UV-Curable Buffer Resins vs. Thermoplastics: A Closer Look at New Flame Retardant, UV-Curable Materials in Tight Buffered Cables

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Abstract

Flame retardant UV-curable materials have shown promise in tight-buffered cables. They provide benefits such as ease of processing compared to thermoplastics and improved attenuation at low temperatures. New, pigmented materials have been designed to provide V-0 flame retardancy along with color identification of the cables. To analyze the effects of the new tight buffer resins, upjacketed fibers were manufactured and compared against Low Smoke Zero Halogen polyethylene (LSZH PE) tight-buffered fibers. All fibers were monitored for attenuation using a standard OTDR after the upjacketing process. In addition, the spools of 900µm tight-buffered fibers were cabled into two 12-fiber distribution cables, one for each of the tight buffer types. Attenuation was checked again after cabling to observe any changes during the process. Subsequent testing of the cables included flame propagation per UL-1666, smoke release per UL 1685 and temperature cycling effects per Telcordia GR-409-CORE Issue 1.

Keywords: Flame retardant; tight buffer; premise cable; UV coating; low smoke; halogen free; thermoplastic

1. Introduction

Tight-buffered cables have been used in premise applications for over two decades. Most commonly the cables are made utilizing a thermoplastic coating which is extruded onto a 250um optical fiber. Common thermoplastics in the industry include Polyvinylchloride (PVC), Nylon 12 and Polyethylene. While variations of these materials meet GR-409 cable specifications and NEC building code requirements for flame retardancy, they can often pose processing problems such as slow line speeds, high scrap rates, etc.

UV-cure resins on the other hand typically have fast line speeds and have been used in the optical fiber industry as protective coatings for over 25 years. While their use as upjacketing materials has been somewhat limited due to their lack of flame retardancy and higher cost, one area where UV materials have been successful is the cushion layer in-between the flame retardant thermoplastic and the fiber. Construction of these types of fibers involves upjacketing a standard 250µm fiber to 400-500µm with a UV coating and then extruding with a colored thermoplastic to bring the final thickness to 900µm[1].

Another approach to tight buffering using UV curable materials involves upjacketing a colored 250µm fiber with a clear UV resin directly to 900µm. While this approach is fast and easy since UV allows for line speeds >900m/min the clear resins available today are not fully rated for UL V-0 flame retardancy.

A new series of opaque, UV-curable resins has been recently developed which is flame retardant, halogen free, lead free and also easy to process. The resins come in 12 colors and have a similar appearance to traditional thermoplastics; however, their on-fiber performance had not been tested. This paper compares the performance of all UV tight-buffered fibers versus those buffered with traditional thermoplastic materials.

2. Opaque UV Curable Resin Properties

As stand alone products, the UV resin has flammability properties similar to thermoplastics (Table 1). The Limiting Oxygen Index (LOI) is a measure of the tendency for a material to sustain a flame, the greater the number, the less susceptible the polymer is to burning. Both the UV-Curable resin and LSZH PE have LOIs >30 and both pass UL 1581 for flammability. In addition, smoke testing according to ASTM E662 resulted in a maximum smoke density rating of 71 for both materials in the flaming mode and the UV-Curable material fared better than the thermoplastic for the non-flaming mode.

Properties	UV-Curable Opaque Resin	Low Smoke Zero Halogen Polyethylene
Halogen content	None	None
Limiting Oxygen Index, %	31	34
Flammability, UL 1581	Pass	Pass
Smoke Density Flaming Mode, D_m	71	71
Smoke Density Non-Flaming Mode, D_m	85	102

Table 1. Flame retardancy comparison

Since smoke and flammability properties of both materials were similar they were expected to behave similarly in this regard during cable testing. The main difference between the two types of resins comes from the application of the materials onto the fiber and the effects each resin has on the fiber's performance.

UV-cure resins are liquid until exposed to UV light of certain wavelength and intensity. They then cure or harden forming a cross linked system which is resistant to chemicals and moisture. Thermoplastic resins must be melted and extruded onto the fiber after which the cable is cooled via a water bath. Line speeds of 900m/min have been reached for UV cure resins with acceptable attenuation results, whereas typical line speeds for thermoplastics are in the 100-200m/min range to minimize attenuation from shrinkage of the thermoplastic upon cooling.

3. Process Conditions for Upjacketing with UV-curable Resins

Opaque UV-curable resins are filled with flame retardant additives that tend to settle over time, therefore to ensure a homogeneous coating, care had to be taken to prevent separation. The resin was packaged in 10 Kg bottles which were tipped upside down for a period of 8-16 hours and then turned right side up for another 8-16 hours. The bottles were rolled for 5 minutes at a rate of approximately 4 RPM directly prior to use. After rolling, the bottle was placed into a 15-liter pressure vessel for the application process.

UV upjacketed fibers were processed with a modified Nextrom OFC-52 coloring machine which was equipped with three Fusion units, each unit had a variable power supply (VPS) and a 10-inch, 11 mm, 600 W/in, D lamp. Only two lamps were utilized for these runs and nitrogen was set at a flow rate of 30L/min to minimize surface tack. All fibers were processed at a line speed of 400 m/min, however, to prevent die drool, the initial speed was set at 100 m/min and then it was quickly ramped up to the desired speed.

Due to the large amount of coating being applied (compared to inking fiber) a slight increase of the payoff tension was needed to offset the fiber vibration. At 400 m/min, the total tension was about 1.5 – 1.6 N, and the coating pressure was 5 bars. Finally during the ramping down step after the targeted fiber length was coated, the speed was reduced to 200m/min and the coating flow was shut off to avoid overflow and ensure a clean stop. The amount of scrapped fiber was approximately 30 meters at each end.

4. Cable Trial Information

Two types of tight-buffered fibers were manufactured. The first type involved coating a 245µm optical fiber to 900µm with a UV curable resin. The second type involved tight buffering a 250µm optical fiber with LSZH FRPE to 900µm. To better understand any macrobending and microbending effects during buffering, cabling, or testing, 50% of the optical fiber used for the experiment was standard matched-clad single-mode fiber (SMF) and the other 50% was 50µm multi-mode fiber (MMF).

The spools of 900µm tight buffer were cabled into two 12-fiber LSZH distribution cables, one for each of the tight buffer types. Each distribution cable contained 12 tight-buffered fibers that were organized in a 9@3 orientation using a reverse-oscillating stranding technique, aramid yarn, a polyester ripcord, and a FRPE outer jacket. Each cable contained six matched-clad SMF and six 50µm MMF. Figure 1 shows a cross-sectional diagram of the distribution cable.

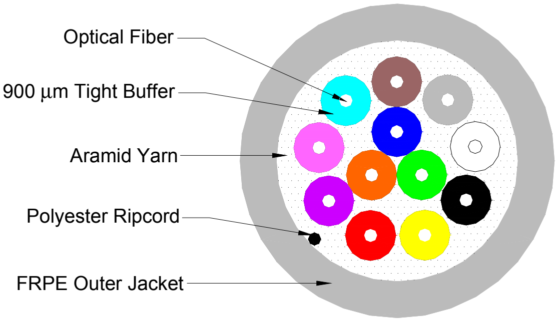

Figure 1: Cross-section of 12-Fiber LSZH Distribution Cable

5. Environmental Test Results

After the optical fibers were tight buffered, the attenuations were monitored using a standard OTDR. The results are shown in Table 2. These initial attenuation results showed the fibers buffered with the UV curable resin had very similar performance to the FRPE tight-buffered fibers.

Tight Buffer Attenuation Measurements (dB/km)								
	SMF w/UV TB		SMF w/FRPE TB		50um MMF w/UV TB		50um MMF w/FRPE TB	
	1310 nm	1550 nm	1310 nm	1550 nm	850 nm	1300 nm	850 nm	1300 nm
Average	0.32	0.18	0.33	0.19	2.27	0.43	2.29	0.44
Maximum	0.32	0.19	0.33	0.19	2.29	0.45	2.31	0.44
Std Dev.	0.001	0.002	0.001	0.000	0.015	0.011	0.016	0.008

Table 2: Tight Buffer Attenuation Results

In addition, the attenuation was checked again after cabling to observe any changes during the jacketing process. These results are shown in Table 3. The SMF with both types of tight buffer material and the 50µm MMF with FRPE compound showed essentially no increase after cabling, while the 50µm MMF with the UV curable resin showed a 0.1 dB/km increase at both 850 and 1300 nm.

Cable Attenuation Measurements (dB/km)								
	SMF w/UV TB		SMF w/FRPE TB		50um MMF w/UV TB		50um MMF w/FRPE	
	1310 nm	1550 nm	1310 nm	1550 nm	850 nm	1300 nm	850 nm	1300 nm
Average	0.33	0.19	0.33	0.18	2.38	0.53	2.26	0.43
Maximum	0.33	0.20	0.33	0.19	2.41	0.58	2.29	0.44
Std Dev.	0.001	0.005	0.002	0.001	0.015	0.025	0.016	0.008

Table 3: Cable Attenuation Results

Typically, the bend sensitivity of an optical fiber can be established by testing the cable at temperature extremes. During these temperature extremes, the tight buffering compound contracts and expands at much higher rates than the optical fiber. This thermal expansion and contraction of the material creates stress on the secondary coating, which is then transferred to the core of the fiber. This resulting pressure causes microbending. In order to compare the bend sensitivity of the SMF and MMF with the two different tight buffering types, all of the tight buffered fibers in the 12-fiber LSZH distribution trial cables were subjected to Temperature Cycling and Cable Aging per Telcordia GR-409-CORE Issue 1, *Generic Requirements for Premises Fiber Optic Cable*. The LSZH cables are rated for indoor and outdoor use, so the temperatures extremes from Telcordia GR-20-CORE Issue 2 *Generic Requirements for Optical Fiber and Optical*

Fiber Cable were used. The actual temperature profile during the environmental testing is shown in Figure 2. Test procedure TIA/EIA-455-3 *Procedure to Measure Temperature Cycling Effects on Optical Fiber, Optical Cable, and Other Passive Fiber Optic Components* was used as referenced by the Telcordia specifications.

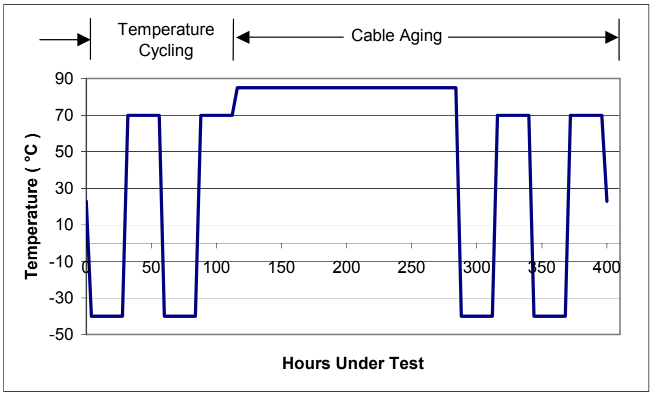

Figure 2: Environmental Testing Temperature Profile

For the Temperature Cycling test, the cables were cycled between temperature extremes of -40 and +70°C. The temperature was maintained for 24 hours at each temperature to ensure that the entire cable was at the correct temperature, and two complete cycles were completed. Per GR-409, attenuation values were monitored and recorded at the second set of temperature extremes. The allowable attenuation limit during this test is 0.30 dB/km for SMF and 0.60 dB/km for all multi-mode fibers. The temperature cycling results for the two trial cables are shown in Table 4.

	Temperature Cycling Attenuation Measurements (dB/km)							
	-40ºC Cycle				+70ºC Cycle			
	SMF w/UV TB	SMF w/FRPE TB	50um MMF w/UV TB	50um MMF w/FRPE TB	SMF w/UV TB	SMF w/FRPE TB	50um MMF w/UV TB	50um MMF w/FRPE TB
	1550 nm	1550 nm	1300 nm	1300 nm	1550 nm	1550 nm	1300 nm	1300 nm
Average	0.19	0.00	0.28	0.25	0.01	0.00	-0.04	0.04
Maximum	0.57	0.01	0.47	0.35	0.01	0.01	0.01	0.11
Std Dev.	0.188	0.006	0.113	0.063	0.00	0.00	0.05	0.05

Table 4: Temperature Cycling Attenuation Results

The Cable Aging test immediately followed the Temperature Cycling test. The cables were soaked at 85°C for 168 hours (7 days), and then were cycled between -40 and +70°C as in the Temperature Cycling test. The allowable attenuation limit during this test is 0.60 dB/km for SMF and 1.20 dB/km for all multi-mode fibers. The cable aging results are shown in Table 5.

	Cable Aging Attenuation Measurements (dB/km)							
	-40ºC Cycle				+70ºC Cycle			
	SMF w/UV TB	SMF w/FRPE TB	50um MMF w/UV TB	50um MMF w/FRPE TB	SMF w/UV TB	SMF w/FRPE TB	50um MMF w/UV TB	50um MMF w/FRPE TB
	1550 nm	1550 nm	1300 nm	1300 nm	1550 nm	1550 nm	1300 nm	1300 nm
Average	0.08	0.04	0.11	0.25	0.02	0.01	-0.01	0.12
Maximum	0.40	0.05	0.28	0.39	0.08	0.04	0.05	0.16
Std Dev.	0.16	0.01	0.11	0.08	0.03	0.03	0.04	0.03

Table 5: Cable Aging Attenuation Results

6. Flammability Testing

Both of the LSZH cables were subjected to flame propagation and smoke generation testing by Underwriters Laboratory (UL) per *UL 1651 Standard for Safety, Optical Fiber Cable*.

For flame propagation, the cables were tested to UL 1666 Standard, *Test for Flame Propagation Height of Electrical and Optical-Fiber Cables Installed Vertically in Shafts*. Per the standard, a cable that complies with this test has a flame propagation height of less than 366 cm (12 ft) and temperatures must be ≤ 454°C (850°F) at a height of 366 cm (12 ft). A cable that complies with UL 1666 can be listed as OFNR rated. The burn results for the two cables are listed in Table 6. The burn results for both cables were very similar. This was expected due to similar LOIs for both the FRPE and UV curable resin materials. Both cables met the UL 1666 requirements with a wide margin.

Tight Buffer Type in LSZH Cable	Flame Height (FT)	Max. Temperature (°F)	PASS/FAIL
Test Limit	*< 12.0*	*≤850*	------
UV Curable Tight Buffer	4.0	372	PASS
FRPE Tight Buffer	4.0	353	PASS

Table 6: UL-1666 Flame Propagation Results

To test the smoke generation of the three cables, they were subjected to UL 1685, Standard *Vertical-Tray Fire-Propagation and Smoke-Release Test for Electrical and Optical-Fiber Cables*. During this test, the peak and total smoke released during the 20-minute flame exposure are recorded. Cable specimens exhibiting a peak smoke release rate ≤ 0.25 m^2/sec and a total smoke release of ≤ 95 m^2 are considered to be in compliance with UL 1685 and can be listed as OFN-LS rated. The smoke generations results on the two cables are listed in Table 7. As with the UL 1666 test results, both cables met the smoke release requirements with a wide margin, and had very similar results.

Tight Buffer Type in LSZH Cable	Peak Smoke Release Rate (m^2/sec.)	Total Smoke Release Rate (m^2)	PASS /FAIL
Test Limit	*≤0.25*	*≤95*	------
UV Curable Tight Buffer	0.01	0.87	PASS
FRPE Tight Buffer	0.01	0.60	PASS

Table 7: UL 1685 Smoke Generation Results

7. Conclusions

Flame retardant UV cure resins show great promise towards their use as tight buffer coatings. In cables, they pass both UL 1685 and UL 1666 tests for smoke and flame propagation, which means they can be used in riser applications. UV cure resins are also halogen free, lead free and can be processed at faster line speeds than thermoplastics. Line speeds of 900m/min have been achieved with UV resins and attenuation immediately after upjacketing was similar to commercial FRPE tight-buffered fibers. Cable attenuation results were slightly mixed. While UV tight buffered multimode fibers pass GR-409 specs for temperature cycling and cable aging, average attenuation increase was slightly higher for UV versus thermoplastic at –40C during the temperature cycling test (0.28dB/km increase at 1300nm versus 0.25dB/km). However, during cable aging, UV actually performed better than the thermoplastic (0.11dB/km increase at 1300nm versus 0.25dB/km). For single mode fibers, even though the average attenuation increase during temperature cycling meets GR-409 specs, one fiber out of six failed the test at –40C. All six fibers passed the cable aging test. The reason for the slightly higher increase in attenuation of SMF upjacketed with UV resin is believed to be due to the lower modulus of the resin versus FRPE. When evaluated, the UV resin used on MMF was slightly harder than the UV resin used on SMF. At lower temperatures, a higher modulus tight buffer material can resist the buckling effect of the outer cable sheath as it contracts better than a lower modulus material. More cable trials are scheduled to determine if increasing the modulus of the resins will indeed improve cable attenuation performance. Also, plenum cable testing is underway to determine if UV cure resins can meet plenum smoke requirements.

8. Acknowledgements

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9. References

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