Performance Evaluation of Composite Polymer Tube and PFM™ Gel in Loose Tube Fiber Optic Cables

Superior Essex has incorporated two new material improvements into its loose tube fiber optic cables. This white paper presents an objective analysis of the performance and benefits of these design changes.

Introduction

Superior Essex has recently introduced two new materials to its product line offering of loose tube fiber optic cables. These two design improvements collectively result in faster cable installation and better tube flexibility than many other fiber cable designs on the market today. The new materials provide these benefits without any compromise on cable performance and are in full compliance with industry specifications (GR-20-CORE and ICEA S-87-640-1999).

The first of these enhancements is a new composite polymer buffer tube material. This material offers the flexibility advantages of polypropylene in combination with the crush resistance advantages of polybutylene terephthalate (PBT). These features result in a tube that is easier to flex within a splice closure, while retaining superior protection for the optical fibers.

The second cable enhancement is a new hydrocarbon-based gel compound that is lower in density than the conventional water-blocking compounds used in OSP fiber optic cables. The unique properties of this gel compound reduce the friction between the buffer tube and optical fibers during the tube removal process. This feature results in lower force required for fiber access and faster removal of the tubes from the optical fibers. The new gel is also much less sticky than conventional gel compounds, which allows for faster clean-up time during the installation process. The new gel compound is a better version of a proven technology, and requires no additional procedures during field access and installation.

Impact Resistance

Industry specifications (GR-20-CORE and ICEA S-87-640-1999) require fiber cables to provide a defined level of impact resistance for optical fibers. Failure to adequately protect the optical fibers can result in attenuation problems. While the aforementioned industry specifications provide adequate requirements for normal situations, additional impact resistance is a valuable benefit when unforeseen traumas occur to the cable. Severe impact to the cable may occur during storage, transport or installation.

Test Procedure

To isolate the impact resistance performance of the buffer tube from other variables in the cable, we designed a simple controlled impact test. In this test, the impact resistance of the three different types of tubes was compared by dropping a one-pound weight through a metal tube a distance of 12 inches (effectively a 1 ft-lb of force) directly over the sample buffer tube. The tubes were placed on a hard surface to avoid transfer of energy during the impact. The three tube types tested were constructed of polypropylene, polybutylene terephthalate (PBT), and Superior Essex Composite Polymer. Each buffer tube had a 3.0 mm OD and a 2.0 mm ID and contained 12 fibers. The weight was 1” in diameter and was flat on the end which impacted the buffer tubes.

Tube Sample	Impact Resistance Test Results
Polypropylene Tube	In repeated tests, the polypropylene tubes split open from the impact of the 1-lb weight. In these cases, filling compound visibly leaked from the split opening created from the impact. Deformation of the tube was also evident after each impact test (see Figure 1).
Polybutylene Terephthalate (PBT) Tube	In repeated tests, the PBT tubes exhibited the least amount of tube indentation following impact and in no case split open. This tube material is the most rigid of the three samples tested and performed as expected.
Superior Essex Composite Polymer Tube	In repeated tests, the composite polymer tubes exhibited more indentation than PBT, but less than the polypropylene tubes. In no cases did the composite polymer tubes split open and consequently no gel-filling compound leaked from the tube in any of the tests.

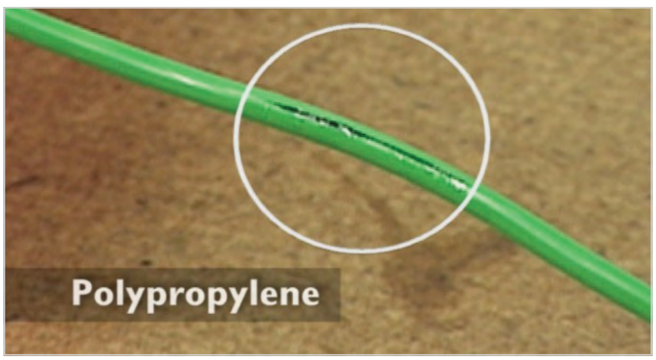

Figure 1: Polypropylene Tube After Impact Test

Conclusion of Impact Resistance Test Results

The more rigid polybutylene terephthalate (PBT) material provided the best protection for optical fibers of the three tube materials tested with no discernible indentation from the force of the impact. The Superior Essex Composite Polymer was second in performance to the PBT material, but did not split or become severely indented. The polypropylene material was the only material to repeatedly split open following impact. While this test did not measure the performance of the optical fibers following impact, the conclusion may be made that the polypropylene tube provided the lowest level of impact resistance for optical fibers.

Compression

To assess the ability of the tube to protect optical fibers under compressive forces, a cable containing the new Composite Polymer tube and a competitor's cable made with polypropylene were both tested to the compressive strength requirements RUS BULLETIN 1753F-601 (PE-90). This test measures the effect that compressive forces have on the attenuation of the optical fibers within a cable product.

The requirements of the RUS BULLETIN 1753F-601 (PE-90) specification are as follows:

Specification	Description
17.3.1	All cables manufactured in accordance with the requirements of this specification must be capable of meeting the following compressive strength test without exhibiting an increase in fiber attenuation greater than 0.10 dB for single mode fibers and 0.40 dB for multimode fibers and without cracking or splitting of the cable jacket when subjected to a minimum compressive load of 440 newtons per centimeter for armored cable and 220 newtons per centimeters for non-armored cable.
17.3.2	Measure the attenuation of the optical fibers in accordance with Paragraph 17.1.2 of this specification.
17.3.3	After measuring the attenuation of the optical fibers, test the cable in accordance with EIA-455-41 using a rate of 3 millimeters to 20 millimeters per minute and maintaining the load for 10 minutes.

Test Procedure

The fibers were fusion spliced to an Optical Fiber Switch (for individual measurements) and monitored with a power meter. The sample was loaded into the mechanical test fixture. The load was applied at a rate of 3 - 20 mm/min until the specified load was reached, and then maintained for 10 minutes. Optical measurements were performed. Sample "A" cable was a 24-fiber single–jacket, single-armor fiber cable made with polypropylene buffer tubes by a leading manufacturer of fiber optic cable. This sample cable was purchased from a distributor and was designated for RUS applications. Sample "B" was a 12-fiber, single jacket, single armor cable made with Composite Polymer buffer tubes by Superior Essex.

Tube Sample	Compression Test Results
Single Jacket, Single Armor Cable with Polypropylene Tubes (A)	This cable failed the requirements of RUS BULLETIN 1753F-601 (PE-90). Specifically, 33% of the fibers exceeded the attenuation change limit of 0.10 dB (see Table 1). The fibers which failed are in red type.
Superior Essex Single Jacket, Single Armor Cable with Composite Polymer Tubes (B)	This cable passed the RUS BULLETIN 1753F-601 (PE-90) specification. None of the optical fibers showed any attenuation problem (see Table 2).

Table 1: Competitor Cable Compression Test Results													
	Fiber Number	1	2	3	4	5	6	7	8	9	10	11	12
	Fiber Color	bl/bl	bl/or	bl/gr	bl/br	bl/sl	bl/wh	or/rd	or/bk	or/yl	or/vi	or/ro	or/aq
Compression	Reference												
baseline (dB)	-12.111	-12.617	-12.541	-12.668	-13.403	-12.533	-12.940	-12.682	-12.577	-14.620	-12.513	-12.573	-12.507
measurement at residual (dB)	-12.117	-12.610	-12.548	-12.673	-13.411	-12.518	-12.938	-14.088	-14.465	-16.232	-13.085	-12.625	-14.033
delta (dB)	0.006	-0.007	0.007	0.005	0.008	-0.015	-0.002	1.406	1.888	1.612	0.572	0.052	1.526
	Fiber Number	13	14	15	16	17	18	19	20	21	22	23	24
	Fiber Color	gr/bl	gr/or	gr/gr	gr/br	gr/sl	gr/wh	br/rd	br/bk	br/yl	br/vi	br/ro	br/aq
Compression	Reference												
baseline (dB)	-12.111	-13.919	-13.090	-12.913	-12.392	-13.103	-12.321	-12.654	-12.373	-13.790	-12.754	-12.606	-14.468
measurement at residual (dB)	-12.117	-14.284	-13.139	-13.018	-12.474	-13.172	-12.456	-12.670	-12.406	-13.806	-12.768	-12.614	-14.479
delta (dB)	0.006	0.365	0.049	0.105	0.082	0.069	0.135	0.016	0.033	0.016	0.014	0.008	0.011

Table 2: Superior Essex Cable Compression Test Results													
	Fiber Number	1	2	3	4	5	6	7	8	9	10	11	12
	Fiber Color	bl/yl	bl/vi	bl/ro	or/aq	or/rd	gr/bk	gr/yl	br/vi	br/ro	br/aq	sl/rd	sl/bk
Compression	Reference												
baseline (dB)	-12.184	-14.047	-12.846	-13.439	-13.803	-12.742	-21.042	-13.141	-13.304	-15.471	-13.068	-13.329	-13.086
measurement at residual (dB)	-12.183	-14.057	-12.845	-13.438	-13.803	-12.740	-21.043	-13.147	-13.303	-15.468	-13.063	-13.330	-13.085
delta (dB)	-0.001	0.010	-0.001	-0.001	0.000	-0.002	0.001	0.006	-0.001	-0.003	-0.005	0.001	-0.001

Conclusion of Compression Test

This test demonstrated that the Superior Essex cable made with Composite Polymer buffer tubes provided significantly better protection for the optical fibers as measured under the RUS-specified compression loading test. The test showed that the cable made with polypropylene buffer tubes did not meet the RUS specification for OSP fiber optic cables. One should not infer from these results that all cables made with polypropylene buffer tubes would fail the RUS 440 N/cm compression test. However, we conclude from these results that, in general, cables made with Superior Essex Composite Polymer tubes will provide better protection for the optical fibers under controlled compression load tests than cables made with polypropylene buffer tubes.

Flexibility

During installations buffer tubes are coiled and compressed into various tight configurations in order to organize them. A flexible buffer tube is desirable so that the installer may minimize wrestling the tubes, which could potentially cause damage to fibers in the process. However, there is a compromise. The tube must also be stiff enough to offer some resistance to easily bending the tube past the optical fibers' recommended minimum bend radius.

The flexibility of the Superior Essex Composite Polymer tubes was compared to PBT and Polypropylene tubes using a method that measures the resistance that coiled tubes may exert during installations.

Test Procedure

The test consists of forming a single piece of each tube (3 mm OD and 2 mm ID) into three coils with a diameter of 250 mm. The coils were taped together at four points (North, South, East and West) and were then twisted into a "figure 8". The top and bottom of the tube configuration were compressed towards one another until the distance between the two points was sufficient to be placed in between two compression plates that were 50 mm apart (see Figure 2). The force exerted by the coils was recorded.

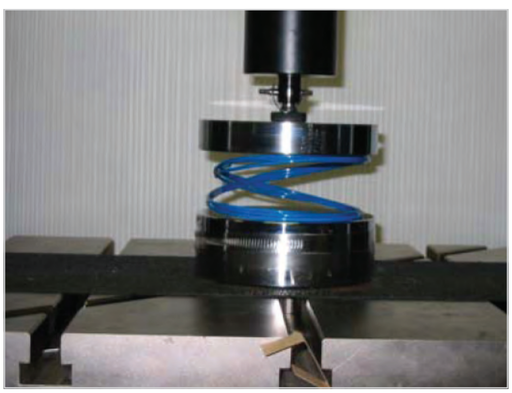

Figure 2: Flex Test Set Up

Tube Sample	Flexibility Test Results
Polypropylene Tube	This tube material exhibited the least amount of resistive force of the three samples and was the most flexible of the three samples tested. The resistive force was on average 60% less than the resistive force of the PBT tube.
Polybutylene terephthalate (PBT) Tube	The PBT tube exhibited the greatest amount of resistive force and correspondingly the least amount of flexibility.
Superior Essex Composite Polymer Tube	The composite polymer resistive force was between the two other samples. On average, the resistive force was 16% less than that of the PBT tube.

Table 3: Flexibility Test Results			
	PBT Tube Measured Resistance (lbf)	Polypropylene Tube Measured Resistance (lbf)	Composite Polymer Tube Measured Resistance (lbf)
Test 1	0.5	0.22	0.4
Test 2	0.6	0.17	0.37
Test 3	0.45	0.18	0.37
Test 4	0.57	0.22	0.5
Test 5	0.4	0.2	0.5
Test 6	0.55	0.18	0.45
Mean	0.51	0.20	0.43
Std. Dev.	0.08	0.02	0.06

Conclusion of Flexibility Test

The results demonstrate that the Composite Polymer tube has flexibility that is in between that of PBT and polypropylene. The greater flexibility attribute of polypropylene may be viewed as an advantage to some installers, but it also carries with it a greater propensity for the tube to be bent beyond the minimum bend radius of the optical fibers. However, installers that have been using PBT tubes are likely to appreciate the moderate flexibility improvement of Superior Essex composite polymer tube.

Kink Resistance

Buffer tubes frequently must be tightly bent in order to place them into enclosures and pedestals. They must offer enough flexibility to minimize the risks of increased attenuations and/or broken fibers that result when tubes kink during cable installations.

The kink resistance of the Superior Essex Composite Polymer tube was compared to PBT and polypropylene tubes using a simple test method that simulates some of the bending that tubes experience during installations.

Test Procedure:

Samples of each tube material were cut to an initial length of 250 mm. The tube was held horizontally and the very end of each tube was supported using a thumb and index finger. The ends were then pressed quickly towards one another forming a loop in the tube. Each time the tube formed a loop with no evidence of kinking, approximately 10 mm of material was cut from an end and the procedure was repeated until kinking was observed. Tube cuts were taken alternately from each end so that the bend was maintained at about the tube center position during testing.

Tube Sample	Kink Resistance Test Results
Polypropylene Tube	In repeated tests, this tube material showed visible signs of kinking at an average sample length of 9.8 cm.
Polybutylene Terephthalate (PBT) Tube	In repeated tests, the PBT tube showed visible signs of kinking at an average sample length of 15.4 cm.
Superior Essex Composite Polymer Tube	In repeated tests, the composite polymer tube showed visible signs of kinking at an average sample length of 9.9 cm.

Table 4: Kink Resistance Test Results

	PBT Tube Length of Tube (cm) at Point of Kink	Polypropylene Tube Length of Tube (cm) at Point of Kink	Composite Polymer Tube Length of Tube (cm) at Point of Kink
Test 1	15	11	9.5
Test 2	16.8	10.8	10.5
Test 3	13.5	10.5	9.4
Test 4	15.5	8.2	8
Test 5	15	9	9.5
Test 6	16	10.7	11.4
Test 7	16.2	8.5	10.8
Mean	15.43	9.81	9.87
Std. Dev.	1.07	1.20	1.13

Conclusion

The PBT tubes exhibited poor kink resistance relative to both the polypropylene tube and the Superior Essex Composite Polymer tube. The average tube length that resulted in a kink was marginally shorter for the polypropylene than for the Composite Polymer, however the difference was statistically insignificant. In practice, an installer would notice a measurable improvement in kink resistance for the new composite polymer tube versus a PBT tube and would likely not notice a difference in kink resistance between polypropylene tubes and the new Composite Polymer tubes.

Fiber Access: Tube Removal Force

In every installation, the buffer tubes are cut several feet from the end of the cable and the separated tube end is pulled off to reveal the optical fibers. This is a time-consuming practice in the installation process, and the time required to "access" the optical fibers is correlated closely to the number of buffer tubes in the cable as well as the amount of force required to remove the tubes.

The use of Polymer Filling Matrix (PFM) gel in place of the industry leading gel material greatly reduces the friction between the optical fibers and the composite polymer buffer tube. The consequence of this is that the installer requires much less pulling force to remove the buffer tube from the fibers during the fiber access practice. Lower force translates into quicker buffer tube removal and consequently faster installation time.

Test Procedure

A "pull force" test was performed on two different tube samples. Sample "A" was a PBT tube, containing 12 optical fibers and filled with the industry leading water blocking gel. Sample "B" was a Superior Essex Composite Polymer tube, containing 12 optical fibers and filled with PFM gel. Samples of each tube were ring cut four feet from the end. One end of the tube was securely fastened to a non-movable object. The other end of the tube was attached to a force gauge, which accurately recorded the maximum amount of force (in ounces) required to remove the tube during the test. The engineer performed the test by exerting a small pulling force on the tube end and gradually increasing this pulling force until the tube began to slide away from the firmly attached optical fibers. The test was complete once the buffer tube was completely removed from the optical fibers. The maximum measurement reading of the force gauge was recorded.

Figure 3: Removal Force Test

Tube Sample	Pull Force Test Results
PBT Tube with Industry Leading Gel (A)	The force required to remove the buffer tube ranged from 84 ounces to 105 ounces and averaged 95 ounces over 6 tests (see Table 5).
Composite Polymer Tube with PFM Gel (B)	The force required to remove the buffer tube ranged from 28 ounces to 35 ounces and averaged 29 ounces over 6 tests (see Table 5).

Table 5: Pull Force Test Results

	PBT Tube with Conventional Gel Measured Force (ounces)	Composite Polymer tube with PFM Gel Measured Force (ounces)
Test 1	84	35
Test 2	84	28
Test 3	105	28
Test 4	91	28
Test 5	105	28
Test 6	105	28
Mean	95.67	29.17
Std.	10.54	2.86

Conclusion

On average, removal of the Composite Polymer tube with PFM gel required 68% less force than required to remove the PBT tube with industry leading gel. It was also observed that the amount of force required to remove the buffer tube was highly correlated to the amount of time required to remove the tube (without risking damage to the optical fibers). In practice, this will translate into a quicker tube removal process for the Superior Essex Composite Polymer tubes with PFM gel. The large difference in force required to remove the tube may also allow the installer to remove two buffer tubes filled with PFM gel in the same time required to remove a single buffer tube filled with the industry leading gel.

Fiber Access: Time Study

To verify the relationship between required pulling force and installation time, a comparison of the time required to prepare the optical fibers for splicing was performed.

Test Procedure

Two fiber cables of similar construction were chosen for the side-by-side comparison test. Sample “A” was a 96-fiber loose tube cable containing polypropylene buffer tubes that were filled with industry leading water-blocking gel. This sample was manufactured by a leading producer of fiber cable in North America. Sample “B” was a 96-fiber Superior Essex loose tube cable made with composite polymer tubes that were filled with PFM gel. Each of the two cables contained 8 buffer tubes, with 12 optical fibers in each tube. The buffer tubes had 3.0 mm OD and 2.0 mm ID.

Prior to the start of the time study, both cable samples had their outer jackets removed 60 inches from the end of the cable and had the eight buffer tubes ringed 48 inches from the end. This was done to eliminate possible time differences that were inconsequential to the test.

For each sample, the clock started with the initial pull of the first buffer tube that had been previously ringed. The person who performed this test has had significant field experience in preparing fiber cables for splicing. The process consisted of pulling the buffer tube off of the optical fibers and simultaneously wiping the optical fibers with lint free wipes to clean them of water-blocking gel. After the buffer tube had been removed, the optical fibers were wiped a second time, if needed, to clean off excess gel so that the fibers would not stick to each other. Fibers from the polypropylene tubes required de-gelling with lint-free wipes and alcohol. The need for alcohol is a consequence of the tackiness of the conventional gel. PFM gel was removed with dry, lint-free wipes. The time to remove each tube and clean the optical fibers was recorded.

Tube Sample	Fiber Access Time Study Results
Polypropylene Tube with Industry Leading Gel Filling (A)	The total time required to remove the buffer tubes and clean all optical fibers of excess gel was 4.2 minutes. This was 200% longer than the comparable time for the Superior Essex cable (see Table 6).
Superior Essex Cable with PFM Gel (B)	The total time required to remove the buffer tubes and clean all optical fibers of excess gel was 1.4 minutes. This was 66% shorter than the comparable time for the competitor’s cable, which used conventional water-blocking gel (see Table 6). 54% of the time savings was due to the ease of pulling the buffer tube away from the optical fibers. 46% of the time-savings was due to the fact that the PFM gel wiped cleanly from the optical fibers the first time and a second wiping process was not required. The PFM gel is much less sticky than the industry leading water blocking gel. This property allows PFM gel to be more thoroughly removed on the first wipe and helps prevent the optical fibers from adhering to each other even if some residue remains on the fibers after wiping the fibers.

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Table 6: Fiber Access Time Study Results						
	Competitor's 96-Fiber SASJ with 3 mm Polypropylene Tubes			Superior Essex 3 mm tubes with PFM gel		
Tube Number	Remove Tube and Initial De-Gel Time (seconds)	Secondary De-Gel Time (seconds)	Total Time (seconds)	Remove Tube and Initial De-Gel Time (seconds)	Secondary De-Gel Time (seconds)	Total Time (seconds)
1	28.26	9.63	37.89	9.25	0.00	9.25
2	20.89	10.13	31.02	14.94	0.00	14.94
3	23.94	8.90	32.84	12.39	0.00	12.39
4	23.57	11.08	34.65	7.82	0.00	7.82
5	21.32	8.51	29.83	8.28	0.00	8.28
6	20.15	8.82	28.97	9.01	0.00	9.01
7	17.64	10.50	28.14	10.96	0.00	10.96
8	16.57	9.20	25.77	11.57	0.00	11.57
Total	172.34	76.77	249.11	84.22	0.00	84.22

Conclusion:

Superior Essex fiber cables with PFM gel and Composite Polymer tubes provided a measurable reduction in fiber preparation time versus a competitive cable made with polypropylene tubes and conventional water-blocking gel. The time-savings experienced in this test are expected to be similar to that experienced in a real installation setting. The reduced “stickiness” of the PFM gel had another benefit that was not measurable in this test. The PFM gel does not require cleaning agents to be removed from the installer's hands. This benefit would further reduce time spent by the installer during the splicing process and would remove the costs associated with hand cleaners.

Comparison to "All-Dry" Fiber Cables

There has been a fair amount of interest recently in new technology that allows for a completely dry cable. That is, a cable that employs the use of water swellable tapes or powders in lieu of any water-blocking gel inside the buffer tubes. The proponents of this cable design have made claims that the "all-dry" fiber cable will provide significant time savings during installation versus cables containing the conventional water-blocking gel. The time-savings advantage of "all-dry" cables may turn out to be a valuable benefit of "all-dry" fiber cables and an installation time-study comparison against the new Superior Essex composite polymer tubes with PFM gel is warranted once an "all-dry" fiber cable is ready for commercial sale.

Until an "all-dry" cable is available for actual test comparison, we offer a comparison to the new Superior Essex design based on facts of both designs that have been made public.

Comparison Feature	Superior Essex Fiber Cable with PFM Gel	"All-Dry" Fiber Cable Design
Fiber Preparation and Clean-Up	Easy clean-up without the need for chemical wipes	Slight moisture from surrounding or hands may cause swellable powder to "gum-up" and coat tools and fibers.
Potential for Attenuation Problems as Cable Contracts and Expands	Provides "fluid" environment during temperature changes so that when cables expand and contract optical fibers float and "seek" lowest levels of stress. This translates into lower attenuations.	Increases the potential for optical fibers to contact the tube wall during cable expansions and contractions; may increase fiber attenuations and physical stress on the optical fibers.
Requirements on Securing Fibers on Opposite end During Installation	Enclosure installations do not require special termination devices to hold fibers in place. PFM gel offers sufficient resistance to hold fibers in place during tube end terminations.	May require special tube and fiber clamping devices to keep fibers from moving back into or protruding out of the tubes during operations.
Low Temperature Operation	PFM gel remains fluid down to -50 degrees centigrade.	Reacted water swellable powder and tapes will freeze at temperatures just below freezing (0 degrees centigrade).
Compression Resistance	PFM gel offers some resistance to external fibers compressing on the cable, thus further protecting the fibers from undue stresses.	An empty tube may be more susceptible to external cable compressive forces, therefore further risking optical fiber performance.
Thermal Stability	PFM gel is thermally stabilized using latest antioxidant technologies to minimize oxidative degradations.	Thermal stability of water-swellable powder is unknown.

Summary

Tables 7 and 8 summarize the relative superiority of the different materials tested and documented in this paper. Polypropylene was clearly the most flexible of the three tube materials, but this may also act as a detriment because the tube might accidentally be bent beyond the minimum bend radius of the optical fibers. The PBT tube displayed the best impact resistance of the three tubes, but its rigidity comes at a large cost in kink resistance and flexibility. The Composite Polymer tube, however, fared well in all of the four tests. It displayed more impact and compression resistance than the polypropylene tubes and more flexibility and kink resistance than the PBT tubes.

The combination of the Composite Polymer tube with PFM gel provided exceedingly better test results than the competitive tubes filled with conventional water-blocking gel. The PFM gel is also a much less sticky substance than conventional gels, which reduces the clean-up time for the installer and the need for cleaning solvents.

Table 8: Tube Material Comparison

Test	PBT Tube	Polypropylene Tube	Composite Polymer Tube
Impact Resistance Test	++	-	+
Compression Resistance Test	Not Tested	-	+
Flexibility Test	-	++	+
Kink Resistance Test	-	+	+

Table 9: Gel Comparison

Test	Tube with Conventional Water Blocking Gel	Superior Essex Tube with PFM Gel
Tube Removal Force Test	-	+
Fiber Access: Time Study	-	+