LOW-SMOKE, ZERO-HALOGEN CABLES: *BRIDGING THE PERFORMANCE GAP*

Next Generation Low-Smoke, Zero-Halogen (LSZH) Thermoset Insulation

A Look at General Cable's GenFree® II Product Line

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OVERVIEW

This white paper provides a detailed overview of the industrial low-smoke, zero-halogen wire and cable market in North America, the market's evolution as compared to the European market, a review of industry testing requirements, and how the new GenFree II product offering from General Cable is leading the way in bridging the performance gap between the two markets.

Historically, the European product safety standards have focused on cable designs that exclude halogens in their designs. U.S. standards, on the other hand, have focused on the product's fire resistance properties and its resistance to propagation of flame during fire conditions. Additionally, as a general rule, North American standards tend to have more strenuous electrical requirement than the European standards, with specific emphasis on wet electrical properties. The current cost-effective compound technology available for the industrial wire and cable market forces engineers to choose either excellent flame performance or halogen-free, low-smoke performance without sacrificing electrical performance.

General Cable has recently seen increased interest by North American industrial customers for products possessing low-smoke, non-halogen characteristics. Currently, when faced with the decision between LSZH and non-LSZH cable designs, the trade-offs between a cable's low-smoke, halogen-free characteristics versus the fire propagation and electrical characteristics makes the decision to go with LSZH cables difficult, especially when the traditionally higher cost of LSZH products are factored in.

With the introduction of General Cable's new GenFree II product line, this decision has now been made easy.These products possess all three critical characteristics at a reasonable cost: excellent wet and dry electrical performance at 90°C; exceptional large scale flame test performance, meeting the requirements of the IEEE 1202 flame test; and a product which is low-smoke and halogen-free, complying with the requirements of ICEA T-33-655 and the UL1685 flame/smoke test.

COMMON WIRE AND CABLE INSULATION MATERIALS

Polyvinyl Chloride (PVC), Cross-linked Polyethylene (XLPE), and Ethylene Propylene Rubber (EPR)

Most wire and cable products available in the North American industrial and building wire markets such as Type THHN/THWN-2, XHHW-2, RHH/RHW-2, and USE-2 are generally insulated with one of a few types of compounds, with the most prevalent being Polyvinyl Chloride (PVC), Cross-linked Polyethylene (XLPE), or Ethylene Propylene Rubber (EPR).

All of these insulation materials have been highly engineered to meet industry requirements for many properties, including dry and wet electrical performance, flexibility, long life, performance under fire conditions, cold temperature resistance, chemical resistance and physical toughness, etc.

In order to achieve these characteristics, a compound is formulated with many separate chemical ingredients, and through decades of industry experience, these time-proven compounds have been proven to do their job well in a wide variety of applications. However, more recently, customers have begun to seek out products with these properties, but also possessing low-smoke and halogen-free properties.

THERMOPLASTIC VERSUS THERMOSET MATERIALS

Wire and cable insulations are generally broken down into two distinct types, thermoplastic and thermoset. The primary difference being that a thermoplastic material will melt when exposed to high heat or fire conditions, while a thermoset material will not melt when exposed to heat, will better resist softening and degrading, and will turn to a char under high heat or fire conditions.

As thermoset materials inherently provide better emergency performance at elevated temperatures, electrical overload conditions, and better flame propagation resistance than a thermoplastic material, they are generally preferred in industrial applications, as the conductor will have a greater propensity to see these types of operating temperatures during normal operation.

The properties of a thermosetting compound are created by an irreversible chemical reaction during processing which causes the molecules to link (cross-link), thereby “strengthening” their molecular structure. While these cross-linking properties are extremely beneficial to cable performance, they also make the development of thermosetting compounds with comparable properties to thermoplastic materials more difficult and have historically presented a greater challenge to the industry.

EUROPEAN VERSUS NORTH AMERICAN STANDARDS

In order to set context, it is important to also understand the primary differences in how the European and North American markets regulate composition and performance requirements for cables.

European standards tend to focus on cable designs generating low-smoke and containing zero-halogens (LSZH) and specific electrical requirements, while the North American standards primarily focus on a combination of fire retardance and specific electrical performance, with a high degree of emphasis on wet electrical qualifications. From a design standpoint, development of insulation material which possesses properties suitable for both markets is quite complex, as these characteristics tend to be diametrically opposed to each other.

While “Low-Smoke, Low-Halogen” compounds have been in existence since the 1970s, they have tended to be used in various specialized applications, primarily for confined spaces like transit, marine, and military applications in North America.

The North American industrial and commercial markets have been slow to adopt LSZH products due to their combination of high cost, as the more affordable LSZH products typically sacrifice either electrical performance or fire propagation resistance properties when compared to their halogenated-equivalent products.

WHAT ARE HALOGENS AND WHAT DO THEY DO?

Halogens are chemicals which use an element from the 17^{th} column of the periodic table as one of their components. In wire and cable compounds, the halogen containing ingredients are typically utilized to impart improved flame retardant properties to polymeric materials, with the most common elements used for this purpose being bromine, fluorine, or chlorine.

The advantages to halogenated flame-retardants, and the primary reason for their historical use in wire and cable is that they are inexpensive, yet highly effective in reducing the flammability of products, while also providing the added benefit of not adversely affecting the processing properties of the polymers.

WHAT DOES LOW-SMOKE, ZERO-HALOGEN (LSZH) MEAN?

The term “low-smoke, zero-halogen” describes two distinct properties of a cable compound. The term “low-smoke” describes the amount of smoke which a compound emits when burned, while “zero-halogen” describes the amount of halogens used to make the compound.

It is important to note that it is possible for a product to be low-smoke but not zero-halogen, or be zero-halogen but not low-smoke. However, these terms have typically been used together because the end user is interested in cables with both properties. This class of compounds can be abbreviated a few different ways, with the most commonly used references being LSZH, LSOH, LSHF, or LSNH, but all are proper references for cables possessing low-smoke and zero-halogen properties.

EVOLUTION OF U.S. MARKET TOWARD LSZH CABLES

If we looked at the North American industrial and commercial markets about a decade ago, there was virtually no demand for low-smoke, zero-halogen products. However, in the past five years, there has been a noticeable increased awareness and demand for these products, as evidenced by the increasing number of customer inquiries with LSZH requirements.

To support this recent trend, industry testing standards have been introduced, allowing for a comparative measurement of a cable’s smoke and halogen content. The main U.S. standards applicable to the industrial market addressing smoke generation are UL 44 and UL 1685, while ICEA T-33-655 and MIL-DTL-24643 address halogen content measurements. These tests will be discussed in more detail later in this paper.

We expect that the trend for industrial cables with LSZH properties will continue to increase going forward, as users seek to gain the benefits of cables with LSZH properties without sacrificing other critical cable characteristics such as electrical performance and flame-resistant properties, and with the introduction of the GenFree II line of industrial cables, these products are now available from General Cable.

HOW ARE THESE CABLES TESTED?

While there is no specific North American standard which exists at this time which would specifically qualify an insulation system to be labeled LSZH, it is incumbent on the end user to familiarize themselves with the applicable tests and standards to ensure that the cable meets their performance expectations. These tests can essentially be separated into four separate categories:

1. Electrical performance
2. Flame propagation
3. Smoke measurement
4. Halogen content measurement

This section will go into detail about each of the major relevant tests applicable in North America to measure the characteristics of a LSZH thermoset cable.

1. Electrical Properties:

The most important compound characteristic that separates an insulation material from a jacket material is electrical performance. This has led many wire and cable manufacturers to advertise products with LSZH jackets as LSZH cables, even though the insulated conductors in the core contain halogenated insulation.

In these cases, the overall construction may meet low-smoke test requirements, but since only the jacket possesses these both low-smoke and zero-halogen properties, the overall cable may not be a full LSZH design due to halogen content of the insulation. To date, LSZH insulations meeting all the wet electrical performance requirements of the North American market have been very difficult to formulate.

The industrial and commercial markets primarily require thermoset insulations rated for use at 90°C wet and dry and meet the requirements of the National Electrical Code as UL Type XHHW-2 or RHW-2 cables. These type constructions are typically tested, certified and listed by a nationally recognized independent testing laboratory, such as Underwriters Laboratories, to ensure that the cable meets the basic requirements, ensuring suitability for installation in a defined application per the National Electrical Code.

Most prominent in this list of these electrical requirements are long-term insulation testing in water and capacitance and relative permittivity testing.

A) Long Term Insulation Resistance (LTIR) Test

LTIR measures the resistance of the insulating material and its ability to resist the flow of electrons and current. It is conducted over a period of 12 to 36 weeks. The insulated conductor is immersed in water at the rated temperature (90^0C for XHHW-2 and RHW-2) while an AC voltage equal to the voltage rating of the product is applied throughout the test. The wire is then measured for its insulation resistance value on a weekly basis. The test measures the strength of the insulation and ensures that the insulation resistance remains above a certain level throughout the test. Additionally, the test measures the stability of the insulation over a prolonged period of time, with any drop in resistance recorded during each measurement. Once it is proven that the resistance has not decreased consistently over a three week period (12 weeks minimum), then the insulation is considered to be electrically stable and appropriate for use in wet and dry locations at the rated temperature.

B) Capacitance and Relative Permittivity Tests

This test measures capacitance and relative permittivity of wet-rated conductors. While these are two separate tests, they are performed in a very similar manner over time, with the relative permittivity of a material being the ratio of the amount of electrical energy stored in the material by an applied voltage relative to that of a vacuum, while capacitance is a measure of the ability of a material to store charge.

The testing involves the wire being immersed in water at the rated temperature with the relative permittivity measured after 24 hours. The acceptance criterion for this test is that the relative permittivity to be 6.0 or less. The capacitance is measured after immersion for 24 hours, 7 days and 14 days, and the requirement is to keep the capacitance value of the insulation from increasing more than a specified percentage at these intervals.

An insulation system meeting the requirements of these tests, along with some other minor testing, is suitable for use at 90°C in both wet and dry locations.

2. Flame Propagation:

There are a number of flame propagation test standards and methods in the wire and cable industry, with the most prominent and recognized flame tests being IEEE 1202, UL 1685 and UL VW-1.

The IEEE 1202 and UL 1685 tests are considered to be large scale flame tests, and are very similar in design, with the differences being a minor change in the angle of the flame application and some minor differences in acceptance criteria, as both tests are designed to measure a cable's resistance to propagate flame in a cable tray.

These large-scale flame tests are conducted by stringing together a specified number of eight foot cable samples, as determined by the outside diameter of the cable, in a vertical tray and placed in a flame chamber.A flame is then applied to the bottom of the cables for 20 minutes. At the end of the test, the flame source is removed, and the cable is allowed to continue to burn until it self-extinguishes, with passing criteria for these tests being that the measured height of char damage on the cables be below the prescribed limit of the standard. This allows for single conductor cables in a size of 1/0 AWG and larger to be listed as approved for cable tray use. In these cases, cables are typically marked within the cable print legend "FOR CT USE" to verify compliance.

While IEEE 1202 and UL 1685 testing covers both single and multiple conductor cables, the UL VW-1 flame test is usually performed on a single insulated conductor and is considered to be an extremely severe and difficult test to pass.

VW-1 testing requires that a cable, approximately 24 inches in length, be prepared with a waxed paper flag at the top of the sample in the test chamber. The sample is set at a 45 degree angle and a Bunsen burner flame of a specified intensity is applied for 15 second intervals, up to five times, to the middle of the sample. A piece of cotton is also placed directly under the sample, and if the sample survives three applications of flame in a row without the flag burning at the top of the sample or the cotton at the bottom igniting due to either insulation drip or hot burning particles falling off, the insulation system can be listed for VW-1.

3. Smoke Generation Measurement:

The UL 1685 (Method 1) test also has an optional smoke measurement component. As the cable is being burned in the tray, a system of instruments measures both the peak smoke release rate and the total smoke released during the test. If the total smoke released is less than 150 m^2 and the peak smoke release rate is less than 0.40 m^2/s the cable can be listed as "limited smoke". For single conductor cables under UL 44, this listing can be identified by the printing of "ST1" on the cable jacket. For multiple conductor tray cables under UL 1277, this listing cable can be identified by the printing of "LS" on the cable in North America.

ICEA T-33-655 is an additional standard which was developed as a guide for low-smoke, zero-halogen cable jackets. This standard can serve as a guide to measure the smoke release rates of insulation as well. The "low-smoke" label according to this standard can be applied to materials which meet the smoke generation requirements on plaques of material when tested per ASTM E662. In this testing, a 0.080" inch thick plaque of material is tested in a smoke chamber, and the smoke release of the material is measured while the material is in "flaming mode" and "non-flaming mode". Passing values are achieved when the results stay below the limits prescribed in the ICEA T-33-655 standard. Another standard to measure smoke release of a material used by the U.S. military is called NES 711 (Naval Engineering Standard), but is not generally used in the industrial product market.

4. Halogen Content Measurement:

The term zero-halogen, or halogen-free, is generally applied to a material having less than 0.2% of halogens by weight. The ICEA T-33-655 standard holds to this description and tests per the guidelines of military standard MIL-C-24643. Additionally, there is an acid gas equivalent measurement included as part of this military standard which typically measures halogen content of the cable with an X-ray fluorescence test, however, other analytical testing is also allowed. Acid gas testing is designed to detect acid with a pH of less than three. If the equivalence exceeds more than 2% of the total weight of the sample then it is considered a failure. To comply with ICEA T-33-655, a material must pass all three testing requirements, for halogen content, smoke release and acid gas equivalence.

CAN USING LSZH CABLES REALISTICALLY MAKE A DIFFERENCE?

The example below shows how much halogen (by pounds) is introduced to the environment for every one million feet of a single conductor 1/0 AWG RHH/RHW-2 construction.

Material	Typical Halogen Content (% of weight)	Typical total weight of insulation on 1MM ft. of product (lbs.)	Total pounds of halogens (lbs.)
GenFree II LSZH	<0.2	85,000	<160
Composite EP/CPE	20		17,000
FR-XLPE	15		12,750
FR-EPR	12		10,200

In this example, and depending on which product the LSZH cables are being substituted for, using a fully LSZH product like General Cable's GenFree II product line would result in a 10,000 - 17,000 pound reduction in halogenated material.

WHY GENERAL CABLE'S GENFREE II PRODUCT?

General Cable's new GenFree II product line offers fully low-smoke, zero-halogen cable designs rated for use in 90°C wet and dry locations, yet possessing all ratings that North American customers are accustomed to with the conventional products.

The initial launch of General Cable's GenFree II product line includes three single conductor product types:

- UL Type XHHW-2 Specification 5125
- Single layer tri-rated UL Type RHH/RHW-2/USE-2 Specification 5275
- Dual layer tri-rated UL Type RHH/RHW-2/USE-2 Specification 5075

All three product constructions share not only the common critical characteristics and listings, but provide them in a fully functional and LSZH product.

ROHS /REACH Compliant:

All materials used are in compliance with current ROHS and REACH directives.

LEED building and tax credits:

In addition to the low-smoke, zero-halogen and environmental benefits of GenFree II cable, there is also potential for additional monetary benefits called LEED credits.

LEED is an internationally recognized green building certification system which provides third party verification of a building's green, sustainable design. LEED certified buildings are designed to provide lower operating costs, reduce harmful waste sent to landfills, and be generally healthier and safer for occupants.

The use of LSZH cables could help qualify a facility for tax credits under the LEED pilot credit 2 for PBT source reduction, which could help reduce costs of getting the LEED certification and may open up the project to additional tax credits and zoning allowances.

HOW DOES GENFREE II COMPARE TO OTHER PRODUCTS AVAILABLE IN THE MARKET?

Comparison of General Cable GenFree II vs. competitors' advertised LSZH specifications:

UL Type XHHW-2

	GC GenFree II	**Competitor A**	**Competitor B**
NEC/UL Type	**XHHW-2 (Spec 5125)**	XHHW	XHHW-2
Wet/Dry Temperature Rating	**90/90**	75/90	90/90
CT Rated (>1/0 AWG)	Yes	Yes	Yes
IEEE 1202	Yes	Yes	Yes
ST1 Listing	Yes	Yes	Yes
-40ºC Cold Impact	**Yes**	No	No
ICEA S-95-658	Yes	Yes	Yes
OIL RES I	**Yes**	No	Yes
SUN RES	**Yes**	No	Yes
ICEA T-33-655	**Yes**	No	No
UL 44 VW-1	**Yes**	No	Yes

UL Type RHH/RHW-2 or USE-2

	GC GenFree II	**Competitor A**	**Competitor B**
NEC/UL Type	**RHH/RHW-2 or USE-2 (Spec 5275)**	RHH or RHW Only	RHH or RHW-2 Only
Wet/Dry Temperature Rating	**90/90**	75/90	90/90
Rated USE-2	**Yes**	No	No
CT Rated (>1/0 AWG)	Yes	Yes	Yes
IEEE 1202	Yes	Yes	No
ST1 Listing	Yes	Yes	No
-40ºC Cold Impact	Yes	No	No
ICEA S-95-658	Yes	Yes	No
OIL RES I	**Yes**	No	Yes
SUN RES	Yes	Yes	Yes
ICEA T-33-655	**Yes**	No	No
UL 44 VW-1	**Yes**	Yes	No

Dual Layer UL Type RHH/RHW-2 or USE-2

	GC GenFree II	**Competitor**
NEC/UL Type	**RHH/RHW-2 or USE-2 (Spec 5075)**	RHH/RHW or USE
Wet/Dry Temperature Rating	**90/90**	75/90
Rated USE-2	Yes	Yes
CT Rated (>1/0 AWG)	Yes	Yes
IEEE 1202	Yes	Yes
ST1 Listing	Yes	Yes
-40ºC Cold Impact	**Yes**	No
ICEA S-95-658	Yes	Yes
OIL RES I	**Yes**	No
SUN RES	Yes	Yes
ICEA T-33-655	**Yes**	No
UL 44 VW-1	**Yes**	Yes

CONCLUSION

General Cable now offers a complete line of LSZH industrial products including UL Type XHHW-2 and UL Type RHH/RHW-2 in both single and dual layer constructions. GenFree II products not only exceed the critical performance characteristics required in today's industrial and commercial markets, but they do it in a cost-effective package comparable to existing halogenated cable designs.

Interested parties are encouraged to contact General Cable.

1 - http://www.nih.gov/news/pr/jan2001/niehs-19.htm
2- http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractdetail/abstract/9594/report/0

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