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Fire-Resistant Cables- Heat Release Measurements

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Abstract

Fire Resistant cables are designed to maintain the circuit integrity of the cable even during fire conditions. In general, the fire-resistant cables are made up of flame retardant zero halogen materials, so that the fire hazard such as flame propagation and smoke release of these cables are controlled. However, one more fire hazard of these fire-resistant cables is nothing but the heat released from these cables during a fire. Heat release of these cables depends upon the fuel loading of the cables and the energy available in the materials of these Fire Resistant or Fire Survival (FS) cables. In this paper, the heat release of FS cables is measured for various construction of the FS cables.

Keywords: Fire Resistant Cables, Glass-Mica Insulation, Heat Release, Silicone Insulation

1. Introduction

Numerous numbers of control cables of 1.1 kV rating are being used in control panels of critical equipment and control devices that are housed inside the closed buildings and industries. Control cables are of low voltage rating and specially designed for the centralized control of electrical equipment. Hence control cables play an important role in life safety and firefighting applications which includes the delivery of power and auxiliary control in fire alarm systems, voice alarm systems, and emergency lighting systems. The hazardous effect of fire involved in the cables is flame spread, the release of smoke and toxic gases, and heat release. In order to improve the flame retardancy and to make it less smoke emission, various thermoplastic materials such as FR PVC, FRLS PVC, HFFR, and LSZH materials are used in sheathing applications of the Fire Resistant cables. However, the Fire resistance property is not the same as that of flame retardancy of cables. Flame retardant cables are designed to retard the spread of fire and control the flame spread. Fire resistant cables are designed to maintain circuit integrity and continue to work for a specified period of duration under the normal operating voltage and specified flame temperature conditions. Fire Resistant cables are mainly used in hospitals, underground railway stations, metro coaches, and hazardous environments such as oil and gas platforms.

2. Overview of Fire Resistant Tests and Applicable Standards

The fire-resistant cables are of single-core and multi-core cables are suitable for use within a number of Control Circuit categories. The fire-resistant cables are required to withstand four different categories of Fire Resistance tests as per national and international standards. They are as follows:

2.1 Fire Resistance Test with Fire Alone

In this category, the cable shall maintain the circuit integrity throughout the prescribed test duration under the fire application alone with a specified flame temperature.

2.2 Fire Resistance Test with Fire and water

In this category, the cable shall maintain the circuit integrity throughout the prescribed test duration under the fire application of specified flame temperature and also water spray or water jet application for a prescribed duration and at specified intervals.

2.3 Fire Resistance Test with Fire and Mechanical shock

In this category, the cable shall maintain the circuit integrity throughout the prescribed test duration under

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the fire application of specified flame temperature and also an indirect mechanical impact application for 20 seconds duration and at specified intervals of either 5minutes or 10 minutes. As per BS 6387, Category Z, the fire is applied for 15 minutes duration and the mechanical impact is applied for every 30 seconds once.

2.4 Fire Resistance Test with Fire, Mechanical Shock, and Water Spray

In this category, the cable shall maintain the circuit integrity throughout the prescribed test duration under the fire application of specified flame temperature and also an indirect mechanical impact application for 20 seconds duration and at specified intervals of either 5minutes or 10 minutes. However, during the last 5minutes duration of the test, a burst of water of 5 s duration at 60 seconds intervals is applied for at least 5 bursts of water application. The applicable standards and the fire resistance test requirements are described in Table 1.

3. Construction of Fire-Resistant Cables

In the case of Fire-Resistant cables, to maintain the circuit integrity and to avoid conductor to conductor short

Table 1. Test method standards for fire resistance tests on fire resistant cables

Sl.No	Standard	Name of the standard	Duration of the test
1	IEC 60331-11-1999 & IEC 60331-21-1999	Fire Alone at 750° C, rated voltage up to 0.6/1 kV	90 minutes
2	BS 6387-2013 Category C	Resistance to fire alone test at 950 °C	180 minutes
3	BS 6387-2013 Category W	Resistance to Fire with Water at flame temperature of 650 °C	15 min – flame 15 min – flame and water
4	BS 6387-2013 Category Z	Resistance to fire with mechanical shock at 950 °C	15 min – flame and impact for every 30 secs
5	IEC 60331-1 -2018	Fire with shock at 830 °C for rated voltage of upto 0.6 / 1 kV & diameter exceeding 20 mm	30 min, 60 min, 90 min or 120 min- Impact of 20 secs at 5 min intervals
6	IEC 60331-2 -2018	Fire with shock at 830 °C for rated voltage of up to 0.6/1 kV & diameter not exceeding 20 mm	30 min, 60 min, 90 min or 120 min-flame, Impact of 20 secs at 5 min intervals
7	IEC 60331-3 -2018	Fire with shock at 830 °C for voltage up to 0.6/1 kV tested in a metal enclosure	30 min, 60 min, 90 min or 120 min- flame, Impact of 20 secs at 5 min intervals
8	BS 8491-2008	Assessment of fire integrity of large diameter power cables of safety systems – Fire, Water & Mechanical shock	30 min, 60 min or 120 min-flame, Impact of 20 secs at 10 minutes intervals, 5 mins before the end of the test, at least 5 bursts of water application of 5 secs at 60 secs intervals.
9	IS 17505 (Part-1)-2021 Category F	Resistance to fire alone test at 950 °C	180 minutes
10	IS 17505 (Part-1)-2021 Category W	Resistance to Fire with Water at 650 °C	15 min – flame At least 5 bursts of water of 5 s duration at 60 seconds intervals.
11	IS 17505 (Part-1)-2021 Category S	Flame and Shock application at 950 °C	15 min –flame Impact for 20 secs at 5 min intervals
12	IS 17505 (Part-1)-2021 Category F-30 F-60 F-120	Flame, Shock, and water jet application at 830 °C	30 mins, 60 mins, 120 mins – flame, the impact of 20 secs at 5 min intervals. 5 mins before the end of the test, at least 5 bursts of water application of 5 secs at 60 secs intervals
13	BS EN 50200: 2015 Annex E 30 minutes	Flame, Shock, and water jet application at 830°C	30 mins-flame, Impact every 5 minutes throughout the test, water spray for the final 15 minutes of the test.
14	BS EN 50200: 2015 PH 30 PH 60 PH 120	Flame and mechanical shock	30 mins, 60 mins, 120 mins - Flame, Impact at 5 every mins interval

circuits, the conductors of the cable should be protected by high-temperature insulation. The mainly used high-temperature insulations are Mica/glass tape, ceramified silicon insulation, mineral insulation, and metal insulation.

3.1 Mica/Glass Tape insulation

In this type of construction of the Fire-Resistant cables, the conductor is of either stranded/flexible annealed copper conductor, followed by Glass Mica Tape as fire-resisting barrier, followed by XLPE/EPR/EVA as primary insulation Material, and Flame Retardant LSZH, HFFR as sheathing material. Figure 1 shows the Fire-Resistant cables with mica/glass tape construction.

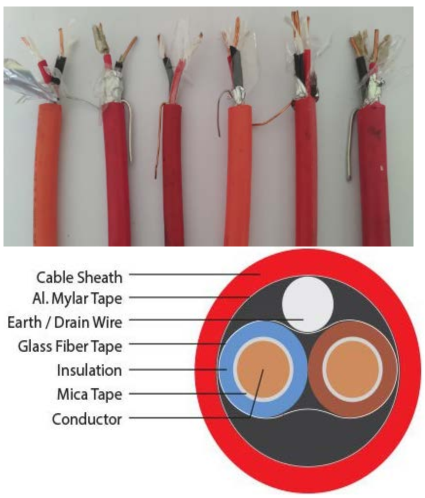

Figure 1. Fire resistant cables with mica/glass tape.

3.2 Silicone Insulation

Silicone rubber insulation is mineral in nature and it is suitable for fire-resistant cables to maintain the circuit integrity during fire. When the silicone insulated cable is under fire, a film of fused silica is deposited onto the conductor which provides the required insulation properties. Special additives can also be added to enhance the strength of this fused silica around the conductor. Silicone insulation is of low smoke zero halogen material and makes them particularly suitable for fire-resistant cable application. Silicone insulation also has good oil and solvent resistance, good corona, and ozone and weathering resistance. Figure 2 shows the construction of fire-resistant cables with silicone insulation.

3.3 Mineral Insulation

These fire-resistant cables are made of solid copper and magnesium oxide. A metal cover protects the wires from oxidation. Because of its insulated design, MI cables will not burn. Instead, they will continue to deliver optimal performance even when confronted with high temperatures. Cable with mineral insulated or metal insulated have excellent fire withstand properties. The Magnesium oxide insulation is generally used along with the metal jacket in MI cable. Figure 3 shows the construction of mineral insulated cable.

Figure 2. Fire Resistant cables with silicone insulation.

Figure 3. Fire Resistant cables with mineral insulation.

4. Fire Hazards of Cables during the Fire

When fire safety is considered, the first and foremost point is to classify the hazards involved during the fire of cables. Most of the fire deaths are caused by the inhalation of toxic smoke and gases, rise in temperature, and depletion of oxygen concentration. The emission of toxic gases is reduced by using halogen-free materials and the impact of the fire is reduced by using the flame retardant property of the halogen-free materials. In general, if the fire spread in the cables is controlled the hazards of the fire in cables can also be reduced to a greater extent. Apart from flame retardancy and smoke release, one of the fire hazards is heat or temperature release from the cables during a fire. Heat release is directly proportional to the oxygen consumed by the burning cable. Hence certain materials release more heat thereby consuming more oxygen available in the atmosphere which in turn creates an increase in the temperature and depletion of oxygen concentration in the environment. If the cable jacketing or sheathing material releases more heat which is also dangerous to humans causing fatality. Heat release of any material is nothing but the energy or fuel content available in the material. In general materials such as polyethylene, polypropylene, and ethylene-propylene rubber have higher fuel content in them even though the smoke release of these materials is very less. When cables are installed inside the theaters, high-rise buildings, underground installations, hospitals, and airports, the volume of insulation of the cables is also more and the fuel content of the electric cables is also high considerably.

5. Heat Release Measurements

In this study, fire-resistant cables of glass mica tape insulated and silicone rubber insulated cables of 1.5 Sq.mm, 2.5 Sq.mm cables are evaluated for their heat release at thermal flux of 50 kW/m^2. The details of 1.5 Sq.mm glass mica tape insulted and silicone insulated cables are shown in Table 2.

Figure 4. shows the mounting of samples in the sample holder before being subjected to burning and as well as after subjecting to burning. The cable samples are analyzed at the thermal output of 50 kW/m2 in cone calorimeter.

Table 2. Details of fire resistant cables of 1.5 Sq.mm

Sample	Sample details
S1	2 X 1.5 Sq.mm, Silicon Rubber Insulated, Overall Shielded, LSZH Sheathed 300/500 V FS Cable
S2	2 X 1.5 rm, 300/500 V, Synthetic Fiberglass Mica Taped, Aluminium Mylar Tape screened, shielded FS cable
S3	2 X 1.5 rm, 300/500 V, Synthetic Fiberglass Mica Taped, Aluminium Mylar Tape screened, shielded FS cable
S4	2 X 1.5 Sq.mm, Silicon Rubber Insulated, Overall Shielded, LSZH Sheathed 300/500 V FS Cable

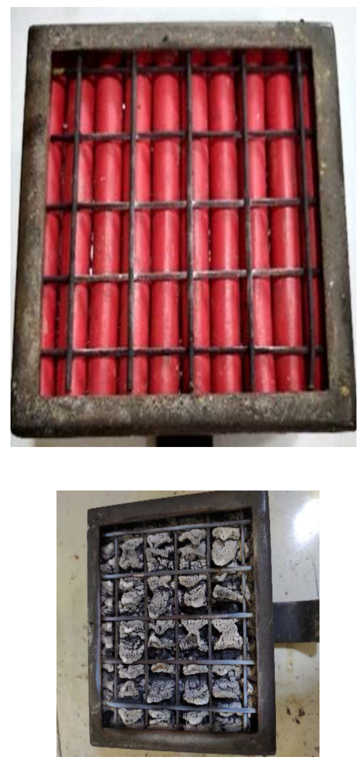

Figure 4. Cables in the sample holder before and after burning.

The cable identified as S1 and S4 are silicone insulated cables and the mass loss observed in this silicone insulated cables are less compared to mica insulated cables as shown in Table 3. Figures 5, 6 and 7 shows the instantaneous heat release rate, total heat release and average rate of heat emission of 1.5 sq. mm FS cables. Peak HRR, mean HRR and total heat release of cable S2 is higher than the other cables.

Table 3. Heat release measurement results of 1.5 Sq.mm fire resistant cables at 50 kW/m²

Parameters	1.5 Sq.mm size FS Cables			
	S1	S2	S3	S4
Initial Mass (g)	120.2	157	162.5	107.8
Mass Loss (g)	36.6	64.8	79.1	34.4
Ignition Time (Secs)	36	47	26	36
Flame out Time (Secs)	895	1121	855	908
Peak HRR (kW/m^2)	294.9	368.3	163.5	327.8
Time to Peak HRR (Secs)	404	644	290	328
Mean HRR (kW/m^2)	126.9	190.9	106.3	124.4
Total HR (MJ/m^2)	121.3	217.6	102.3	119.2
MAHRE (kW/m^2)	169.8	223.9	126.7	186.7

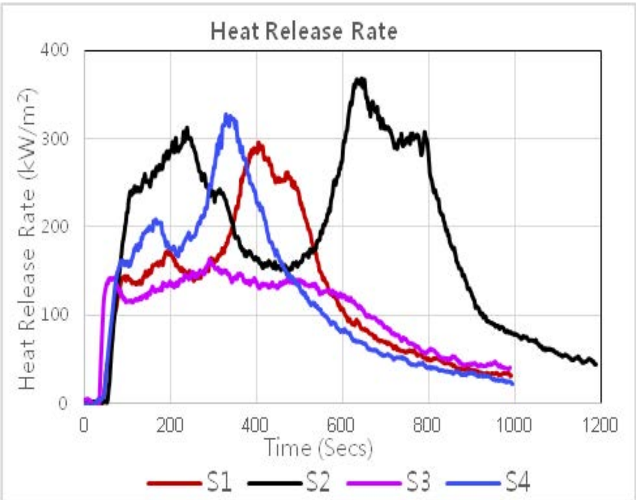

Figure 5. Heat Release Rate of 1.5 Sq.mm FS Cables at 50 kW/m².

Even though the cables S2 and S3 are of the same construction, the heat release parameters of cable S2 is two times higher than the cable S3. In Figure 5, the HRR of Cable S3 has two distinct peaks, indicating the burning of the two different cable components in layers. In cable S3, the multi peaks are not observed which indicates that one of the inner components was not of signifying mass and contribute to the increase in heat release. Cable S3 does not meet the requirement of circuit integrity in the fire-alone test for 90 minutes duration as per IEC 60331.

From Table 3 and Figures 5, 6 and 7, it is evident that the heat release parameters of S1 and S4 are almost the same signifying the same construction in both cases. Total

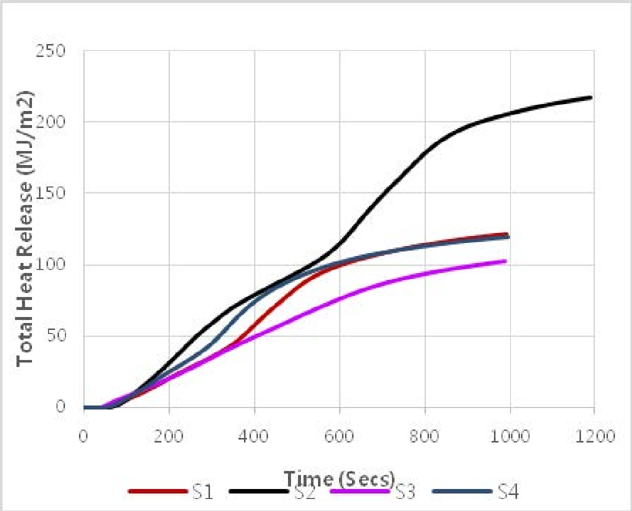

Figure 6. Total Heat Release Rate of 1.5 Sq.mm FS Cables at 50 kW/m².

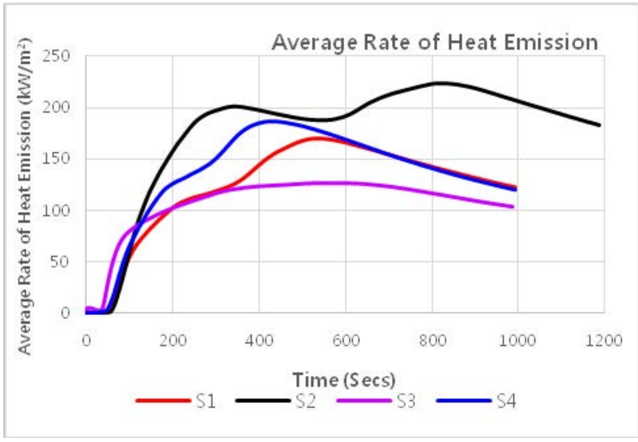

Figure 7. Average rate of heat emission of 1.5 Sq.mm FS cables at 50 kW/m².

Table 4. Details of fire resistant cables of 2.5 mm²

Sample	Sample details
S5	2 X 2.5 Sq.mm, 300/500 V, FR insulated FR Sheathed, Synthetic Fiberglass Mica Taped, Aluminium Mylar Tape screened shielded FS cable
S6	Synthetic Fiberglass Mica Taped, Aluminium Mylar Tape screened shielded FS cable
S7	2 X 2.5 Re, 300/500 V Cable, Synthetic Fiberglass Mica Taped Aluminium Mylar Tape screened, shielded FS cable
S8	2 X 2.5 Sq.mm, Silicon Rubber Insulated, Overall Shielded, LSZH Sheathed 300/500 V FS Cable

Table 5. Heat release measurement results of 2.5 Sq.mm fire resistant cables at 50 kW/m^2.

Parameters	2.5 Sq.mm Size FS Cables			
	S5	S6	S7	S8
Initial Mass(g)	176.1	181.4	193	131.8
Mass Loss (g)	65.2	69.6	88.4	37.9
Ignition Time (Secs)	25	38	16	32
Flame out Time (Secs)	991	1320	1010	922
Peak HRR (kW/m^2)	277.3	357.9	208	303.2
Time to Peak HRR (Secs)	314	738	494	404
Mean HRR (kW/m^2)	179.7	177.4	144.5	134
Total HR (MJ/m^2)	211.4	239.1	156.9	129.2
MAHRE(kW/m^2)	205.9	210.8	164.8	179.2

heat release signifies the fuel content in the construction of the cable. If the fuel content is more heat release is also more. The details of 2.5 Sq.mm size,glass mica tape insulted and silicone insulated cables are shown in Table 4.

Table 5 shows the heat release results of 2.5 sq.mm FS cables. Among these four cables, S8 is a silicone insulated cable and the loss of mass of this cable is less than the other cables. S5, S6 and S7 are of the same construction, however, the mean HRR and MARHE values S5 and S6 are the same. Peak Heat Release and total heat release of S6 is more than cable S5, signifying the higher fuel content in cable S6 than S5. Figure 8, 9 shows the heat release rate and total heat release graph of 2.5 sq.mm FS cables. The cables S5, S6 meet the circuit integrity test as per IEC 60331. Cable S7 failed in the fire-alone test as per IEC 60331.

Figure 10 shows the plot of the average rate of heat emission for 2.5 sq.mm cables.

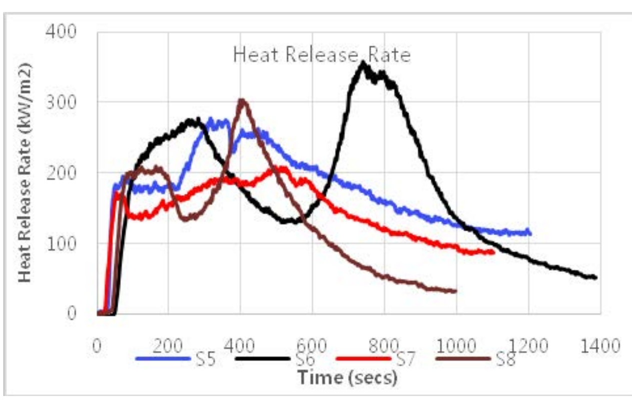

Figure 8. Heat Release Rate of 2.5 Sq.mm FS Cables at 50 kW/m^2.

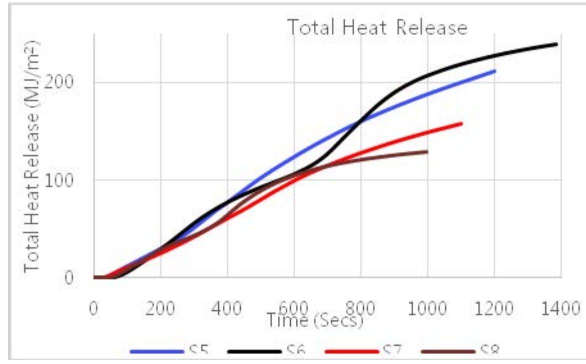

Figure 9. Total Heat Release Rate of 2.5 Sq.mm FS Cables at 50 kW/m^2.

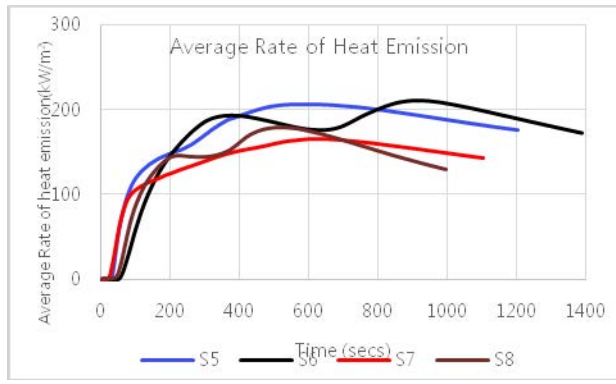

Figure 10. Average rate of heat emission of 1.5 Sq.mm FS cables at 50 kW/m^2.

6. Analysis of Results

The following observations are made from the heat release measurements of fire-resistant cables of 1.5 sq.mm and 2.5 sq.mm

i) The HRR plots of the cables show multiple peaks indicating different layers of burning and more oxygen is consumed by the burning material during the peak.

ii) Good quality of the glass mica tape insulation is wrapped over the conductor in 2 to 3 layers so that it passes the circuit integrity test.

iii) The cables with mica tape and failed in the circuit integrity test releases less heat compared to the passed cables of the same type. This could be due to the number of layers of glass mica insulation and its quality which acts as a fuel content for the fire.

iv) Mass loss in the case of silicone insulation is less indicating the smoke emission of silicone insulation is very low.

v) Maximum value of the Average Rate of Heat Emission plot is known as MARHE which is an index used to assess the hazard level of the materials. The value of MARHE for mica insulated and silicon rubber insulated FS cables are the same except for the failed mica insulated cables for both 1.5 and 2.5 sq.mm sizes.

vi) Total heat release of silicone insulated FS cables is less than the mica insulated FS cables, except the failed mica cable.

7. Conclusion

From the heat release parameters of FS cables, it is evident that the heat release of individual material in the construction of the FS cable plays an important role in determining the overall heat release of the entire FS cables. Materials that are used in the construction of FS cables to maintain the circuit integrity should not pose another threat of heat release when the FS cables are under fire. During the design of the FS cables along with the properties of fire resistance, flame retardancy, and low smoke emission, heat release from the FS cables also needs importance.

8. Acknowledgment

The authors would like to thank the management of Central Power Research Institute for giving an opportunity to publish this technical paper.

9. References

1. BS 6387 - Test method for resistance to fire of cables required to maintain circuit integrity under fire conditions
2. IEC 60331 - Tests for electric cables under fire conditions - Circuit integrity
3. BS 8491 - Method for assessment of fire integrity of large diameter power cables for use as components for smoke and heat control systems and certain other active fire safety systems
4. IS 17505 - Specification for Thermosetting Insulated Fire Survival Cables for Fixed Installation having Low Emission of Smoke and Corrosive Gases when Affected by Fire for Working Voltages upto and including 1100 Vac and 1500 Vdc
5. BS EN 50200 - Method of test for resistance to fire of unprotected small cables for use in emergency circuits.