ARMAFORM PET

FIRE PERFORMANCE IN RAILWAY APPLICATIONS

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armacell®

// Sustainable solutions of Armacell

ENVIRONMENT

Fully based on recycled materials
Fully recyclable
No CFCs of HFCs
No halogenated flame retardants
The best GWP or ODP for the core materials
Helps in LEED or BREEM certification

HEALTH & SAFETY

Meets stringent fire and smoke standards
Fulfills requirements of toxicity during fire
Health related issues as bacterial growth

PET Core
Structural foam cores

PET Foil
Thin flexible sheets

PET Beads
Particle foams

THERMAL PERFORMANCE

Help to comply with energy conservation regulations
Thermal efficiency
Sustainability
Long term performance

COST EFFECTIVENESS

Very good cost to performance ratio
Positive full life cycle balance
Outstanding fatigue behavior
Excellent thermal stability

// Fire regulations revision

/ Railway and transportation

The USA/ Canada

- **NFPA130** *„Standard for Fixed Guideway Transit and Passenger Rail Systems”*
- ASTM E162 „Standard Test Method for Surface Flammability of Materials Using a Radiant Heat Energy Source”
- ASTM E662 „Standard Test Method for Specific Optical Density of Smoke Generated by Solid Materials”
- ASTM E 648 „Standard Test Method for Critical Radiant Flux of Floor-Covering Systems Using a Radiant Heat Energy Source”

Europe (traditional)

- **Germany/ Austria/ Switzerland**
- DIN5510: DIN 54837:2007 „Testing of materials, small components and component sections for rail vehicles - Determination of burning behavior using a gas burner”
- DIN5510: DIN EN ISO 5659-2 „Plastics – Smoke generation. Part 2: Determination of optical density by a single-chamber test”
- **France**
- NF X 10-702: smoke density
- NF X 10-100: smoke toxicity
- NF P 92-501, 503, 504: M class flammability
- **Russia**
- GOST 12.1.044-89 USSR (20 diff. tests)
- **Spain - DT-PCI/5A**
- UNE 23721

Europe (traditional)

- **UK - BS 6853** *„Fire Test to Railway Components”*
- BS 476 - part 6: fire propagation
- BS 476 - part 7: surface flammability
- EN 9239: critical heat flux
- BS 6853 Annex B: smoke toxicity
- BS 6853 Annex D: smoke density
- ISO 4589-2: oxygen index
- BS 476-15: heat release
- **Italy - UNI CEI11170-3**
- UNI 9174: flame test
- UNI 8457: ignition test
- UNI 9175: ignition test to furniture
- ISO 11925-2: ignition test
- ISO 5660-1: heat release
- EN 50305: fire test to cable
- NF F 16-101: fire test to roll stock

// Fire regulations revision

/ Railway and transportation

Asia	Europe (harmonized)
• **China** • TBT 3138 • DIN 5510-2 • BS 6853 • NF F 16-101/102 • **Korea** • ISO 5658-2: • ISO 4589-2: • BS 6853 Annex B • ASTM E 662 • **...**	• **EN 45545-2: 2013** *„Fire protection of railway vehicles - Part 2: Requirement for fire behaviors of materials and components”*

// Fire regulations in the USA and Canada

/ NFPA 130

Category	Function of Material	Required Testing	Test Method
Other vehicle components	Seat and mattress frames, wall and ceiling lining and panels, trays and other tables, partitions, shelves, opaque windscreens, roof housings, exterior shells, and component boxes and covers (...)	Surface Flammability	ASTM E 162
		Smoke Density	ASTM E 662
	Thermal and acoustical insulation	Surface Flammability	ASTM E 162
		Smoke Density	ASTM E 662
	HVAC ducting	Surface Flammability	ASTM E 162
		Smoke Density	ASTM E 662
	Floor covering	Critical Radiant Flux of Floor-Covering System	ASTM E 648
		Smoke Density	ASTM E 662

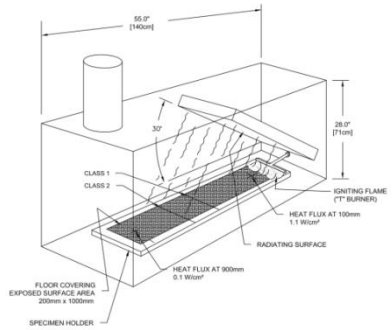
// Fire regulations in the USA and Canada

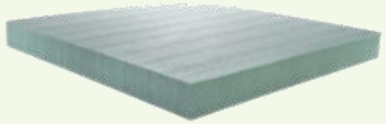
/ NFPA 130 - floor covering - the floor radiant panel test

ASTM E 648

- The Floor Radiant Panel apparatus involves a horizontally mounted floor covering test sample which receives radiant energy from a gas-air fueled radiant panel mounted above one end of the sample and inclined at an angle of 30º.
- The radiant panel generates a radiant flux profile along the length of the sample ranging from a maximum of 1.1 W/cm^2 immediately under the panel to approximately 0.1 W/cm^2 at the end of the test sample. A gas fired pilot burner is used to initiate the ignition in the sample.
- The distance the flooring system burns to extinguishment is converted to watts per square centimeter (W/cm^2) and is reported as critical radiant flux (CRF). This is the minimum radiant energy a fire needs to sustain flame propagation in the flooring system.
- The higher number, the more flame-resistant system.

Class limits:
Class I: CRF ≥ 0,45 W/cm^2
Class II: CRF ≥ 0,22 W/cm^2





PET Core
Structural foam cores

ArmaForm PET GFR70
Class I (CRF>10,9 W/cm^2)

ArmaForm PET GR70
Class I (CRF>11 W/cm^2)

ArmaForm PET FR100
Class I (CRF>11 W/cm^2)

ArmaForm PET GR115
Class I (CRF>9,7 W/cm^2)

// Fire regulations in the USA and Canada

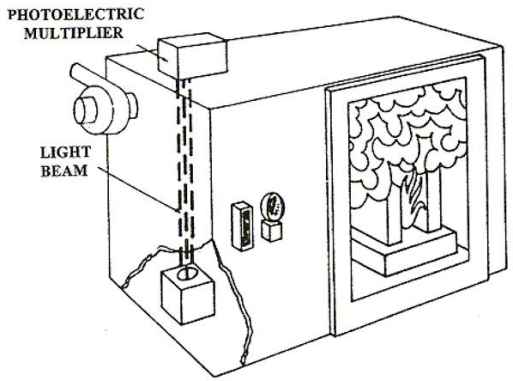
/ NFPA 130 - floor covering - the smoke chamber test

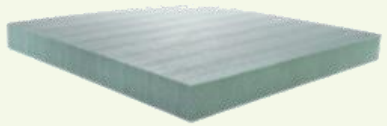
ASTM E 662

- Using either a radiant panel, or a combination of the panel and a six-prong burner, the specimen can be exposed to non-flaming (smoldering) as well as flaming conditions in this test.
- Exposed sample size is approximately 2-1/2 inches (63,5 mm) square, and it is held in a vertical position facing a radiant heat source.
- The radiant heater exposes the specimen to 2-1/2 W/cm^2 of radiant energy. Generally the results of this test are expressed as the Maximum Specific Optical Density, Dm.
- The measurement is based on the obscuration of a columnated light beam passing vertically through the test chamber.

Class limits:

$D_{s1.5}$ or $D_{s90} \leq 100$
$D_{s4.0}$ or $D_{s240} \leq 200$





PET Core
Structural foam cores

ArmaForm PET GFR70
$D_{s90} \leq 14,3$
$D_{s240} \leq 27,7$

ArmaForm PET GR70
$D_{s90} \leq 40,7$
$D_{s240} \leq 44,6$

ArmaForm PET FR100
$D_{s90} \leq 87,6$
$D_{s240} \leq 88,4$

ArmaForm PET GR115
$D_{s90} \leq 49,7$
$D_{s240} \leq 55,1$

// Fire regulations in Germany

/ DIN5510: DIN 54837

DIN 5510-2: DIN 54837

„Testing of materials, small components and component sections for rail vehicles - determination of burning behaviour using a gas burner”

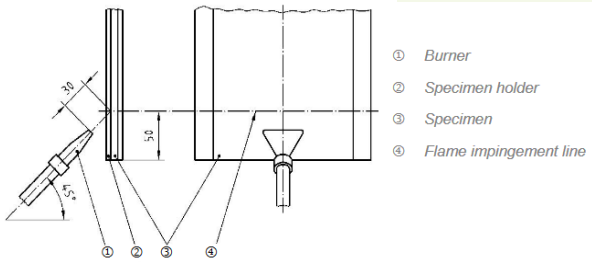
- fire test to railway components structures (seal, flooring, wall)
- provides fire classification of railway vehicle materials and structures (incl. seal, flooring, wall)
- it classifies burning behavior, smoke density, dropping behavior and toxicity, classifying the material in one of the following categories:
- burning class S2-S5, drop class ST1-ST2, and smoke class SR1-SR2

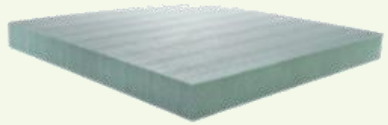
Class limits:

Burning Class	S2	S3	S4	S5
Destroyed length	≤30 cm	≤25 cm	≤20 cm	0 cm
After flame	extinguish after test	≤100 s	≤10 s	=0 s

Drop Class	ST1	ST2
Dropping	yes, after flame >20 s	no drops

Smoke Class	SR1	SR2
Smoke	integral ≤ 100 %*min	int. ≤ 50 %*min





PET Core
Structural foam cores

ArmaForm PET GFR70
S4 ST2 SR2

ArmaForm PET FR100
S4 ST2 SR2

// Fire regulations in Germany

/ DIN 5510-2:2009, Annex D; EN ISO 5659-2

DIN EN ISO 5659-2:2013

„Plastics - Smoke generation; Part 2: Determination of optical density by a single chamber test. Smoke toxicity testing according to DIN 5510-2:2009, Annex D"

The test takes place on specimens arranged horizontally with an irradiation intensity of 25 kW/m². A pilot flame is used for the test. The smoke released is collected in the chamber. The toxicity analysis is performed after 4 and 8 mins (Conventional toxicity index, CIT_4 and CIT_8):

$$CIT = 0{,}085 \cdot \sum_{i=1}^{8} \frac{c_i}{C_i}$$

FED (fractional effective dose) is then caluclated based on CIT:

$$FED(t_{zul}) = \frac{(CIT_4 + 0{,}5\,CIT_8) \cdot 4\,\text{min} + CIT_8 \cdot (t_{zul} - 8\,\text{min})}{30\,\text{min}} \leq 1$$

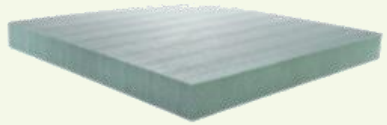
The thickness of the test specimens must not exceed 25 mm.

Class limits:

CIT limits in the Table

FED(t) ≤ 1 t=15 min or 30 min.

Gas component		CIT [mg/m³]
Carbon dioxide	CO_2	72000
Carbon monoxide	CO	1380
Hydrogen fluoride	HF	25
Hydrogen chloride	HCl	75
Hydrogen bromide	HBr	99
Hydrogen cyanide	HCN	55
Nitrogen oxides	NO_x	38
Sulfur dioxide	SO_2	262



PET Core
Structural foam cores

ArmaForm PET GFR70
FED(15) = 0,02
FED(30) = 0,03

ArmaForm PET FR100
FED(15) ≤ 0,01
FED(30) = 0,01

Gas	CIT4 / CIT8 [mg/m³]	
	GFR70	FR100
CO_2	10017 / 12362	1407 / 2851
CO	369 / 408	53 / 88
HF, HCl, HBr, HCN, NO_x, SO_2 - not detected		

// Fire regulations in France

/ NF F 16-101 and NF F 16-102: smoke gas index (F-class)

NF X 10-702: smoke density

Sample is arranged vertically and exposed to an electric radiant heat source (25 kW/m^2) both with a pilot flame for 20 min.
The specific smoke optical density (D_s) is calculated based on the measured transmission:

$$D_s = 132 \quad \lg \frac{100}{T}$$

and its maxmimum value (D_m) is determined. VOF4 is the smoke obscuration value after the first 4 min. of the test.

Gas component		CC [mg/m³]
Carbon dioxide	CO_2	90000
Carbon monoxide	CO	1750
Hydrogen fluoride	HF	17
Hydrogen chloride	HCl	150
Hydrogen bromide	HBr	170
Hydrogen cyanide	HCN	55
Sulfur dioxide	SO_2	260

NF X 10-100: smoke toxicity

The test is conducted within a tube furnace at 600°C for a 1g sample. The concentration of toxic emission is evaluated vs. the critical concentration (CC), and recalculated to CIT (ICT) value:

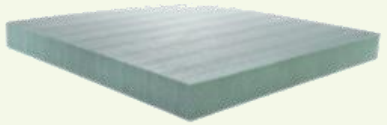
$$I.T.C. = 100 \sum \frac{t_i}{CC_i}$$

The final smoke gas index (I.F.) is calculated using the D_m, VOF4 and I.T.C. acc. to formula:

$$I.F. = \frac{D_m}{100} + \frac{VOF4}{30} + \frac{I.T.C.}{2}$$

Class limits:

F-rating	I.F.
F0	≤ 5
F1	≤ 20
F2	≤ 40
F3	≤ 80
F4	≤ 120
F5	> 120



PET Core
Structural foam cores

ArmaForm PET GFR70
F1
Dm = 62
VOF4 = 114
I.F.=17

ArmaForm PET FR100
F1
Dm = 62
VOF4 = 114
I.F.=17

Gas	CC GFR70	CC FR100
CO_2	2205,8	1430
CO	400,6	312,4
HCl	-	0,54
HF, HBr, HCN, SO_2 – not detected		

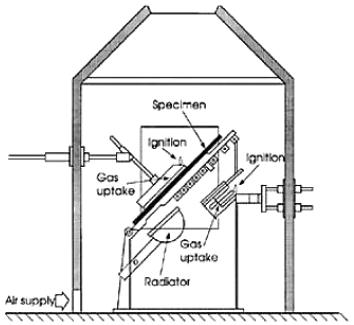
// Fire regulations in France

/ NF F 16-101: NF P 92-50X – reaction to fire (M-class)

NF P 92-501: Epiradiator Test

- the sample is placed at 45° and heated for 20 min. with a radiation exposure of 30kW/m²
- the propagation of combustion is observed and the heat release (q) is measured acc. to:

$$q = \frac{100 * \sum h}{t_i * \sqrt{\Delta t}}$$

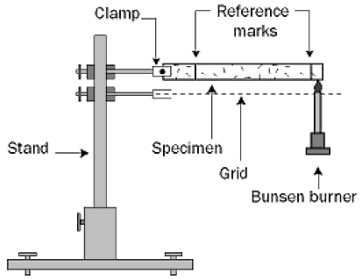


Class limits:

Rating	q-value	classification
M1	0 ≤ q < 2,5	non flammable
M2	2,5 ≤ q < 15	low flammability
M3	15 ≤ q < 50	moderately flammable
M4	q ≥ 50	flammable

NF P 92-504: Flame propagation

- the horizontal test on fire propagation and indicative dripping behaviour:

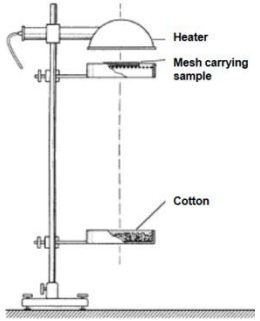


Class limits:

M rating	observation
M1	no combustion, none or non-burning droplets
M2	<5s combustion, none or non-burning droplets
M3	<5s combustion, burning
M4	>5s combustion, burning

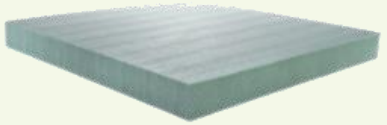
NF P 92-505: Dripping

- the horizontal test on fire propagation and indicative dripping behaviour:



Class limits:

M rating	observation
M3	burnig drips
M4	Ignition of cotton



PET Core
Structural foam cores

ArmaForm PET GFR70
M1
q < 2,5
no combusion
non-flaming droplets

ArmaForm PET FR100
M1
q < 2,5
no combusion
non-flaming droplets

// Harmonized fire regulations in Europe

/ EN45545-2:2013

- Evaluation of reaction to fire are spread of flame in terms of ignitability, heat release, smoke, and toxicity
- The test methods are unique, taking in account the different materials classes like
- Considered train's hazard levels (HL): HL1, HL2, HL3
- A higher HL suggests passengers will take longer to reach safety on that train, so the materials need to be extra fire safe.

Operation category	Design category			
	N	A	D	S
1	HL1	HL1	HL1	HL2
2	HL2	HL2	HL2	HL2
3	HL2	HL2	HL2	HL3
4	HL3	HL3	HL3	HL3

- HL is determined by two parameters:
  - design category:
    A - an automatic train with no emergency staff on board
    D - double deckers,
    S - sleeping cars, couchettes,
    N - regular trains.
  - route's operational category: how the train routinely operates:
    A category of 1 is for trains that would be easiest to escape from in an emergency, ranging up to category 4 for the hardest. The vast majority of trains in operation are classified as HL2.

- Lists products and respective testing requirements from R1-R26, for the composites and applications of ArmaForm PET the most important ones are:

Requirement	Name	Test Method
R1	Interior surfaces Window frames Display screens	ISO 5658-2 ISO 5660-1 ISO 5659-2 Ds ISO 5659-2 VOF ISO 5659-2 CIT
R10	Floor composites	EN ISO 9239-1 ISO 5560-1 EN ISO 5659-2 Ds EN ISO 5659-2 CIT

// Harmonized fire regulations in Europe

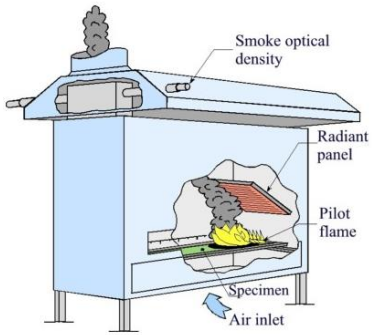
/ EN45545-2:2013 R10 - EN ISO 9239-1

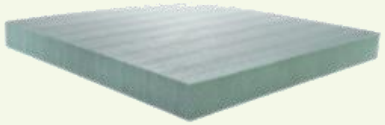
EN ISO 9239-1
„Reaction to fire tests for floorings – Part 1: Determination of the burning behaviour using a radiant heat source”

- The test specimen is placed in a horizontal position below a gas-fired radiant panel inclined at 30° where it is exposed to a defined heat flux. A pilot flame is applied to the hotter end of the specimen. Following ignition, any flame front which develops is noted and a record is made of the progression of the flame front horizontally along the length of the specimen in terms of the time it takes to spread to defined distances.
- The heat energy measured at the point of extinction is the Critical Heat Flux (CHF). AKA the Critical Radiant, and it reflects the lowest energy a fire requires to keep burning (so the higher, the better). The smoke production is also recorded during the test.

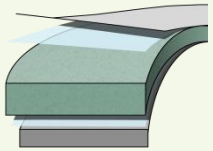
Class limits:

Parameter [unit]	HL1	HL2	HL3
CHF [kW/m²]	4,5	6	8





PET Core
Structural foam cores



PET sandwich
Structural composites

ArmaForm PET GFR70
CHF> 11 kW/m²
HL3

ArmaForm PET FR100 with aluminium layers
CHF> 11 kW/m²
HL3

// Harmonized fire regulations in Europe

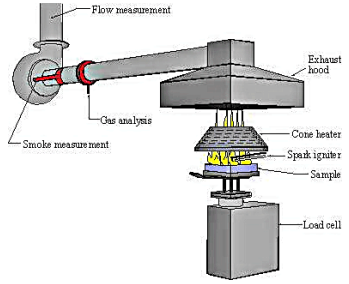
/ EN45545-2:2013 R10 - ISO 5660-1

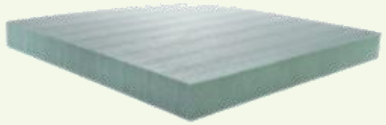
ISO 5660-1
„Reaction to fire tests - Heat release, smoke production and mass loss rate - Part 1: Heat release rate (cone calorimeter method) and smoke production rate (dynamic measurement)”

- In the Cone Calorimeter, specimens of 0.1 by 0.1 m are exposed to controlled levels of radiant heating. The specimen surface is therefore heated up and an external spark ignitor ignites the pyrolysis gases from the specimen. The gases are collected by a hood and extracted by an exhaust fan.
- The heat release rate (HRR) and the maximum average rate of heat emissionis (MAHRE) are determined by measurements of the oxygen consumption derived from the oxygen concentration and the flow rate in the exhaust duct. The specimen is placed on a load cell during testing. A retainer frame covers the periphery of the specimen. Smoke production rate is measured with a laser system.

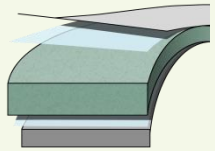
Class limits:

Parameter [unit]	HL1	HL2	HL3
MARHE @25 kW/m² [kW/m²]	-	-	-





PET Core
Structural foam cores



PET sandwich
Structural composites

ArmaForm PET GFR70
MAHRE –
HL3

ArmaForm PET FR100 with aluminium layers
MAHRE –
HL3

// Harmonized fire regulations in Europe

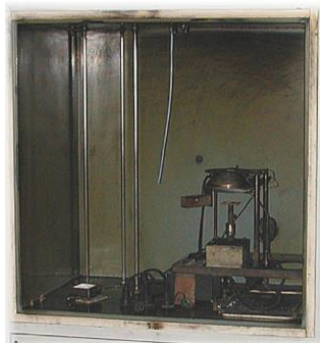
/ EN45545-2:2013 R10 – EN ISO 5659-2:2017

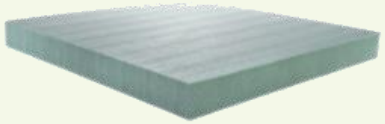
EN ISO 5659-2:2017
„ Plastics - Smoke generation - Part 2: Determination of optical density by a single-chamber test”

- The test is conducted in a sealed chamber. The test sample is placed horizontally and subjected to thermal radiance. When the specimen is subjected to the irradiance it starts to emit smoke which is collected in the chamber.
- The smokes specific optical density (transparency) is measured with a light source and a photo cell.
- Analysis is performed for one of the three irradiance levels, in this case it was 25 kW/m2.

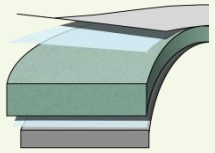
Class limits:

Parameter [unit]	HL1	HL2	HL3
$D_{s\,max}$ at 25 kW/m	600	300	150





PET Core
Structural foam cores



PET sandwich
Structural composites

ArmaForm PET GFR70
D_{s4} = 33
VOF_4 = 49
D_m = 270 → HL2

ArmaForm PET FR100 with aluminium layers
D_{s4} = 0
VOF_4 = 1
D_m = 3 → HL3

// Harmonized fire regulations in Europe

/ EN45545-2:2013 R10 – EN ISO 5659-2:2017

EN ISO 5659-2:2017 Annex C – Smoke toxicity

- Testing procedure identical to the described earlier smoke toxicity test (the same German standard **EN ISO 5659-2:2013)**
- During the test some of the produced smoke is taken out of the chamber for analysis.
- Analysis is performed for the irradiance level of 25 kW/m^2, with a pilot flame. The limits for conventional toxicity index (CIT) are defined as follows:

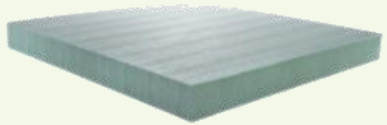
Class limits:

CIT limits

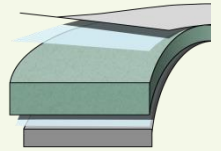
ITC (French naming for FED)

ITC(t) ≤ 1 t=4 min or 8 min.

Gas component		CIT [mg/m^3]
Carbon dioxide	CO_2	72000
Carbon monoxide	CO	1380
Hydrogen fluoride	HF	25
Hydrogen chloride	HCl	75
Hydrogen bromide	HBr	99
Hydrogen cyanide	HCN	55
Nitrogen oxides	NO_x	38
Sulfur dioxide	SO_2	262



PET Core
Structural foam cores



PET sandwich
Structural composites

ArmaForm PET GFR70

ITC_{4min} = 0,00

ITC_{8min} = 0,01

ArmaForm PET FR100 with aluminium layers

ITC_{4min} = 0,00

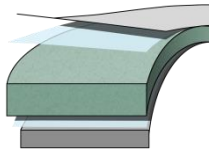
ITC_{8min} = 0,01

Gas	CIT4 / CIT8 [mg/m^3]	
	GFR70	FR100/alu
CO_2	1908 / 4472	1792 / 4463
CO	37 / 113	12 / 35
HF, HCl, HBr, HCN, NO_x, SO_2 - not detected		

// Harmonized fire regulations in Europe

/ EN45545-2:2013 R1

- Testing accordingly to the R1 requirements in on-going for the sandwich of ArmaForm PET FR100 with aluminium skins
- Results are expected to come in Q2 2018



PET sandwich
Structural composites

- Slide to be updated – we have pass results…

For further questions or comments please contact:

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