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Low Smoke Acidity PVC Compounds for Electrical Cables: Flammability and Smoke Production Versus Halogen-Free Options

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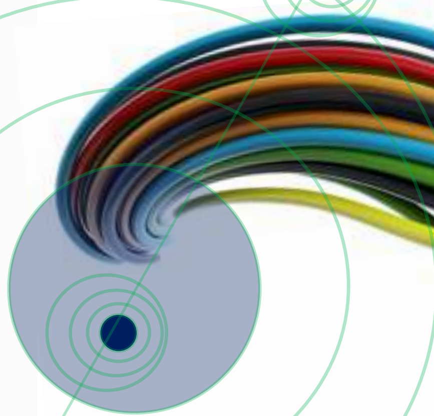
Index

1. Combustion of PVC and mechanism of smoke production
2. Aim of the work
3. New Low Smoke acidity cables
4. Conclusions
5. References

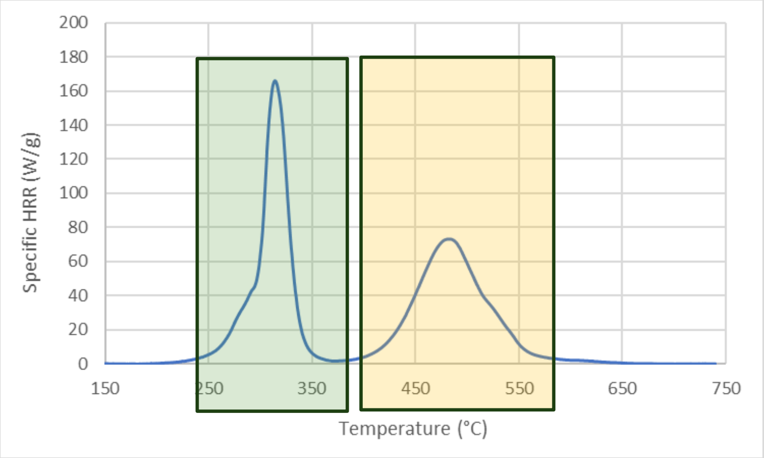


1 Combustion of PVC and mechanism of smoke production

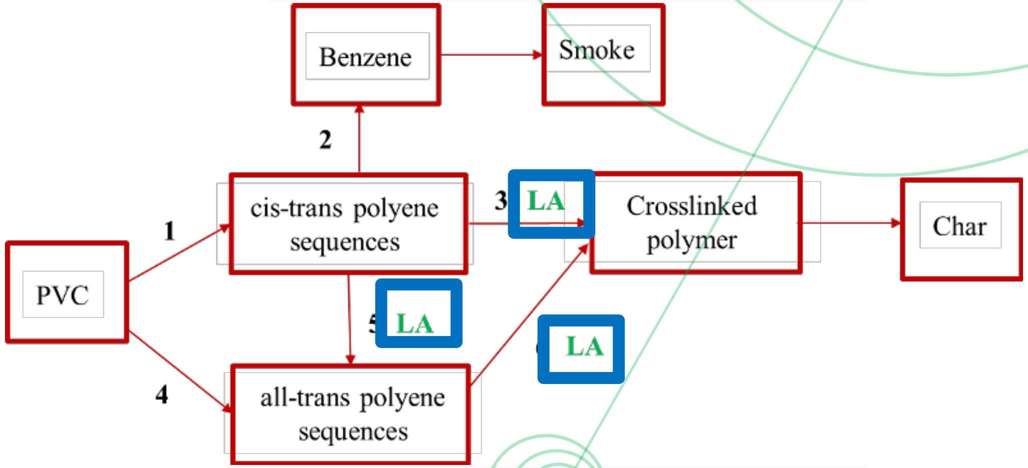
Plasticizer and HCl are released and polyene sequences (PES) formed.
Depending on their cis/trans configuration, PES can combine intermolecularly (all-trans configuration) yielding condensation products through crosslinking reactions, or/and intramolecularly (cis-trans configuration) releasing benzene and producing smoke.

The crosslinked pattern start to release moieties: other aromatic hydrocarbons (substituted), hydrogen and aliphatic hydrocarbon (the majority), which burn with lots of energy, but with few smoke.

Smoke suppressants in PVC are Lewis acids (LA) capable of modifying the decomposition pattern yielding more all trans PES, which can give only condensation products and therefore char.



Specific Heat Release Rate (HRR) curve of a PVC compound of quality R16, measured with MCC ASTM D 7309 method A



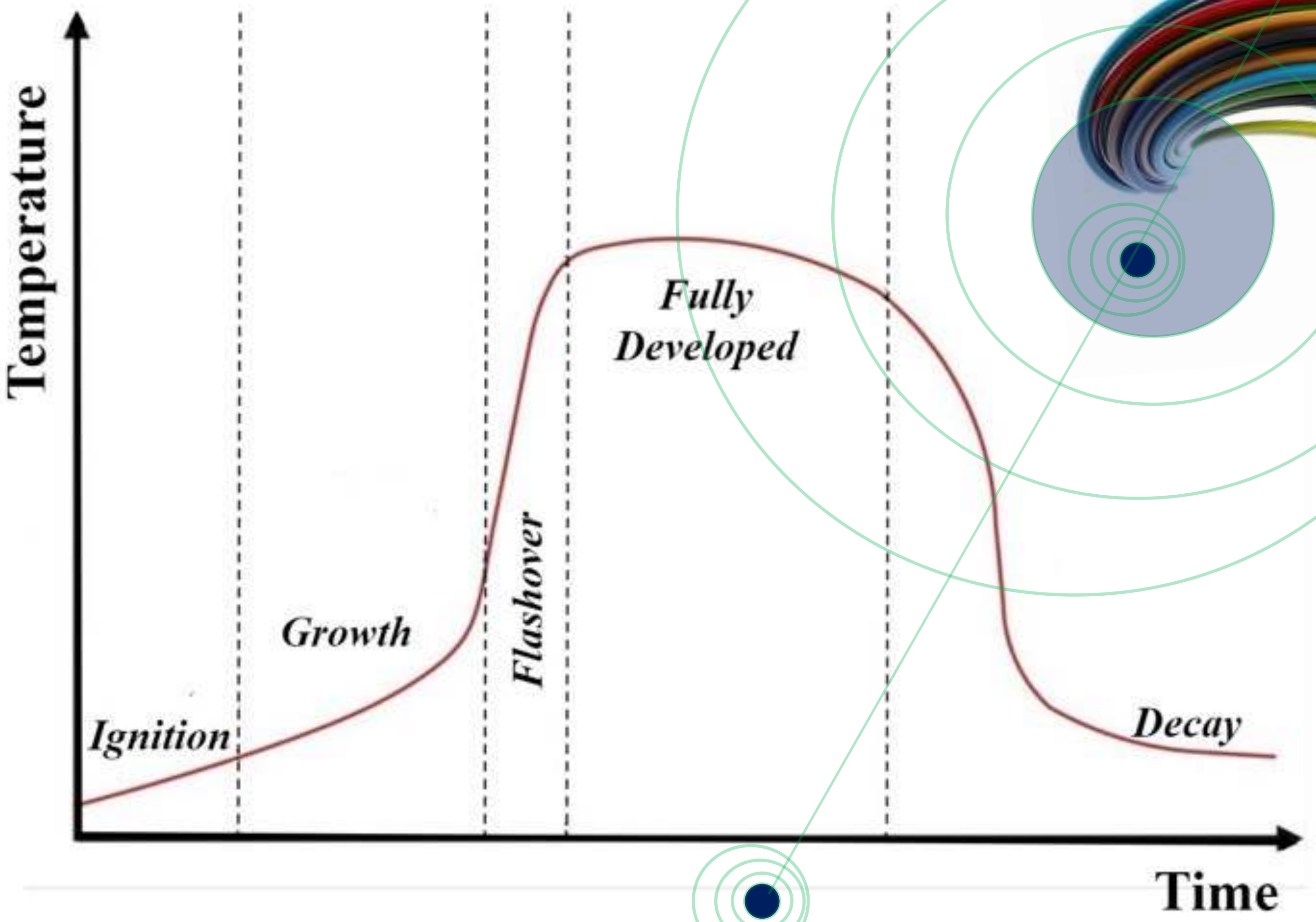
Processes involved in the decomposition pattern of PVC

1 Combustion of PVC and mechanism of smoke production

COMBUSTION
exothermic reaction of a substance with an oxidizing agent

FIRE
process of combustion characterized by the emission of heat and fire effluent and usually accompanied by smoke, flame or glowing or a combination thereof

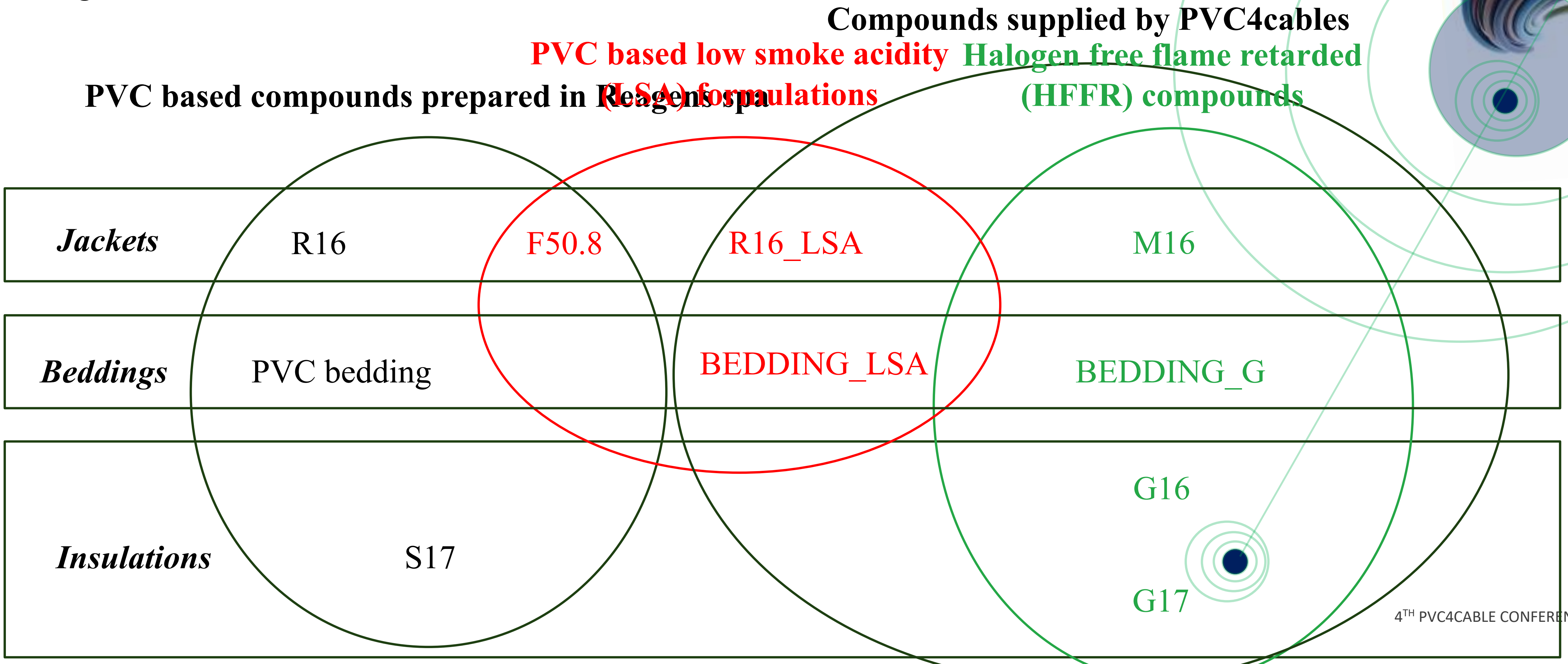
FLAME
rapid, self-sustaining, sub-sonic propagation of combustion in a gaseous medium, usually with emission of light



2 Aim of the work

Common **misconceptions** regarding PVC cables, particularly the belief that they **release thicker** and **denser smoke compared to** Halogen-Free Flame-Retardant (**HFFR**) cables.

PVC inherently has **the potential** to **reduce smoke emissions** to levels comparable with HFFR cables, especially when using smoke suppressants and specific additives that promote matrix cross-linking during PVC combustion.



Aim of the work

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CPR: Regulation (EU) No 305/2011 [1]

EN 50575 [2]

Testing procedures

EN 13501-6 [3]
Reaction-to-fire Classification
=
Main classes (heat release) +
Additional classes
(s) Smoke emissions
(d) Flaming droplets
(a) Smoke acidity

Italy: CEI UNEL 35016 [4]

Main Class	Additional classes
B2ca	s1a d1 a1
Cca	s1b d1 a1
Cca	s3 d1 a3
Eca	none

[1] Regulation (EU) No 305/2011 of the European parliament and of the council of 9 March 2011 laying down harmonized conditions for the marketing of construction products and repealing Council Directive 89/106/EEC. Consolidated version 16/07/2021. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02011R0305-20210716.

[2] EN 50575. Power, control and communication cables. Cables for general applications in construction works subject to reaction to fire requirements. Current version EN 50575:2014+A1:2016.

[3] EN 13501-6. Fire classification of construction products and building elements - Classification using data from reaction to fire tests on power, control and communication cables. Current version EN 13501-6:2019.

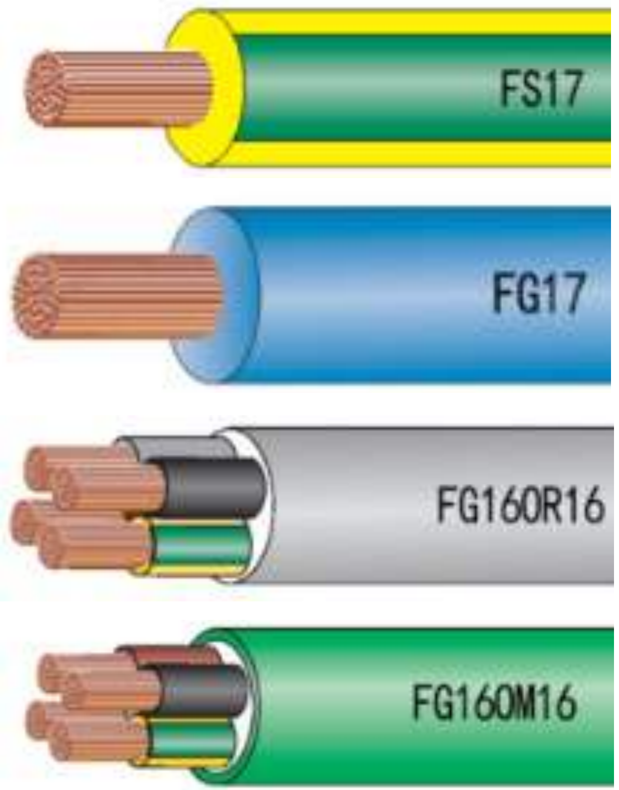
[4] CEI-UNEL 35016 Class of reactions to fire of the cables in relation to the EU "Construction Products Regulations" (305/2011).

2 Aim of the work

Different strategies to shield the inner insulation of G16 quality

Unipolar cables (only insulation)

Multipolar cables

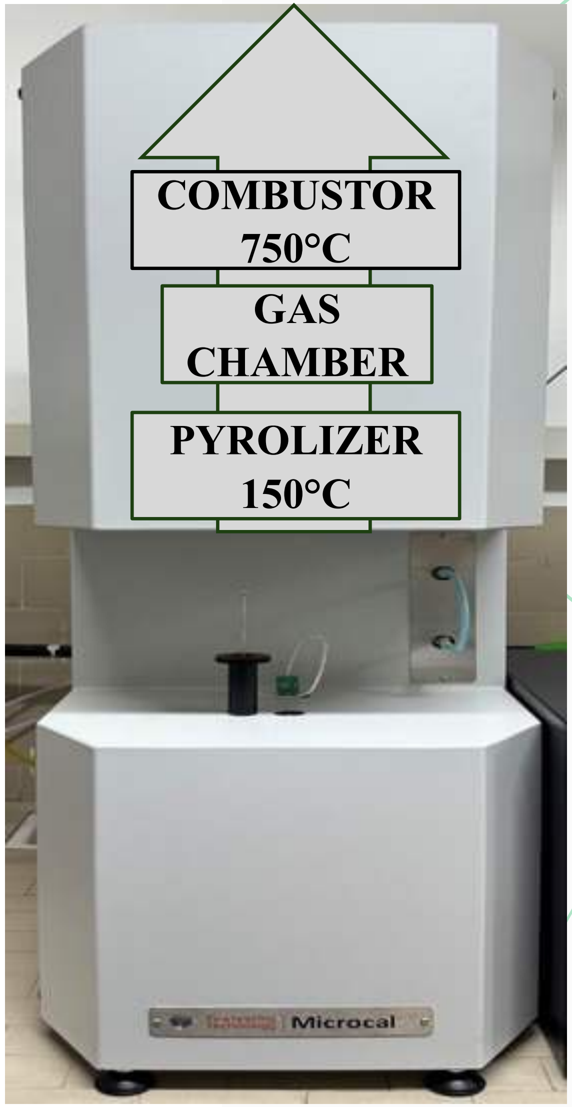


Cable geometry	Fire class	Smoke class	Droplets class	Acidity class
FS17	C_{ca}	s_3	d_1	a_3
FG17	C_{ca}	s_{1b}	d_1	a_1
FG16OR16	C_{ca}	s_3	d_1	a_3
FG16OM16	C_{ca}	s_{1b}	d_1	a_1

[5] cables' images: https://www.baldassaricavi.it/distribution/cavi-nazionali/

3 New LSA Cables: heat released from compounds at MCC

Parameter	Acronim	Unit	Description
Fire Growth Capacity	FGC	$\frac{J}{g * {}^{\circ}C}$	It is defined as a measure considering chemical processes responsible for igniting and burning combustible materials (ignitability and flame spread). It is derived from other MCC measure measures such as ηc, ignition and burning temperatures.
Heat release capacity	η_c	$\frac{J}{g * {}^{\circ}C}$	It is the maximum rate of heat release divided by the heating rate
Specific (total) Heat Release	h_c	$\frac{J}{g}$	It is derived from the specific HRR(T) integral and represent the total heat released in the test



All measurements were performed in accordance with Method A provided by ASTM D 7309 [7]

[7] ASTM D 7309 Standard Test Method for Determining Flammability Characteristics of Plastics and Other Solid Materials Using Microscale Combustion Calorimetry

3 New LSA Cables: heat released from compounds at MCC

- Jacket R16 vs. R16 LSA vs. M16 (where R16 is a PVC compound and M16 the HFFR)
- Bedding vs. Bedding LSA vs. Bedding G (where bedding is a standard PVC one, LSA the low smoke acidity PVC based and G the HFFR)
- Insulation G16, vs. G17 vs. S17 (where G16 is a HF, G17 a HFFR and S17 a PVC compound)

MCC measures the flammability of the material.
All PVC compounds have a better flammability than the HF or HFFR counterparts.

Compound	Description of compound	h_c (J/g)	h_c gas (J/g)	FGC (J/g·K)
R16	PVC jacket	12,26	18,59	96,51
R16_LSA	LSA PVC jacket	8,65	16,70	76,22
M16	HFFR jacket	16,59	31,47	281,57
BEDDING	PVC bedding	6,29	11,30	51,80
BEDDING_LSA	LSA PVC bedding	5,36	10,56	40,36
BEDDING_G	HFFR bedding	10,27	45,62	97,71
G16	HF insulation	49,75	52,89	1094,66
S17	PVC insulation	13,7	19,57	115,32
G17	HFFR insulation	18,67	33,06	231,43

4 New LSA Cables: LOI of compounds

- LOI shows that G16 (an insulation typical for FG16OR16 and FG16OM16) is not flame retarded.
- HF bedding (bedding_G) in FG16OM16 is mildly flame retarded hence, in order to contain both G16 and HF bedding weaknesses, M16 must have a remarkable LOI.
- In FG16OR16 the protection is provided by R16 and the bedding for avoiding the flaming dripping of G16 due to its incompatibility with PVC over staking compounds .

Compound	Description of compound	LOI (O_2%)	h_c (J/g)	h_c gas (J/g)	FGC (J/g·K)
R16	PVC jacket	34	12,26	18,59	96,51
R16_LSA	LSA PVC jacket	28	8,65	16,70	76,22
M16	HFFR jacket	45	16,59	31,47	281,57
BEDDING	PVC bedding	36	6,29	11,30	51,80
BEDDING_LSA	LSA PVC bedding	49	5,36	10,56	40,36
BEDDING_G	HFFR bedding	21	10,27	45,62	97,71
G16	HF insulation	$\leq$ 18	49,75	52,89	1094,66
S17	PVC insulation	29	13,7	19,57	115,32
G17	HFFR insulation	30	18,67	33,06	231,43

3 New LSA Cables: fire behaviour at Cone Calorimeter

Heat release through CC performed at two incident heat fluxes, 35 kW/m² and 62 kW/m,² showing:

- **Jackets R16 vs. R16 LSA vs. M16**:

THR confirms the trend seen in MCC at both incident fluxes. FIGRA of HFFR M16 is extremely low due to the high TTP. However, TFO (Time to Flame Out) of M16 (471 s) is higher (items extinguishes much more delayed in comparison to PVC, 140 s and 157 s for R16 and R16 LSA).

- **Bedding vs. Bedding LSA vs. Bedding G:**

HFFR bedding show all parameters lower than PVC ones at both incident fluxes with the exception of FIGRA for the same reasons of M16. TFO is again higher than the PVC counterparts (226 s vs. 137 s vs. 76 s).

- **Insulations G16, vs. G17 vs. S17:**

S17 has better THR at both heat fluxes than the HF or HFFR counterparts. FIGRA is worse but TFO is remarkably better.

Compound	Description of compound	LOI (O_2%)	THR (MJ/m^2) 35 KW/m^2	$FIGRA_{0,2MJ}$ (W/s) 35 KW/m2	THR (MJ/m^2) 62 KW/m^2	$FIGRA_{0,2MJ}$ (W/s) 62 KW/m2	h_c (J/g)	h_c gas (J/g)	FGC (J/g·K)
R16	PVC jacket	34	18,8	2481	22,8	4538	12,26	18,59	96,51
R16_LSA	LSA PVC jacket	28	17,7	2822	20,3	5411	8,65	16,70	76,22
M16	HFFR jacket	45	30,9	587	34,2	1641	16,59	31,47	281,57
BEDDING	PVC bedding	36	13,8	2101	15,6	3772	6,29	11,30	51,80
BEDDING_LSA	LSA PVC bedding	49	9,8	687	11,6	1325	5,36	10,56	40,36
BEDDING_G	HFFR bedding	21	18,6	2371	22,4	5334	10,27	45,62	97,71
G16	HF insulation	≤ 18	39,2	4620	39,2	9[illegible]23	49,75	52,89	1094,66
S17	PVC insulation	29	20,2	2557	24,9	5435	13,7	19,57	115,32
G17	HFFR insulation	30	22,5	1307	29,1	3656	18,67	33,06	231,43

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3 New LSA Cables: fire behaviour at Cone Calorimeter

Samples pre- and post-analysis

All measurements were performed in accordance with ISO 5660-1 [8]

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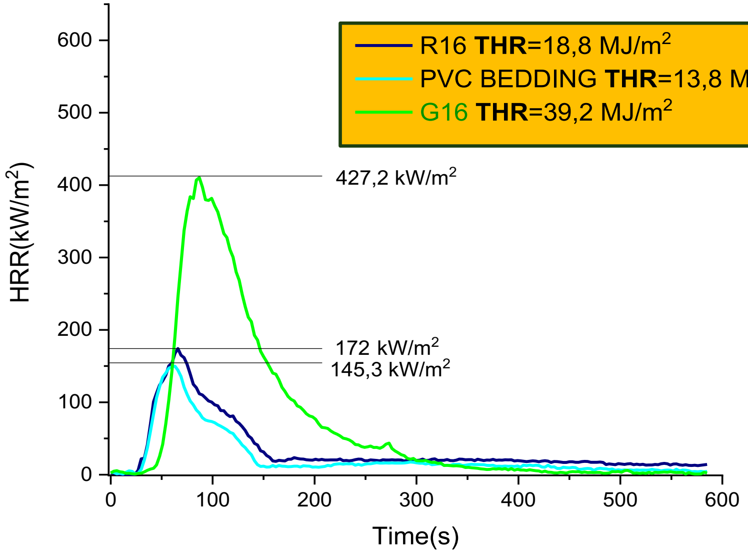
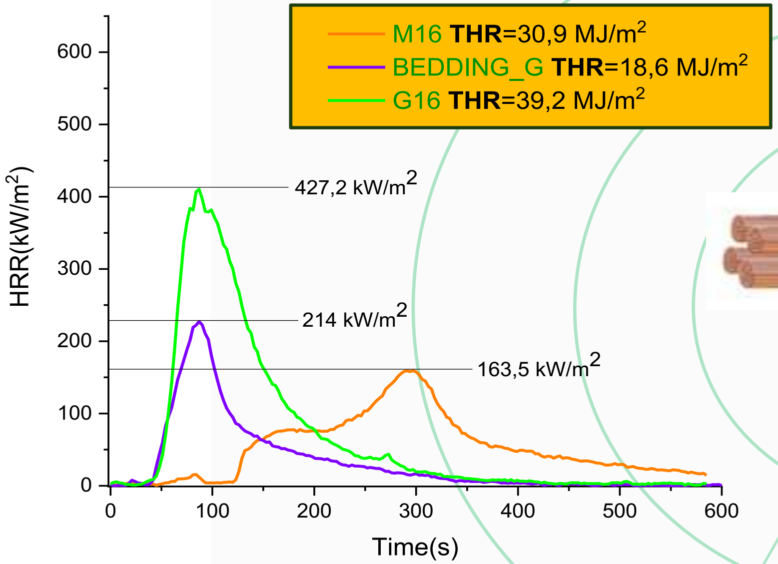
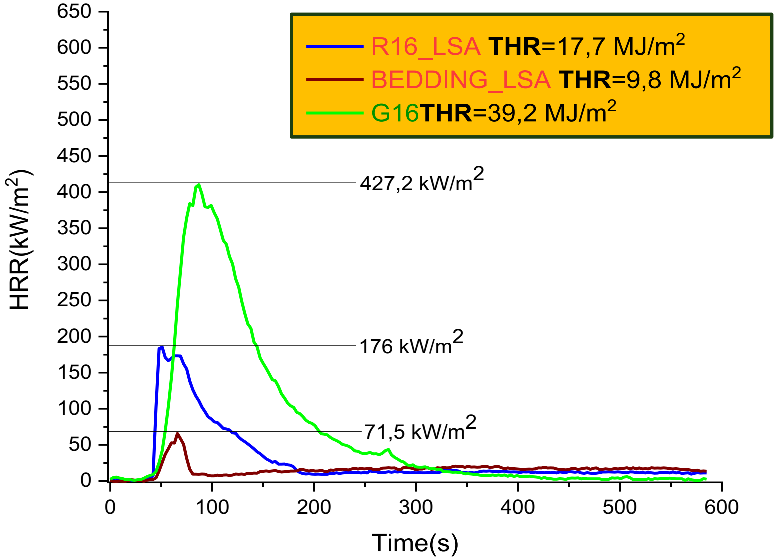
4 New LSA Cables: heat released from Cone Calorimetry

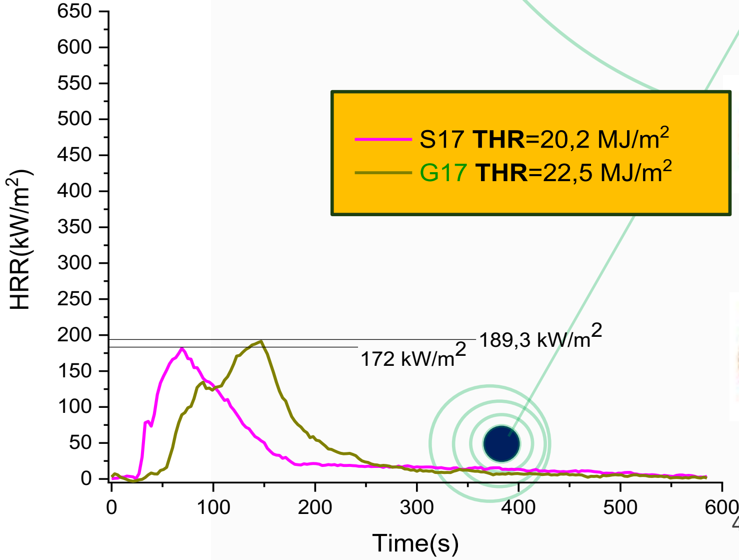
HRR curves and Total Heat Release (THR) – 35kW/m²





LSA alternative





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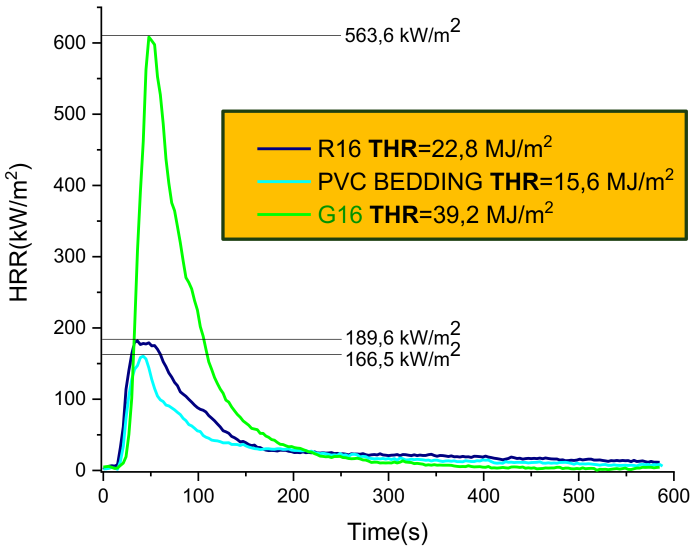
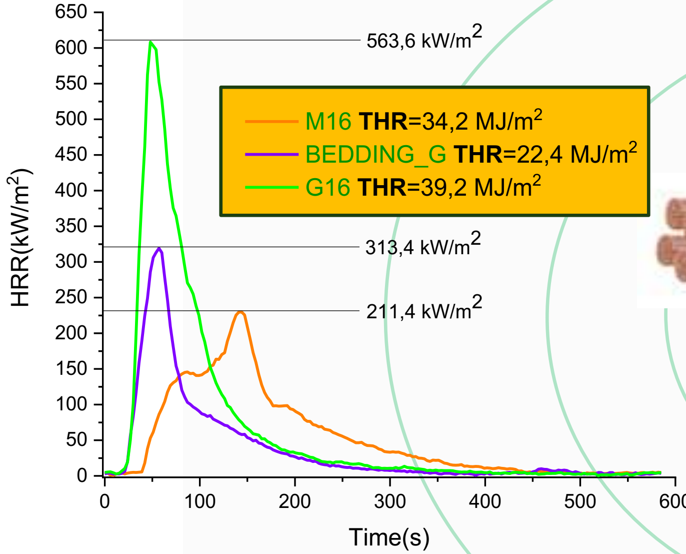
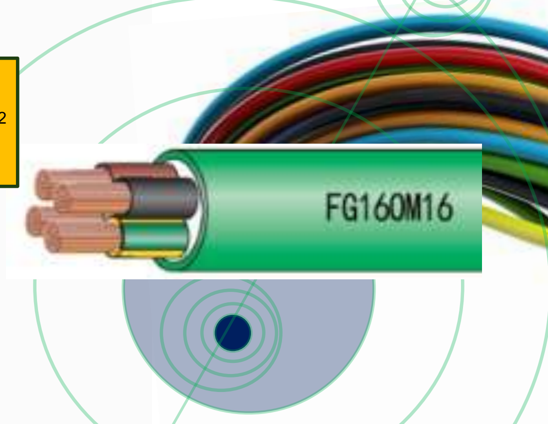
4 New LSA Cables: heat released from Cone Calorimetry

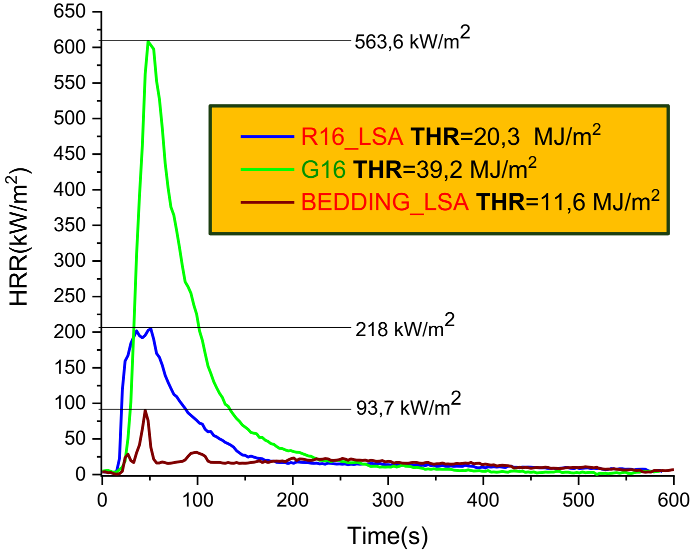
HRR curves and Total Heat Release (THR) – 62 kW/m^2

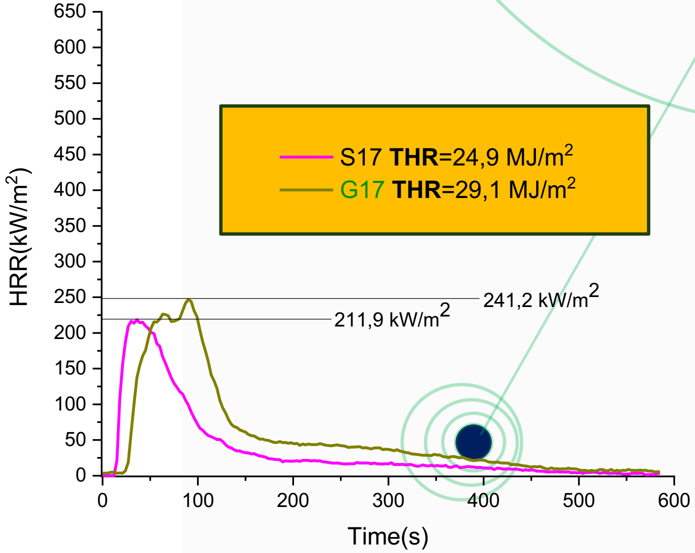


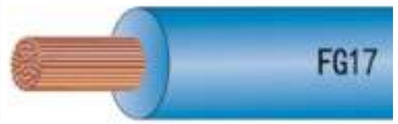




LSA alternative







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4

New LSA Cables: heat released from Cone Calorimetry

Compound	Description of compound	FIGRA (W/g*s) *(35 kW/m²)*	FIGRA (W/g*s) *(62 kW/m²)*	FIGRA 62/ FIGRA 35	THR (MJ/g*m²) *(35 kW/m²)*	THR (MJ/g*m²) *(62 kW/m²)*	THR 62/ THR 35
R16	PVC jacket	122.1	242.6	2.0	0.92	1.21	1.3
R16_LSA	LSA PVC jacket	121.9	227.3	1.9	0.76	0.85	1.1
M16	HFFR jacket	24.5	73.2	3.0	1.29	1.51	1.2
BEDDING	PVC bedding	84.9	161.8	1.9	0.56	0.66	1.2
BEDDING_LSA	LSA PVC bedding	26.3	56.7	2.2	0.38	0.49	1.3
BEDDING_G	HFFR bedding	110.0	234.9	2.1	0.86	0.99	1.2
G16	HF insulation	505.3	1049.3	2.1	4.29	4.45	1.0
S17	PVC insulation	143.2	277.9	1.9	1.13	1.37	1.2
G17	HFFR insulation	70.4	191.9	2.7	1.21	1.15	1.0

- At higher incident heat fluxes HFFR compounds (M16 and G17) deteriorate their performances more than PVC counterparts

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4 New LSA Cables: smoke release from Cone Calorimetry

Smoke production through CC performed at two incident heat fluxes, 35 kW/m² and 62 kW/m,² showing:

- **Jackets R16 vs. R16 LSA vs. M16**:

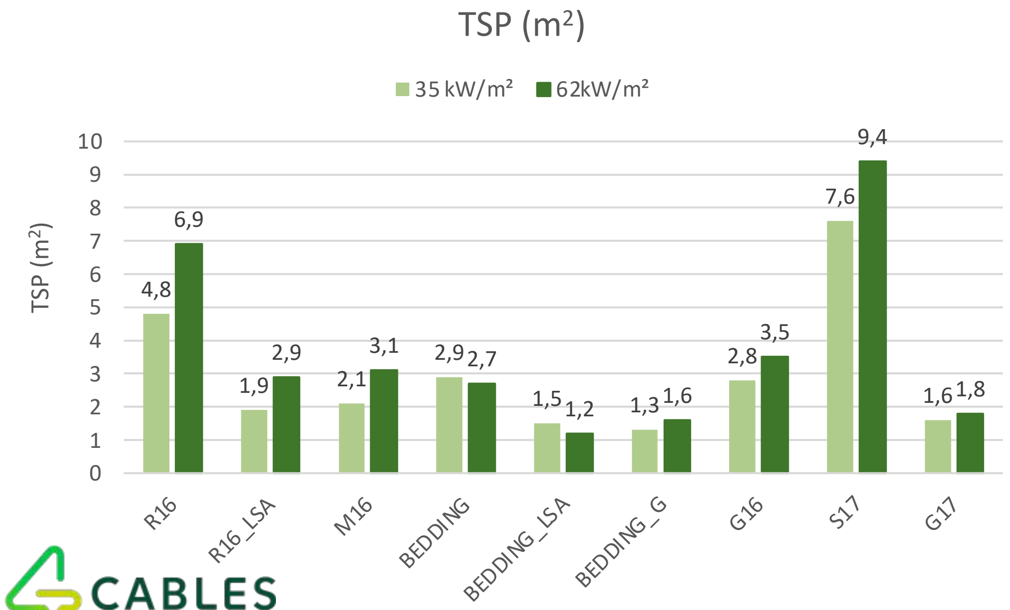
The total smoke produced (TSP) by R16 LSA PVC compound is equal to the amount of HFFR M16 compounc heat fluxes, and much lower than the standard PVC R16.

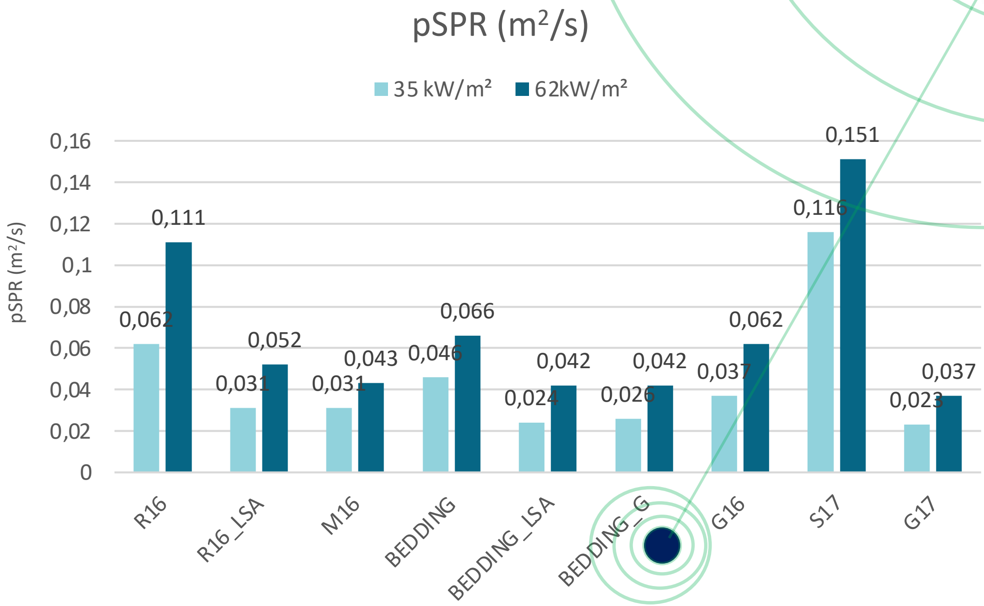
- **Bedding vs. Bedding LSA vs. Bedding G:**

As for jackets, the LSA PVC bedding shows a TSP similar to the HFFR bedding, and lower of the PVC standard

- **Insulations G16, vs. G17 vs. S17:**

S17 PVC compound produces a much higher amount of smoke with respect to the HFFR correspondent insul the different smoke classification for standard grade PVC cable FS17 vs FG17.





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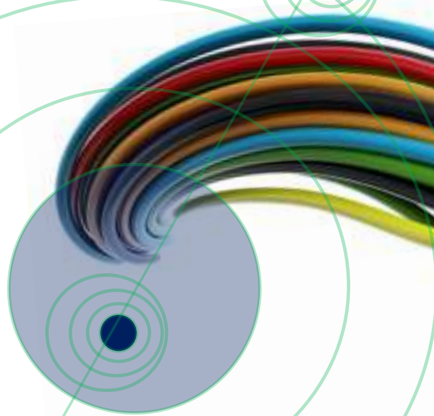
Conclusions



- The bench scale tests such as Micro Combustion Calorimetry (MCC) and Cone Calorimetry (CC) take in consideration the single component performance.
- In MCC PVC compounds R16 and S17 show parameters altogether better than HFFR counterparts (M16 and G17).
- In CC M16 has the best FIGRA, because TTP (time to peak) is longer due to PO thermal decomposition, and highest TTI (time to ignition).
- M16 also releases more energy (30,9 MJ/m^2 at cone) having higher peak and longer TFO (time to flame out).

5 Conclusions

HFFR

PVC

MCC Testing

- G17 showed inferior performances compared to the PVC based counterpart.

Cone Testing

- G17 displayed higher TTPs.
- At higher incidental heat fluxes, G17 showed drastic loss of performances, regarding TTPs, THR and FIGRA values.
- At both incidental heat fluxes, the TSP from S17 is about 5 times higher than G17

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Conclusions

In PVC based multipolar cables, it is exploited the ability of PVC based beddings in enhancing the reaction-to-fire of the cable system to shield G16 due to different **compatibility**.

LSA alternative

HFFR

PVC LSA

MCC Testing

- All HFFR compounds showed inferior performances compared to the PVC based counterparts.
- LSA formulations exhibited better results than their standard PVC based counterpart, across all parameters.

CC Testing

- All HFFR compounds displayed higher TTPs.
- All HFFR compounds showed drastic loss of performances, regarding TTPs, THR and FIGRA values at higher incidental heat fluxes.
- LSA formulations displayed similar (jackets) or better (beddings) THR and FIGRA than both the standard PVC bedding.
- LSA formulations exhibited better smoke results, comparable to HFFR counterparts.

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Thank you for your attention

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