Comparison of HFFR Jacket Compound Solutions: Polyolefin vs. TPE

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Abstract
The wire and cable industry continues to research and develop new plastics materials that are halogen-free, flame retardant, and produce low acid gas and smoke generation during combustion. Metal hydrate filled polyolefins (MHPOs) are an important compound technology that meet these requirements, but due to the high flame retardant concentrations required to achieve high flame test performance, they are high density, possess high melt viscosities which make them challenging to process, and exhibit low elongations at break. This paper compares the performance of a commercial MHPO compound to that of two new thermoplastic elastomer compounds, each formulated with a different intumescent flame retardant system (IFR-TPEs). Test results show that both new grades pass the UL-1581 VW-1 and Cable Flame tests on 18 AWG wire, they exhibit high elongation at break, low density and low melt viscosity. One IFR-TPE passes the IEC 61034-2 smoke cube test and the other exhibits extremely high short-term insulation resistance in water. Results show both new formulas comply with other properties required of 105°C-rated UL-62 TPE materials. In addition, results of testing the halogen content and acidity of combustion gases by IEC 60754-1 and -2 are also reported.

Keywords: halogen-free flame-retardant; halogen-free flame-retardant; HFFR; Low Smoke Zero Halogen; LSZH; Low Smoke Zero Fume; LS0H; UL-1581 Section 1080; VW-1; Cable Flame; UL-1581 Section 1061; IEC 61034; thermoplastic elastomer; TPE; intumescent; IFR

1. Introduction
Flexible PVC (FPVC) continues to be the most commercially significant plastic material in the global wire and cable market. In 2011, it accounted for nearly two-thirds of total plastic consumption in the NAFTA market or 1.47 billion lbs. (667 million kg) [1]. The industrial success of FPVC technology has been largely attributed to the broad range of desirable compound properties which have been successfully achieved through careful selection of ingredients. Using this approach over the years has enabled the regular development of new compounds to meet continually more stringent technical requirements, such as: improved thermal stability, oven aging performance, electrical properties, and flame retardancy.

More recently, new FPVC compounds were commercialized to meet more stringent regulatory requirements and improved sustainability initiatives. A full range of FPVC compounds are now available that are RoHS and REACH compliant and are formulated with phthalate-free, biorenewable plasticizer systems with a reduced carbon footprint. Furthermore, special grades have been developed that evolve significantly reduced acid gas upon combustion [2]. However, because the PVC macromolecule is comprised of 57% chlorine by weight, it will never be halogen-free and commercial grades to date continue to evolve some acid gas during combustion. Therefore, for applications that require they be halogen-free, and evolve no acid gas, other polymers are used.

In the 1980s, HFFR compounds based on physical blends of metal hydrate powders and polyolefin polymers were first introduced in Europe, where they are now commonly used. Examples of metal hydrates used in these formulations are alumina trihydrate (ATH) and magnesium hydroxide (MDH); and examples of polyolefins are polyethylene and their copolymers. As a class, these metal hydrate filled polyolefins (MHPOs) have a reputation for generating low smoke density and no acid gas under combustion conditions. This "clean" burning characteristic is largely due to the three step flame retardant mechanism of the metal hydrate. First, upon reaching its degradation temperature, the metal hydrate begins to decompose to its respective metal oxide and water. This reaction is highly endothermic, which cools the polymer and delays the onset of ignition. As the reaction progresses, water vapor is continuously evolved that dilutes the oxygen at the polymer-air interface, which further impedes ignition. Finally, the metal oxide residue forms an insulating barrier that protects the polymer below [3].

MHPO compounds are often selected due to their excellent low smoke density and no acid gas generation for applications that are within enclosed spaces where the means to evacuate the area are limited or where corrosive gas has the potential to damage electronics. Grades have been commercialized in the NAFTA region that passed flame retardancy requirements ranging from VW-1 to Riser on special cable constructions.

In order to achieve the high degrees of flame retardancy required from MHPO compounds for wire and cable applications, however, concentrations as high as 65 weight percent of metal hydrate are required [4]. Such high inorganic content produces compounds with high density, comparatively low elongation at break values, and high melt viscosities. In addition, due to the polymers commonly used, their resistance to deformation at high temperatures is limited.

More recently, new HFFR compositions have been commercialized based on thermoplastic elastomers (TPEs) flame retarded with intumescent flame retardants (IFRs). TPEs are a classification of polymers with both thermoplastic and elastomeric properties. Examples of TPEs used in HFFR compounds are styrenic block copolymers (TPE-S), thermoplastic polyurethanes (TPU), and thermoplastic copolyesters (TPE-E). Their elastomeric properties enable the development of compounds with significantly higher elongation at break performance, and they also increase the compound's resistance to deformation under load at elevated temperatures.

Intumescent flame retardants are reactive additives that upon combustion form an expanded protective char layer that acts as a thermal barrier and seals in pyrolysis gases thereby preventing further combustion [5]. There are several IFR chemistries in commercial application, and the exact chemical identities of most are kept as trade secrets by the flame retardant suppliers. What is known is that they are typically blends of organic phosphorus and nitrogen compounds. The basic flame retardancy mechanism is very efficient, requiring fairly low additive concentrations to achieve high flame test performance compared to MHPOs. These lower additive concentrations impart the following advantages to the end composition

- Higher elongation at break and flexibility for higher durability and easier handling
- Reduced melt viscosity for increased output
- Reduced density for improved weight reduction

IFR additives are not new, and have been used in other industries since the late 1930s [6]. However, unlike metal hydrates which have been used to flame retard wire and cable compounds since the 1980's, IFRs have only recently been used in this area [7]. Not all IFR compounds provide the same flame retardancy and low smoke characteristics. The investigation of their use in wire and cable represents a growing development trend, the results of which are a focus of this paper.

1.1 Determination of the Performance Profiles of VW-1 Rated HFFR Cable Solutions

This paper will compare the performance of three newly developed RoHS and REACH compliant IFR-TPE wire and cable compounds formulated for applications requiring VW-1 and higher flame performance to a commercial metal hydrate-based polyolefin HFFR compound. The objectives of the IFR-TPE development were to:

- Create highly flame resistant compositions
- Formulate compounds that generate low smoke, and evolve low acid gas during combustion
- Produce compounds that meet the UL-62 requirements for the 105°C rated TPE material category
- Provide an excellent balance of properties to enable broad use for other wire and cable applications

The applied test protocol presented in this paper was designed to characterize the performance profile of the evaluated compounds in each of these areas.

2. Experimental

2.1 Materials

The results from testing four thermoplastic compounds are summarized and compared in this paper. The labels used to refer to each along with their descriptions are included in Table 1. The first material, labeled as MHPO, is a commercially successful compound that represents traditional metal hydrate based polyolefin formula chemistry. The other three materials, IFR-TPE 1A, 2A, and 2B, are all TPE-based compounds formulated with one of two different intumescent flame retardant systems.

Table 1. Sample Labels and Descriptions

Test Label	Flame Retardant Type	Jacket Compound Description
MHPO	Metal hydrate	A commercial polyolefin based LS-HFFR compound that passes VW-1 as jacket.
IFR-TPE 1A	Intumescent Flame Retardant Type #1	A commercial first generation, LS-HFFR TPE compound that passes VW-1 as jacket and Cable Flame on larger cables only.
IFR-TPE 2A	Intumescent Flame Retardant Type #1	A second generation, LS-HFFR TPE compound that is designed to improve the flame retardancy of IFR-TPE 1A to pass Cable Flame testing on smaller cables as well as large.
IFR-TPE 2B	Intumescent Flame Retardant Type #2	A second generation, HFFR TPE compound that passes VW-1 and CABLE FLAME as jacket.

2.2 Benchmarking Approach

Each of the four compounds were tested and compared for a series of properties on compound, and on wire to assess their capability as insulation and jacket for wire and cables. From compound, properties measured include: density, flexibility, melt viscosity, dielectrics, and flame retardancy. In addition, the halogen content, and degree of acidity of combustion gases released were tested. From wire, specific tests from UL-62 were performed to evaluate their performance for the requirements of 105°C rated TPE SJE (hard usage, thermoplastic elastomer type) and SJEW (hard usage, thermoplastic elastomer, weatherable type) type materials, and smoke density was measured. Where relevant, conclusions regarding any correlation between compound and wire test results are presented. A list of the tests methods used are defined in the next two sections

2.3 Laboratory Sample Preparation and Tests Performed on Compound

The IFR-TPE 2A and 2B samples were melt-mixed using a pilot scale 2.5 liter Banbury mixer, processed into sheets on a two-roll mill, and then diced into pellets for further processing and testing. The MHPO and IFR-TPE 1A pellet samples were produced using a commercial compounding line. Table 2 lists all of the properties measured from compound, the test methods used, and either the pass criteria, when defined by the standard, or whether higher or lower values are desired for the property.

The apparent shear viscosity, the testing for halogen acid gas and degree of acidity of the released combustion gases were performed on the pellets. Testing for specific gravity, flexural modulus, brittle point, dielectric constant and dissipation factor, and limiting oxygen index were performed on specimens die-cut from compression molded plaques to the dimensions required by the respective method. All compression-molded plaques were pressed at between 350 – 400°F (177 - 204°C), and all specimens were tested after conditioning for 24 hours in a room controlled at 73°F (23°C) and 50% relative humidity.

Table 2. Test Methods Performed on Compound

Properties Measured	Test Standard and Pass Criteria
Specific Gravity	ASTM D 792 Lower is desired
Flexural Modulus	ASTM D 790 Lower is desired
Brittle Point	ASTM D 746 Lower is desired
Apparent Shear Viscosity	ASTM D 3835 Lower is desired
Dielectric Constant and Dissipation Factor	ASTM D 150 Lower is desired
Oxygen Index	ASTM D 2863 Higher is desired
Halogen Acid Gas Released Upon Combustion	IEC 60754-1 Lower is desired
Degree of Acidity of Gas Released Upon Combustion	IEC 60754-2 1.pH ≥ 4.3 2. Conductivity ≤ 10 µS/mm

Specific gravity measurement was performed on compression molded specimens that were die-cut into 1¾ ” diameter x ¼” thick (44.5 mm x 6.4 mm) discs. Flexural modulus results were reported based on the average of five tests performed on 5” x ½” x ⅛” (127.0 mm x 12.7 mm x 3.2 mm) specimens at a strain rate of 0.05”/min (1.27 mm/min). Brittle point testing was performed on specimens 1¼” x ¼” x 0.075” (31.8 mm x 6.4 mm x 1.9 mm) using a Type B holding clamp in an isopropyl alcohol test medium. Six to eight specimens were tested to achieve each result. Automatic capillary rheometer (ACR) testing was performed to measure the apparent shear viscosity at ten different shear rates ranging from 100 – 1,000 s^{-1}. The testing was performed at 392°F (200°C) using a 20/1 length/diameter die and a 300 second dwell time was held before testing. The dielectric constant and dissipation factor testing was performed on ⅛” (3.2 mm) thick plaques. Finally, the Limiting Oxygen Index was measured from ASTM 2863 type IV specimens and by observing the top surface ignition method (Method A).

2.4 Tests Performed on Wire

Pellets of each material evaluated were extruded as 0.016” (0.406 mm) thick insulation over 18 AWG stranded copper wire. The same extruder and tooling was used to make the wire samples for each of the materials tested. Table 3 lists all of the properties measured from wire, the test methods observed, and either the pass criteria, when defined by the standard, or whether higher or lower values are desired for the property.

Tensile property measurements were performed on tubular insulation specimens using an extension rate of 20”/min (508 mm/min) and a mechanical extensometer automatically determined the elongation at break values. The results reported were an average of five tests conducted at 73°F (23°C), and again after short-term oven-aging conducted in a convection oven for seven days at 276.8°F (136°C). This oven aging condition represents the UL test conditions for a 221°F (105°C) temperature rating. All of the remaining wire tests were performed on intact wire samples with the conductor in place. The test conditions applied were those required in UL-62 for 18 AWG insulated wire for a 105°C rated TPE material.

Table 3. Test Methods Performed on Wire

Properties Measured	Test Standard and Pass Criteria
Ultimate Tensile Strength	UL-62, Section 5.1.1 Insulation: ≥800 psi (5.52 MPa) Jacket: ≥1,200 psi (8.27 MPa)
Elongation at Break	UL-62, Section 5.1.1 ≥200% for insulation and jacket
Tensile Property Retention After Oven Aging for 7 days at 136°C	UL-62, Section 5.1.1 ≥75% for both tensile strength and elongation at break
Deformation at 150°C	UL-62, Section 5.1.3.1 ≤50%
Heat Shock at 150°C	UL-62, Section 5.1.8.1 Pass (no cracks)
Cold Bend at: 1. -20°C for standard flexible cords 2. -40°C Outdoor flexible cords	UL-62, Section 5.1.6 Pass (no cracks)
Short-Term Insulation Resistance	UL-62, Section 5.2.3 Indoor: ≥2.5 MΩ·1000 ft (0.76 GΩ·m) tested in air Outdoor: ≥170 MΩ·1000 ft (52 GΩ·m) tested in water
VW-1 Flame Test	UL-1581, Section 1080 Pass
Cable Flame Test	UL-1581, Section 1061 Pass
Smoke Density	IEC 61034 ≥60%

Deformation was tested after one hour at 302°F (150°C) with a 300 g weight applied, and the results reported were an average of three tests. Heat shock was tested after one hour at 302°F (150°C) while the wire was wrapped six turns around a mandrel with a 0.11” (6.5 mm) diameter. For cold bend, the wire was conditioned for four hours at -40°F (-40°C), and then was wrapped six turns around a mandrel with a 0.25” (6.5 mm) diameter. The short-term insulation resistance was performed on a 55 ft. (16.8 m) length of wire after immersion in 15°C (59°F) water for 6 hours, and then 500 V was applied to determine the result. The results reported were an average of two tests for each compound. VW-1 flame testing was performed in a UL specified test chamber, and Cable Flame testing was then performed on the wires that passed VW-1. For both VW-1 and Cable Flame testing, each sample was tested three times and all of the test results were reported. Finally, smoke density was measured according to IEC 61304 on a bundle of 49, one meter lengths of wire, and two tests were performed and reported for each sample.

3. Results and Discussion

3.1 Physical, Rheological, and Mechanical Properties

Automatic capillary rheometry was applied to measure the apparent shear viscosity of each of the four compounds from 100 – 1,000 s^{-1}, which is a range representative of most extrusion processes. In general, plastics with higher viscosities are more difficult to melt process as they require higher extruder torques, and exhibit higher melt temperatures and pressures. As a commercial product, the MHPO compound has successfully proven its extrusion processability for several applications and, for a metal hydrate polyolefin type HFFR compound, it is relatively easy to process. However, Figure 1 shows that all three of the IFR-TPE materials exhibit significantly lower viscosities than the MHPO compound, which indicates all will process easier. Although the polymer chemistry is different between MHPO and IFR-TPE compounds, this decrease in viscosity is largely attributed to the significant reduction in the flame retardant concentration in the latter formulations.

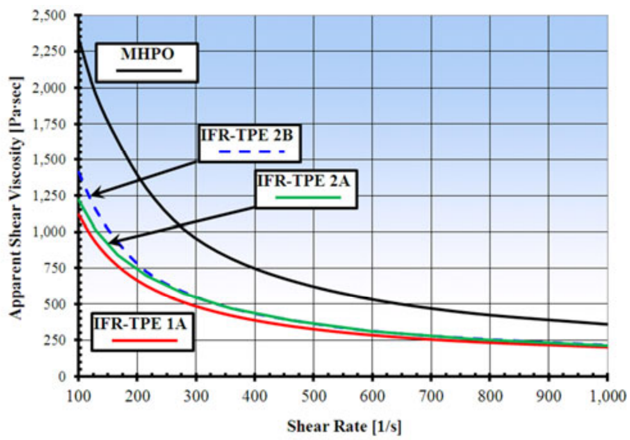

Figure 1. Automated Capillary Rheology Comparison at 392°F (200°C)

The specific gravity values reported in Table 4 also show that all three IFR-TPE materials have significantly lower density than the MHPO compound. In particular, the IFR-TPE 2B has the lowest density. This is another indication of lower flame retardant concentration in the IFR-TPEs, and their lower densities offer opportunity for weight reductions of the finished cable.

This particular MHPO compound is further characterized by high tensile strength and flexibility, combined with a good elongation at break considering its high flame retardant concentration. Table 4 shows that all four of the compounds exhibit tensile strength values far in excess of the ≥1,200 psi UL-62 requirement for TPE materials, with the highest value reported for the MHPO formulation. However, only the IFR-TPE materials meet the ≥ 200% elongation criteria, which they exceed by a wide margin. Furthermore the IFR-TPE 1A and 2A were formulated with a similar flexural modulus to the MHPO compound. However, the IFR-TPE 2B exhibits higher flexural modulus, but is still low enough for thinner wall constructions on wire requiring high flexibility.

Table 4. Physical and Mechanical Properties

Property	MHPO	IFR-TPE 1A	IFR-TPE 2A	IFR-TPE 2B
Specific Gravity	1.56	1.12	1.13	1.08
Tensile Strength[1]	2,844 psi 19.61 MPa	2,664 psi 18.37 MPa	2,547 psi 17.56 MPa	2,348 psi 16.19 MPa
Elongation at Break[1]	173%	543%	589%	483%
Flexural Modulus	16.0 kpsi 110.3 MPa	15.8 kpsi 108.9 MPa	16.1 kpsi 111.0 MPa	59.3 kpsi 408.9 MPa

NOTE 1: Measured from 0.016” (0.406 mm) thick insulation.

3.2 Thermomechanical Properties

To qualify for use in wires and cables, plastics and elastomers must demonstrate that they can perform without cracking or deforming in specialized, high and low temperature performance tests. At low temperatures, UL-62 requires that general purpose flexible cords pass cold bend at -20°C or at -40°C or lower for constructions labeled as weatherable. The results in Table 5 show that all four compounds evaluated pass at -40°C. Furthermore, brittle point test results also reported in the table, show that compounds with as high as a -32°C result are still able to pass cold bend at that temperature.

At elevated temperature conditions, UL-62 also requires that TPE materials must pass both heat shock and deformation testing at 302°F (150°C). All four of the compounds passed the heat shock testing. However, only the IFR-TPE samples passed deformation testing and thereby show their performance advantage for this property requirement.

Table 5. Brittle Point and Wire Testing at Temperature Extremes

Property	MHPO	IFR-TPE 1A	IFR-TPE 2A	IFR-TPE 2B
Brittle Point	-25°F (-32°C)	-57°F (-50°C)	-35°F (-38°C)	-53°F (-47°C)
Cold Bend[1] at -40°C	PASS	PASS	PASS	PASS
Heat Shock[1] at 150°C	PASS	PASS	PASS	PASS
Deformation[1] at 150°C	59%	10%	0%	0%

NOTE 1: Measured from insulated 18 AWG wire

Another requirement for plastics and elastomers used in wires and cables is that they retain their tensile properties after exposure to elevated temperatures for extended periods of time. Table 6 shows the tensile strength and elongation at break retention after oven aging the insulation tubing of each compound for seven days at 276.8°F (136°C), which corresponds to a UL temperature rating of 221°F (105°C). These results show that each of the three IFR-TPE compounds meet the ≥75% retention for both tensile strength and elongation at break for a TPE material. It should be noted that although the MHPO formula did not meet ≥75% elongation at break retention, it is still 105°C rated. UL currently does not have a material category for the MHPO material class. To achieve the approval, long-term aging was performed on different cables using the MHPO as jacket where it met the required tensile strength and elongation at break retention.

Table 6. Tensile Property Retention After Oven Aging

Property	MHPO	IFR-TPE 1A	IFR-TPE 2A	IFR-TPE 2B
Aged for 7 days at 276.8°F (136°C) in air				
Tensile Strength Retention[1]	104%	112%	113%	104%
Elongation at Break Retention[1]	71%	86%	85%	83%

NOTE 1: Measured from 0.016” (0.406 mm) thick insulation.

3.3 Electrical Performance

Although not important for flexible cords, low dielectric properties are desired for communication cables to improve signal transmission in high frequency, low loss applications. Plaques of each of the four compounds were tested to determine the dielectric constant and dissipation factor when tested at a frequency of 1 MHz. The MHPO sample exhibited very good dielectric properties with values that are slightly better than are reported for typical plenum grade FPVC compounds used for communication cables [8]. However, all three of the IFR-TPE compounds exhibited significantly lower values, which will allow them to improve signal transmission quality further for this application.

UL-62 defines the short short-term insulation resistance values that must be met by individual insulated conductors for use in flexible cords, but the requirements are different depending on whether the cable will be used indoors or outdoors. The resistance requirement for indoor cords is lower, and the testing is performed in air, where the requirement for outdoor cords is higher and is performed in water. The requirements for both indoor and outdoor cables for an 18 AWG wire are listed below:

- Indoor requirement: ≥2.5 MΩ·1000 ft (0.76 GΩ·m) tested in air
- Outdoor requirement: ≥170 MΩ·1000 ft (52 GΩ·m) tested in water

Because the requirement is more difficult to pass, and to better differentiate the samples, all fours wires were tested for short-term insulation resistance by the outdoor method and the results are reported in Table 7. Both the MHPO and IFR-TPE 2B sample easily exceeded the ≥170 MΩ·1000 ft requirement. It should be noted that the IFR-TPE 2B sample showed exemplary performance by exceeded this requirement by a factor of 300x. The IFR-TPE 1A and 2A wires failed to meet the outdoor requirement, but their results indicate that they would easily pass the indoor requirement of ≥2.5 MΩ·1000 ft.

Table 7. Dielectric and Short Term Insulation Resistance Properties

Property	MHPO	IFR-TPE 1A	IFR-TPE 2A	IFR-TPE 2B
Dielectric Constant at 1 MHz	3.33	2.88	2.92	2.88
Dissipation Factor at 1 MHz	2.03×10^{-2}	3.64×10^{-3}	9.30×10^{-3}	3.64×10^{-3}
Short-Term Insulation Resistance[1]				
MΩ·1000 ft	3,438	107	77	49,500
GΩ·m	1048	33	23	15,088

NOTE 1: Measured from insulated 18 AWG wire

3.4 Flame Resistance Testing

Limiting oxygen index measures the percent of oxygen required to maintain combustion of a plastic plaque for three minutes, or over a 2" (5.08 cm) burn length, whichever occurs first. It is a simple test that can be performed quickly, and for this reason is commonly used in the industry for the quality control testing of flame retardant compounds. Figure 2 shows the results from testing all four of the compounds. The MHPO formulation achieved 40%, where the IFR-TPEs achieved significantly lower results ranging from 27 – 33%. Although this difference is statistically significant, it must be determined whether this Oxygen Index difference helps predict whether insulated wires will pass the VW-1 or Cable Flame tests.

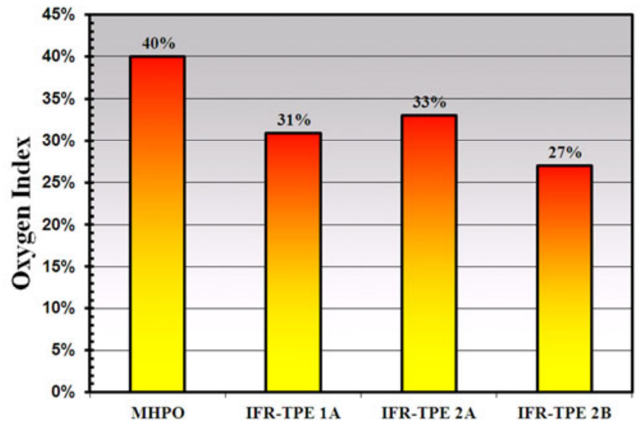

Figure 2. Oxygen Index Results from Compound

In order to determine compliance to UL-62 for flexible cord applications, cables must at least pass least the FT-2 flame test, which is a horizontal flame test on a single wire. But to enable use in a broader range of constructions, the cables must pass the more stringent VW-1 flame test or the even more difficult Cable Flame test. It should be noted here that the MHPO composition passes VW-1, and the IFR-TPE 1A formula both VW-1 and Cable Flame testing when tested as jacket in different commercial cable applications with wall thicknesses ≥0.030" (0.76 mm).

For the VW-1 test, a 500 W burner is applied for five 15-second applications to a ≥24" (610 mm) length of wire that is oriented in a vertical position in a draft-free chamber. As part of the test, a kraft paper indicator flag is affixed to the wire at a point 10" (254 mm) above the point of burner application, with the flag facing the opposite side of the wire from the burner. In addition, surgical cotton is spread out in a thin layer directly below the wire and burner. All three of the following conditions must be met to achieve a passing result:

- The wire may not burn longer than 60 seconds after each burner application is removed
- No more than 25% of the indicator flag may burn
- The cotton shall not ignite

Table 8 shows results from testing all four wire samples for VW-1 three times each. Despite its 40% Oxygen Index value, the MHPO material failed VW-1 on the first flame application three consecutive times, first by burning longer than 60 seconds after burner was removed. Rather than stop the test, the flame was allowed to continue until the flame ignited the flag, and those are the times reported. The flame propagation rate was slow at first, presumably until the metal hydrate endothermic decomposition reaction was expended. After this, despite having formed a solid char, the fire grew in size and spread faster until the flag was ignited. IFR-TPE 1A also failed after only the first flame application three consecutive times. In this case, however, the flag was ignited in less than 60 seconds each time, ending the tests. Although in each of the tests an intumescent char formed, it did not form quickly enough or grow thick enough to protect the flag from igniting. These failing VW-1 test results on wires insulated with the MHPO and IFR-TPE 1A, which are already used commercially as jackets on larger VW-1 rated cables, shows how difficult it is to pass this test on a small wire with a thin coating of insulation.

Despite this difficulty, the wires insulated with IFR-TPE 2A and 2B passed VW-1 easily, and both only exhibited 27% and 33% Oxygen Index values, respectively. They achieved this by forming robust chars after the first flame application that resisted the remaining applications. These two compounds were then tested further by the Cable Flame test.

Table 8. UL-1581 Section 1080 (VW-1) Results

Insulation Material	Flaming Time After Each Burn Application [sec] #1	#2	#3	#4	#5	Flag / Cotton Ignited?	RESULT
MHPO - TEST #1	109	---	---	---	---	Yes / No	FAIL
MHPO - TEST #2	112	---	---	---	---	Yes / No	FAIL
MHPO - TEST #3	97	---	---	---	---	Yes / No	FAIL
IFR-TPE 1A - TEST #1	40	---	---	---	---	Yes / No	FAIL
IFR-TPE 1A - TEST #2	50	---	---	---	---	Yes / No	FAIL
IFR-TPE 1A - TEST #3	48	---	---	---	---	Yes / No	FAIL
IFR-TPE 2A - TEST #1	4	4	0	0	0	No / No	PASS
IFR-TPE 2A - TEST #2	8	4	0	0	0	No / No	PASS
IFR-TPE 2A - TEST #3	6	3	0	0	0	No / No	PASS
IFR-TPE 2B - TEST #1	10	1	0	0	0	No / No	PASS
IFR-TPE 2B - TEST #2	3	1	0	0	0	No / No	PASS
IFR-TPE 2B - TEST #3	6	1	0	0	0	No / No	PASS

The test apparatus and specimen specified for the Cable Flame test is identical to that of the VW-1 flame test, but the test procedure is different. For the test, three flame applications are applied for 60 seconds with a 30 second delay between each. Similar to the VW-1 test, neither the indicator flag nor the cotton is permitted to ignite in order to achieve a pass. Finally, the wire may not burn longer than 60 seconds after the third burner application is removed. In practice, it is reported that this test is more difficult to pass than the VW-1, presumably due to the increased time that the burner is applied.

Table 9 shows that both IFR-TPE 2A and 2B pass the Cable Flame test easily as well. A thick intumescent char formed during the first flame application that protected the wire from later applications. IFR-TPE 2A performed slightly better because no flame persisted after the third flame application was removed for all of the tests. IFR-TPE 2A and 2B passing both the VW-1 and Cable Flame tests represents a significant improvement in flame retardancy over the commercial compounds that they were compared against.

Table 9. UL-1581 CABLE FLAME

Insulation Material	Flaming Time After the 3rd Burn Application [sec]	Flag / Cotton Ignited?	RESULT
IFR-TPE 2A - TEST #1	0	No / No	PASS
IFR-TPE 2A - TEST #2	0	No / No	PASS
IFR-TPE 2A - TEST #3	0	No / No	PASS
IFR-TPE 2B - TEST #1	0	No / No	PASS
IFR-TPE 2B - TEST #2	10	No / No	PASS
IFR-TPE 2B - TEST #3	3	No / No	PASS

3.5 Smoke Density and Acid Gas Performance

To show the comparative performance for these properties, the IEC 61034 test was performed on the wire samples to measure smoke density and the IEC 60754-1 and -2 on the compound samples to measure the acidity and conductivity of the combustion gases. Of particular interest will be the determination how results differed between the MHPO and IFR-TPE samples, and also if the intumescent flame retardant type produced different results.

For the IEC 61034 testing, the wire bundles for each sample were mounted on a stand over a one liter alcohol fuel source in the 3m x 3m x 3m test chamber. The alcohol was then ignited under the wire bundle, and the density of the smoke buildup while burning the cable was monitored throughout the test by the transmittance reduction of a light beam directed through the chamber. The test is stopped after 40 minutes or after six minutes of no smoke density increase after the alcohol fuel source is extinguished. In order to pass, the light transmittance must be maintained ≥ 60% throughout the test.

Two IEC 61304 tests were performed on each wire sample and Table 10 shows the lowest light transmission values reported for each, along with their average. Figure 3 illustrates the percent light transmittance as a function of time throughout the 40 minute test period. The MHPO sample easily passed the test with an average transmission of 93%, and achieved the highest result of the four wires. IFR-TPE 1A and 2A also passed the test achieving similar average results of 69% and 66%, respectively. Unexpectedly, the IFR-TPE 2B sample dramatically failed the test with an average of 15%.

Table 10. IEC 61034-2 Transmission Results

Property	MHPO	IFR-TPE 1A	IFR-TPE 2A	IFR-TPE 2B
Test #1	93%	71%	65%	16%
Test #2	93%	67%	68%	15%
Average	93%	69%	66%	15%

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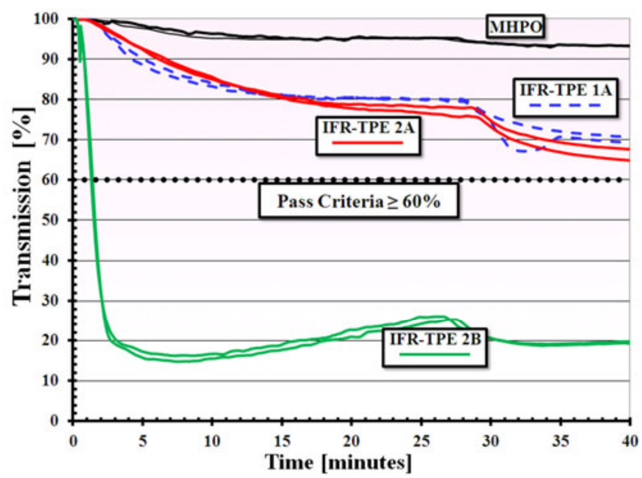

Figure 3. IEC 61304-2 Transmission vs. Time

The IEC 60754-1 and -2 test methods were performed to analyze the decomposition gases generated from each of the compounds for acidic properties. The procedures for both tests involve thermally decomposing a compound sample of approximately one gram in a tube furnace, and then absorbing the decomposition fumes into defined test solutions. The IEC 60754-1 then tests its solution for the combined concentration of hydrochloric acid (HCl) and hydrobromic acid (HBr), and the 60754-2 for pH and conductivity. No pass criteria are defined in IEC 60754-1, but it is expected that results close to zero should be exhibited by a compound to be classified as HFFR. The 60754-2 standard recommends ≥4.3 pH, and ≤10 µS/mm conductivity criteria to be met in the absence of any specification limits that supersede from a cable standard.

Results in Table 11 confirm that all four of the compounds are halogen-free by exhibiting no detectable levels of HCl or HBr in the decomposition gases. All four of the compounds also meet the >4.3 pH criteria recommended by the IEC 60754-2 standard. But it should be noted that the MHPO sample result of 4.35 is very close to this specification limit. Also, the pH value reported for IFR-TPE 2B was very close to 7, which indicates that its decomposition gases were virtually pH neutral. Finally, while the conductivity value of the MHPO sample easily passed, the results for all the IFR-TPE samples exceeded the 60754-2 recommended limit of <10 µS/mm limit.

Table 11. Combustion Gas Analysis Results by IEC 60754-1 and -2 Test Results

Property	MHPO	IFR-TPE 1A	IFR-TPE 2A	IFR-TPE 2B
Halogen Acid Gas Released	< 0.5%[1]	< 0.5%	< 0.5%	< 0.5%
pH	4.35	8.09	8.36	7.36
Conductivity [µS/mm]	0.2	27.2	24.6	13.1

NOTE 1: Values <0.5% are below the detection limit of the test method.

3.6 Summary of new HFFR IFR-TPE Compounds

Table 12 provides a summary of properties for two HFFR IFR-TPE compound technologies that were developed for VW-1 and Cable Flame rated applications and presented in this paper. Both are 105°C temperature rated, RoHS and REACH compliant, phthalate-free, brominated flame retardant free, antimony trioxide free, and contain low VOC content. Neither emits acid gas during combustion, but the conductivity of the combustion gases evolved exceed the IEC 60754-2 limit.

The first new compound, labeled IFR-TPE 2A, is a new low smoke formulation that should be used in TPE jacket applications that are required to pass IEC 61034. Its short-term insulation resistance results indicate that it would be suitable for the insulation in cords intended for indoor use.

The second compound, labeled as IFR-TPE 2B, is a new formulation that exhibits extremely high short-term insulation resistance when tested in water that indicates it is suitable for use as insulation in both wet and dry locations, as required in UL-62 for outdoor cords. However, it achieved low transmission results by IEC 61034 that indicates that it generates dense smoke generation while burning. As a result, it should not be used in constructions that must meet smoke density criteria and are achieving only marginally passing results. Also, this formulation exhibits higher flexural modulus so it should be used as insulation coating or as jacket on constructions were high flexibility is not needed.

For best results, it is recommended that both of these formulations be evaluated together, with the IFR-TPE 2B as the insulation, and the IFR-TPE 2A as jacket.

Table 12. Properties of New HFFR IFR-TPE Compounds for Wire and Cable

PROPERTY	TEST METHOD	IFR-TPE 2A	IFR-TPE 2B
PROPERTIES DETERMINED FROM COMPOUND			
Hardness A [Instant/15 sec delay]	ASTM D2240	87/85	93/92
Specific Gravity	ASTM D792	1.13	1.08
Tensile Strength [psi (MPa)][1]	ASTM D412	1,535 (10.58)	2,100 (14.48)
Elongation [%][1]	ASTM D412	530%	540%
Flexural Modulus [kpsi (MPa)]	ASTM D790	16.1 (111.0)	59.3 (408.9)
Brittle Point [°C]	ASTM D746	-38	-47
Kayeness ACR @ 392°F (200°C) at 1000 sec^{-1}[Pa·sec]	ASTM D3835	213.2	216.1
Dielectric Constant / Dissipation Factor @ 1 MHz	ASTM D150	2.92	2.88
Oxygen Index [%]	ASTM D2863	33%	27%
Halogen Acid Gas Released Upon Combustion [%]	IEC 60754-1	<0.5%	< 0.5%
Degree of Acidity of Gas Released Upon Combustion	IEC 60754-2	8.36 pH 24.6 µS/mm	7.36 pH 13.1 µS/mm
PROPERTIES DETERMINED FROM WIRE			
Tensile Strength [psi (MPa)][2]	UL 2556	2,547 (17.56)	2,348 (16.19)
Elongation [%][2]	UL 2556	589%	483%
Maximum Operating Temperature[2] [°C]	UL 1581	105	105
Deformation[2] (150°C with 300g weight)	UL-1581	0%	0%
Short-Term Insulation Resistance[2,3]	UL-62	77	49,500
VW-1 Vertical Burn Test[2]	UL-1581	PASS	PASS
Cable Flame Test[2]	UL-1581	PASS	PASS
Smoke Density[2]	IEC 61034-2	66%	15%

NOTE 1: Tested from 0.020” (0.508 mm) thick specimens die-cut from extruded tapes.
NOTE 2: Tested from 18 AWG wire coated with 0.016” [0.406 mm] insulation.
NOTE 3: Wire tested in 15°C water, after immersion for six hours.

4. Conclusions

Two new HFFR IFR-TPE compound solutions were compared to two different commercial HFFR compounds: a traditional low smoke and acid gas metal hydrate-based polyolefin (MHPO) compound used as jacket in VW-1 (UL-1581) rated applications; and an IFR-TPE compound used as jacket in Cable Flame (UL-1581) rated applications. Both new HFFR IFR-TPE compounds were successful in demonstrating improved flame retardancy over the commercial grades by passing both VW-1 and Cable Flame testing on 18 AWG wires coated with 0.016” (0.406 mm) thick insulation of each material. Both of the commercial HFFR compounds failed both tests on this construction. In addition, they showed passing results for the following tests required of a UL-62 105°C-rated TPE material: tensile and elongation, oven-aging, deformation and heat shock at 150°C. In addition, both passed for cold bend at -40°C, which is required for outdoor cords. However, they did exhibit different property balances for the other characteristics tested.

The MHPO sample exhibited the highest light transmission results by IEC 61034-2 smoke cube testing by passing the ≥60% criteria with an average of 93%. This result shows the highly effective low smoke generation performance of MHPO chemistry. Lower transmission results were achieved with the IFR-TPE samples. Both IFR-TPE 1A and 2A samples also passed this test with an average 69% and 66%, respectively, albeit with a narrower margin. However, the IFR-TPE 2B failed by achieving only a 15% average result. These results show that the type of intumescent flame retardant selected can greatly influence the density of smoke generated during combustion.

All four of the compounds exhibited no detectable levels of hydrochloric acid (HCl) or hydrobromic acid (HBr) in their combustion gases tested by IEC 60754-1, thereby confirming all are indeed halogen-free. Furthermore, all four samples passed the ≥4.3 pH requirement recommended in IEC 60754-2. However, only the MHPO sample passed ≤10 µS/mm conductivity criteria. All three IFR-TPE samples exceeded this limit, but the IFR-TPE 2B outperformed the others by achieving a value of 13 µS/mm. These results show that some ions are released from the IFRs into the combustion gases that affect conductivity, and the IFR type selected also influences the result.

UL-62 short-term insulation resistance (IR) testing in water showed the IFR-TPE 2B sample exhibits dramatically higher IR than the other three samples by exceeding the ≤ 170 MΩ·1000 ft requirement for outdoor cord with an average value of 49,500 MΩ·1000 ft. The MHPO sample also passed this requirement with a 3,438 MΩ·1000 ft. average result. However, both the IFR-TPE 1A and 2A samples failed to meet this outdoor requirement by achieving only 107 and 77 MΩ·1000 ft., respectively. However, these results are suitable to meet the requirement for indoor cables of ≤ 2.5 MΩ·1000 ft. for insulation or it can be used for jacket applications. These test results show that the type of IFR selected can dramatically affect short-term IR results.

The dielectric properties for all four compounds were low and indicate they are suitable for high frequency, low loss communication cable applications. The IFR-TPE achieved the lowest dielectric constant results, ranging from 2.88 – 2.92, and the type of IFR did not influence this result in this case. The MHPO sample followed with a 3.33 result.

The oxygen index testing performed proved to be a poor and misleading indicator of predicting whether a compound will pass the VW-1 and Cable Flame testing. The MHPO sample achieved the highest oxygen index result of 40%, while the IFR-TPE samples achieved values ranging from 27% - 33%. Yet the MHPO sample failed the VW-1 test, while the IFR-TPE 2A and 2B samples both passed the wire flame test, achieving only 33% and 27% oxygen index values, respectively. Finally, IFR-TPE 1A achieved a 31% and failed VW-1 as well. No correlation existed between oxygen index results and passing VW-1.

Testing in this paper showed the following performance advantages of all three IFR-TPE samples when compared to the MHPO sample: dramatically higher elongation at break, significantly reduced melt viscosity, and the passing of UL-62 deformation results when tested at 150°C. Both the IFR-TPE 1A and 2A grades were formulated with equivalent flexibility as indicated by flexural modulus. But the IFR-TPE 2B sample was stiffer.

In conclusion, we have developed two new HFFR IFR-TPE compound solutions for VW-1 and Cable Flame-rated applications; each is formulated with a different IFR type. Both compounds meet the properties required of a UL-62 105°C-rated TPE material, exhibit low density for lightweight cables, and low melt viscosity for easy processing compared to MHPO technology. One is highly flexible, offers passing transmission results by IEC 61034-2 and short-term IR performance suitable to meet UL-62 indoor cord requirements. The other compound is stiffer, exhibits higher short-term IR performance suitable for outdoor applications, but should not be used in applications where low smoke density is required. Both are RoHS and REACH compliant, phthalate-free, brominated flame retardant-free, antimony trioxide-free, and contain low VOC content. Neither emits acid gas during combustion, but the conductivity of the combustion gases evolved exceed the IEC 60754-2 limit. By understanding the performance advantages of each compound and matching them with the right application requirements, these materials are well-positioned to fulfill the demand in this area.

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