Dry Central Tube Ribbon Cables for the Outside Plant Environment

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Abstract

Historically, optical fiber cables for the Outside Plant (OSP) environment have employed filling compounds to immediately surround the fibers within the core tube or buffer tubes. The primary function of filling compound is to impede the migration of water within the interior of the cable. Additional benefits provided by filling compounds include increasing hydrostatic resistance to compressive forces and vibrational damping. The performance and reliability of filled cables has been demonstrated over the past 15 years.

However, during cable installation, filling compound is generally a nuisance. The most significant difficulty is removal of the filling compound and cleaning of the fiber units before splicing. This is a time-consuming process that increases expense and reduces productivity during installation operations. Filling compound can also contribute significantly to the total weight of cables, increasing the equipment and personnel required for long-haul installations. Filling compounds tend to be sticky or greasy, and therefore are a housekeeping annoyance to installers. In recent years, to overcome these drawbacks, many cable manufacturers have offered new designs that minimize the amount of filling compound, as reviewed briefly here.

The focus of this paper is the development of a family of new central tube ribbon cables that completely eliminate all filling compounds and/or oils within the central core tube. This new design family has been applied to fiber counts ranging from 12 to 216, in both metallic and dielectric sheaths. All of the cables in this family are fully compliant with the Telcordia GR-20 standard requirements for Outside Plant cables. Compared to conventional filled OSP cables, the new family of cables has equivalent or better optical, mechanical and environmental performance. We also summarize the results of a rigorous battery of installation simulation tests that show the performance of this family of cables is generally better than that of standard filled cables. Finally, we present time-study results that demonstrate that these new cables offer installers substantial time and cost savings during splicing operations.

Keywords: fiber optic cable, filling compound; waterswellable; superabsorbent.

1. Introduction

Ingress of water into fiber optic cables can be a serious threat to network reliability. If water penetration is not controlled, water can travel along the interior of cables to splice closures, potentially leading to damage to the telecommunications system and interruptions in service. Water may penetrate a cable sheath by two means: by diffusion through the cable jacketing, or as the result of damage to the cable.

In wet conditions, diffusion of water through the cable sheath could conceivably result in condensation of free water within the cable. However, a recent study [1] has shown that superabsorbent materials can prevent condensation of water that diffuses through the jacket. The study found that, in an undamaged dielectric cable, waterswellable superabsorbent materials limit condensation of water for at least 20 to 25 years at 23°C. Therefore, damage to the cable jacket is the most likely scenario by which water can enter the interior of a fiber optic cable. Jacket damage can occur as the result of dig-ups, accidental impacts, lightning strikes, or chewing rodents.

In the initial deployment of optical fiber networks, pressurized air core cables were introduced into outside plant applications. In these designs, ribbonized fibers were surrounded by poly(tetrafluoroethylene) tape within a polyethylene core tube, contained within a crossply metallic or dielectric sheath [2][3]. To block the migration of water, cable cores were pressurized with nitrogen gas. Because of the expense and difficulty of maintaining the required pressure, the air core design eventually gave way to new means of blocking water migration in cables: filling or flooding compounds. These compounds are typically petroleum-based gels that are used to fill void areas within the cable sheath, including the voids directly surrounding the optical fibers. The use of filling compounds in fiber optic cables has been an established practice for over 15 years.

However, there are several drawbacks to the use of filling compounds. Filling compounds increase cable weight, making installation and handling more difficult. These gels are also a housekeeping nuisance, as they can easily contaminate clothes, tools or closures – essentially anything they contact. Special care must be taken to clean splicing machines and optical test sets contaminated by gel. Residues from gel can eventually lead to long-term reliability problems with these types of costly installation equipment.

Most significantly, filling compounds lead to increased installation costs for telecommunications service providers. During installation of filled cables, it is necessary to carefully remove all gels in order to prepare fibers for splicing. Skilled craftspeople are required to spend a great deal of their time cleaning gel, instead of focusing on splicing and testing of fibers. In addition, any gel residues remaining on fibers during fusion splicing will likely cause process errors and/or defects. As a result, removal of filling compound is a significant component of cable installation time and costs.

To address problems resulting from use of filling and flooding compounds, many manufacturers have introduced designs that minimize the use of gels. These include dry loose tube designs [4] and "tube in tube" central core designs [5][6][7]. However, these new designs still use filling compounds within the fiber-containing tubes, and as such still require installers to perform extensive cleaning. Recently, two types of dry, central core ribbon cables have been documented. A completely dry central-core design using a large number of superabsorbent yarns within the cable core has been described in the literature [8]. However, this design is apparently only available in dielectric sheaths. In an alternate cable design described in the literature, the core tube houses a specially designed water blocking laminated tape and uses intermittent resin plugs in the tube in order to fix the fibers in the cable [9].

In this paper, we describe the development of a complete new family of totally dry, central core ribbon cables in which a single piece of superabosrbent tape provides waterblocking. These cables, marketed under the trade name AccuRibbon® DC, are fully compliant with all requirements of Telcordia GR-20-CORE [10]. The family of cables is commercially available in both dielectric and armored metallic sheaths, in fiber counts ranging from 12 to 216. As discussed below, the complete elimination of filling compound provides substantial reductions in the time required for cable splicing operations. Therefore, this family of cables can afford service providers considerable installation cost savings.

2. Cable Design

2.1. Core Design

The optical fibers are arranged in 12-fiber ribbons within a central core tube. Ribbonized fibers provide inherently high fiber packing density in central core constructions, and ribbons can be easily routed and managed in splice closures. In addition, ribbons allow for increased productivity through mass fusion splicing. However, the ribbons used in these new dry central-core cables may also be spliced and managed as subunits or single fibers. Breakout of these 12-fiber ribbons into robust subunits is straightforward, and separation of the ribbon into individual fibers is simple, as the matrix material is engineered to be removed from the fibers easily [11]. Depending upon fiber count, three different core tube sizes are employed, as shown in Table 1.

TABLE 1 –Dimensions and Fiber Counts of Core Tubes

Fiber Count	Ribbon Count	Core OD mm(in)
12 to 48	1 to 4	6.0 (0.236)
60 to 144	5 to 12	7.9 (0.310)
156 to 216	13 to 18	10.4 (0.410)

Figure 1 shows a schematic of a representative 144-fiber cable core. As seen in the schematic, the ribbons are wrapped by a single piece of an engineered superabsorbent tape, referred to as the core tape, which replaces the filling compound. As described below, the core tape acts to block water propagation along these cables, in compliance with Telcordia GR-20. The ribbons and superabsorbent tape are contained within a hollow impact-modified polypropylene central core tube.

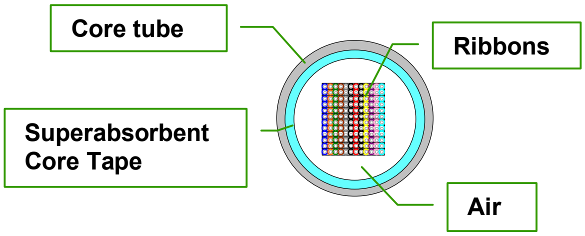


Figure 1 – Schematic of Core Design

The dimensions of the cable core tubes are similar to those of common filled central core cables. As is the case with filled central core cables, the cores are sized to provide for minimum fiber strain during installation and service. The cores are also engineered to have sufficient excess fiber length to ensure excellent optical performance under mechanical stress and at temperature extremes.

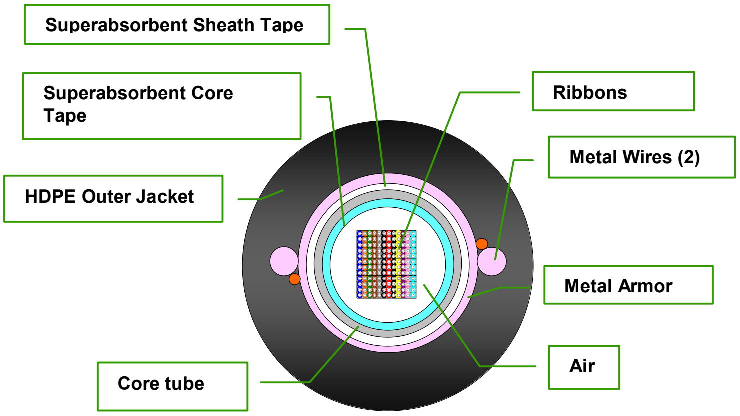
2.2. Sheath Design

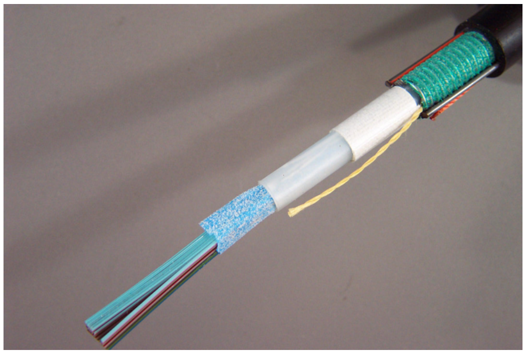
These dry ribbon cables are available in both metallic and dielectric sheath configurations. The cables are available in three sizes, depending upon fiber count, as summarized below in Table 2. For a given fiber count, the metallic and dielectric cables have the same outer diameter. Figure 2 is a schematic of the metallic sheath design, detailing the individual components; a picture of a metallic cable is shown in Figure 3. The metallic sheath is a standard, proven design that has been utilized in multiple service conditions for many years. The strength system in the metallic sheath is comprised of a corrugated ECCS armor and two diametrically opposed linear steel wires. The dielectric sheath, as illustrated by the schematic in Figure 4 and the picture in Figure 5, is appropriate for use in areas where lightning or stray electrical currents may be a problem. Two diametrically opposed, linear glass/epoxy rods provide strength in the dielectric sheath. The rods are coated with a UV-cured "frictional coating" that provides ample mechanical coupling between the rods and jacket over a broad temperature range. Both dielectric and metallic strength systems provide a tensile rating of 2700N for all members of this cable family.

In each design, a standard superabsorbent waterblocking tape is used to wrap the core tube, to prevent water ingress between the jacket and core. All cables in the family are jacketed with high-density polyethylene. HDPE has been selected because of its hardness, ruggedness, and low coefficient of friction, all of which enhance the installation performance of these cables.

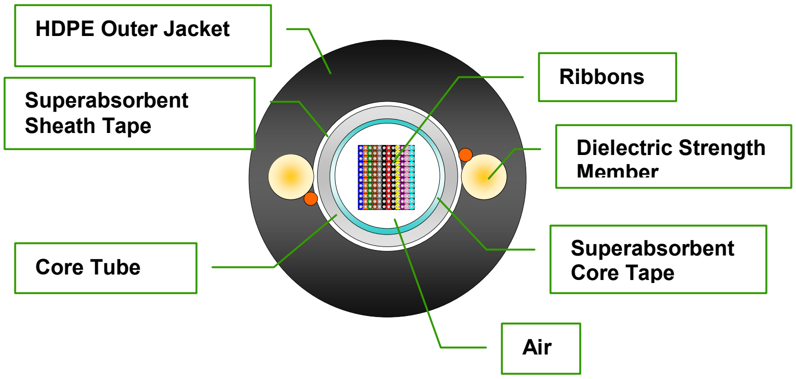
TABLE 2 – Dimensions and Fiber Counts of Cables

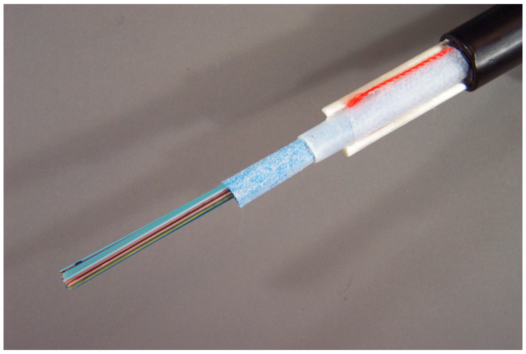
Fiber Count	Ribbon Count	Cable OD mm(in)
12 to 48	1 to 4	13.0 (0.510)
60 to 144	5 to 12	15.5 (0.610)
156 to 216	13 to 18	18.0 (0.710)





Figures 2 and 3 - Schematic of Metallic Dry Ribbon Design (left) and Picture of Cable (right).





Figures 4 and 5 – Schematic of Dielectric Dry Ribbon Design (left) and Picture of Cable (right).

Table 3. Results of extended water penetration tests on dry cable core tubes

Core Tube OD mm (in.)	Fiber Count	Number of Samples Tested	Results per FOTP-82
6.0 (0.236)	12	15	All samples pass
6.0 (0.236)	24	112	All samples pass
6.0 (0.236)	48	80	All samples pass
7.9 (0.310)	60	116	All samples pass
7.9 (0.310)	144	109	All samples pass
10.4 (0.410)	156	111	All samples pass
10.4 (0.410)	216	110	All samples pass

3. Design Qualification

All cables in the family have passed a complete series of qualification tests, including tests of optical performance under mechanical loads and at temperature extremes. In addition, these cables have been subjected to a rigorous battery of installation tests that simulate both standard and abusive installation practices. Performance of this family of cables is similar to or better than comparable filled cables. Details of the findings follow.

3.1. Telcordia Testing

The AccuRibbon® DC has been extensively tested in accordance with Telcordia GR-20, "*Generic Requirements for Optical Fiber and Fiber Optic Cable - Issue 2*" and has been found to be in conformance with the waterblocking, mechanical and environmental test requirements.

3.1.1. Water Penetration Performance

The waterblocking core tape in this new design family replaces filling compound. The core tape must block water penetration within the central core tube per Telcordia GR-20 and FOTP-82. All qualification cables that have been tested pass this standards requirement. However, since the core superabsorbent tape is required to block water penetration within a large void space in the cable core, an extended series of water penetration tests were performed on cable core tubes to verify the waterblocking performance. A pressure-head manifold was designed to allow testing of multiple core tube samples by continuous exposure of the samples to the equivalent of a 1-meter pressure head. Results of these tests are given above in Table 3.

3.1.2. Mechanical Testing

Numerous metallic and dielectric cables with the new dry core design have been qualified to the mechanical requirements of Telcordia GR-20. Below, in Table 4, results at 1550nm are presented for a typical, representative cable, a 216-fiber dielectric cable with an 18.5 mm (0.710 inch) outer diameter. As shown in Table 4, for this cable, median and maximum added losses are both much less than is allowed under the GR-20 standard.

3.1.3. Environmental Testing

Numerous metallic and dielectric dry ribbon cables have also been qualified to the environmental performance requirements of Telcordia GR-20. To demonstrate this, results for a 48-fiber metallic cable with an outside diameter of 13.0 mm (0.510 inch) are used as an example of typical cable performance. Full test results, with maximum and median added loss results, are presented below in Table 5. Results of environmental cycling tests are illustrated in Figure 6, which plots the maximum added attenuation measured at each temperature during the test. Results of cable aging tests are illustrated in Figure 7, which also shows maximum added attenuation. As indicated by the data, this dry 48-fiber cable passes the requirements of these tests by a wide margin.

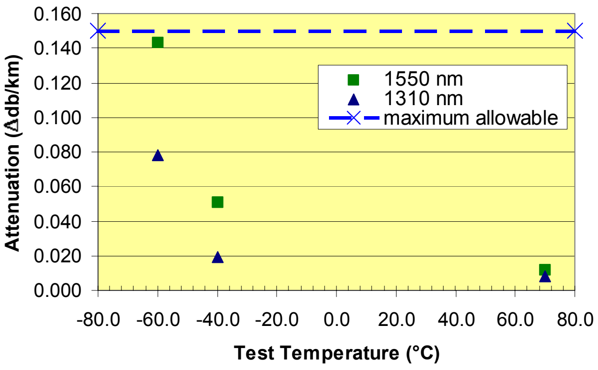


Figure 6 – Temperature Cycling Data

Table 4 – Telcordia Mechanical Testing Results

Cable Test	Test Level	Requirement: Maximum Δ Loss	Measured Maximum Δ Loss (dB)	Requirement: Median Δ Loss	Measured Median Δ Loss (dB)
Impact	4 kg	< 0.15	0.004	< 0.05	-0.008
Tensile Load & Bend	801 N	< 0.15	0.027	< 0.05	0.010
High Temperature Bend	60ºC, 356 mm	< 0.15	0.011	< 0.05	-0.001
Low Temperature Bend	-30ºC, 356mm	< 0.15	0.020	< 0.05	0.009
Compression	1112 N	< 0.15	0.011	< 0.05	0.001
Twist	2 m, 180º	< 0.15	0.022	< 0.05	0.008
Cyclic Flex	356 mm	< 0.15	0.004	< 0.15	-0.003

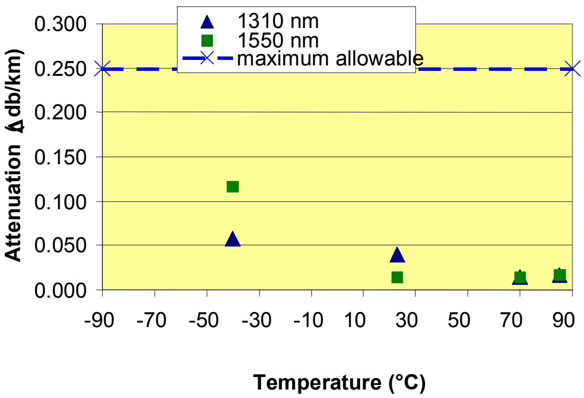


Figure 7 – Cable Aging Data

Measurements of added attenuation taken at –60ºC during the environmental cycling test are also included in Table 5 and Figure 6. Although no requirements currently exist for this temperature, the median loss is similar to that observed at –40°C, and the maximum loss is less than the maximum allowed by the standard at -40ºC. This response is characteristically not observed in cables containing filling compound. At low temperatures, filling compounds typically become highly viscous, generally resulting in significant attenuation losses

3.2. Installation Simulation Testing

The installation performance of multiple dry ribbon cables has been evaluated at OFS' installation simulation test facility in Chester, NJ. The testing emulates both standard and abusive field installation practices. Although no standards body requires these tests, they do provide valuable information on the "real world" performance of these dry outside plant cables. Table 6 summarizes the tests performed.

Table 5 – Typical Environmental Maximum and Median Values

Test Temperature (ºC)	Δ Loss (dB/km)			
	Temperature Cycling		Cable Aging	
	Median	Maximum	Median	Maximum
-60	0.007	0.143	—	—
-40	0.001	0.051	0.018	0.116
23	—	—	0.005	0.015
70	0.004	0.012	0.006	0.015
85	—	—	0.008	0.017

Table 6. Installation Simulation Tests

Test	Description
Initial attenuation measurement	Pre-test baseline
Pulling grip	Determine performance of pulling grips
Cable jetting	Determine cable jettability in underground duct
Underground placing	Determine cable behavior during underground placing
Tension/Bending	Pull cable around quadrant block and various sheaves
Capstan Assist	Determine performance on intermediate capstan assist winch
Aerial Coiling	Attenuation performance in coils
Direct Buried Plowing	Performance during plowing operation
Abusive Tests	Truck run-over, cable kinking
Final attenuation measurement	Comparison to baseline
Ultimate strength tests	Attenuation at ultimate tensile load
Sheath Dissection	Evaluate internal components for test-related damage
Ribbon Inspection	Evaluate ribbons for test-related damage

Table 7 displays results of installation simulation tests for three representative dry central-core ribbon cables: a 48-fiber, 13.0 mm (0.510 inch) outer diameter dielectric cable; a 60-fiber, 16.5 mm (0.610 in.) outer diameter metallic cable; and a 216-fiber, 18.0 mm (0.710 inch) outer diameter metallic cable. The results are excellent, even in abusive tests performed beyond accepted practice.

Table 7 – Results of Installation Simulation Tests for Three Representative Dry Ribbon Cables

Test	***Maximum residual attenuation (dB)***		
	48–fiber dielectric	60-fiber metallic	216-fiber dielectric
Coiling tests			
Foldover method (18" dia)	0.07	-0.05	0.08
Tear drop method (24" dia)	0.10	0.13	-0.08
Garden hose (18" dia)	0.11	-0.04	0.12
Iterative capstan (10 pulls)			
Maximum Δ attenuation ***(dB/km)***	0.01	0.02	0.01
Intermediate capstan			
7 wraps w/70ft slack	-0.01	0.07	0.07
2-2-3 wraps w/25ft slack	0.04	-0.03	-0.09
7 wraps, 1 at a time w/15ft slack	0.01	0.09	0.09
Tension & bending (non-abusive)			
600 lb @ 12 inch radius	0.04	0.06	-0.14
Tension & bending (abusive)			
600 lb @ 4 inch radius	0.05	0.04	0.04
Cable jetting – 3 loops attempted	***Maximum blowning distance (m[ft])***		
1" innerduct	4360(1330)	NA	NA
1¼" innerduct	4360(1330)	NA	4358 (1242)

Table 8 – Performance Specification for Dry Central Core Cables

Tensile Strength:	2670 N (600 lb.)
Temperature Range:	
Operation:	-40°C to 70°C (-40°F to 158°F)
Installation:	-30°C to 60°C (-22°F to 140°F)
Storage/Shipping:	-40°C to 75°C (-40°F to 167°F)
Bending Diameter:	No load – 20 times cable diameter Loaded – 40 times cable diameter

3.3. Performance Specifications

The performance specifications for this family of dry ribbon cables are identical to those for similar filled central core cables. All cables in this new family meet the specification shown above in Table 8, as required by Telcordia GR-20 for the North American market.

4. Benefits for Service Providers

With complete elimination of filling compound, this family of dry ribbon cables has many attractive features that afford service providers significant savings in installation time and costs. Removal of filling compound allows rapid access to fibers and reduced splice preparation time. The design also provides substantial reductions in weight that result in installation advantages.

4.1 Weight

In typical central core cable designs with 216 fibers or less, the filling compound contributes approximately 10 to 20 percent of the total weight of the cable. Reducing the weight of cables through removal of the filling compound provides several benefits. Shipping is simplified, and cables are easier to handle and manipulate. Cost savings due to weight reduction can be realized in installation. Compared to similar filled cables, these dry ribbon cables can achieve longer distances in cable jetting, as described in a companion paper [12]. In addition, capstan-pull installation simulation tests have found that, compared to filled cables, reduced loads are required to install these dry cables in underground duct. Therefore, the reduced weight of the design can translate into longer cable pulls or blows, reducing the overall time and cost required for installation of a given cable route.

4.2 Reduced Splice Preparation Time

The most significant cost savings that a service provider may realize through deployment of these dry ribbon cables results from time savings during splice preparation. To quantify this, a trial splicing simulation has been performed, comparing a 108-fiber metallic dry ribbon cable with a metallic, grease-filled, central core ribbon cable with an identical fiber count. The trial was performed by qualified installation trainers in a controlled environment. The time required to prepare the end of each cable for splicing was measured. Results of the trial are illustrated below in Figure 8. The full end preparation time for the dry ribbon cable was approximately 4¼ minutes, as compared to approximately 30¼ minutes for the filled cable. In this model experiment, use of the dry cable led to a time savings of over 85%. Looking at Figure 8, it can be seen that cleaning of ribbons and cleaning of tools and hands accounts for the majority of the time required for preparation of the filled cable.

Using the results of the time study described above, the cost savings due to deployment of these dry ribbon cables may be modeled for a typical long-haul installation scenario. The assumptions made in these calculations are shown in Table 9.

Table 9 – Installation Scenario Assumptions

Fiber count	108
Length of route	160.9km (100 miles)
Length of cable per reel	6.4km (4 miles)
Length of work day	6 hours

Along the intended route, there would be a total of 25 splices, therefore a total of 50 cable ends to be prepared for splicing. Based on the model time study, the time savings resulting from use of the dry ribbon cable is assumed to be 26 minutes per cable end preparation. Therefore, the total time savings realized during installation of this route would be 22 hours, or 3.6 days. To put this into perspective, the *total* time required for cable end preparation with dry ribbon cables would be 3½ hours, roughly ½ work day. The total time required for end preparation of conventional grease-filled cables is 25 hours, approximately 4.2 workdays.

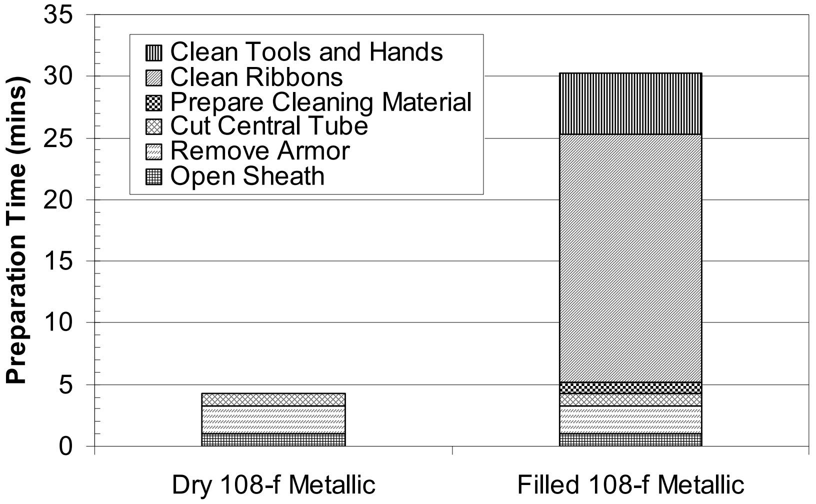


Figure 8 – Splice Preparation Comparison

4.3 Cleanliness

In addition to the time savings realized in cable end preparation, the removal of filling compound also provides significant housekeeping advantages in the field. Filling compounds are typically messy and sticky, and tend to contaminate splice trays, other areas of closures, tools, splicing equipment, test equipment, work areas and clothing. Specialized solvents are generally required for cleaning or removal of filling compounds. Contamination with gel can affect long-term reliability of splicing and test equipment. Removal of filling compounds eliminates all of these concerns. Also, during fusion splicing, residual filling compound on fibers can cause splicing defects that could require additional unwanted rework.

5. Conclusions

This paper describes the performance of a new family of totally dry, central core ribbon cables that contain no filling compounds or gels. The design is available in both metallic and dielectric sheaths, with fiber counts ranging from 12 to 216. All cables in the family are fully compliant with all requirements of Telcordia GR-20, including requirements for water penetration, mechanical performance, and environmental performance. A series of installation simulation tests has demonstrated that the field performance of these cables is equivalent to or better than that of comparable filled cables. The cables have been carefully engineered to eliminate the need for painstaking cleaning of ribbons. A time study has demonstrated that, for these dry ribbon cables, end preparation for splicing can be accomplished much more quickly than with comparable filled cables. This allows telecommunications service providers significant savings in both installation time and expense.

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