polyimide X - 125µm glass / 155µm coating
- Polyimide Y - 125µm glass / 150µm coating

All samples were generated on the same draw tower, but from different glass preforms. The acrylate coatings are telecommunications-grade coatings which are applied to the glass fiber and cured with ultraviolet lamps. The polyimide coatings, on the other hand, are cured with thermal ovens.

For the abrasion test, we wanted to approximate the conditions that a fiber might see under aggressive installation conditions. A 2m long, 19mm-square aluminum U-bracket was set up and capped on either end with Teflon guides (see Figure 1). The test fiber was then fed through the guides and common sand (average particle size: 300-500µm) was poured into the channel. A 2m long aluminum bar was then slotted into the top of the bracket and a 20kg weight was placed on top of the bar. The fiber was then pulled through the channel at a constant speed of 1m/second onto a take-up.

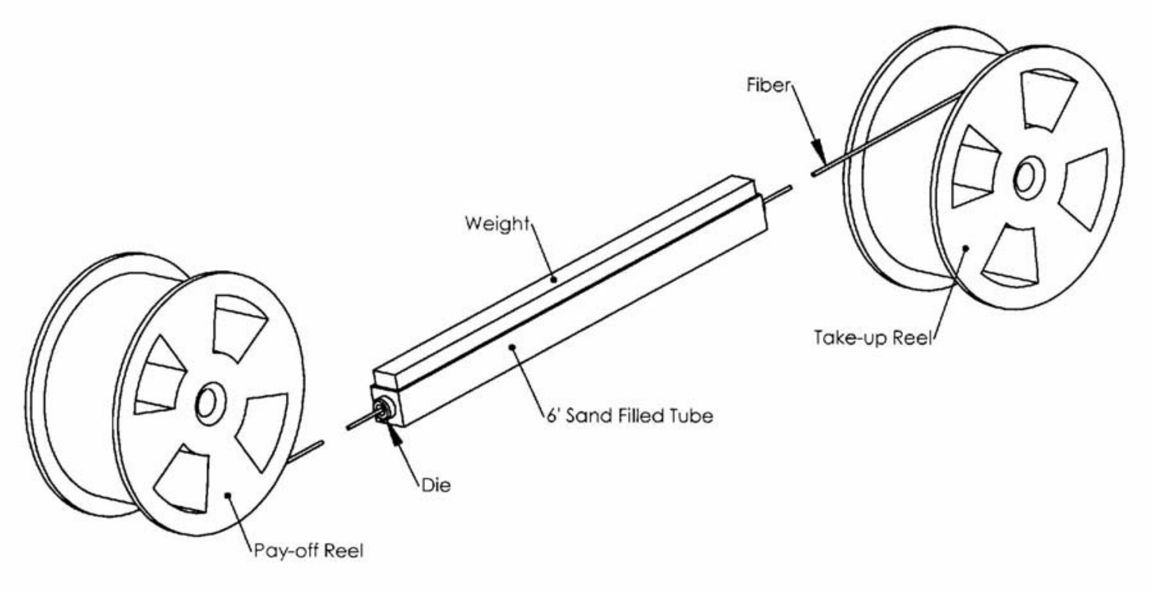

Figure 1: Apparatus to abrade optical fiber

The effect of this abrasion procedure is apparent in the following micrographs of the acrylate 'X' fiber before and after passing through the apparatus:

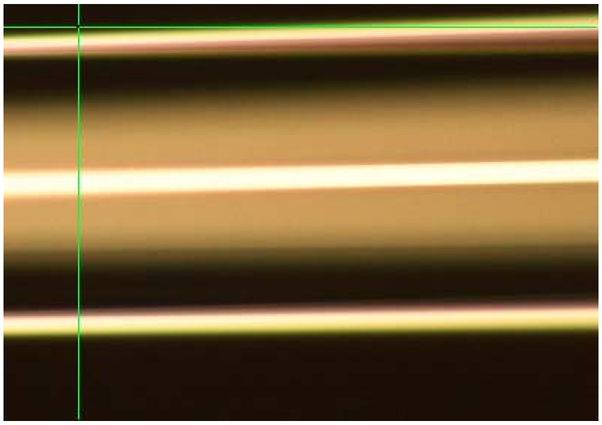

Fig. 2: Micrograph of unabraded acrylate fiber.

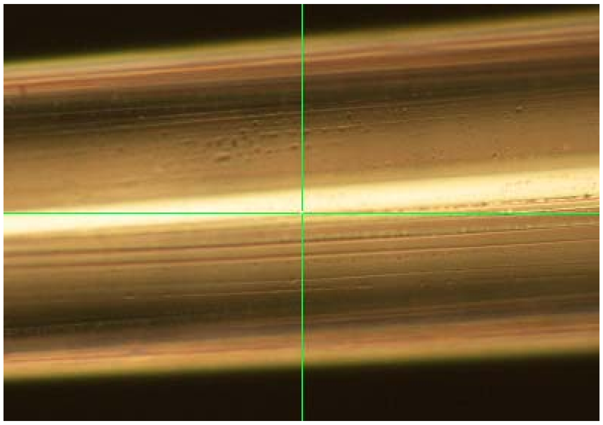

Fig. 3: Micrograph of abraded acrylate fiber.

As the micrographs illustrate, the abrasion process resulted in a visible roughening of the acrylate coating with thin striations running along the length of the fiber surface. Based on the scale of the fiber, the grooves appear to be <10μm in depth such that the surface of the secondary coating is abraded but the primary coating will not be affected.

Fiber samples from the supply spool and the take-up spool were then tested for strength on an Instron tensile strength tester, strained at a rate of 4%/minute on a 0.5m gage length. Abraded and control fiber samples were placed into water baths inside of a thermal chamber held to a temperature of 50°C. Samples were removed after 7, 14, and 28 days of soaking at this temperature and tested for strength.

3. RESULTS AND DISCUSSION

The tensile strength curves for the acrylate fiber samples are presented below:

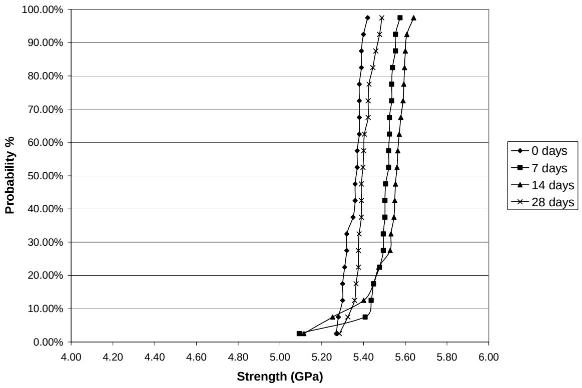

Fig. 4: Strength of acrylate ‘X’ fiber.

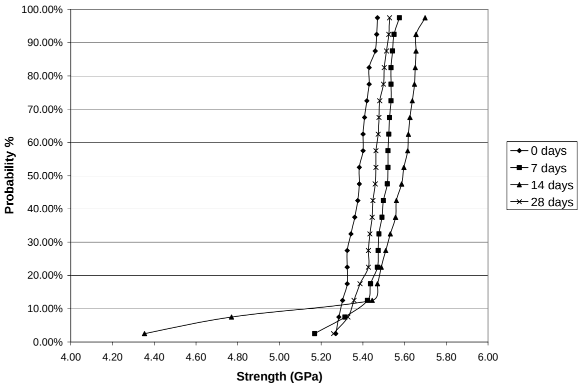

Fig. 5: Strength of abraded acrylate ‘X’ fiber.

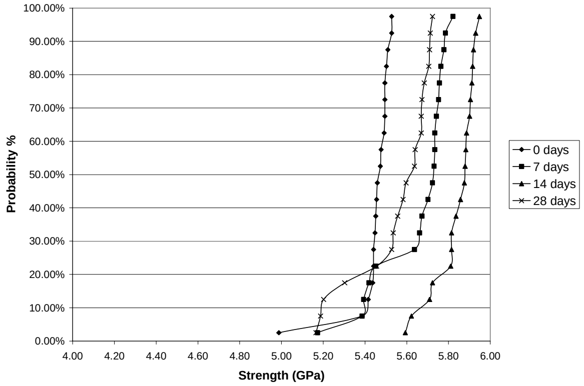

Fig. 6: Strength of acrylate ‘Y’ fiber.

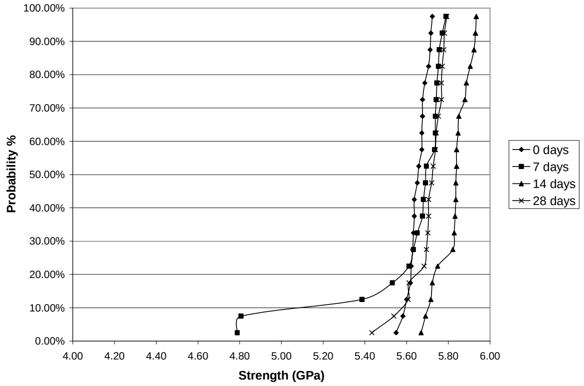

Fig. 7: Strength of abraded acrylate ‘Y’ fiber.

As the data indicate, the acrylate fibers exhibited no appreciable drop in strength after submersion in 50°C water for 28 days; in addition to maintaining a median strength > 5 GPa, the fibers also showed a tight strength distribution with Weibull slopes above 30. The tensile strength data for the abraded fibers indicate that the abrasion had no impact on either the strength of the fiber or the aging characteristics; it is virtually identical (if not slightly better) than the unabraded fiber.

Similar behavior was observed for the polyimide fiber samples. Both the control and abraded polyimide ‘X’ fiber samples started with a median strength ≈5.5 GPa and, 28 days later, ended with the same median strength and a Weibull slopes > 100.

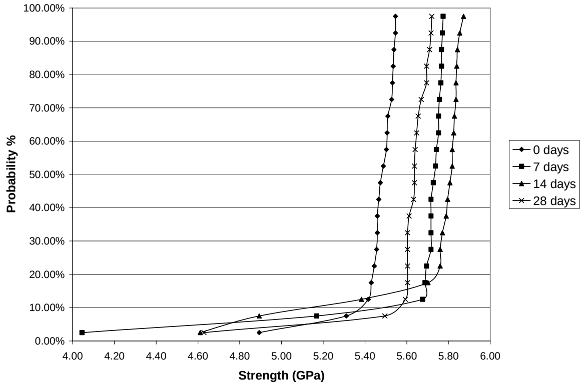

Fig. 8 Strength of polyimide ‘X’ fiber.

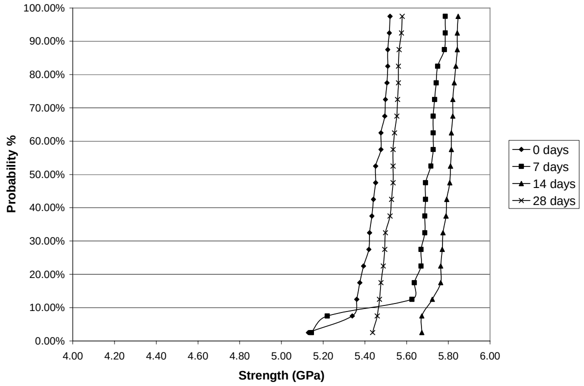

Fig. 9: Strength of abraded polyimide ‘X’ fiber.

The polyimide ‘Y’ fiber presented somewhat of a different picture. The control fiber started with a median strength of 5.1 GPa, but with a significant tail down to 1.2GPa and a Weibull slope of 2. The abraded polyimide ‘Y’ fiber exhibited a similar strength distribution with a median of 5.2 GPa, a minimum of 0.66 GPa and a slope of 4. Both fiber samples appeared to be more susceptible to the effects of moisture since both the abraded and unabraded samples dropped to a strength of 1 GPa after a week in the 50°C water. However, by the conclusion of the aging test, the abraded and control fibers exhibited similar strength results with a wide distribution.

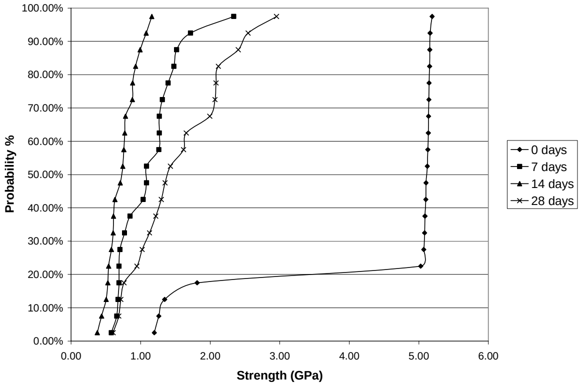

Fig. 10: Strength of polyimide ‘Y’ fiber.

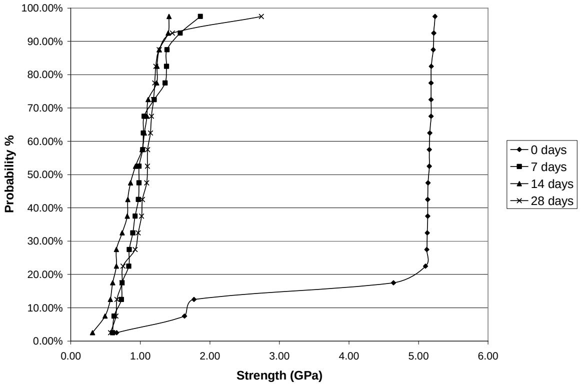

Fig. 11: Strength of abraded polyimide ‘Y’ fiber.

The following table details the median strength and Weibull slopes for the control and abraded fiber samples before exposure to water and after 28 days submersion in 50°C water:

	Baseline median strength (GPa)	Baseline Weibull slope	Post-aging median strength	Post-aging Weibull slope
Acrylate ‘X’ control	5.37	145	5.39	147
Acrylate ‘X’ abraded	5.38	101	5.46	98
Acrylate ‘Y’ control	5.47	168	5.62	30
Acrylate ‘Y’ abraded	5.65	140	5.72	85
Polyimide ‘X’ control	5.48	118	5.64	134
Polyimide ‘X’ abraded	5.45	95	5.53	153
Polyimide ‘Y’ control	5.11	2	1.39	2
Polyimide ‘Y’ abraded	5.15	4	1.10	4

Table 1: Strength data for control and abraded fiber samples.

A primary concern for the abrasion resistance study was designing a test that would replicate real-life expectations during fiber handling while setting a standard that could be easily duplicated. The sand-filled channel appeared to have the advantage of abrading around the entire circumference of the fiber. Initially the abrasion procedure seemed very aggressive and the scratching of the fiber against the sand could be felt tactilely on the fiber line; several times the fibers broke in the channel and had to be re-stringed. Under a microscope, the coating on the fiber surface appeared striated with shallow grooves. Despite this rough treatment, it is apparent from the strength data that unless the coating is breached down to the glass surface the fiber will largely maintain its original strength.

The 50°C water soak condition was based in part on the temperature extreme most fibers would see in typical applications. From previous studies[7,8] there was a reasonable expectation that water would diffuse through the fiber coatings in a matter of hours at this soak temperature. However, if moisture migrated to the glass surface, there was no immediate indication based on the tensile strength data. Furthermore, the (slightly) more open surface area on the abraded fiber appeared to have no detrimental effect on the aging behavior in this particular study.

4. CONCLUSIONS

Acrylate and polyimide coated fibers were abraded in a sand-filled channel and then exposed to zero-stress aging over a period of twenty-eight days. Although the abrasion test was designed to recreate severe handling conditions, no appreciable drop in strength was detected either after abrasion or zero-stress aging. A difference in behavior between abraded and un-abraded fibers may be apparent under more extreme test conditions performed under an extended test period. However, for typical handling and application conditions, fiber strength and reliability will not be adversely affected by abrasion.

ACKNOWLEDGEMENTS

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