Covestro Coatings for Optical Fibers

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Next Generation Optical Fiber Coatings with Excellent Accelerated Aging Performance, While Maintaining Robust Draw Processing Capability

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Abstract
Next generation, microbending resistant, optical fiber primary coatings have been developed to maintain excellent optical and mechanical properties, after subject to environmental test (accelerated aging) conditions. Such coating system is also fit-for-use for modern fiber draw processes, including super-fast draw speed, optimized Helium consumption rate, as well as UVLED curing.

Keywords: Optical and mechanical properties after accelerated aging, microbending resistance, robust draw process operation window, super-fast draw speed, optimized Helium consumption rate, UVLED curable

1. Introduction
It is well known [1] that reduced microbending loss is beneficial to overall performance of optical networks. With the ongoing 5G network deployment, such a requirement is becoming even more crucial for modern high speed, and high bandwidth networks.

It has been reported in IWCS of last year about the development of microbending resistant, next generation primary coatings [2]. Particularly, such coatings demonstrated superior microbending resistance, when tested with IEC 62221 TR Method D (basket weave), at temperature of -40 °C and at wavelength of 1625 nm.

It was also reported [2], that, *in-situ* modulus was reduced by about 70%, from 0.49 MPa of Current Coating, to about 0.15 MPa of Next Generation Coating, as shown in Figure 1. Concerns have been raised, *w.r.t.* how such low modulus primary coatings would perform under severe accelerated aging conditions, such as 85°C/85% Relative Humidity.

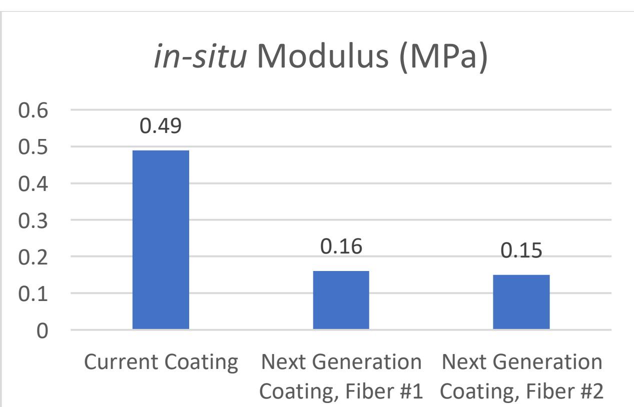

Figure 1. On-fiber *in-situ* Modulus [2]

In this report, optical and mechanical properties, after accelerated aging, are evaluated for fibers coated with Next Generation Coating system. At the same time, Next Generation Primary Coating maintains its fit-for-use for modern fiber drawing processing conditions, such as fast draw speed, optimized Helium consumption rate, as well as UVLED curing [3][4].

2. Experiments

2.1 Damp Heat Environmental Test
Damp Heat Environmental Test was conducted under 85°C/85 Relative Humidity condition, for 30 days, according to IEC 60793-1-50, "Measurement methods and test procedures – Damp heat (steady state)", (Figure 2). De-ionized water was used in the test.

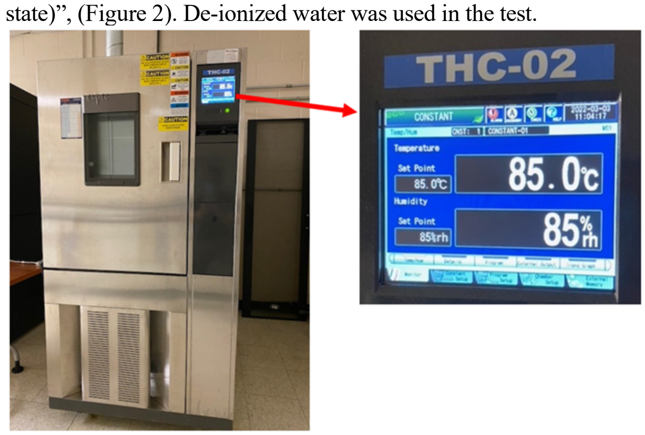

Figure 2. Damp Heat Test Setup

2.2 Change in Attenuation
Change in attenuation was measured according to IEC 60793-1-40 and IEC 60793-1-46. Precise measurement of attenuation was performed at 1310, 1550 and 1625 nm for every 5 minutes in initial 16 h, and then every 30 minutes for the remainder of the test duration, with Photon Kinetics 8000 OTDR.

2.3 Coating Strip Force
Strip force was measured, according to FOTP 178, "Measurements of Strip Force for Mechanically Removing Coatings from Optical Fibers".

2.4 Fiber Tensile Strength
Fiber tensile strength was measured, according to IEC 60793-1-31, "Measurement methods and test procedures – Tensile strength". A detailed description of the test setup is in the following "Results and Discussion" section.

2.5 Stress Corrosion Susceptibility
Stress Corrosion Susceptibility Constant (a.k.a. n_d) was measured, according to IEC 60793-1-33, "Measurement methods and test procedures – Stress corrosion susceptibility". Two-point bending method was used to generate results in this report.

3. Results and Discussion

3.1. Attributes and Requirements, after Damp Heat Environmental Test
In 2002, a Technical Report [5] was published by the International Electrotechnical Commission (IEC), to estimate the reliability of fiber under a constant service stress, based on a power law of crack growth. Since then, such accelerated aging methodology has been widely adopted by the community. The most common accelerated aging condition is 85°C/85% Relative Humidity (R.H.) for 30 days, as described in IEC 60793-1-50.

In a recent report [6], 60°C/85% R.H. was suggested to be a more realistic aging condition, as harsher conditions could introduce unrealistic aging mechanisms and give rise to misleading results under prolonged testing periods.

In this report, 85°C/85% R.H. was still employed as the accelerated aging condition, since no official IEC revision of aging condition has been published.

Table 1 summarizes the attributes and requirements, dictated by IEC 60793-2-50, after optical fiber specimen have been subjected to accelerated aging.

Table 1. Summary of IEC Standards, upon Damp Heat Environmental Test (Accelerated Aging)

Attribute	Descriptor	Requirement
Change in attenuation	1550nm wavelength	<= 0.05 dB/km
Coating strip force	Average	1.0 N <= F_{avg} <= 5.0 N
	Peak	F_{peak} <= 8.9 N
Fiber tensile strength	Median	>= 3.03 GPa
	15 percentile of the tensile strength distribution	>= 2.76 GPa
Stress corrosion susceptibility constant, n_d		>= 18

3.2. Change in Attenuation

Change in attenuation upon accelerated aging is of great interest, to monitor the change in optical transmission, therefore, to ensure the optical fibers are still fit-for-use for decades, based on the power law prediction of reliability.

Shown in Figure 3, is the change of attenuation, measured at 1550 nm wavelength, after the fibers were subject to 85°C/85 R.H. for 30 days. Change in attenuation of Current Coating was 0.004 dB/km, while the change in attenuation of Next Generation Coating was essentially zero. It's encouraging that the change in attenuation for both Current Coating and Next Generation Coating was well within the IEC standards of <= 0.05 dB/km, indicating excellent retention of optical transmission under accelerated aging conditions, predicting reliable optical transmission performance over the fiber's expected lifetime.

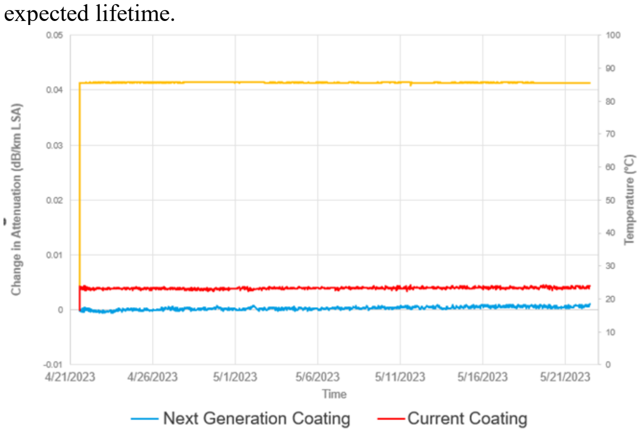

Figure 3. Loose Coil Change in Attenuation (dB/km LSA), Measured at 1550 nm

3.3. Coating Strip Force

Coating strip force is of interest in field operations, and is one of the recommended attribute to monitor, upon accelerated aging.
The test results are summarized in Table 2.

Table 2. Coating Strip Force, Upon Accelerated Aging

	Initial		After Accelerated Aging	
Strip Force (N)	Current Coating	Next Generation Coating	Current Coating	Next Generation Coating
Average	1.6	1.3	4.5	4.1
Peak	2.9	2.2	5.9	4.9

It's apparent that both Average and Peak Strip Forces increased substantially upon Accelerated Aging, by roughly 3 times in Average Strip Force, and by roughly 2 times in Peak Strip Force, when comparing to their initial values (unaged fiber). It's worth noting that, despite of such increases, both Average and Peak Strip forces are still within the IEC Requirements (Table 1).

It was reported [7] that strip force test is mainly affected by secondary coating viscoelasticity and is actually not correlated to primary coating *in-situ* modulus. Therefore, the substantial increase in strip force in this report, was likely caused by secondary coating property changes upon accelerated aging (secondary coating was not tested in this study).

3.4. Fiber Tensile Strength

It's utmost important to ensure that optical fiber retains sufficient tensile strength in the duration of application (decades in cable).

One of the challenges with soft (low modulus) primary coating is the difficulty in measuring fiber tensile strength, due to the coated fiber tends to slip on the capstan, as well as random breaking at capstan location (not in the middle of fiber specimen). As a result, the tensile strength data are often scattered, and therefore misleading.

It was reported [8] that a "sandwich tape method" could be applied in most challenging case, to effectively reduce the data scattering. The fiber tensile strength data in this report was measured, using a custom-made setup, as shown in Figure 4. Larger capstan size of 20 cm in diameter is used (vs. previously capstan size of 10 cm in diameter), coupled with a pre-winding 6 cm OD capstan, to greatly improve the stability of fiber on the main capstan. Another improvement is to use low friction tape, to further reduce the friction between fiber and capstan, therefore reducing the likelihood of fiber breaking at capstan.

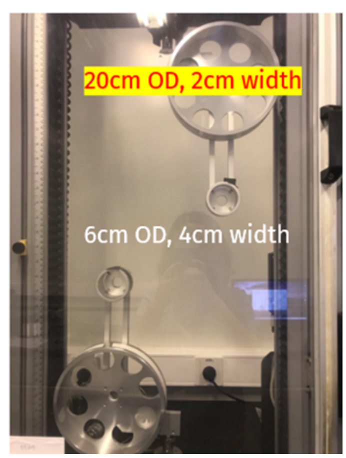

Figure 4. Fiber Tensile Strength Test Setup

The actual fiber tensile strength test results, before and after accelerated aging, are illustrated in Figure 5. For each fiber/condition, 15 fiber specimen were tested. The gauge length was 0.5 m, and the strain rate was 50mm/min (*i.e.* 10%/min).

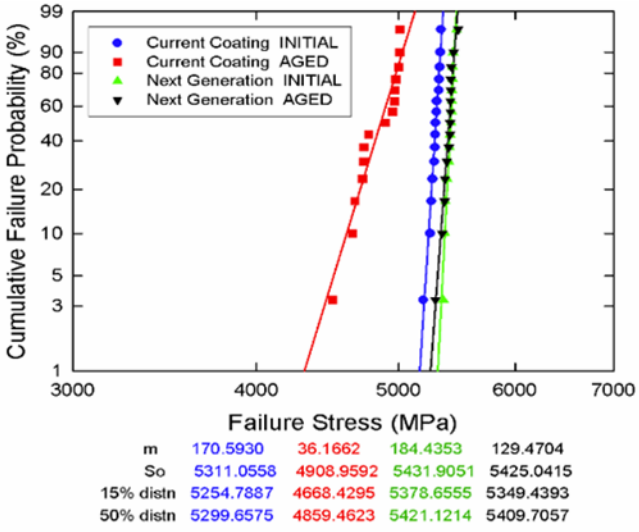

Figure 5. Weibull Plot, Fiber Tensile Strength

In the case of Current Coating, fiber tensile strength reduced from 5.3 GPa (Initial, blue round dots) to 4.9 GPa (Aged, red square). In addition, the data points of aged fiber is more scattered, indicated by reduction in m value (from 171 of Initial to 36 of Aged). Despite of the reduction, fiber tensile strength after aging is still well within IEC Standard (Table 1).

In the case of Next Generation Coating, fiber tensile strength was little changed at 5.4 GPa of both Initial (green triangle) and Aged (black triangle). In addition, data scattering was also better maintained, as measured by m value (from 184 of Initial to 129 of Aged).

Overall, Next Generation Coating system retained fiber tensile strength better than Current Coating system, upon accelerated aging. This is quite remarkable, considering Next Generation primary coating is much softer than Current Coating (Figure 1).

3.5. Stress Corrosion Susceptibility

To predict long term reliability of fiber tensile strength, stress corrosion susceptibility (n_d) is measured. It was reported [9], with improved tensile test method, excellent correlation between tensile method and two-point bending method has been obtained, in testing n_d. In this report, n_d was measured with two-point bending test method. The Fatigue Plots are included in Figure 6 and Figure 7.

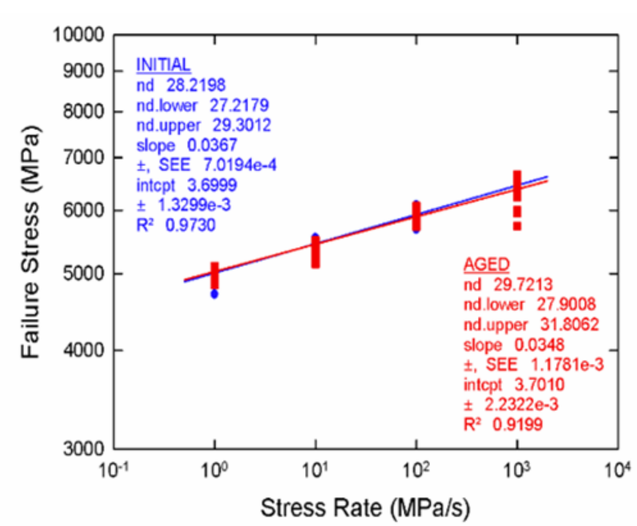

Figure 6. Fatigue Plot of Fiber Coated with Current Coatings

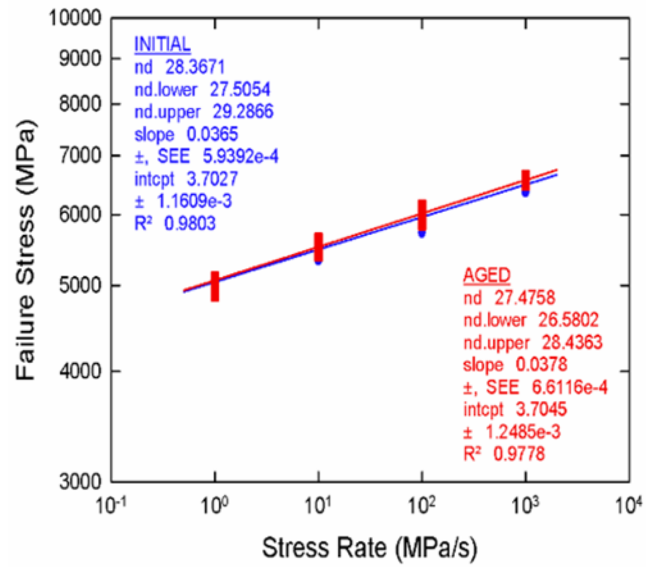

Figure 7. Fatigue Plot of Fiber Coated with Next Generation Coatings

In case of current coating, n_d value increased slightly from 28.2 (Initial) to 29.7 (Aged); while in case of Next Generation Coating, n_d value decreased slightly from 28.4 (Initial) to 27.5 (Aged).

All of these n_d values are well above the IEC Standards of 18.

4. Conclusions

In this paper, Next Generation Coating's long term reliability was evaluated, by monitoring both optical and mechanical properties, after accelerated aging.

Specifically, Next Generation Coating has essentially no attenuation change, during the 30 days of under 85°C/85 R.H. aging condition. Both Average and Peak Strip Force increased and were still within IEC requirement. Next Generation Coating had excellent fiber tensile strength retention, as well as n_d being well above IEC requirement, before and after accelerated aging.

At the same time, Next Generation Coating maintains robust processing capability [4], particularly, its fit-for-use for super high draw speed (>= 3000 m/min), as verified by in-house Draw Tower Simulator trials.

In addition, viscosity of Next Generation Coating is designed to be less sensitivity to temperature [3], making it more robust for demanding draw process, in terms of maintaining proper geometry, as well as reducing Helium flow rate/consumption.

And, Next Generation Coating is formulated to be UVLED curable.

5. Acknowledgments

The authors would like to thank Covestro Technical Service Group for performing the tests.

6. References

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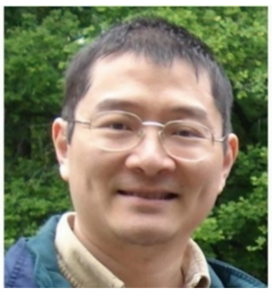
7. Authors



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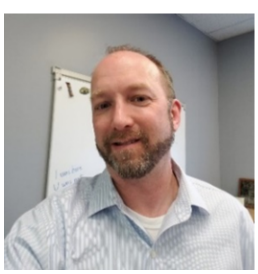

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Edition: September 2023