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Fire Hazard of Fire-Resistant Cables Below the Ignition Point

I have previously proposed the introduction of so-called hazard classes, which follow the real-life classification of cables exposed to different thermal stresses. My experience has shown that the causes of fires, i.e. temperatures, can be classified into three ranges, which also cover the mechanism of action on plastics, i.e. the type of damage. Accordingly, cables should be tested in three temperature ranges according to the high operating temperatures that can be expected in the application environment. Temperatures below the flash point can be ensured by radiant heat rather than flame. The heat load is usually expressed in literature in terms of heat flux (W/m^2) rather than temperature. So, following the professional protocol, we built a radiant source and measured the heat load on the cables with a Gardon pyrometer. The polymer sheaths of the cables showed typical degradation characteristics (fouling, smoke formation, sheath rupture) well below the ignition point (range 150–220 °C).

Keywords: *cable sheathing, degradation, thermal stress*

Introduction

Electrical wires and cables are found in modern applications (not just in industrial applications), and evaluating their fire hazards has become important as a priority. As the demand for electrical energy continues to rise, cables must be designed to resist higher electrical and thermal loads.[2] The new regulatory attempts of electrical vehicles predict more expectations and requirements for more reliable and fire-safe electrical wirings.[3] The development and choice of cables and their layers, in particular polymeric outer sheaths, has so far been primarily based on environmental considerations. Today, other almost exclusively halogen-free polymers may be used. The issue of the flammability of cable sheathing has rapidly come to the fore. In particular, fatalities caused by electrical fires are at the top of the global list.[4]

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[2] Benke et al. 2023.

[3] Kuti et al. 2025.

[4] Pissinos 2015.

There is a need to improve the resistance of cables and their layers, especially polymeric outer sheaths, to heat and flame. Thermal stress can be internal, caused by overheating of metallic conductors (mostly copper) or external e.g. due to fires or other heating.

Among the wide range of plastic coverings, there is one that I think is worth highlighting. The latest trend in current developments is the use of heat-resistant XLPE (cross-linked polyethylene) polymers. XLPE insulated cables generally operate in a temperature range between –40 °C and +90 °C. However, they can withstand higher temperatures for short periods, for example in the event of a short circuit. XLPE can withstand temperatures up to 250 °C for short periods in the event of a short circuit.[5]

XLPE, as a material, has been around for a long time (XLPE was invented in 1963) and has effectively replaced paper insulation in high-voltage power cables. The advantages of XLPE insulation include low electrical loss, high dielectric strength, low cost and high thermal stability. Different types of XLPE insulation have different operating temperature limits. Raising the temperature of XLPE insulation beyond the operating limits has an irreversible detrimental effect on performance and reduces cable life. The temperature limits of XLPE come from the raw material, polyethylene (PE). PE is thermally stable up to about 85 °C. Most commercially available PE grades have melting temperatures between 105 °C and 110 °C. High-density PE has a melting temperature of 130 °C. Conventional XLPE and heat-resistant XLPE have melting temperatures of 103 °C and 123 °C, respectively. HVDC (High-voltage direct current) cables insulated with XLPE have an additional temperature limitation, the temperature gap through the insulation. The well-known temperature limit of XLPE has been in existence for a long time, and given the technological advances in cables, advanced numerical software modelling and live temperature monitoring, and the pressure on network operators to operate at higher temperatures, its relevance is nowadays being questioned.[6]

XLPE material temperature limit explained

XLPE was introduced in 1963 and has since replaced paper insulation in high voltage cables and effectively replaced paper insulation in high voltage power cables. The advantages of XLPE insulation include its low electrical loss, high electrical breakdown strength, low cost and high thermal stability. Different grades of XLPE insulation will have different operating temperature limits. Increasing the temperature of XLPE insulation beyond its operating limits has irreversible degrading effects on performance and reduces cable lifespan.

The temperature limits of XLPE come from the base product upon which it is derived which is polyethylene (PE). PE is thermally stable up to about 85 °C. The melting temperature of most commercial PE grades is between 105 °C and 110 °C. High-density PE has a melting temperature of 130 °C.

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[5] Temperature Limits for XLPE Insulated Cables [s. a.].

[6] Yamada et al. 2003.

The melting temperatures for conventional XLPE and heat-resistant XLPE are 103 °C and 123 °C, respectively. Thus, it makes sense to limit the continuous operating temperature of XLPE to 90 °C.

HVDC cables that are insulated using XLPE have an additional temperature limit constraint which is the temperature drop across the insulation.

The well-known temperature limit of XLPE has been around for a long time, and considering the technological advances in cable design, with advanced numerical software modelling and live temperature monitoring being commonplace, and with pressure for network owners to operate at higher temperatures, its relevance today is being questioned.

Another direction of development is the development of cables and accessories for heat-resistant XLPE polymers that can be operated at the maximum conductor temperature of 105 °C in normal operation. With this cable system, higher transmission capacity can be achieved by using existing cable ducts and without increasing the conductor size of the cable. The problem of hot splices through the cable traces can also be solved by replacing the conventional XLPE cable with a newly developed a heat resistant XLPE cable. We have developed a heat resistant XLPE insulation material with a higher melting point than conventional XLPE. The new material has a lower thermal deformation at 105 °C than conventional XLPE at 90 °C.

However, the cost of building underground ducts is much higher than the cost of building cable systems, and the difficulties of building new cable lines have increased, especially in urban areas. It is therefore necessary to increase transmission capacity by using existing ducts to avoid the costs of building new ducts. For this reason, we have developed heat-resistant XLPE cables and accessories that raise the maximum allowable temperature in normal operation from the traditional 90 °C to 105 °C.[7]

We have developed heat-resistant XLPE cable and accessories that can be operated at 105/spl deg/C as the maximum permissible conductor temperature in normal operation. Through this cable system, greater transmission capacity can be achieved using existing cable ducts and without increasing the conductor size of the cable. Also, the problem of hot spans through the cable route can be solved by replacing conventional XLPE cable with the newly developed heat-resistant XLPE cable. We have developed a heat-resistant XLPE insulation material which has a higher melting point than conventional XLPE. The heat deformation of the new material at 105/spl deg/C is less than that of conventional XLPE at 90/spl deg/C. The breakdown strength of heat-resistant XLPE cable at 105/spl deg/C is almost the same as that of conventional XLPE cable at 90. Conventional self-pressurised rubber joints (hereinafter: SPJ) can be applied to heat-resistant cable lines with the new waterproof joint compound with low heat resistivity.

Even major cable manufacturers specify an operating temperature range e.g. 40 °C – 125 °C.[8]

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[7] Pilgrim et al. 2024.

[8] TA YU Science Co. 2023.

The importance of radiant heat and the purpose of my studies

In my previous work I have already pointed out that the commonly used and mainly standard cable ratings are generally based on flame tests. A closer examination of the conditions to which cables are exposed reveals that damage to the plastic sheathing can be expected long before the flame temperature is reached. In fact, thermal degradation, i.e. pyrolysis, is triggered before the ignition temperature of the plastic materials.[9]

I have previously proposed the introduction of so-called hazard classes, which follow the real-life classification of cables exposed to different thermal stresses.[10] In my experience, the causes of fires, i.e. temperatures, can be classified into three ranges, which also cover the mechanism of action on plastics, i.e. the type of damage. Accordingly, cables should be tested in three temperature ranges according to the high operating temperatures that can be expected in the application environment.

In this work I investigate the effects of the *first temperature range* on the most typical samples, when the plastics are exposed to temperatures below the ignition point, i.e. 300–400 °C. This is considered the most critical range from a fire safety point of view, because the heat is not visible, but it already starts degradation processes that can produce combustible gases and vapours. At this point, the plastic structure decomposes, which can lead to smoke formation. I would also like to explain the importance of this with Figure 1.

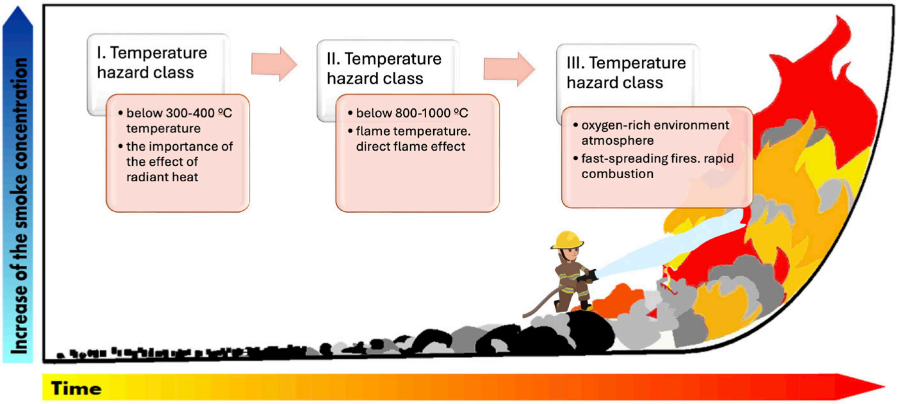

Figure 1: Temperature hazard classes
Source: compiled by the author

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[9] Yong et al. 2024.
[10] Gyöngyössy 2024.

Presentation of the study

A device had to be used that would provide a temperature below about 300 °C. A radiant iron core is the best way to achieve this. By moving away from the surface of the glowing iron core, we can ensure or adjust the temperature at which our cable sample is exposed. We have also provided the heat flux to the sample in the usual W/m⁽²⁾.

Structure of the measurement

The complete measurement setup is shown in Figure 2, which consists of two independent parts.

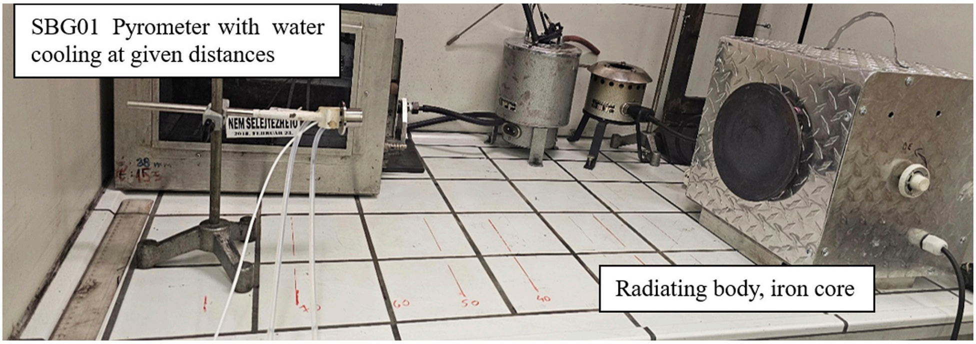


Figure 2: Measurement setup
Source: photographed by the author

Radiating body: (Figure 3) A conventional single-burner electric cooker was modified for the test. Its components are placed in a 30 cm × 30 cm box of 2 mm thick aluminium ribbed plate as follows: the 15 cm diameter hotplate (glowing iron core) is placed in a vertical position on one side of the cube-shaped box. The centre of the circular hotplate is vertically 18 cm from the plane of the test table and is positioned horizontally exactly in the centre of the apparatus. The hob was operated from mains power, maintaining the original parameters (230 V, 50 Hz, 1500 W). Adequate ventilation and protection against overheating is ensured by the 3 cm high feet and the ventilation holes drilled in the plate cover.

The iron bulb core is temperature adjustable, protected against overheating and factory dimmed. In operation, it heats up to 650 °C when checked by a thermocouple with a digital display, which was sufficient for my experiment.

Figure 3: Radiating body with iron core in the middle
Source: photographed by the author

Heat flux measurement

Principle of measurement: values calculated from the radiation of a black body with a total angle of view of 180° using the Stefan-Boltzmann law. Radiant heat flux and corresponding blackbody temperature.

Typical heat flux ranges:

Table 1: Typical heat flux ranges

Heat flux ($\times 10^3$ W/m^2)	Equivalent black body temperature (°C)
1	0.4
10	2
20	500
30	750
40	1,000
50	1,100
60	1,200

Source: compiled by the author

I used the SBG01 water-cooled sensor, which measures heat flux in the range (5–200) x 10^3 W/m². The Hukseflux SBG01 sensors are calibrated according to ISO 14934-3. The SBG01 measures heat flux in the range (5–200) x 10^3 W/m². Equipped with a black absorber, this type of heat flux sensor is designed to measure in environments where the heat flux is mainly generated by radiation. When used with an open sensor, the SBG01 is also sensitive to convective heat flux, although this contribution is usually ignored.

The thermocouple sensor of the SBG01 generates an output voltage that is proportional to the incoming irradiance. The SBG heat flux sensor measures radiation incident on a flat surface from a 180° angle of view. This quantity, expressed in W/m², is called the irradiance (irradiances) and is also referred to informally as the heat flux. The SBG01 sensor is designed to measure high heat fluxes in the range of about 5×10^3 W/m² and above. The spectrum of such radiation sources typically ranges from 300 to 3000×10^{-9} m. The SBG01 is a passive sensor that does not require any power supply. The body temperature of the sensor shall not exceed 80 °C. The contribution due to convection must be taken into account. If the SBG01 sensor is not shielded, convective heat transfer caused by hot gases may cause measurement errors.

The heat flux, Φ (W/m²), is calculated by dividing the SBG01 output voltage, U, by the sensitivity, S.

$\Phi = U/S$

Table 2: Typical heat flux ranges according to ISO 14934-4

Heat flux ($\times 10^3$ W/m²)	**Comment**
300	Maximum heat flux level of a fully developed fire
200 – 100	Wall heat flux in a developed fire area
Around 100	Heat flux from a burning house
Around 30	Heat flux from wood ignition
20–10	Heat flux from wood ignition
Around 7–8	The lowest heat flux that causes a wood wall to ignite is a pilot flame
Around 4	The lowest heat flux that causes burns
Around 2.5	The highest heat flux that humans can tolerate
1.5	Solar radiation constant, maximum level of solar radiation

Source: compiled by the author

Samples

I selected three typical cable samples as shown in Table 3. A thermocouple was attached to the surface of the samples to give as accurate a temperature as possible for the observed phenomena.

Table 3: Main characteristics of the cable samples tested

Number of samples	Name of cable type	Fire safety properties	Description of the type	Usage
1	NOBURN XPS 2×1.9 mm$_2$ LPCB 682E/01 300/500V (MADE IN UK)	PH30	XPS, ceramic-silicone vessel insulation, halogen-free Flame spread prevention	Shielded cable for fire alarm, public address and access control systems with 30 minutes fire resistance 300/500 V
2	KABTEK JE-H(St.)H.Bd 2×2×0.8 mm$_2$ E90/ FE180	E90 FE180	Halogen-free, solid copper conductor with Mica tape with vascular insulation	Halogen-free flame retardant safety cable
3	S.FIRE PROOF JB-H(ST.) H 1×2×1,0 mm$_2$ EMI LIC.NUM. 20-CPR-37-(C-14/2014) No: U/021145	PH120	Polyolefin outer sheath and vascular seal; Mica tape and flow-through fibre	Halogen-free safety cable

Source: compiled by the author

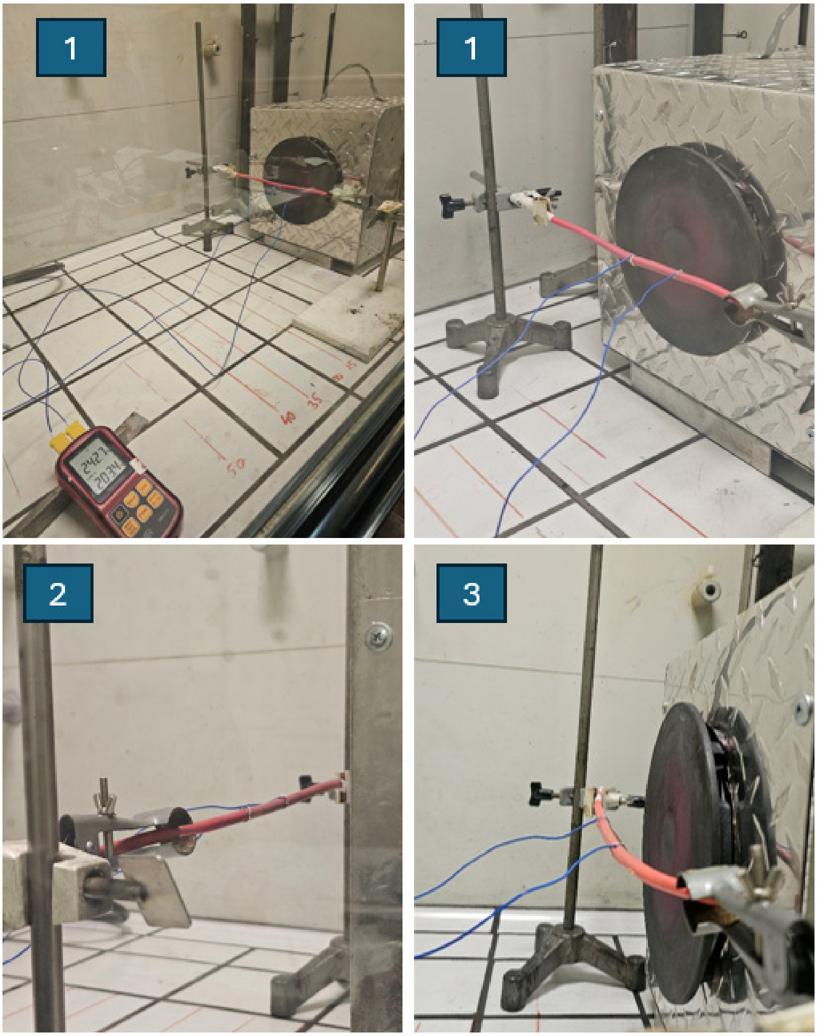


Figure 4: Sample measurement layout, showing thermocouple placement
Source: compiled by the author

Measurement of the base load curve (heat flux calibration)

The temperature and the associated heat flux, i.e. mV, were measured at different distances from the iron core. The heat flux is obtained by calculation according to Table 4.

$\Phi = U/S$ (W/m^2)
Manufacturer's data $S = 0.303 \times 10^{-6}$ V/(W/m^2)
Calibration uncertainty $+ 0.017 \times 10^{-6}$ V/(W/m^2)

The measured values and calibration are shown in Figure 5.

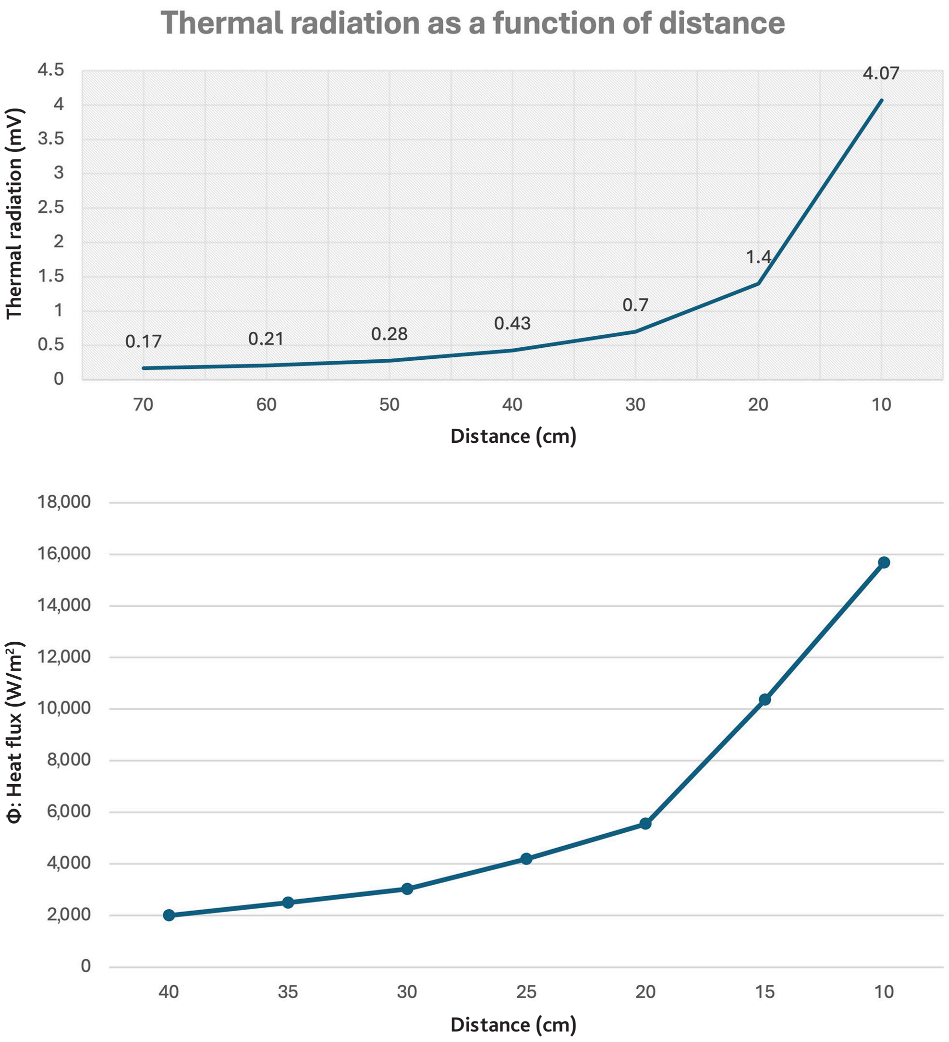


Figure 5: SBG01 voltage and calculated heat flux values by distance from the iron core
Source: compiled by the author

Table 4: Voltages and calculated heat flux values at distance from iron core

Distance from the iron core (cm)	**mV SBG01**	**Φ (W/m²)**
10	4.07	15,677.84
15	2.7	10,362.51
20	1.4	5,553.55
25	1.1	4,191.90
30	0.7	3,030.75
35	0.6	2,494.55
40	0.43	2,007.39
50	0.28	–
60	0.21	–
70	0.17	–

Source: compiled by the author

Results

Our observations, the behaviour of the samples under different heat fluxes are shown in the Figures 6, 7, 8 below. Typically, three phenomena were observed:

- discoloration, which is the first sign of thermal decomposition
- appearance of smoke
- the appearance of fusion (blistering)

For each sample, I have indicated at which temperature and at which heat load each damage starts. The distance from the iron core was only used to ensure the desired heat flux in this way.

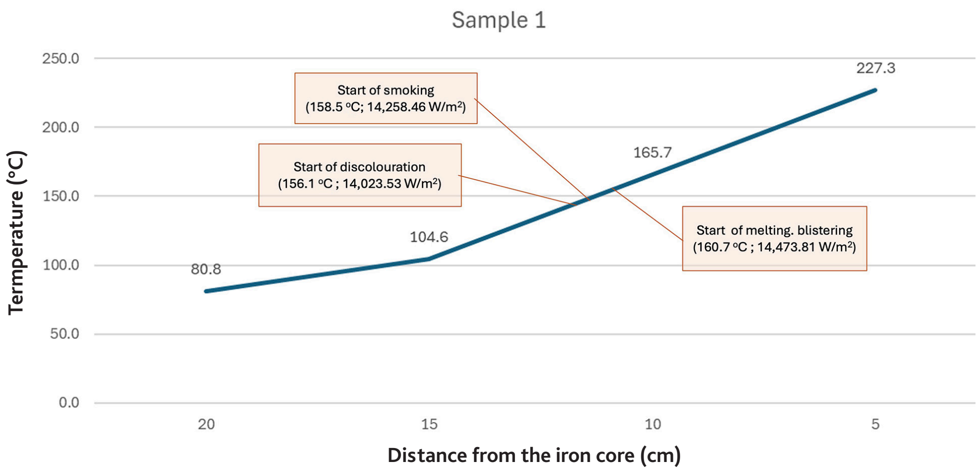


Figure 6: Visual thermal behaviour of NOBURN XPS. type, Sample 1
Source: compiled by the author

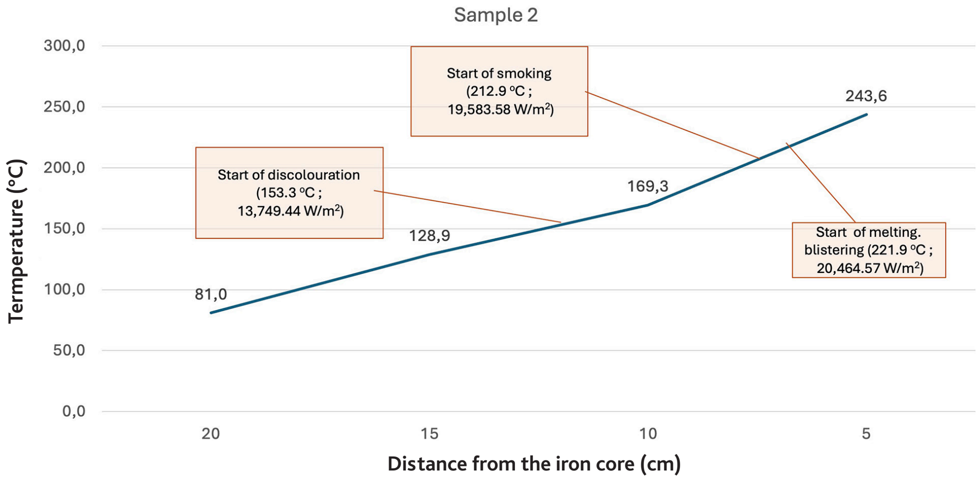
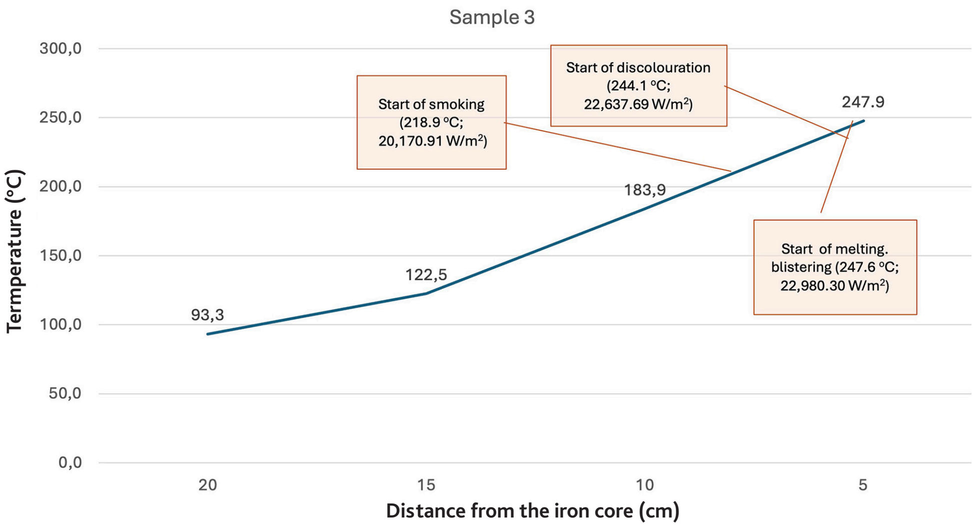


Figure 7: Visual thermal behaviour of KABTEK JE-H(St.)H.Bd. type Sample 2
Source: compiled by the author



Start of smoking (218.9 °C; 20,170.91 W/m^2)

Start of discolouration (244.1 °C; 22,637.69 W/m^2)

Start of melting. blistering (247.6 °C; 22,980.30 W/m^2)

Figure 8: Visual thermal behaviour of S.FIRE PROOF JB-H(ST.)H type Sample 3
Source: compiled by the author

Table 5: Visual thermal behaviour of samples

Observed phenomenon, behaviour	**Sample 1**		**Sample 2**		**Sample 3**	
	Temperature (°C)	Heat flux (W/m^2)	Temperature (°C)	Heat flux (W/m^2)	Temperature (°C)	Heat flux (W/m^2)
Start of discolouration	156.1	14,023.53	153.3	13,749.44	244.1	22,637.69
Start of smoking	158.5	14,258.46	212.9	19,583.58	218.9	20,170.91
Start of melting, blistering	160.7	14,473.81	221.9	20,464.57	247.6	22,980.30

Source: compiled by the author

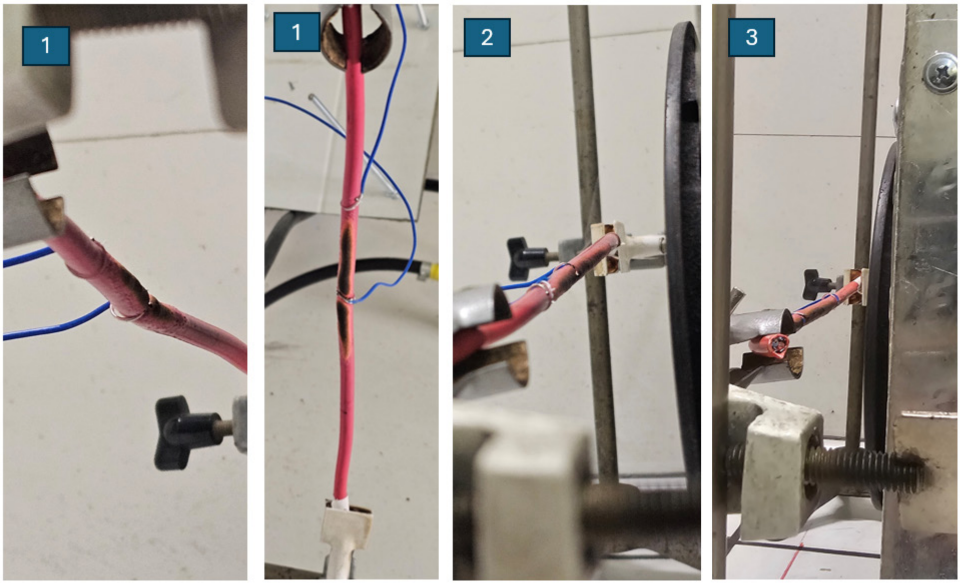


Figure 9: Damages to samples due to heat stress
Source: photographed by the author

Conclusions

I observed various signs of damage and pyrolysis in all three samples as you can see the summarised data in Table 5. Uniformly, at 150 °C, thermal degradation began with carbonisation. The discolouration is already the result of chemical decomposition. The next process at 200 °C is the formation of smoke, with pyrolysis behind it, i.e. combustible vapours appear. This temperature range is also uniform. All three polymer claddings are ruptured, i.e. perforated, exposing the metallic conductor. Here we can only distinguish between the cables in terms of temperature, the sheath rupture of Sample 1 is 170 °C, which is the least resistant sample, however the most resistant is Sample 2 (250 °C). These cable types are factory-classified as fire-resistant cables, yet I found during my tests that, as I suspected, the damage process visibly begins even at low temperatures.

Summary

I examined the effects of the first (lowest) temperature range on the most commonly used cable samples when the plastics are exposed to temperatures below the ignition point, i.e. below 300–400 °C. My hypothesis that the plastic sheathing had already been damaged at very low temperatures and was even showing signs of thermal decomposition (discolouration, smoke formation) was confirmed. This is considered the most critical range from a fire safety point of view, because the main hazard is the heat which is not visible but it already starts degradation processes that can produce combustible gases and vapours. At this point, the plastic structure decomposes which can lead to the formation of smoke, as shown by the samples tested. The maximum operating temperature specified by the manufacturers can be up to 125 °C which requires special care when using the material.

It is worth noting that fire-resistant cables do not show early thermal degradation even at moderate temperatures.

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