Fast Curing Next Generation Primary Coating Designed Around Regulatory Landscape

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Abstract

As regulatory uncertainty surrounds many chemicals used in fiber optic coatings, it is obviously important to design next generation coatings around these restrictions to ensure future fit for use. In addition to these regulatory roadblocks, the next generation coatings will need to meet the increasing draw speed demands and LED curing technology. High-speed LED next generation fiber optic primary coatings have been developed around chemicals receiving increased regulatory scrutiny.

Our next generation primary coating exhibited significantly improved cure speed and modulus buildup compared to the current technology. Additionally, high-speed LED trials resulted in excellent microbending performance, cavitation resistance, and adhesion to glass fiber. The high-speed trial success demonstrates this new primary technology's capability to meet the industry trends towards high draw speed and LED lamps while navigating the regulatory landscape.

Keywords:

High-speed, UVLED curable, fast cure, high pullout-force, low temperature microbending, cavitation resistance

1. Introduction

As the demand for fiber optic continues to increase due to the rollout of fiber to the home and 5G, fiber optic manufacturing aims to increase production efficiency. The push to increase production and efficiency has led to increasing draw speeds, with targets now in excess of 3000 m/min [1], and the switch to UVLED curing lamps [2,3]. Major concerns associated with high draw speeds are maintaining coating geometry, as higher draw speeds have led to large reductions in the primary coating thickness [1,4,5]. Next generation coatings must provide significantly improved cure speed to meet these increasing draw speed demands while providing improved properties as well.

In addition to the challenges provided by increasing draw speeds, the regulatory landscape is ever changing. As more and more photoinitiators and UV-curable monomers receive greater attention and risk of regulatory action, the field of available photoinitiators and monomers is limited. Finding suitable alternative photoinitiators while developing robust high-speed LED primary coatings is extremely challenging given their different absorption spectra and initiation efficiencies. Next generation coatings must be adapted and designed around high-risk chemicals that threaten fit for future use while meeting the fast cure speed and robustness requirements associated with increased draw speeds.

Developing next generation coatings considering the current regulatory landscape that meet the cure demands of the increased draw speed, one of the next generation coatings is described within. The next generation coating demonstrated superior cure and mechanical property buildup compared to the current technology as well as a successful high-speed LED trial. While being run up to 40% faster, the next generation coating exhibited consistent geometry, improved cavitation resistance, microbending, and pullout force.

2. Experiments

2.1 Draw Tower Simulator (DTS)

DTS has been described in recent IWCS papers [6,7]. 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 [8]. 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 810cm^{-1} acrylate double bond peak [7]. 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 B and Method D [9]. Method D was performed for 6 cycles, spanning a range of +80°C to -60°C, with each cycle having a duration of 13hr. 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 2402. Fiber dragging test was adopted from Ning et al. [10] using a rod diameter of 3mm and dragging speed of 3 m/min. Pullout force was measure following FOTP-105, and strip force and residue were conducted following FOTP-178 using a 0.006" Micro-Strip® and a wet Kimwipe with IPA.

3. Results and Discussion

3.1 Next Generation Coating DTS Comparison

Utilizing lower regulatory risk photoinitiators and monomers in today's regulatory landscape, a next generation primary coating was developed to also meet high-speed LED draw requirements. As shown in Figure 1, this next generation primary coating cures significantly faster than our current coating. At the smallest exposure time of 4ms, this next generation coating already achieved about 75% cure, while the current coating is significantly slower at only about 55%. Additionally, the time to reach 90% cure was reduced by 40%, from 30ms to 18ms, meeting the cure demands of faster draw speeds. On the other hand, if current speeds and cure levels are satisfactory, this new faster next generation coating could achieve the same degree of cure using fewer lamps or reduced lamp power, providing some possible cost savings.

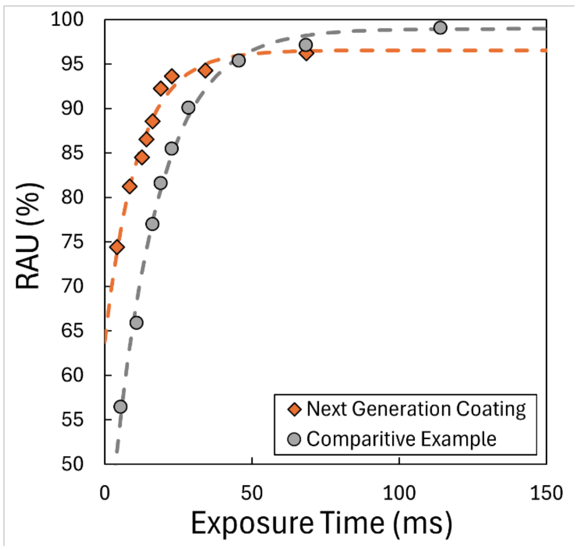

Figure 1: DTS RAU Comparison of High-Speed LED Primary Compared to Current Technology

In addition to the significantly improved cure speed of this next generation high speed LED primary, the mechanical property buildup has also been improved as shown in Figure 2. Mechanical property buildup is very important as draw speeds are increased to ensure protection of the glass fiber and prevent coating defects post-draw processes. As shown in Figure 2, this next generation coating builds up its mechanical properties significantly faster, reducing the time needed to achieve 90% plateau ISM by 74%, from 95ms to 25ms.

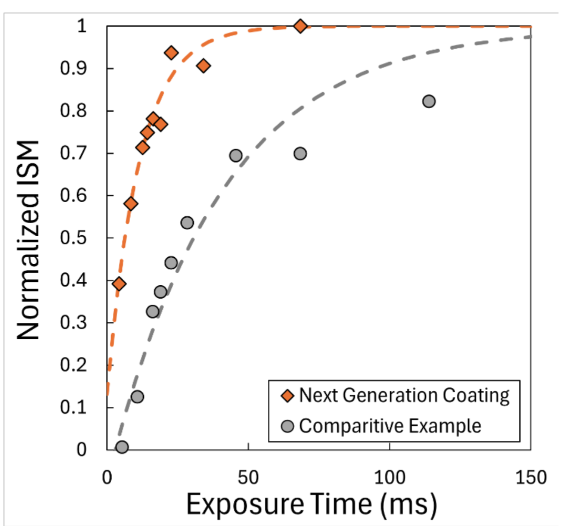

Figure 2: DTS Normalized ISM Comparison of High-Speed LED Primary Compared to Current Technology

With significant improvements in cure speed and mechanical property buildup of this next generation primary coating compared to the current technology, it is also important to look at the modulus consistency during the draw process. Looking at the sensitivity of the normalized ISM as a function of the degree of cure, shown in Figure 3, this next generation coating can be seen to be more consistent than the current technology. The current technology sharply increases as complete cure is approached, leading to large variations in ISM with small variations in the draw process and resulting RAU. Conversely, this next generation coating demonstrates a more linear relationship between the modulus buildup and degree of cure, providing a less sensitive ISM with small variations in draw process and degree of cure. This linear relation can be explained by the reaction kinetics of the cure and modulus buildup being very similar, explored deeper in [11].

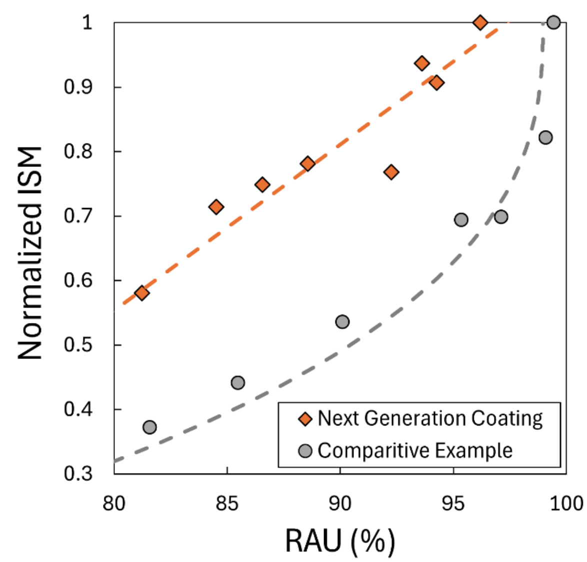

Figure 3: DTS Modulus Consistency of High-Speed LED Primary Compared to Current Technology

3.2 High Speed LED Drawing on Fiber

During high-speed drawing on glass fiber using LED lamps, this next generation coating demonstrated excellent performance at speeds up to 40% faster than the current technology. Fiber performance at these high speeds is demonstrated by excellent geometry consistency, modulus consistency, cavitation resistance, microbending, and adhesion to the glass.

3.2.1 Geometry and Modulus Consistency

Despite previous reports and investigations into increasing draw speeds demonstrating the challenge to maintain coating geometry [4,5], this next generation coating drawn at high speeds using LED lamps can be seen to exhibit very consistent geometry control, shown in Figure 4. The primary thickness can be seen to remain relatively constant around 25μm over the range of high draw speeds explored, with only about 0.5μm variation. The improved geometry performance can be attributed to increased viscosity and controlled temperature sensitivity to the hot glass surface [5].

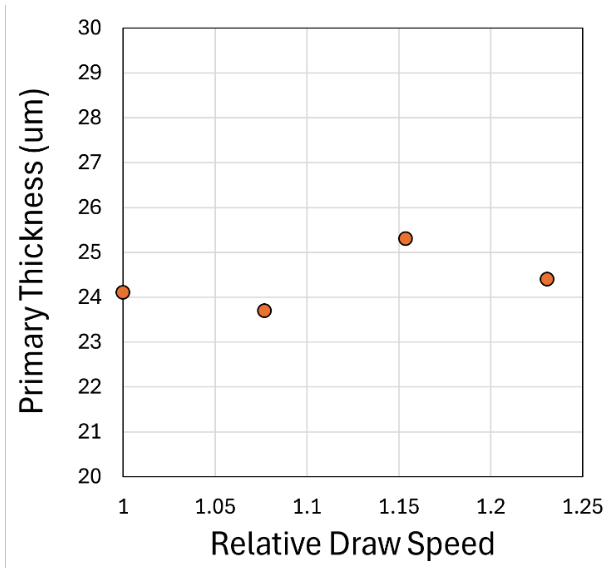

Figure 4: Primary Coating Thickness Consistency over Range of High-speed Drawing

In addition to the excellent geometry over the high draw speeds, this next generation coating also achieved fast cure, fast modulus buildup, and good modulus stability as shown in Figure 5. As the fastest draw speeds exceeded 3000 m/min, this next generation coating was still able to achieve 88% cure and 80% of its maximum ISM. Drawing over various speeds, the next generation coating demonstrated its improved modulus consistency as the normalized ISM increases linearly with RAU. This linear relationship between the RAU and ISM that was also seen on DTS enables improved modulus stability, being able to hit the target ISM on the draw tower even with small fluctuations in process conditions.

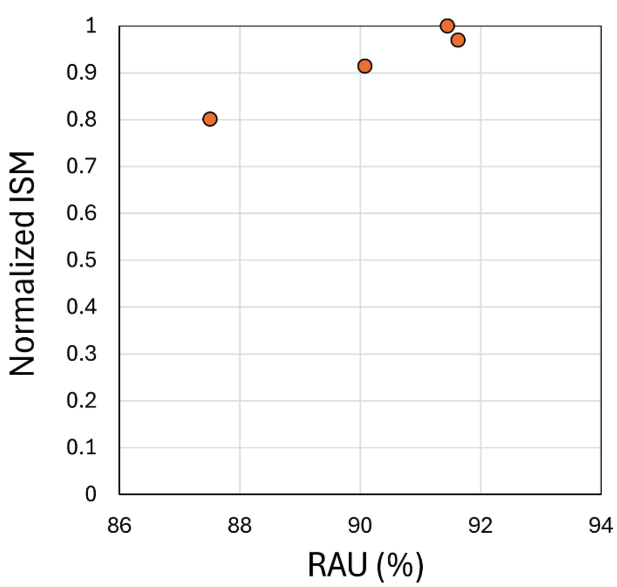

Figure 5: High-speed LED Draw Consistency of Next Generation Primary Coating

3.2.2 Improved Cavitation Resistance

Despite being run at high draw speeds, this next generation coating also demonstrated improved cavitation resistance. Compared to the current technology run 10-40% slower, the cavitation resistance was significantly higher. Cavitation defects appeared in the control at a threshold dragging force of 500g, while delamination defects were seen at 450g at the fastest draw speed with no cavitations. Following work in [12], we have been able to develop a very robust primary coating resistant to cavitations for high-speed LED applications.

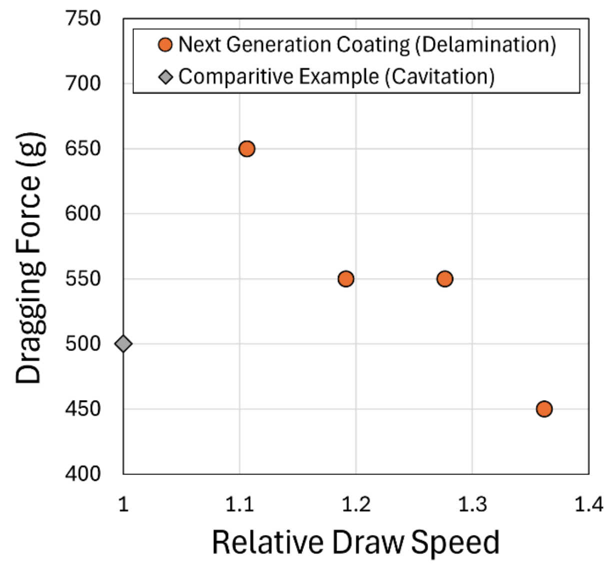

Figure 6: Dragging Force of High-Speed LED Next Generation Primary Coating

3.2.3 Microbending Performance

This next generation primary coating from high-speed LED drawing also demonstrated excellent Method B and Method D microbending performance compared to the current technology at lower draw speed. The results from Method B microbending can be seen in Figure 7. For both the control and next generation coating, the microbending loss can be seen to increase with increasing wavelength as expected and well understood [13]. Comparing this next generation coating to the control, this next generation coating can be seen to perform just as well if not better than the control. While the control coating already performs well with a loss about 1 dB/km at 1625nm at low draw speeds, this next generation coating run at high-speed LED draw exhibits a loss of 0.55 dB/km at 1625nm. The low attenuation loss using Method B of this next generation coating drawn at high-speed LED indicates excellent performance of added loss after cabling at room temperature.

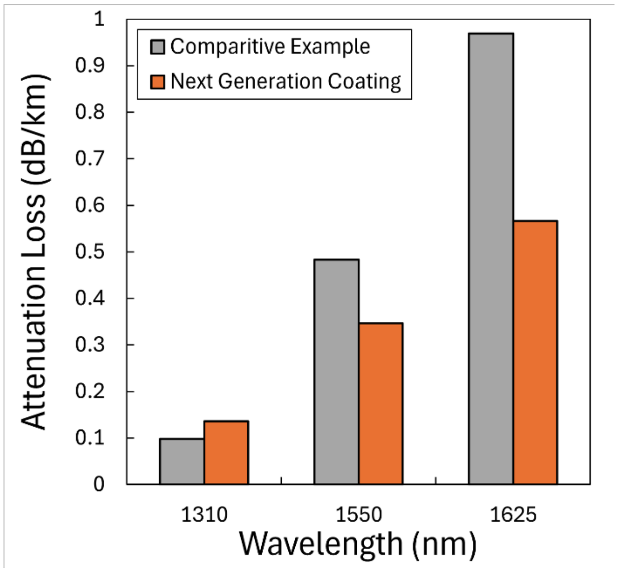

Figure 7: Method B Microbending Performance

Microbending Method D was also performed to correlate with cable TCT performance, shown in Figure 8 for -60°C. At -60°C, the superior low temperature microbending performance of this next generation coating can be seen. The control coating resulted in microbending loss around 0.1 dB/km at 1625nm, well above the acceptable loss threshold of 0.05 dB/km. While the low-speed control resulted in a large microbending loss, this high-speed next generation coating resulted in microbending losses 2-3 times lower, remaining well below the 0.05 dB/km threshold. The superior low temperature microbending performance of this next generation coating over the control can be attributed to the relative glass transition temperatures of the two, reducing the effect of the transition from the rubbery state to glassy state.

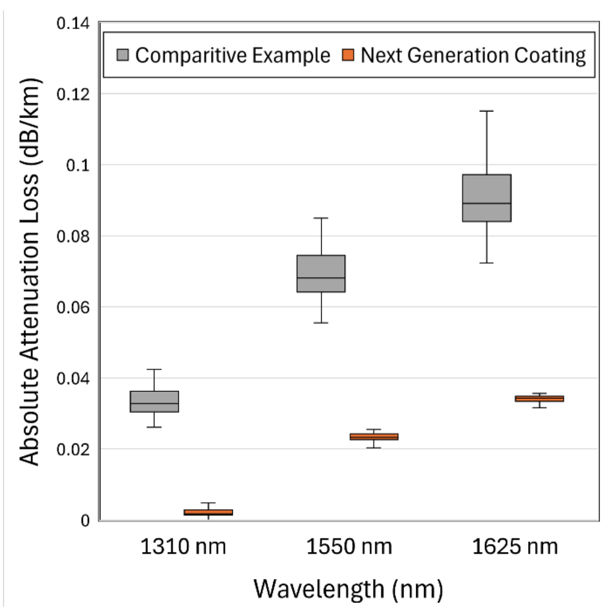

Figure 8: Method D Microbending Performance at -60°C

3.2.3 Optimized Pullout and Strip Force

Pullout and strip force were also tested for this next generation primary coating run at high draw speeds. As shown in Figure 9, excellent pullout and strip forces were achieved over all draw speeds tested, with pullout force averaging 8 N and strip force averaging 1.7 N. In addition to the excellent pullout force and strip force, the values remained relatively constant over all draw speeds even at speeds exceeding 3000 m/min.

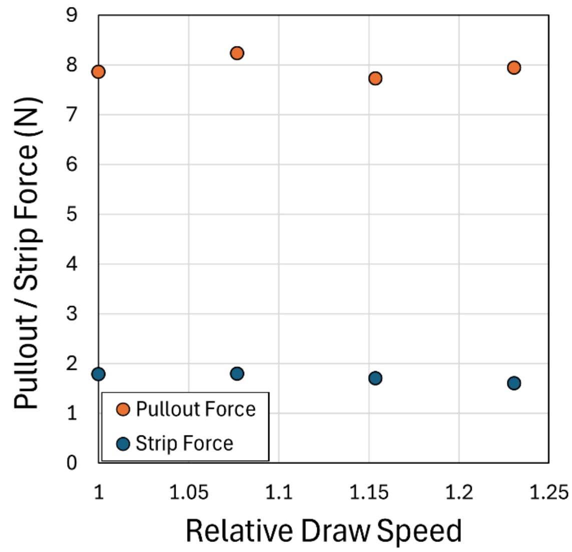

Figure 9: Next Generation Primary Pullout Force and Strip Force at High Draw Speeds

One concern with high pullout force coatings is strip residue, thus it is important to keep this in mind when designing coatings and optimizing the mechanical and adhesive properties. Even with the high pullout force seen for this next generation coating, there was no strip residue remaining after 1 wipe with an IPA wipe as shown in Table 1. Two other existing coating examples with similar modulus levels were shown for comparison, requiring two wipes to completely clean the fiber. Despite having similar modulus and slightly lower pullout force, shown in Table 2, the comparative examples require more wipes to clean the fiber.

Table 1: Clean Strip Residue for Next Generation Primary Coating

Primary Coating	1 Wipe	2 Wipes
NG-1		
CE-1		
CE-2		

Table 2: Pullout Force Comparison for Strip Residue Testing

Coating	Pullout Force (N)
NG-1	7.9
CE-1	7.3
CE-2	6.2

This difference emphasizes the need to optimize mechanical and adhesive properties, and that higher pullout is not always better. Demonstrated in Figure 9, strip residue occurs when the primary cohesive strength is lower than the adhesive strength during stripping. Coatings that are not robust enough for the level of adhesion will fail before the adhesion to glass, leaving strip residue as in the comparative examples. Developing a robust coating with high cohesive strength to match the high pullout force, this next generation high-speed LED coating did not leave strip residue despite high pullout and strip force.

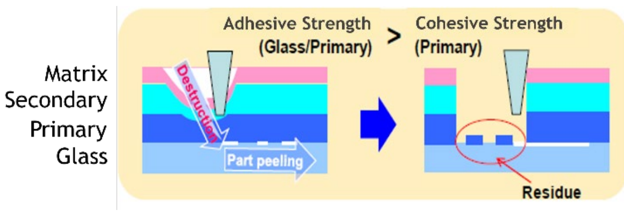

Figure 9: Strip Residue Mechanism Cartoon

4. Conclusion

With emerging complex regulatory landscapes and high-speed LED draws, a next generation coating technology has been developed. Designed around avoiding high regulatory risk photoinitiators and monomers, this new primary coating is able to meet the demands of high-speed LED draw processes, exhibiting improved cure speed and modulus buildup, geometry, cavitation resistance, microbending, and adhesion to the glass over a range of fast speeds.

On DTS, the next generation primary coating was able to reach 90% cure 40% faster, and 90% of its plateau ISM 74% faster. The great improvements in cure speed and modulus buildup enable improved modulus consistency as full cure is approached. This improved modulus consistency was also shown by high-speed LED drawing, where the ISM was linearly related to the RAU.

Despite avoiding high regulatory risky photoinitiators and monomers, this next generation coating demonstrated improved robustness and cavitation resistance being run at up to 40% faster than the control. The next generation coating also demonstrated superior low temperature microbending at -60°C due to controlling the glass transition temperature. Mechanical properties were also optimized to provide high pullout force while still maintaining strip cleanliness, as the higher the pullout the greater the risk of strip residue if the coating is not robust enough.

The improved performance of this next generation coating demonstrated on DTS and by high-speed LED drawing, while avoiding the regulatory risky photoinitiators and monomers, ensures meeting high draw speed demands from fiber manufacturers while maximizing the fit for future use in today's regulatory landscape. 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. References

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