The Changing Face of Power Cable

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Abstract

Woven textile covered RHW class power cable has long been the mainstay of U.S. telephone companies. It is rugged stuff with good cold flow and abrasion characteristics. After nearly a century of manufacture and deployment, this genre of cable is now becoming obsolete. Textile RHW is expensive and a declining base of wire and cable manufacturers still make the product. Many modern thermoplastic insulation types hold up well and have the necessary characteristics to carve a niche for themselves in the network.

This paper will describe tests that Bell Atlantic used to see how a number of commercially available cable types stacked up against woven textile covered RHW cable. The tests determined the cold flow and cut-through strength of these cables using cable samples of several vendors and cables of different stranding types.

The paper will also explore a number of case studies of power cable insulation failure that resulted in arcing faults to the grounded cable tray system.

Finally, this paper will address the rationale for abandoning a long-held policy that required the use of tinned copper conductors in favor of simple copper.

1 Background

Cotton textile was the insulation of choice from the earliest days of the telephone business.

Figure 1 Vintage Cotton Braid Cable From Western Electric Telephone Apparatus and Supplies Catalog No. 6 January 1925

Figure 2 Rubber and Friction Insulating Tapes Circa 1925

This cable literally built the business and cotton braid was used for both power and multiconductor cables often called "Switchboard cable." Some versions of the cable had a coat of fireproofing paint and others did not. Generally the rubber insulation was sulfur bearing and so the copper wiring needed protection from the corrosive effects of the sulfur. Usually tinning was the protection scheme of choice and on some of the switchboard cables the wire insulation was black enamel.

Black enamel was chosen because it was very solderable and most connections back then were lead and rosin-flux solder.

While switchboard cables have seen numerous advances over the years, the staid old power cable hasn't changed very much. In fact, its use is something of a paradigm, perhaps overdue for a shift.

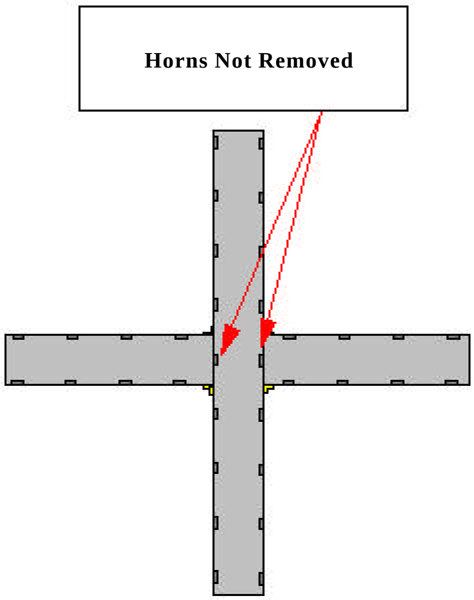
2.0 Go With Your Gut, Then Test

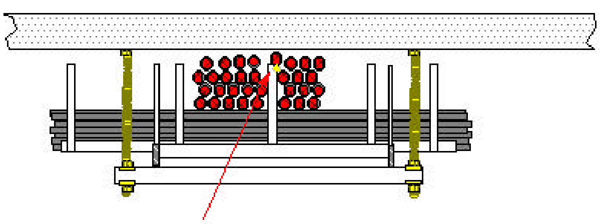
Bell Atlantic needed to reassess its position in order to control cost and because a "textile-only" requirement often results in job delays because of unavailability. Thermoplastic is more readily available but there were fears that it could experience a higher failure rate than textile. Usually, such failures are a result of cold flow or cut-through of the insulation.

While the textile textile standard is deeply entrenched, one fact is that every arcing cable fault this engineer has encountered in a nearly 35-year career involved textile cable. In each case (some of them covered herein in case studies) the root cause of the cable fault was human error due to improper installation. So the question boiled down to whether thermoplastic would compare with textile in terms of cable rack trauma, cold flow and cut through. The tests were designed around that premise.

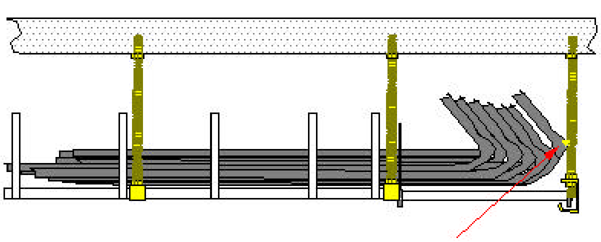
3.0 Case Studies Of Arcing-Fault Insulation Failures

An insulation failure that occurred at Philadelphia's Pilgrim Central Office at the intersection of a ladder-type cable tray system that was equipped with integral cable retention horns. Normally the horns are removed at intersections for an unobstructed path. In this case, horns were left in the intersection and cable pileup eventually grew until a 750 KCMIL power cable rested atop one of the horns. Over time, the insulation became damaged until it faulted and began arcing.





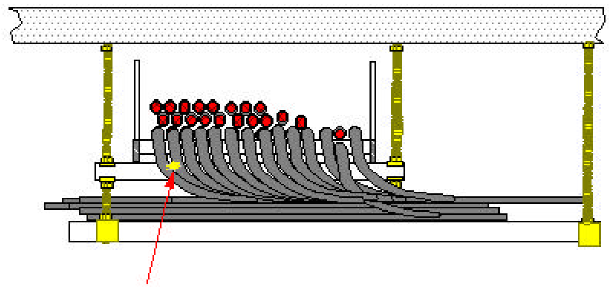
Pilgrim Central Office: Cable Chaffed Because it Rested Atop a Horn



Ambler Central Office: Cable Chaffed at Threaded Rod

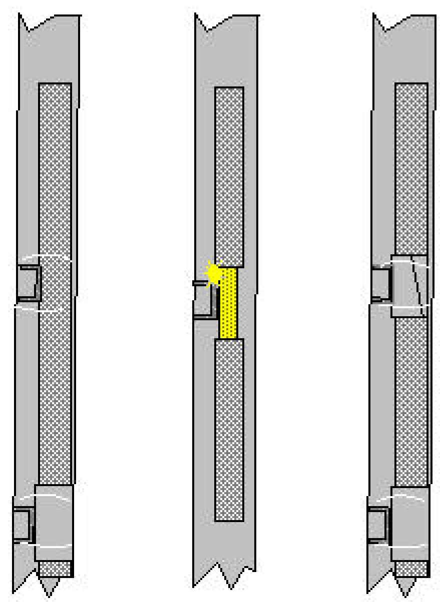
The cause of a similar failure at Ambler Central Office was a cable that was in contact with the edge of the rack or support structure, a threaded rod as shown in the above figures. This installation predates a relatively new requirement for insulation on threaded rods and horns imposed in the early 1990's.

Another failure occurred at the Hatboro Central Office because a cable was under mechanical stress to "waterfall" to a lower level. The weight of added layers of cable increased the mechanical stress and eventually caused the insulation to fail at the chafe point.



Hatboro - Cables on an Improperly Built "Waterfall." One of Them Faulted to the Channel Iron.

Cut-through, another installation failure mechanism, can result when lashing cord exerts pressure on the insulation, making a lateral cut into the insulation. Once cut, the insulation can shrink from the severance point exposing the conductor as shown in the figure below.



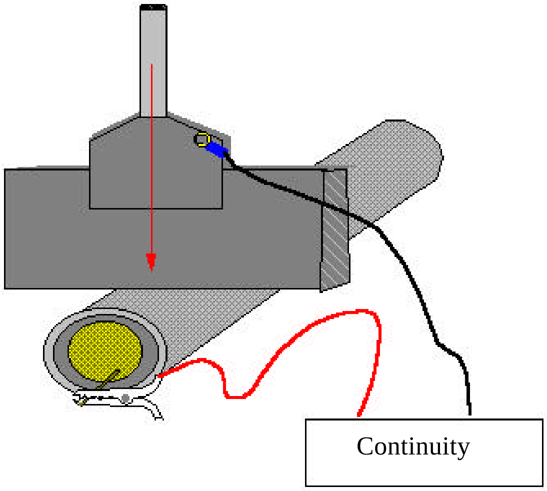
Left: Hypalon or Similar Insulation Secured with Lacing Cord.

Center: Cord Cuts Insulation Which Then Migrates Exposing Copper

Right: Cable Properly Protected with Fiber Wrap

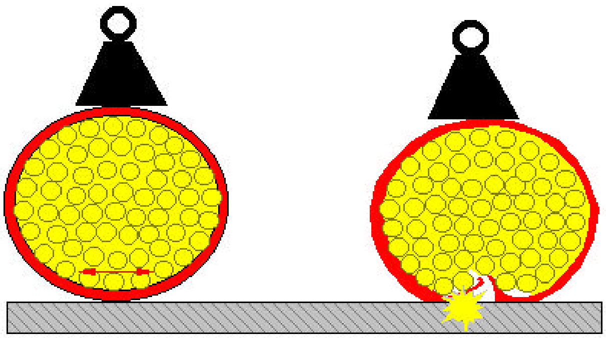
4.0 Testing

Working with a test lab, together we custom-built fixtures that would press a small section of cable rack stringer into the test specimens as shown in the figure.



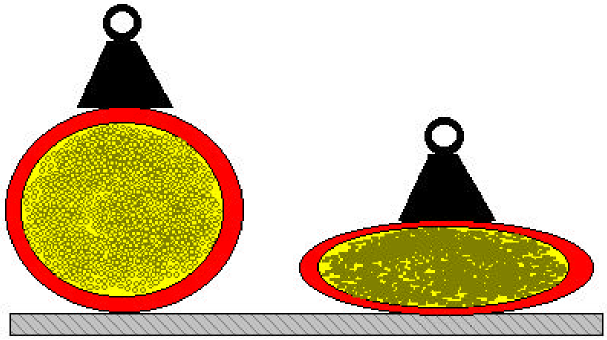
Arbor Pushed Edge of Cable Rack Into Specimen Until Continuity is Established

The test fixture was placed in a calibrated arbor press and pressure gradually increased until there was electrical continuity between the fixture and the cable conductors. Under field conditions, this path would result in an arcing fault. The test metric was the relative amount of mechanical pressure measured as weight in pounds needed to establish electrical continuity between the fixture and the conductors.

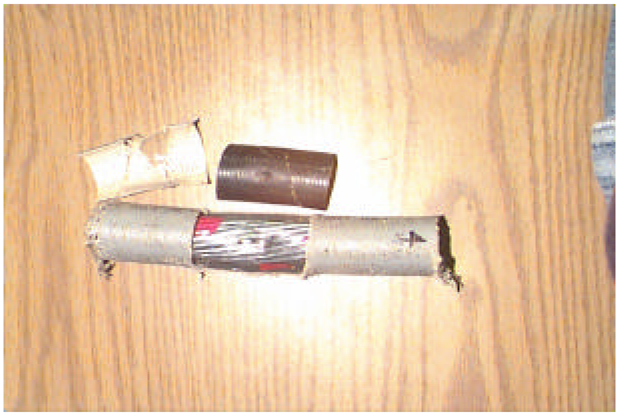


Left: Under Mechanical Pressure of Increasing Load Some Strands Shift Bilaterally Forming a "Pocket" Between Them. Right: Insulation Cold-Flows Into This Pocket, Stretching Thinner Until Failure.

Interestingly, the mechanical damage "signature" observed on the B stranded cable was exactly the kind of mechanical damage observed in the field, absent the burns from arcing, thus lending confidence in the test.



I-Stranded Cable Tends to Flatten Out Under Mechanical Load, Forming a Supportive Bed. Accordingly, the Insulation on I-Stranded Cable Can Tolerate More Than 200% Weight Than B-Stranded Cable.



Textile-Covered RHW Cable With Strand Displacement Typical of B-Strand Failure Mechanism

Textile-Covered RHW Following Tests

Plastic Insulated B-Strand Cable After Tests

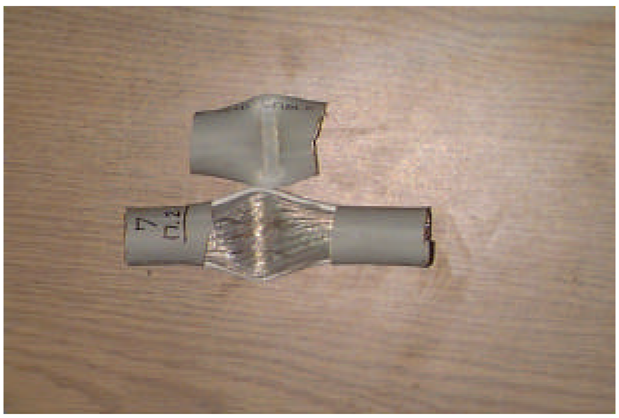
Plastic Insulated B-Strand Cable After Tests

Cutaway of Plastic Insulated B-Strand Cable Showing Typical Strand Displacement

Plastic Insulated B-Strand Cable After Tests

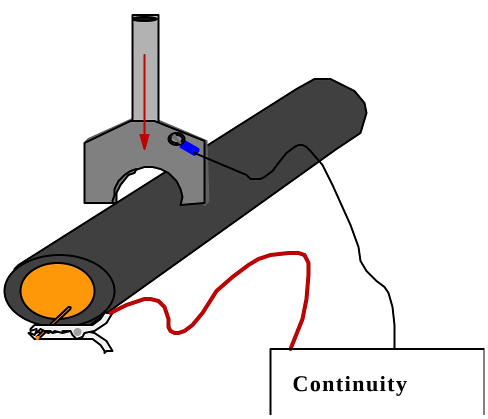
4.1 Cable Construction As a Structural System.

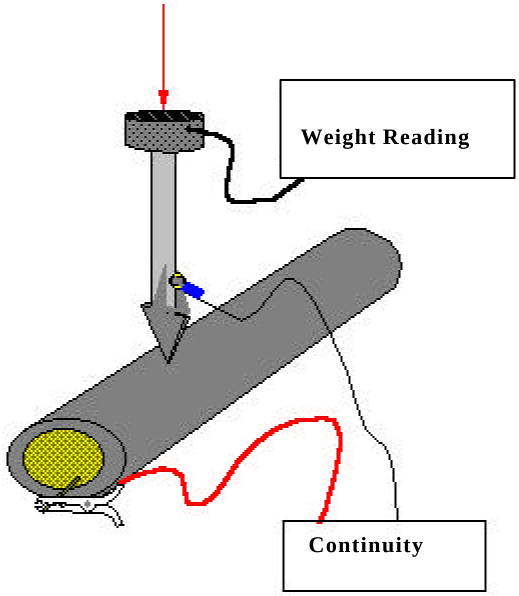
The I-stranded cable outperformed all B-stranded cable regardless of insulation. We believe that this is a function of its construction. Basically, cable integrity in the face of longitudinal compressive loading is a structural relationship where the strands form a support system for the insulation. In the case of the B stranded cable, the load would increase and eventually cause some of the conductor strands to shift bilaterally forming a hole or pocket approximately 0.25 inches wide. In the case of the I-stranded cable the strands tended to migrate away from the weight source and flatten out. Thus, it provided a better "bed" to support the insulation evenly.



4.2 Cut Through Tests

The second test was designed to test for cut-through resistance. A custom built fixture similar to the figure was designed to simulate the tightly concentrated pressure of a lacing cord. The test metric was the arbor force- measured in pounds - needed to breach the insulation and establish electrical continuity between the fixture and the conductors.





Point Penetration Test: Load Cell Signal Couples to Measurement Device to Indicate the Mechanical Load in Pounds Until Insulation Breach is Indicated by Electrical Continuity.

During our tests, we found that point penetration provided a more repeatable test than the cut-through simulation and so an arrowhead type fixture similar to the above was designed and fabricated. Like the others electrical continuity indicated a breach of the insulation and a load cell measured the weight in pounds.

Compression Tests of New Generation Cloth Insulation 350 MCM Power Cable (left and right) and Point Penetration Tests (center).

4.3 Sustained Load Tests

A final test was to secure lengths of cable to a cable rack, load the cable with 25 pounds per linear foot and suspend a 100 pound weight from one end of the cable for a stressed waterfall (see photos) simulation. This was allowed to age and then the insulation was examined for evidence of cold flow or other mechanical damage after 30 days of sustained heavy load.

4.4 Test Data

Data from tests simulating cable compressed by cable rack stringer. First column weight in pounds. Second column weight in Kilograms.

Vdr 111 750 KCMil Plastic I strd		
16000lbs	7257.5KG	
16200	7348.2	
17100	7756.4	
17900	8119.3	
17900	8119.3	
17200	7801.8	
17900	8119.3	
17800	8073.9	
17200	7801.8	

Average 17244lbs 7821.7Kg

Standard Deviation 730Lbs 331.1Kg

750 KCMil Tex-RHW B strd		
3200Lbs	1451.5 KG	
3600	1632.9	
3200	1451.5	
2800	1270.1	
3600	1632.9	
3600	1632.9	
3200	1451.5	
3400	1542.2	
3000	1360.8	
3600	1632.9	
3400	1542.2	

Average 3327Lbs 1509.1Kg

Standard Deviation 272Lbs 123.4Kg

Vdr 111 500 KCMil Plastic I strd		
15100Lbs	6849.2Kg	
17200	7801.8	
17700	8028.6	
15800	7166.7	
17700	8028.6	
17700	8028.6	
17200	7801.8	
15900	7212.1	
14100	6395.6	
17900	8119.3	

Average 16630Lbs 7543.2Kg

Standard Deviation 1319Lbs 598.3Kg

Vdr 222 750 KCMil Plastic B strd		
5200Lbs	2358.7Kg	
5600	2540.1	
5800	2630.8	
5600	2540.1	
5400	2449.4	
6000	2721.5	
5600	2540.1	

Average 5600Lbs 2540.1Kg
Standard Deviation 258Lbs 117.0 Kg

Vdr 333 750 KCMil Plastic B strd XPLE		
3800Lbs	1723.7Kg	
3600	1632.9	
3600	1632.9	
3500	1587.6	
3600	1632.9	
3800	1723.7	
3700	1678.3	

Average 3657Lbs 1667.0 Kg
Standard Deviation 113Lbs 51.3Kg

Vdr 444 750 KCMil Plastic B strd		
5500Lbs	2494.8Kg	
5800	2630.8	
6000	2721.6	
6000	2721.6	
5200	2358.7	
6200	2812.2	
6200	2812.2	
4900	2222.6	
5200	2358.7	
5100	2313.3	

Average 5610Lbs 2544.7Kg
Standard Deviation 489Lbs 221.8 Kg

Test No.	Cable Type	Load (lbs.)
Point Penetration Compression Static Test Lbs/Kg		
33	U1B22EC (Red)	70/31.8
34		62/28.1
35		79/35.8
36	XLPE 750 KCMIL (Black)	59/26.8
37		56/25.4
38		56/25.4
42	Tex RHW 750 KCMIL (Red)	41/18.6
43		44/20.0
44		47/21.3
45	Tex RHW 750 KCMIL (Blue)	47/21.3
46		41/18.6
47		47/21.3
30	Tex RHW 350 KCMIL (Red)	41/18.6
31		59/26.8
32		54/24.5
39	Tex RHW 4/0 AWG (Blue)	26/11.8
40		32/14.5
41		32/14.5
48	Tex RHW 4/0 AWG (Red)	26/11.8
49		29/13.2
50		21/9.5
51	Tex RHW 8/0 AWG (Red)	35/15.9
52		41/18.6
53		56/25.4
54	Tex RHW 4/0 AWG (Red)	32/14.5
55		38/17.2
56		35/15.9

The Sustained Load Tests Were Inconclusive Because No Damage Was Observed In Any Specimen After 30 Days.

5.0 To Tin Or Not To Tin…

Like most American Bell operating companies, Bell Atlantic used tinned copper cable for more than a century. It was necessary because sulfur has an affinity for copper and is chemically used in butyl rubber insulation as a vulcanizing agent. Early cable insulation materials usually contained butyl rubber and thus would corrode the copper conductors. Coating the copper strands with tin provided them with barrier protection from the sulfur, thus preventing corrosion. This is the same reason for lead plating on the copper straps and lugs used for interconnecting lead acid storage batteries.

Additional to power, tinning was used for switchboard cable as well and soldering usually terminated these leads. Tinning (with a hot-dip process) tended to improve the solderability of wire.

Over time, wire manufacturers switched to a less expensive plating operation for applying a thinner more uniform coating of tin on copper conductors. While this offered the same protection from sulfurous corrosion, it tended to degrade solder connections.

All of this is obsolete technology however, and we haven't used butyl rubber in many years. We use PVC or crossed linked polyethylene (doped with fire retardant chemicals) and insulation displacement connections and wire wrapping have replaced soldered connections.

There simply is no reason for specifying tinned wire or cable except for connection to lead acid storage batteries.

6.0 Conclusions

In our tests, every plastic insulated cable tested performed as well or better than the textile-braid covered RHW and so, Bell Atlantic has revised our Engineering and Material standards to include fire rated (*LOI >28%) plastic insulation. Bell Atlantic no longer requires tinning on power cable, switchboard cable, P-wire and distributing frame cross-connect wire. Based on the reduced cost of untinned cross-connect wire we anticipate cost savings and improved reliability, especially on older distributing frames where C50 protectors and similar units still require soldered connections.

*** Limiting Oxygen Index is a rating based on a materials ability to self extinguish in an O_2 enriched atmosphere. Material that extinguishes when the O_2 level is reduced to 28% has an LOI of 28. Since earth's atmosphere at sea level contains approximately 24% O_2, materials with a 28 or better LOI are fairly flame resistant.**

7.0 References

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