PVDF in Limited Combustible Cables

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Abstract

Fluorinated plastics were a significant part of a plenum cable's construction when first introduced. Plenum cables containing predominantly fluoropolymers provide superior flame and smoke performance properties, and exhibited inherently low heat contribution in the event of a fire. As producers of cable products searched for lower cost materials, the market answered by developing low smoke PVC compounds and other inexpensive materials for the plenum market. Manufacturers of plenum cables took advantage of these new products and substituted them in for fluoropolymers where possible. The resultant cables often times were of marginal quality, exhibiting flame spread and smoke generation properties barely within plenum requirements. In addition, compared to fluoropolymers and other limited combustible products, PVC containing cables contribute higher fuel loading to plenum spaces. The potential hazard of increased fuel loading due to abandoned PVC cables had not been realized at the time plenum cable requirements were being defined.

Over the past several years, the Wire and Cable Industry has developed a new class of cables having superior "flame and smoke" performance properties. These cables, referred to as "Limited Combustible" or "Duct" cables, provide superior fire resistance by offering minimal flame spread, very low smoke generation, reduced fuel loading, and by themselves, are not capable of supporting combustion. Until recently, the only commercially available electrical insulation material capable of meeting Limited Combustible (LC) requirements was Fluorinated Ethylene-Propylene (FEP). It has since been determined that polyvinylidene fluoride (PVDF) based resins can be used to produce cables that meet these requirements. These new PVDF resins not only meet Limited Combustible requirements, but also provide the highest level of flame and smoke performance available in a polymeric material.

A Research Program was undertaken at Atofina Chemicals to develop PVDF based resins that could be used to produce cables meeting LC requirements. The PVDF resins were prepared at our development labs located in King of Prussia, PA, and processed into cables at Coleman Cable located in Hayesville, NC. The cables consisted of twisted pair and multi pair count jacketed cables built to standard and NYC local law 5 construction guidelines. Coaxial and shielded control cable constructions were also prepared. The cables were tested at Underwriters Laboratories located in Northbrook, IL per NPFA-255 (Limited Combustible) and NFPA-262 (Plenum) as well as potential heat measurements taken per NFPA-259. It was concluded that cables produced with newly developed PVDF resin formulations and tested per NFPA-255 and/or NFPA-262 produced extremely low levels of smoke, well below that observed for typical Plenum cables.

Keywords: PVDF; Kynar; Limited Combustible; Duct Cable; Low smoke; Jacket; Insulation; 255; plenum

1. Introduction

Plenum cables, since their introduction in the mid 70's, represent the highest level of fire safety offered by the Wire and Cable Industry. Plenum cables provide lower flame propagation and smoke generation compared to other standard cable products. The primary test method used to validate flame and smoke performance is UL 910; a well recognized fire test method for plenum cables. UL 910 was developed in late 1970's by a consortium lead by Underwriters Laboratories. The Steiner Tunnel, a test apparatus commonly used to evaluate construction materials for fire safety, was chosen to test cable products. Conditions of the test were modified from those used to test building materials in order to model the environment envisioned for cables installed in plenum spaces. In the early 1980's, the National Fire Protection Agency (NFPA) chose to establish its own test standard identified as NFPA 262, which was written directly from UL 910 guidelines. The NFPA 262/UL 910 standard requires plenum cables to display a flame propagation no greater than 5 feet, a peak smoke optical density (POD) no greater than 0.50 and an average smoke optical density (AOD) no greater than 0.15 to pass the test.

During the development of UL 910, a variety of cables insulated with polyolefin's (PO) and polyvinyl chloride (PVC) were tested both inside metal conduit (considered the benchmark) and without metal conduit protection. Additional cables were prepared with fluoropolymers and tested without the protection of metal conduit. It was shown that fluoropolymers, specifically Fluorinated Ethylene Propylene (FEP), exhibited flame spread and smoke generation characteristics comparable to or better then PVC and/or PO cables tested inside metal conduit. The culmination of work concluded that UL 910 was a reproducible test capable of differentiating fire and smoke performance of cables with varied material compositions and manufacturing processes. UL 910 has since been designated the test method defining cable products installed into plenum spaces.

The first plenum cables introduced to the market contained primarily fluoropolymers such as FEP and PVDF, and provided superior flame and smoke performance properties, as well as inherently contributing lower fuel values inside plenum spaces. The primary drawback with these cables, however, was their higher costs. As producers of cable products searched for lower cost polymers, industry answered by developing highly filled PVC compounds for the plenum market. Manufacturers of plenum cables took advantage of these PVC compounds and substituted them in for fluoropolymers where possible. The quest to continually reduce costs propelled PVC compounds as the material of choice for applications not adversely effected by their inclusion. There were many compromises accepted by industry to allow the use of PVC compounds in plenum cable designs including but not limited to significantly higher smoke generation, higher fuel load contributions, reduced physical properties, and deterioration with age. The quantity of PVC in a cable construction is ultimately limited by the flame and smoke requirements specified for plenum cables.

A problem was raised regarding the high levels of abandoned cables in plenum spaces and its contribution to the fuel load in the event of a fire. When plenum cable requirements were initially conceived, the potential for excessive quantities of abandoned cables filling plenum spaces was not envisioned. As the need for improved cable products necessitated installation of more cables, these spaces filled with abandoned cables that remained after obsolescence. To address this concern, and through many thoughtful discussions that still continue today, the testing requirements of a limited combustible cable were defined. This new class of cables, referred to as "Limited Combustible" or "Duct cables", provide significantly higher levels of flame and smoke performance, and have significantly lower fuel loading then existing plenum cables.

The test method used to define the flame and smoke properties of a limited combustible cable is defined by the Steiner Tunnel test method NFPA-255 "Standard Method of Test of Surface Burning Characteristics of Building Materials". NFPA-255 is modeled after ASTM E-84 "Standard Test Method for Surface Burning Characteristics of Building Materials", however, unlike NFPA-262, the procedure uses the traditional measurement of Smoke Developed Index (50 maximum) and Flame Developed Index (25 maximum) used to define building materials. The cables are mounted close to the ceiling cover of the tunnel and the test duration is 10 minutes. This is different from Plenum tests per NFPA-262, which require the cables to be mounted in a central tray that runs the length of the tunnel, and is subjected to test duration of 20 minutes. It is important to understand that the requirements of NFPA-255 are significantly more stringent then those specified in NFPA-262. It is estimated that smoke generation of a plenum cable when tested per NFPA-262 will need to have an Average Optical Density (AOL) well below 0.03 in order to meet the Smoke Developed Index (SDI) requirement of 50 defined in NFPA-255.

In addition to the flame and smoke requirements, a potential heat limit of 3500 Btu/lb has been defined for limited combustible products. The test method used to determine the potential heat of a cable is defined in NFPA 259 "Standard Method for Potential Heat of Building Materials". By defining a maximum potential heat value, the fuel load entering a plenum can be controlled, addressing one of the primary issues raised concerning abandoned cables in plenum spaces.

In the late 1990's, the Fire Protection Research Foundation (FPRF) conducted a study called "International Limited Combustible Plenum Cable Fire Test Project". The participants of the study, primary material supplier, plenum cable manufacturers, independent test labs and consultants, initiated this effort to validate the use of NFPA-255 (Steiner Tunnel), and NFPA-259 (Oxygen Bomb Calorimeter) as a means of validating Limited Combustible properties in cables. The final conclusions made by the project's participants included that these tests could be used to define cables meeting limited combustible requirements. An important discovery, that did not become part of the project's conclusions, but was clearly evident in the published data, was that the only existing polymer capable of passing the limited combustible requirements was FEP. Cables produced using plenum grade PVDF consistently failed NFPA-255 for excessive smoke developed index (SDI).

Industry interpreted these results as supporting a potential new market for cables meeting Limited Combustible requirements. Industry also concluded that PVDF resins were inferior to FEP resins (relative to combustion properties) and that PVC based compounds were so poor that they could never be used to produce limited combustible cables. The results of this study were available to industry in late 1999 and a final report was published in March of 2001. During this time, cable manufacturers began to develop and qualify Limited Combustible Cables. All limited combustible cable constructions commercialized from 1999 forward contained FEP as both the primary and jacket insulation. Alternative plastic materials commonly used in Plenum applications such as PVDF and PVC were not considered due to higher smoke generation and potential heat values. From 1999 through 2003, many suppliers of plenum cables tested and qualified limited combustible cables having all FEP constructions.

Industry has long since realized that PVDF resins provide superior flame and smoke properties, and are ideally suited for many plenum type applications ranging from cable jacketing to raceway conduit. PVDF resins offer a good balance of properties, providing good performance at a price well below that of other fluoropolymers. It was understood that these "premium" PVDF plenum products, classified as having a high LOI ranging between 95 and 100 LOI, were the best grades for use as plenum jacketing compounds. PVDF plenum formulations were developed to provide superior flame and smoke properties for such applications, and allowed the use of greater amounts of PVC in the construction. Although these PVDF products are formulated to exceed plenum requirements, they do not possess all the necessary properties required to meet limited combustible applications.

The ability of a PVDF jacket to help meet plenum requirements has never been more important then with cable products containing high quantities of PVC compounds as primary insulation. PVDF resins formulated to provide 95 to 100 LOI have proven to be the premium product for this application. These higher LOI PVDF products contain additives that as a class promote the formation of a stable char in the PVDF layer during combustion. A PVDF char is believed to be an important component of the mechanisms responsible for reducing smoke generation in such cables. Once formed, this stable char will provide an insulation layer that will protect underlying materials, including PVC compounds. It is well understood in industry that increasing the thickness of a PVDF jacket is one method of reducing smoke generation in a cable containing PVC insulation.

It was apparent that new PVDF products would be required to support this new market. To fill this void, new PVDF resins have been developed that not only meet LC requirements, they offer ultra low smoke generation and flame spread well in advance of any PVDF formulation currently commercially available. This paper discusses some of the earliest work conducted to produce PVDF insulated copper cable products capable of meeting limited combustible requirements.

2. Main Body of Submission

A development effort was undertaken to produce a PVDF resin that could be used for copper cable constructions meeting limited combustible requirements. The PVDF resins were prepared at our development labs located in King of Prussia, PA, and processed into cables at Coleman Cable located in Hayesville, NC. The first cables tested consisted of a single twisted pair with a jacket. We used standard New York City (NYC) local law 5 construction guidelines, which specify a heavy insulation wall thickness of 0.015 inches for primary insulation, and 0.025 inches for jacket insulation. The cables were tested per NPFA-255 using a Steiner Tunnel located at Underwriters Laboratories located in Northbrook, IL. It was concluded from this work that PVDF based copper cables can meet the limited combustible smoke generation requirements.

Two Ultra Low Smoke (ULS) Limited Combustible (LC) PVDF compositions were prepared from a powder blend of vinylidene fluoride copolymer and a proprietary additive package. The additive package was developed during a previous effort where low smoke properties as well as improved char formation was observed. The components were introduced together as a powder blend in the appropriate ratio and then were melt blended on a 40 mm WP twin screw. In addition to the ULS-LC PVDF resins, standard 100 LOI PVDF plenum grades and FEP were included as control materials. As mentioned before, it was our understanding that FEP would meet all LC requirements whereas standard PVDF plenum grades would not meet the smoke requirements.

The various products were used as both the primary insulation and jacketing materials to produce simple cables for NFPA-255 testing. The cables were produced with 22 AWG copper conductors insulated with one of the products defined above. A single twisted pair was jacketed with one of the products to produce the final cable being tested. Different combinations of primary insulation and jacket resins were prepared to look for interactions between materials. A summary of the cable constructions can be found in Table 1.

Cable 1 was produced using FEP as both the primary insulation and jacket material. This cable was produced as a control cable to validate the construction. At the time of testing, it was understood that cables produced with all FEP constructions inherently met LC requirements. As expected, the all FEP cable met the flame and smoke requirements for limited combustibility. The Smoke Developed Index (SDI) value of 22, with approximately 0 Flame Developed Index, was consistent with what had been reported in previous studies. Visual observations made during the test noted that the all FEP cables would start to drip within 1 to 2 minutes into the test and form a melt pool at the bottom of the tunnel. Approximately 5 to 6 minutes into the test, smoldering of the melt pool could be observed. Visual smoke generation continued throughout the remainder of the test.

Cable 2 was produced using an ULS-LC PVDF formulation (LC PVDF 1) for both the insulation and jacket materials. It was shown that the cable produced with ULS-LC PVDF 1 met the LC requirements for flame and smoke, with a response comparable to FEP. A low SDI value of 24 and a FSI of 0 were recorded for this cable. This is believed to be the first PVDF insulated cable ever produced capable of meeting limited combustible requirements. In addition to the exceptionally low smoke properties observed, other positive attributes were noted. From visual observations made during this test, it appeared that the cable produced with ULS-LC PVDF 1 exhibited a minimal, almost non-detectable quantity of visible smoke. The PVDF resin did not exhibit any dripping from the cable throughout the test and formed a very stable char that remained on the cable. From visual observations made after the test, it was noted that the PVDF resin appeared only slightly melted and discolored outside of the burn zone.

Cable 3 was produced with a second ultra low smoke PVDF formulation identified as ULS-LC PVDF 2. This formulation contained a similar additive package to ULS-LC PVDF 1, but utilized a resin system containing additional modifications to the polymers composition and structure. The cable produced with ULS-LC PVDF 2 exhibited an even lower level of smoke generation compared to the cable produce with ULS-LC PVDF 1. A smoke developed index of 5 and a flame spread index of 0 was reported for Cable 3. The ultra low smoke generation and complete lack of burning of the cable were unprecedented results that confirmed the success of this new PVDF formulation. As previously observed in PVDF cables, there was no dripping from the cable, and smoke generation was visually non detectable during the test.

Two additional cables were prepared, identified as cables 4 and 5, containing FEP as the primary insulation and an ULS-LC PVDF as the jacket. These cables were produced to evaluate the potential for interactions associated with a multiple fluoropolymer construction, and the potential advantages (disadvantages) associated with introducing a ULS-LC PVDF jacket over FEP insulation. This type of construction could be envisioned for category type cables or coaxial cable.

Cable 4 was prepared using FEP as the primary insulation and ULS-LC PVDF 1 as the jacket resin. The SDI value for this cable was 10, which was lower then observed in the all FEP construction (Cable 1). There did not appear to be any negative interactions between FEP and ULS-LC PVDF, indicating such constructions could be used to produce cables meeting LC requirements. The presence of the PVDF jacket over FEP improved the overall cable performance by further reducing smoke generation (compared to an all FEP construction). It was noted that approximately half way through the test; the FEP began dripping off the cable in the fire zone. The presence of the ULS-LC PVDF jacket appeared to delay the dripping of the FEP primary insulation. The reduction of FEP in the cable construction also reduced the volume of FEP capable of dripping. The lower SDI value compared to Cable 1 is the result of including an ULS-LC PVDF jacket.

Cable 5 was prepared using FEP as the primary insulation and ULS-LC PVDF 2 as the jacket resin. The smoke and flame characteristics were similar to that reported for Cable 4. The inclusion of ULS-LC PVDF 2 over FEP provided the lowest recorded SDI of 3 in this set of experiments. All visual observations made during this test were similar to those recorded for Cable 4.

Cables 6 and 7 were prepared using FEP as the primary insulation and commercially available 100 LOI PVDF plenum resins as the jacket. These cables were included to evaluate these premium PVDF plenum grades as LC jacket resins. As expected, these standard plenum resins produced significantly higher levels of smoke compared to the ULS-LC PVDF resins and FEP. Cable 6 produced a "barely passing" SDI of 49. The use of this resin for developing a series of PVDF cables meeting LC requirements would most likely be problematic and limited in scope. For Cable 7, it was clearly noted that this resin could not meet LC requirements. Significant smoke generation was observed throughout the test for both of these cable constructions.

Table 1 NYC FIRE ALARM CABLE

Cable #	Cable Construction		SDI	FSI
	Primary	Jacket		
1	FEP	FEP	22	1.6
2	ULS-LC PVDF 1	ULS-LC PVDF 1	24	0
3	ULS-LC PVDF 2	ULS-LC PVDF 2	5	0
4	FEP	ULS-LC PVDF 1	10	0
5	FEP	ULS-LC PVDF 2	3	0
6	FEP	Plenum (100 LOI) PVDF 1	49	0
7	FEP	Plenum (100 LOI) PVDF 2	77	0

A standard Fire Alarm Cable construction was tested at Underwriters Laboratories and was shown to meet all LC requirements. The cables consisted of a 2 conductor (one twisted pair) and a 12 conductor (6 twisted pairs). The primary wires were produced with 22 AWG copper with 0.010 inches of ULS-LC PVDF 2 insulation. The wires were jacketed using 0.015 inches of ULS-LC PVDF 2. The Fire Alarm cables were tested per NFPA-255 to verify Limited Combustible smoke and flame properties. Select cables were also tested per NFPA-262 to verify that they also met standard plenum requirements. The results of this effort can be found in Table 2.

In all cases, the cables exhibited very low SDI values ranging between 3 and 9. The effect of slitting the jacket did not appear to have any adverse effect on SDI or FDI. Visual observations made during the test confirmed what was previously understood which was that cables produced using ULS-LC PVDF would not burn and produced virtually zero smoke.

What was interesting to note was that these cables, when tested per NFPA 262, also exhibited extremely low average optical density (AOD) and peak optical density (POD). The Average Optical Density was reported as 0 and the Peak Optical Density (POD) was reported at 0.01. These values are well below what is observed for typical plenum type cables.

Potential heat measurements were also determined for these cables per NPFA-259. It was verified that the cables met the LC potential heat requirement of 3500 Btu/lb maximum. The single pair conductor exhibited a potential heat of 3300 Btu/lb and the 12 conductor cable exhibited a potential heat of 2100 Btu/lb.

Table 2 STANDARD FIRE ALARM CABLE

Cable #	Test Configuration	NFPA 255		NFPA 262	
		SDI 50	FDI 25	POD 0.50	AOD 0.15
6	ULS-LC PVDF 2 2 conductor, unslit	3	0	0.01	0
7	ULS-LC PVDF 2 2 conductors, slit	9	0		
8	ULS-LC PVDF 2 12 conductors, unslit	5	0		
9	ULS-LC PVDF 2 12 conductors, slit	5	0		
10	ULS-LC PVDF 2, shield tape, 2 conductors, unslit	9	0	0.01	0

A Coaxial Cable construction was also tested at Underwriters Laboratories and was shown to meet all LC requirements. The cable construction consisted of a single copper conductor containing a foamed FEP layer, a conductive metal braid and an ULS-LC PVDF jacket layer. The PVDF composition used as the jacket material was ULS-LC PVDF 2. The Coaxial Cables were tested per NFPA-255 to verify limited combustible smoke and flame properties. Select cables were also tested per NFPA-262 to verify that they also met standard plenum requirements. The results of this effort can be found in Table 3.

Table 3 COAXIAL CABLE

Cable #	Test Configuration	NFPA 255		NFPA 262	
		SDI 50	FDI 25	POD 0.50	AOD 0.15
11	ULS-LC PVDF, unslit	2	0	0.01	0.01
12	USL-LC PVDF, slit	4	0	0.01	0.01
13	ULS-LC PVDF Aged @ 100 C for 7 days, unslit	15	0		
14	ULS-LC PVDF Conditioned 25% RH for 7 days, unslit	7.0	0		
15	ULS-LC PVDF Conditioned @ 75% RH for 7 days, slit	5	0	0.01	0

In all cases, the cables exhibited very low SDI values ranging between 2 and 15. It was shown that the coaxial cable met the requirements of a limited combustible material when tested per NFPA-255. Similar results were observed for cables conditioned at 25% and 75% RH, as well as in the slit configuration. Slightly higher SDI values were reported for cable samples aged for 100 ˚C for 7 days and tested unslit (Cable 13). Visual observations made during the test supported previous observations where the cables made with ULS-LC PVDF will not burn and produce virtually zero smoke.

Select Coaxial Cables were also tested per NFPA-262, and like the Fire Alarm Cables, exhibited extremely low Average Optical Density (AOD) and Peak Optical Density (POD). The AOD was reported as 0.01 and the POD was reported as 0.01. These values are well below what is observed for typical plenum cables. Potential heat measurements were also established for the Coaxial Cables per NPFA-259. It was determined that the coaxial cable met the LC potential heat requirement of 3500 Btu/lb maximum with a recorded measurement of 3300 Btu/lb.

3. Conclusions

PVDF resins can be used to produce a range of copper cable products capable of meeting limited combustible requirements. In this paper, three types of cables were capable of meeting these requirements and they include NYC Fire Alarm, Standard Fire Alarm and Coaxial Cables. It was determined that PVDF formulations developed to meet Limited Combustible requirements exhibit ultra low smoke properties well below current plenum standards, zero flame spread, and acceptable potential heat values. The general principals guiding the development of ULS-LC PVDF center on the specifics of the additive package in conjunction with the PVDF base resin composition and structure.

When developing copper cables to meet limited combustible requirements, it is important to properly consider the potential heat weighted averages of individual components to ensure the entire cable is below the 3500 Btu/lb maximum. The grades of PVDF tested in this body of work, as well as commercial PVDF grades, exhibit a relatively high potential heat value ranging between 5900 and 6300 Btu/lb. The potential heat value of PVDF is acceptable for copper cable applications because the low potential heat of the copper can offset that of the PVDF insulation. With proper considerations of copper gauge and insulation wall thickness, appropriate cable designs can be achieved.

Most recently, efforts to reduce the potential heat of PVDF to allow development of LC fiber optic cable products have proven successful. The primary challenge is to develop methods for reducing the potential heat of PVDF without adversely effecting the superior smoke and flame performance. As of the writing of this paper, this challenge has been met, and newer development grades of LC PVDF have been developed. These new development grades inherently provide low potential heat values as well as ultra low smoke performance and zero flame spread. Efforts are being conducted to investigate the use of these new development grades to support limited combustible fiber optics development as well as limited combustible raceway conduit.

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