Development of an Alternative Solution to Mica Tape for Fire Resistant Cables

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ABSTRACT

Until recently fire resistant cables used Mica tapes as the fire resistant insulation material. The problem with this design was that Mica tapes were very brittle and may break during normal handling of these cables. Therefore to improve the mechanical properties a small polymeric layer was extruded over these tapes.

Recent developments have taken place that include a combination of these two layers into the one tape and the removal of the extrusion process covering the Mica tapes. This paper will demonstrate, with examples, the advantages of these tapes as compared to the conventional construction using Mica tapes. Currently these tapes are mainly used for low voltage cable applications, but tests are on going to use these tapes for medium and even lower high voltage cable applications where fire performance is required.

There are also compounds available based on these materials, which could be extruded as a filling compound.

Test are ongoing using these tapes for higher voltage cable, even currently is no real demand for that application. However these cables could replace Mica cables and also PVC sheathed cables, since the are more economically friendly than the latter and create less hazardous gases in case of fire, which might destroy sensitive equipment in the area.

KEYWORDS

Fire Resistant Cables, Mica Tape Alternative

INTRODUCTION

Various methods are used to make safety cables fire resistant. One proven method is to apply a Mica tape insulation layer directly on the metal wire. The layer protects against short circuit in case of fire and helps to significantly extend the system integrity for emergency power supply, fire alarm and evacuation systems in buildings, tunnels and rolling stock materials or in other safety related applications.

There have been early developments using Mica-loaded paper for EHV power cable [1]. Nowadays with the development of ceramifying polymers, these polymers can be produced either as compound or as tape.

In the past the most widespread technologies to guarantee the electric cables connection integrity during a fire were the following:

- ceramified silicone-rubber
- Mica-glass tape and cross-linked polyolefine

The taping with Mica tape is the most typical solution; it allows the use of several insulation materials since the fire resistance is guaranteed by the tape. The silicone rubber is currently the most frequently used solution and simplifies and speeds up the installation, thanks to the easy peeling and to the lack of tape.

The materials that we are presenting in this paper are based on silicon.

Silicon is one of the most widely used elements. A considerable amount of research has shown that the addition of relatively small amounts of silicon compounds to various polymeric materials can significantly improve their flame retardancy. Silicon-containing flame retardants are considered to be environmentally friendly additives because their use leas to a reduction in the harmful impact on the environment when compared with existing materials. Many forms of silicon compounds have been explored as potential flame retardants to polymeric materials.

Silicone materials exhibit relatively low rates of heat release, a uniquely low dependence of rate of heat release on external heat flux. One of the causes of the lower burning rate is attributed to the accumulation of the silica ash at the surface results from the deposition of silica particles, one of the major combustion products of silicone oligomers in the gas phase. [2]

REQUIREMENTS

The requirements for cables differ depending on the application and are especially strict in tunnels were traffic and people can pass.

Fire requirements in a tunnel

The requirements for fire resistant cables are outlined in European Standard EN 1991-1-2 [3]. A tunnel has to be constructed in such a way that its construction does not put human life at risk. Personnel must be able to save themselves and any rescue team should not be endangered. Additionally the fire should not transfer to an adjacent structure.

Figure 1 gives an example of the complexity of cables installed in a tunnel in the Alps. (Courtesy of Symalit AG, Switzerland)

Figure 1: Installation at the new Swiss Gotthard Tunnel from the Tescino side

Table 1: DIN EN 13501-2, Requirements

Building authority designation	non-bearing inside	non-bearing outside
Fire resistant	F 30	W30
Fire resistant	EI 90	E90

The fire regulations for tunnels in Europe are outlined in EN 13501-2 and an extract of the requirements are outlined in table 1 and 2.

Table 2: DIN EN 13501-2 Material Requirements

Building authority designation	Additional Requirement		European Classification according to EN 13501-1
	No Smoke	Non burnable drops	
Non burnable	■	■	A1, A2
hardly inflammable	■	■	B, C
normally inflammable		■	D, E
highly flammable			F

Consider that a normal car will create an energy load of up to 6000 MJ and a maximum temperature of up to 200 °C and a lorry will have fire load of up to 88 GJ with a maximum temperature of 120°C [4], the potential fire load for cables inside a tunnel can be substantial.

Normally fire resistant cables use a Mica tape with a polymer to protect the weak tape. During production these tapes already show some weakness in terms of mechanical strength and tear resistance. For low voltage cables there has been development replacing these tapes with ceramic silicon tapes. These tapes are easier to handle, stronger and have:

- Improved mechanical properties
- No screen mechanical damage during handling
- Improved fire performance

There are developments also ongoing using these tapes for higher voltage cables.

Figure 2: Picture of a small cable sample undergoing fire testing

Table 3: Classification of cables

Flame-Retardant	These cables ensure that flames extinguish by themselves
Fire-Retardant	These cables ensure that there is no fire propagation, but do not assure circuit integrity
Fire-Resistance	These cables must guarantee circuit integrity during specified fire conditions

What is a ceramifying polymer?

Traditional passive fire protection materials rely on hydrated inorganic intumecents such as sodium silicates and expandable graphites, which form a thermally insulating char. High expansion factors of over 30 can be achieved, providing excellent thermal resistance. However, these chars have some limitations in fires where they must also have sufficient mechanical strength to resist falling away from the protected substrate in the presence of turbulent airflows and mechanical stresses.

One approach to improving fire protective coatings is through the use of ceramifying polymers. These materials contain inorganic filler systems that form a coherent ceramic at high temperatures.

Ceramifying polymers generally consist of a polymer matrix with refractory silicate minerals that form the ceramic framework in combination with a flux system. This can allow a coherent ceramic structure to form at a relatively low temperature. Other functional additives may be added including stabilizers and flame retardants [5].

Ceramifying polymers are not inherently flame retardant. However, they can be modified with organic or inorganic flame retardant systems to achieve low flammability ratings. Ceramification can also assist fire performance by producing a stable surface layer that insulates the underlying layers and may inhibit volatile emissions. This can delay ignition and reduce heat release rates.

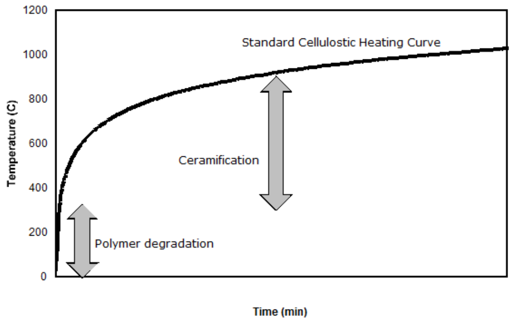

Figure 3: Ceramification process [6]

Most polymers begin to decompose through oxidative reactions at temperatures of around 200 °C. Higher performance polymers such as silicones persist to over 300°C. But typical fire tests require exposure to a temperature profile (Fig 3) based on the combustion of a cellulose fuel load in a representative room (e.g. BS476 Part 23, AS1530 Part 4, ISO 834, ASTM E119). This reaches 700°C in about 10 minutes at which all polymers, including silicones, rapidly decompose. The temperature continues to increase to 1000°C after 1 hour. Hence, conventional polymers are generally unable to provide a barrier to fire, or thermal insulation, in systems which require a rating of 60 minutes or longer in these tests. These fire ratings are usually achieved by using intumescent materials, which produce an inorganic char with limited cohesive strength, or thick protective structures made from gypsum board or similar materials.

A key characteristic of ceramifying polymers is their ability to form a self-supporting structure throughout the temperature range from ambient service temperature to over 1000°C. Reactions in the inorganic ceramic forming systems can commence from temperatures as low as 350°C and continue to 800 °C or higher. This is achieved with fluxes which produce a controlled, low level of liquid phase at these temperatures. Ceramification in these materials is not simply the bonding or fusing of the silicate particles by a viscous liquid phase, such as with relatively high levels of low melting point glasses. Such materials tend to collapse at high temperatures and are not self-supporting. Ceramification involves reaction sintering assisted by the controlled level of liquid phase.

A consequence of the self-supporting and low shrinkage characteristics is that the resulting ceramic product has a cellular structure. While ceramifying polymers are not inherently good thermal insulators, due to the relatively high thermal conductivity of the inorganic components, the cellular structure improves thermal resistance. The presence of liquid phases within the temperature range at. which the polymer is degrading and the evolving gases produced by pyrolysis, also allows intumescence by trapping the gases to cause expansion of the cellular structure. This can greatly increase the thermal resistance.

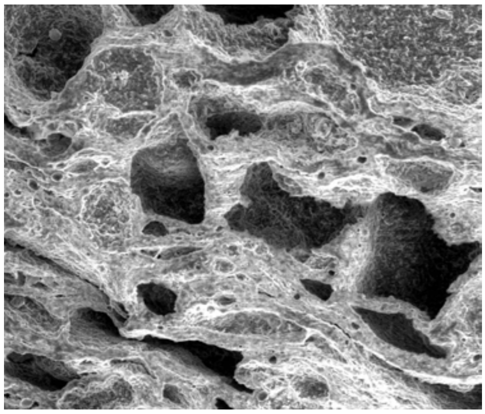

Figure 4: SEM picture of the structure after ceramification

Mechanical properties

The recent advance of modern technology has resulted in an increasing demand for new high performance materials in a wide variety of engineering applications. Such materials are increasingly expected to function under unusual service conditions. For example, in the aerospace industry, especially the need for high temperature elastomers, plastics, and ceramics that have thermal, thermo-oxidative, and hydrolytic stability and that can also maintain flexibility to well below ambient temperature in severe conditions In this respect several different siloxanes have been developed and one of these has been used to produce ceramic tapes that are more flexible than the normally used Mica tapes for this application.

Table 4: Properties of tapes in comparison

Properties	Standard	Ceramic Silicon tape	Sample of a conventional Mica tape
Thickness		0.2 mm	0.11 mm
Tensile Strength	ASTM D 412	~7 MPa	2.3 – 9.0 MPa
Dielectric Strength	IEC 60243	30 kV/mm	> 1.2 kV/mm
Tear Strength	ASTM D 624	20 kN/m	7 KN/m
Water absorption	ASTM D 570	< 0.75 %	< 2.0 %
Volume Resistivity	IEC 60093	3* 10^{15} Ωcm	~10^{15} Ωcm

In table 4 some properties of a ceramic silicon tape and a typical Mica tape are compared. The ceramic silicon tape is far more flexible and has a high tear strength.

As an alternative there are also ceramifying silicon compounds available for direct extrusion.

The process of ceramification and char formation can be measured via the thickness of the coating before and after the fire test. The expansion in the furnace is considered as a key parameter in the development of fire protective coatings. Indeed, one of the major characteristics of an intumescent coating is its ability to swell. This parameter is necessarily but not sufficient to ensure fire protection. So, a high swelling does not necessarily lead to the best performance, because the char formed can be too light and not sufficiently mechanically resistant.

TESTING OF MATERIAL

The material has been tested according to ISO 4589-2, 1996 and UK 94-1996, Rev 15 for its flame retardant properties. The requirements according to UL are listed in table 5. [7]

Table 5: Requirements according to UL 94

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Criteria Conditions	V-0	V-1	V-2
After-flame time for each individual specimen	≤ 10 s	≤ 30 s	≤ 30 s
Total after flame time for any condition set for 5 specimen	≤ 50 s	≤ 250 s	≤ 250 s
After-flame plus afterglow for each individual specimen after the second application	≤ 30 s	≤ 60 s	≤ 60 s
After-flame or afterglow of any specimen up to the holding clamp	No	No	No
Cotton indicator ignited by flaming particles or drops	No	No	Yes

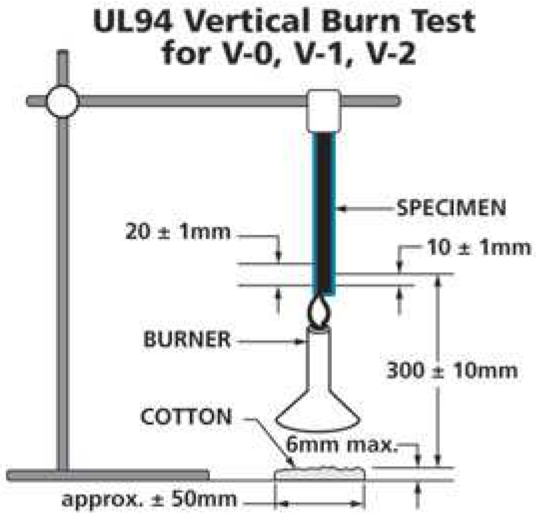

Figure 5: UL 94 burning test

The UL 94 standard specifies bench-scale test methods to determine the acceptability of plastic materials for use in appliances with respect to flammability under controlled laboratory conditions.

The flame is maintained for 10 s, and them removed to a distance of at least 150 mm. Upon flame removal, the specimen is observed for flaming and its duration time recorded (t_1). As soon as the flame ceases, the burner flame is reapplied for an additional 10 s, then removed again. Duration of flaming or glowing after the second flame application is also recorded (t_2). Ignition of the cotton by dripping particles from the test specimen is noted.

Specimen thickness affects performance in the test as was recently demonstrated in a study involving different plastics [8].

In the following figures we show the spread of the results in the flame test according to UL 94. Even the sum of all test results is lower than for the total requirement of all results.

Table 6: Fire test results

Conditioning	23 ± 2 °C, 50±5 % RH, 48h					70 ± 2 °C,168h, desiccator, 23 ± 2 °C, 4h				
Test N°	1	2	3	4	5	1	2	3	4	5
Flame time after first application, (s)	0.9	0.5	1.0	0.4	0.6	0.9	0.6	0.6	0.8	0.7
Flame time after second application (s)	1.1	0.6	1.0	0.8	1.2	0.9	1.3	1.1	1.9	0.8
After glow time after second application (s)	0	0	0	0	0	0	0	0	0	0
Total after flame time for any condition set	8.1					9.6				
After-flame plus afterglow time for each individual specimen after the second flame	1.1	0.6	1.0	0.8	1.2	0.9	1.3	1.1	1.9	0.8
Flames/glow reached holding clamp	No					No				
Cotton indicator ignited by flaming particles or drops	No					No				

Table 6: Summary of the test results

Test item	Test method	Result
Oxygen Index	ISO 4589-2, 1996	40.5 %
20 mm vertical Burning Test	UL 94-1996	V-0

The results summarised in table 6 show that this material will fulfil the requirements of UL94 for V-0 with a big margin. The spread of the results is very low.

The following figures show the spread of the results in the flame test according to UL 94. Even the sum of all test results is lower than for the total requirement of all results.

Further tests on cables are being done to evaluate the fire-resistance of these cables.

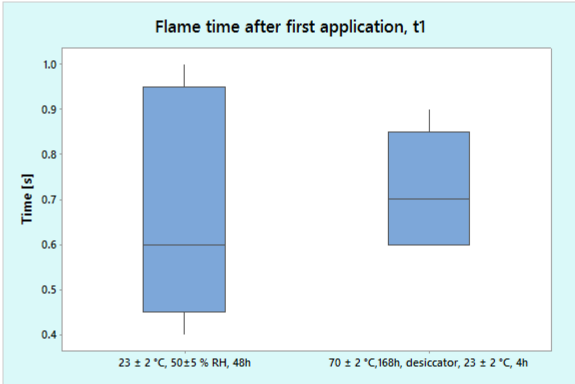

Figure 6: Flame time after first application, t_1

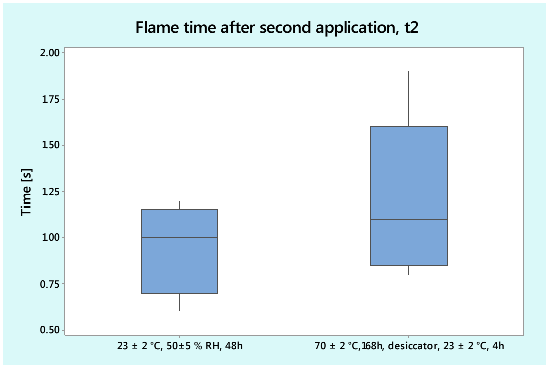

Figure 7: Flame time after second application, t_2

EXAMPLE OF A PRODUCTION

These tapes can be handled like a normal swelling or bedding tape, since the mechanical properties of these types of tapes are very strong. Also the risk compared to Mica tapes of breaking is very low. They have been used for E30 up to E180 as installation cables and for trial purposes above the metallic screens of power cables.

Figure 8: Example of a Production

CONCLUSION

This paper presents an alternative solution to Mica tapes for fire resistant cables. The solution of ceramifying silicon tapes can replace Mica tapes for nearly all applications. They are easier to handle since they are more robust and do not need an additional layer of polymer for protection.

The mechanical strength of these tapes is higher than Mica tapes.

There are also compounds available based on these materials, which could be extruded as a filling compound.

Tests are ongoing using these tapes for higher voltages even though currently there is minimal demand for this application. In addition, it is anticipated that these tapes could replace both Mica and PVC sheathed cables since they are more environmentally friendly and create less hazardous gases during a fire.

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