Fast Curing Next Generation Primary Coating Technology Providing Improved Consistency in Optical Fiber Performance and Draw Tower Process

Grant S. Sheridan, Todd Anderson, Katherine Roberts, Meng He, Brett Register and Eric Urruti

Covestro LLC

1122 St Charles Street, Elgin, IL, 60120, USA

+1-847-468-7768 · grant.sheridan@covestro.com

Abstract

Next generation fiber optic primary coating technology has been developed to meet fast curing demands as fiber optic manufacturing switches to UVLED lamps and draw speeds exceeding 3000 m/min. A new such coating was tested on a draw tower simulator with stainless steel wire and at Nextrom's Fiber Draw R&D Center using the High-Speed Wet-On-Wet Coating System and UVLED lamps with varying draw speed, lamp power, and fiber temperature.

The next generation primary coating exhibited significantly improved cure speed as observed from degree of cure and modulus buildup compared to current Covestro primary coatings. Additionally, the new primary coating exhibited much improved draw tower process consistency, with exceptional modulus stability across all draw speeds and fiber temperatures. All improved performances indicate that our new primary coating technology could not only address the industrial need for fast draw speeds, but also offer additional benefits for energy and helium savings.

Keywords:

Robust draw process, fast draw speed, fast cure speed, draw tower consistency, Helium consumption rate reduction, UVLED curable

1. Introduction

With the ever increasing market demand and rollout of 5G Technology, the draw speed of fiber optic manufacturing is continually increasing, nearly doubling in the past decade from 1500 m/min to greater than 2500 m/min, with current processing aiming to exceed 3000 m/min [1]. With the increasing draw speeds there has also been a shift to more energy efficient UVLED lamps [2,3], providing additional challenges for next generation coatings.

High draw speed leads to high fiber temperature, which in turn causes a series of problems including the need of high helium consumption for more fiber cooling and poor coating layer geometry performance [1]. A report from 2018 identified that while high draw speeds may be able to satisfy fiber strength, microbending, and environmental performance, coating geometry remains a concern [4]. A decrease in the coating viscosity in contact with the hotter glass fiber leads to a reduction in the coating thickness [5]. With the development of a next generation coating described within, the coating geometry is well controlled over a wide range of draw speeds and glass temperatures.

In addition to high fiber temperature concerns, cure speed and mechanical property buildup pose a significant challenge associated with fast draw speeds and short exposure times [6]. Using draw tower simulator and actual draw tower data over a range of UV doses, a next generation coating was developed with very fast cure speed and mechanical property buildup to meet the increasing draw tower speeds in production. Not only were the cure rate and mechanical property buildup improved, but also better modulus consistency with increasing degree of cure was achieved, improving the processability of the coating.

2. Experiments

2.1 Draw Tower Simulator (DTS)

DTS has been described in recent IWCS papers [7,8]. This study uses wet-on-wet (WOW) configuration with up to 3 UVLED lamps.

2.2 In-situ Modulus (ISM)

In-situ modulus testing methodology and data processing for primary coatings on glass fiber has been described previously [9]. The test method was also adapted for primary coatings on DTS metal wire.

2.3 Reacted Acrylate Unsaturation (RAU)

The reacted acrylate unsaturation (RAU) testing methodology and data processing for primary coatings on glass fiber has been described previously using FTIR-ATR measurement and the $810 cm^{-1}$ acrylate double bond peak [8]. The test method was also adapted for primary coatings on DTS metal wire.

2.4 Microbending Test

Microbending was measured according to IEC 62221 TR Method D [10] for 6 cycles, spanning a range of +85°C to -60°C, with each cycle having a duration of 15 hours. Precise measurement was performed at 1310nm, 1550nm, and 1625nm every 5 minutes, with PK8000 OTDR.

2.5 Fiber Tests

Primary geometry was measured using Photon Kinetics (PK), Model 2302. Fiber tensile strength was measured according to international standard FOTP 28.

2.6 Draw Tower

Nextrom laboratory draw tower with High-Speed Wet-On-Wet Coating System was used for the fiber draw experiments at Nextrom's Fiber Draw R&D Center. Six Phoseon FJ228 G7 395nm LED lamps from Excelitas Technologies were used for the draw. Glass temperature was varied by adjusting draw speed, lamp power, UV dose and helium flow. Relative UV dose was estimated from draw speed and lamp power. Helium was recycled.

3. Results and Discussion

3.1 DTS

To compare our new next generation coating to one of our current coatings on the market, both coatings were run on DTS. As shown in Figure 1, the cure speed of the next generation coating is significantly faster than the current coating, with a RAU of 83% compared to 56% at the lowest exposure time respectively. Additionally, the RAU buildup can be seen to be much faster, with a 37% increase in the cure speed rate constant shown in Table 1. As a result, the time takes to reach a practical level of 90% RAU is 59% faster for the new next generation coating.

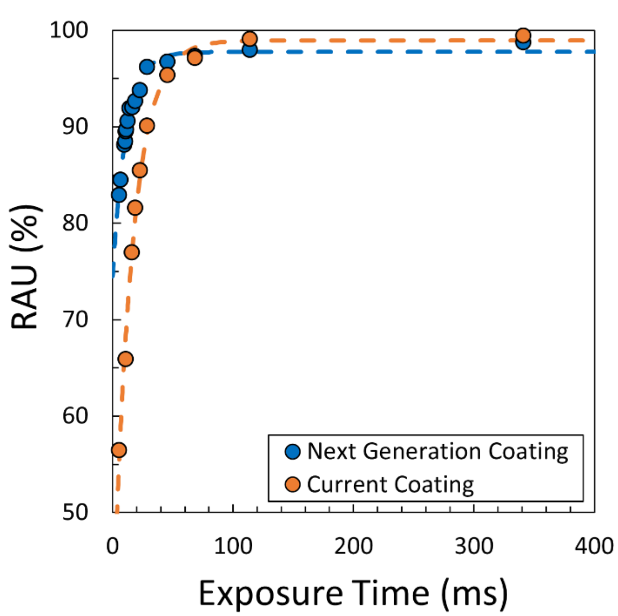

Figure 1: RAU vs. Exposure Time from DTS

Table 1: DTS Cure Data vs. Run Conditions

Draw Speed (m/min)	Lamps	Exposure Time (ms)	RAU (%)	
			New	Current
2100	1	5.4	82.9	56.4
3500	2	6.5	84.5	-
3500	3	9.8	88.1	-
3300	3	10.4	88.5	-
2100	2	10.9	89.5	65.9
3000	3	11.4	89.7	-
2700	3	12.7	90.6	-
2400	3	14.3	91.9	-
2100	3	16.3	92.0	77.0
1800	3	19	92.6	81.6
1500	3	22.8	93.8	85.5
1200	3	28.5	96.2	90.1
750	3	45.6	96.7	95.4
500	3	68.4	97.3	97.1
300	3	114	98.0	99.1
100	3	341.3	98.8	99.4
k (fit constant)			0.09	0.06

While providing a modest increase in the cure speed over the current coating, the next generation coating also provides significantly improved modulus buildup over the current coating shown in Figure 2. The new next generation coating modulus buildup plateaus almost immediately at low exposure time, while the current coating slowly reaches its plateau. From the normalized ISM fits, the next generation coating has 4400% increase in the ISM rate constant compared to the current coating shown in Table 2.

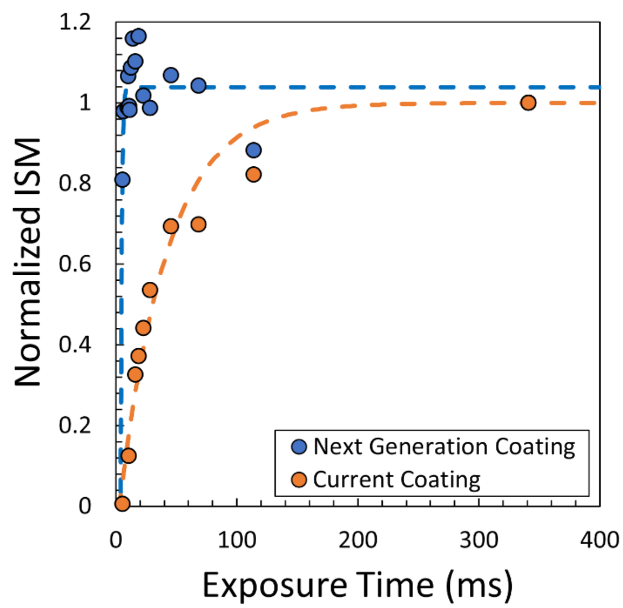

Figure 2: Normalized ISM vs. Exposure Time from DTS

Table 2: DTS Normalized ISM Data vs. Run Conditions

Draw Speed (m/min)	Lamps	Exposure Time (ms)	E'/E'_{max}	
			New	Current
2100	1	5.4	0.81	0.01
3500	2	6.5	0.98	-
3500	3	9.8	0.99	-
3300	3	10.4	1.07	-
2100	2	10.9	0.99	0.13
3000	3	11.4	0.98	-
2700	3	12.7	1.09	-
2400	3	14.3	1.16	-
2100	3	16.3	1.10	0.33
1800	3	19	1.16	0.37
1500	3	22.8	1.02	0.44
1200	3	28.5	0.99	0.54
750	3	45.6	1.07	0.69
500	3	68.4	1.04	0.70
300	3	114	0.88	0.82

100	3	341.3	1.00	1.00
k (fit constant)			1.14	0.03

This significant increase in the normalized ISM buildup rate is key to providing good draw tower consistency of the next generation coatings, where the normalized ISM is less dependent on RAU than the current coating shown in Figure 3. As the current coating approaches full conversion, the normalized ISM increases sharply, leaving a small margin of error to achieve the target ISM. Thanks in part to the extremely fast normalized ISM buildup of the next generation coating, the next generation coating normalized ISM plateaus rather quickly as a function of RAU, providing excellent draw tower consistency for achieving the target ISM.

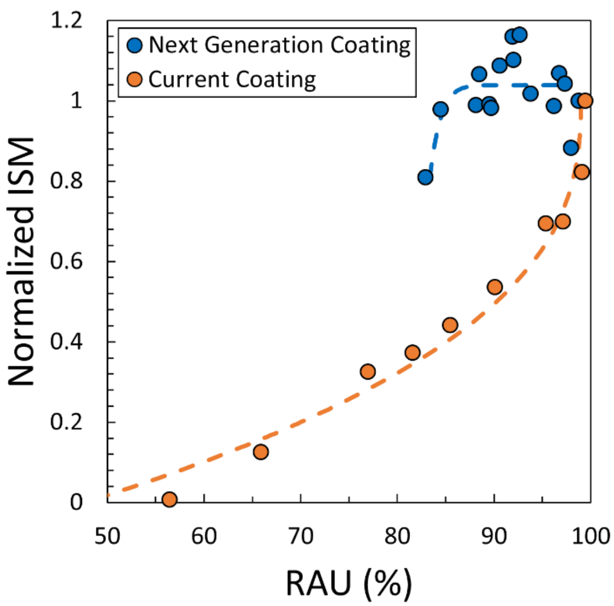

Figure 3: Normalized ISM vs. RAU from DTS

3.2 Nextrom Laboratory Draw Tower

After demonstrating the improvements of this next generation coating over the current coating on DTS, the next generation coating was trialed on an actual glass fiber and draw tower at Nextrom's Fiber Draw R&D Center. A robust next generation coating should be able to provide consistent coating thickness, fast cure to meet increasing draw tower speed demands, and modulus buildup stability for improved consistency. Running the next generation coating on an actual draw tower with glass fiber, the next generation coating exhibited all these ideal properties. Table 3 shows the run conditions used, varying the draw speeds from 1300-2800 m/min and the glass temperature from 42-120°C.

Table 3: Draw Tower Run Conditions on Glass Fiber

Run	Draw Speed (m/min)	Lamp %Power	Relative UV Dose	He Flow (lpm)	Glass Temp (˚C)
1	1623	85	0.67	29	55.0
2	1924	85	0.56	35	52.0
3	2200	85	0.50	38	57.3
4	2500	85	0.44	41	69.5
5	2800	85	0.40	43	79.5
6	2800	65	0.29	44	77.5
7	2792	45	0.21	50	78.0
8	2792	45	0.21	50	78.0
9	2800	85	0.40	-	100.0
10	2800	85	0.40	-	120.0
11	1300	85	0.85	21	43.7
12	1300	100	1.00	22	42.0
13	2200	85	0.50	38	50.1
14	2800	100	0.46	50	74.2
15	2800	85	0.40	50	74.2

Primary thickness consistency is an important property of the next generation primary coatings as increased draw speeds and high glass temperatures may cause a drastic decrease in coating thickness due to thinning. As shown in Figure 4, the next generation primary coating has minimal decrease in primary coating thickness applied on glass temperatures ranging from 42-120°C. Over this large glass temperature range, there is only a 1.2um standard deviation in the primary coating thickness, demonstrating very high coating thickness consistency.

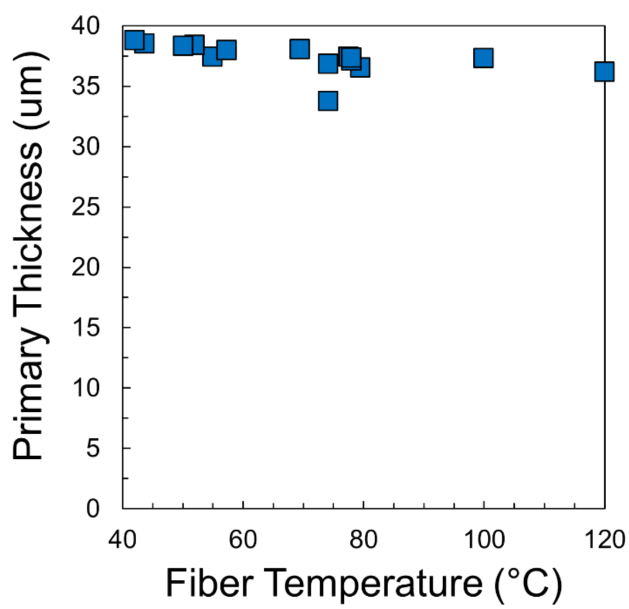

Figure 4: Coating Thickness as a Function of Glass Temperature

As shown in Figure 5, the next generation coating cures extremely fast to meet high draw speed processing demands. The RAU remained relatively constant over all relative UV dose conditions even with the glass temperature ranging from 42-120°C. The next generation coating was able to achieve about 90% RAU even at 20% of the relative UV dose, exhibiting extremely fast cure speed at low lamp power and fast draw speeds.

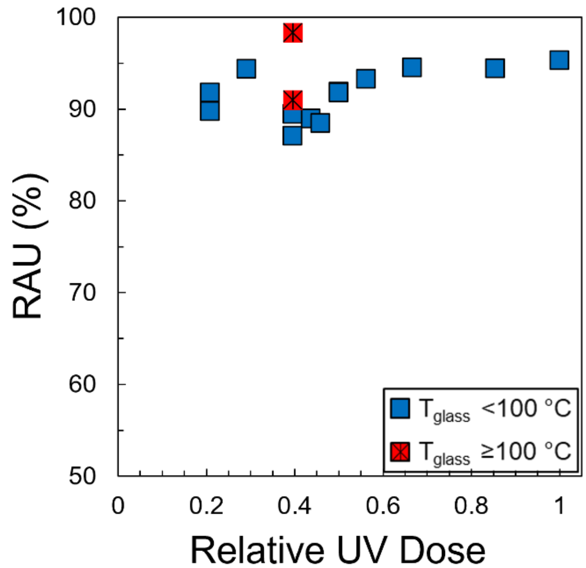

Figure 5: RAU vs Relative UV Dose with Different Draw Conditions on Glass Fiber

In addition to the fast cure and high RAU over all relative UV doses run, the next generation coating also exhibited extremely fast modulus buildup as shown in Figure 6. Despite only 20% relative UV dose, the next generation coating still achieves 80% of its maximum ISM for glass temperatures kept under 100°C. For glass temperatures from 42-100°C, there is only a 10% standard deviation in the normalized ISMs over all relative UV doses. For glass temperatures of 100°C and 120°C, indicated by the red data points, the ISM was 10-20% higher than lower glass temperature runs, however this shift of ISM is a result of many factors combined with high fiber temperature to be one of them.

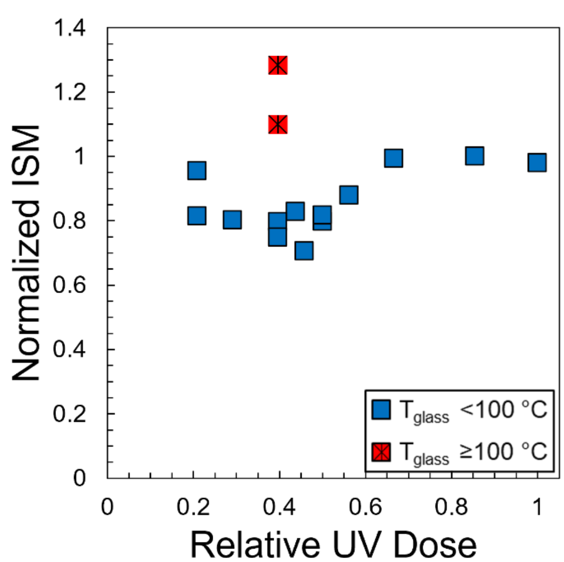

Figure 6: Normalized ISM vs Relative UV Dose with Different Draw Conditions on Glass Fiber

Plotting the RAU and ISM data from Nextrom's laboratory draw tower trial in Figure 7, the next generation coating shows excellent draw tower consistency over the many processing conditions in Table 3. At glass fiber temperatures below 100°C, the next generation coating ISM quickly plateaus and exhibits little dependence on the RAU. With a less dependent ISM on RAU, the next generation coating is able to maintain an ISM level even with drifts in the process conditions and reduced modulus jump with subsequent curing [11].

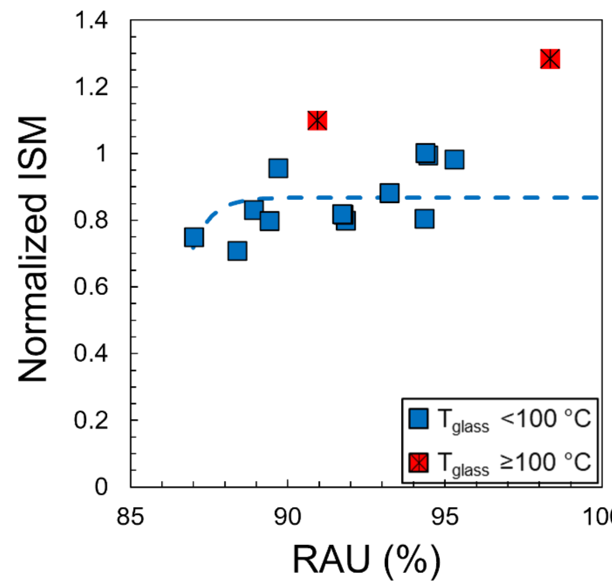

Figure 7: Normalized ISM vs RAU with Different Draw Conditions on Glass Fiber

The fiber strength was also investigated as previous publications were concerned with the effect of high draw speeds on fiber strength [12,13]. As shown in Figure 8, five fibers with the next generation primary coating were selected with draw speeds ranging from 1300-2800 m/min and glass temperatures ranging from 42-120°C. Despite the extreme range in draw speed and glass temperature, all five fibers have excellent fiber strength of over 5.1 GPa with m values close to or over 100 (indicating excellent data point consistency).

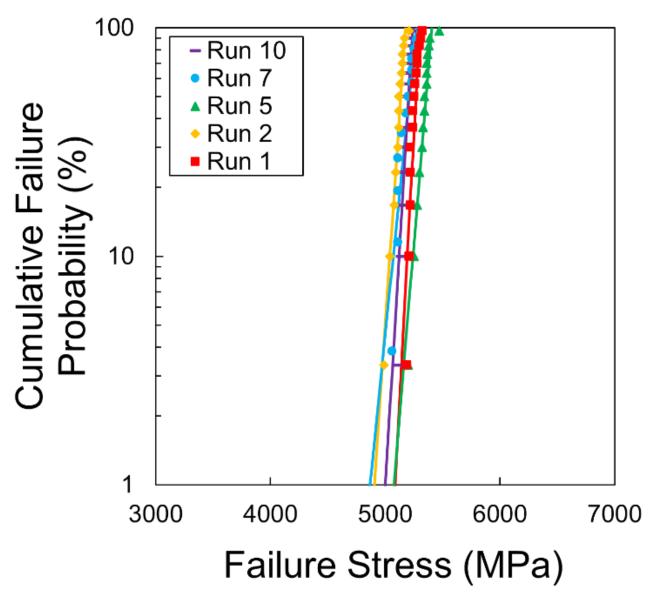

Figure 8: Weibull Plot of Fiber Tensile Strength Tests for Varying Draw Speed and Glass Temperature

Microbending testing was also performed on various runs undergoing temperature cycling from -60°C to +85°C, with the change in attenuation shown at -40°C and -60°C for 1310nm, 1550nm, and 1625nm wavelengths for a representative well cured sample shown in Figure 9. The microbending loss can be seen to increase with increasing wavelength, which is expected and well understood in the field. This next generation coating exhibits exceptional low temperature microbending loss, remaining under 0.05 dB/km even at -60°C. The microbending loss can be seen to increase an order of magnitude from -40°C to -60°C as the primary coating undergoes a "glass transition".

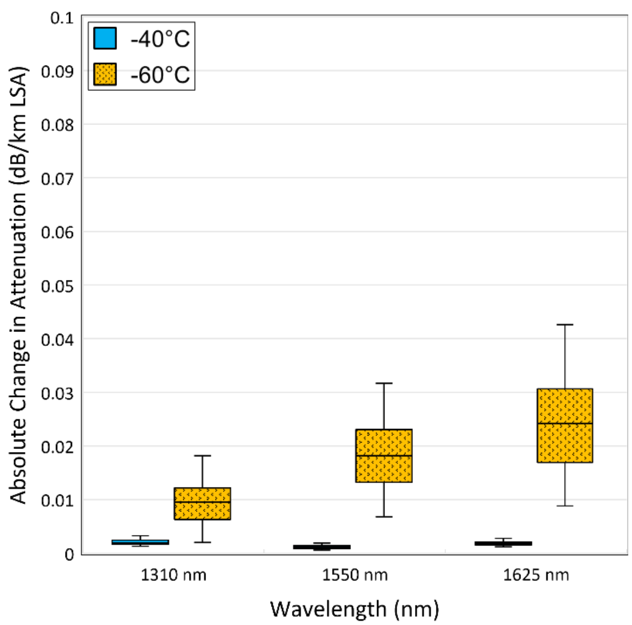

Figure 9: -40°C and -60°C Microbending Performance

4. Conclusions

To meet the increasing curing and geometry demands associated with the switch to UVLED lamps and draw speeds in excess of 3000 m/min, a next generation coating technology has been developed. The next generation coating has significantly improved cure speed and modulus buildup leading to better draw tower consistency, as well as consistent coating geometry over wide range of glass temperatures and draw speeds.

On DTS, the next generation coating reached to draw speed of up to 3500 m/min and saw a 37% increase in RAU buildup speed and a 4400% increase in ISM buildup speed as observed from rate constant over the current coating technology. This leads to greater draw tower consistency as the modulus plateaus with increasing RAU while the current coating modulus exponentially increases as full conversion is achieved.

On Nextrom's laboratory draw tower, the next generation coating also demonstrated robust draw tower consistency across 1300-2800 m/min draw speeds and 42-120°C glass temperatures. Primary coating thickness had only a 1.2 um standard deviation over all glass temperatures. The ISM also plateaued as high degrees of cure were approached while maintaining fiber strengths in excess of 5.1 GPa. Superior low temperature microbending loss was also achieved, with attenuation loss below 0.005 dB/km at -40°C and 0.05 dB/km at -60°C. All improved performances indicate that our next generation primary coating technology could not only address the industrial need for fast draw speed, but also offer additional benefits for energy and helium savings.

What's described is only one of the coatings from the next generation coating technology. Based on this new technology platform, adjustments and fine tuning on coating and on fiber performances for different fiber optic applications can be done with excellent flexibility.

5. Acknowledgements

The authors would like to thank Nextrom for the successful collaboration of testing our next generation primary coating technology at Nextrom's Fiber Draw R&D Center and Excelitas Technologies for kindly providing the Phoseon LED lamps that were used in the study.

6. References

[1] Q. Yuan, *et. al*. "Effect of Optical Fiber Temperature on Fiber Performance", IWCS, 2018.

[2] S. Ning, *et. al*. "Experiments of Optical Fibre Drawing Using UV-LED Lamps for Coating Cure", IWCS, 2016.

[3] Y. Han, *et. al*. "Application of UV LED in high speed drawing", UL and IWCS China, 2019.

[4] W. Zhao, *et. al.* "Fiber Coating Quality Control under High Draw Speed", UL and IWCS China, 2018.

[5] A. Bogaerds, *et. al.* "High Speed Fiber Drawing: A Resin's Point of View", IWCS, 2016.

[6] X. Wu, *et al*., "Optical Fiber Coatings With Both Robust Draw Process Capability, and Enhanced Optical Performance with Reduced Microbending Sensitivity", IWCS, 2020

[7] H. Cao, *et. al*. "Characterization Methods and Cure Kinetics Study on Cure Speed of Optical Fiber Coatings", IWCS, 2019.

[8] H. Cao, *et. al*. "Kinetic Study on Cure Speed of Optical Fiber Coatings by Draw Tower Simulator", IWCS, 2020.

[9] P. Steeman, *et. al*. "Mechanical Analysis of the In-situ Primary Coating Modulus Test for Optical Fibers", IWCS, 2003.

[10] S. Schmid, *et. al*. "Development and Characterization of a Superior Class of Microbend Resistant Coatings for Today's Networks", IWCS, 2009.

[11] X. Wu, *et al*. "Mitigated Inking Impact of Next Generation Optical Fiber Coatings, While Maintaining Robust Draw Processing Capability", IWCS, 2024

[12] C. Hao, *et. al.* "Research on Ultra-high Speed Fiber Drawing Technology", UL and IWCS China, 2019.

[13] X. Wu, *et al*. "Optical Fiber Coatings Capable of Super High Speed Draw Process", IWCS, 2019

7. Authors

Dr. Grant Sheridan, currently Research Scientist, Fiber Optical Materials at Covestro. He holds a Ph.D. degree in Materials Science and Engineering, and is involved in primary coating development.

Todd Anderson is Laboratory Technical Expert at Covestro. He has been working in the application process and testing of optical fiber coatings for over 20 years. Todd graduated with a B.S. in Biology from Northern Illinois University.

Kate Roberts is a Laboratory Technical Expert at Covestro. She specializes in customer related issues and assists with application development projects (FTIR, microscopy, fiber fatigue etc.). She holds a B.S in Zoology from Eastern Illinois University.

Dr. Meng He is R&D manager of Fiber Optics Material Development Group at Covestro, with the role of leading the team on material development for optical fiber applications. His expertise area is on organic chemistry and polymer chemistry.

Brett Register is currently Covestro Fiber Optic Materials Technical Service Manager. He has worked for R&D since 2000 in various groups including Analytical and Physical Testing, New Business Development of display coatings, Additive Manufacturing, and Fiber Optic Materials.

Dr. Eric Urruti is currently Head of R&D, North America, at Covestro. He has a diverse background encompassing research development, manufacturing, and business management, with a substantial track record of successful new product introductions.