THE HONG KONG INSTITUTION OF ENGINEERS
香港工程師學會

CPD Seminar:

Importance of Reaction-to-Fire Properties of Materials:

Combustibility, Spread of Flame and Smoke Generation

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Agenda

Section 1: Reaction to fire test standards

Section 2: Reaction to fire tests – BS 476 series

Section 3: Reaction to fire tests – BS EN 13501-1 series

Section 4: Q & A

Section 1

Reaction to fire test standards

Reaction-to-fire tests

- Testing of material, not a system!
- Testing for lining or decorative material
  - Check the combustibility, flame spread, smoke development, ignitability or heat release rate
  - Material that likely to catch fire and its contribute to fire
- BS 476 Series:
  - BS476: Part 4, BS 476: Part 6, BS 476: Part 7 and BS 476: Part 12
- BS EN 13501-1: 2007 + A1: 2009
  - Class A1: ISO 1182 and ISO 1716
  - Class A2: ISO 1182 and ISO 1716 or EN 13823 (SBI)
  - Class B to E: EN 13823 and ISO 11925-2
  - Class F: ISO 11925-2

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Reaction to fire tests

- Testing of material, not a system!
  - Specimens may not in the form as its used in practice

- BS 476-4 test

- BS 476-7 test

Reaction to fire tests

- **London fire: Grenfell Tower**

Section 2

Reaction to Fire Tests – BS 476 series

Reaction to fire tests

- Reaction to fire tests – BS 476 series
- BS 476: Part 4 – Combustibility of materials
- BS 476: Part 6 – Test for fire propagation (heat release rate)
- BS 476: Part 7 - Test for surface flame spread
- BS 476: Part 12 – Ignitability of materials
  - Lack of smoke generation rate considered
  - Limitation due to orientation and jointing method

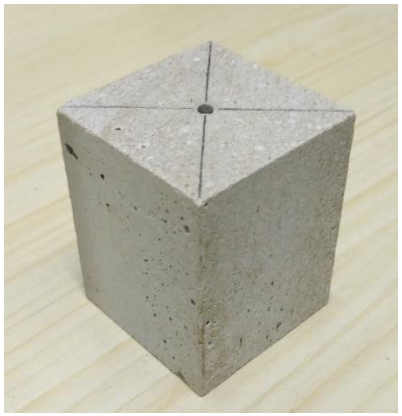
BS 476: Part 4 - Combustibility

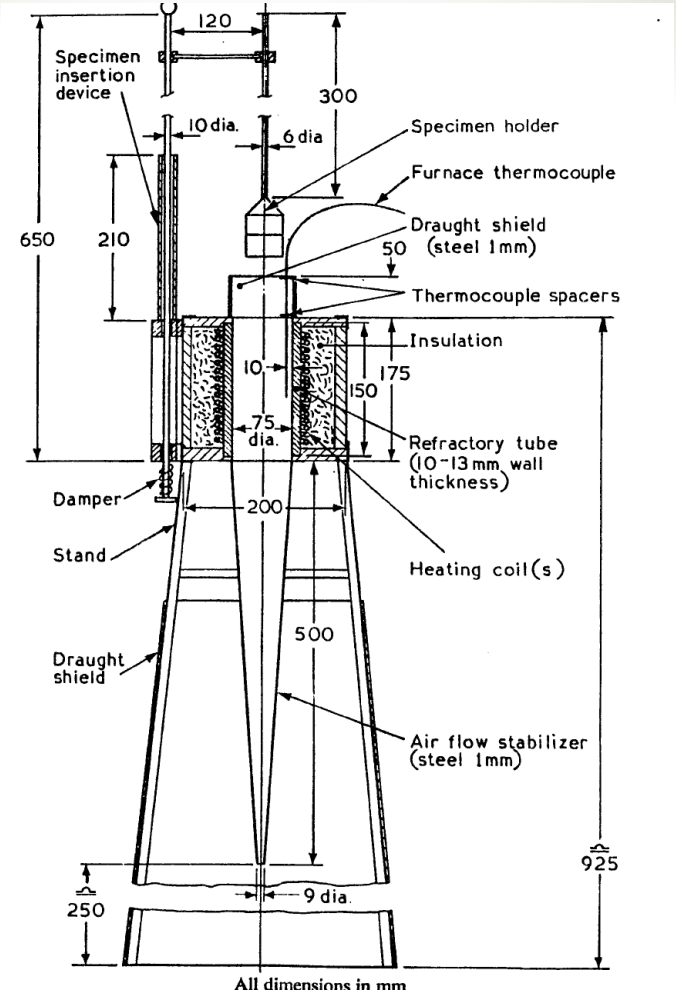
- Checking of the combustibility of a material
- Specimens in a cube form
  - 40 mm (w) x 40 mm (l) x 50 mm (h)
- At least three specimens to be tested
- Specimens put into a tube furnace maintained at 750 ^{o}C
- Performance criteria for non-combustible
  - Furnace temperature rise more than 50 ^{o}C
  - Specimen center temperature rise more than 50 ^{o}C
  - Flaming continuously for more than 10s during the test

BS 476: Part 4 - Combustibility

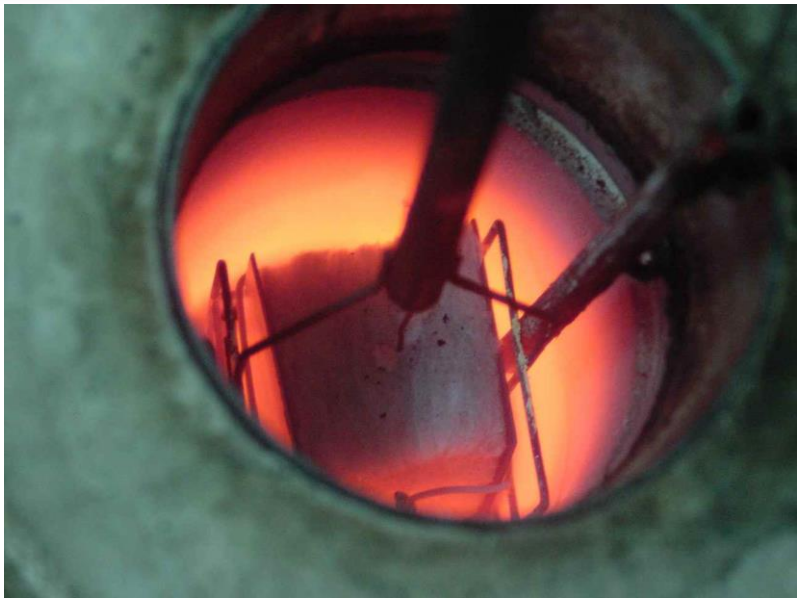
- So what is definition of combustible?
  - Flaming observed when the material subjected to 750 ^{o}C
  - Exothermic reaction occurs, even there are no flame observed

BS 476: Part 4 - Combustibility





BS 476: Part 4 - Combustibility



BS 476: Part 4 - Combustibility

- **Limitation**
  - Furnace temperature up to 750 ^{o}C only?
  - Flame temperature usually up to 1000 ^{o}C
- **Product arrangement**
  - Insulation foam sandwiched with aluminum facings
  - Aluminum with coatings, test separately?

BS 476: Part 11 or Class '0' – Limited Combustibility

- **BS 476-11 – Test to determine limited combustibility**
  - Not been required in HK
  - Test procedure similar to BS 476-4
  - No criteria given in the standard, refer to project specification or approval justice

- **Class '0'**
  - Combine the results from BS 476-6 and BS 476-7
  - BS 476-6, Total index < 12, sub index <6
  - BS 476-7, Class 1
  - i.e. limited flame spread (< 165 mm) and low heat release

BS 476: Part 6 – Fire Propagation

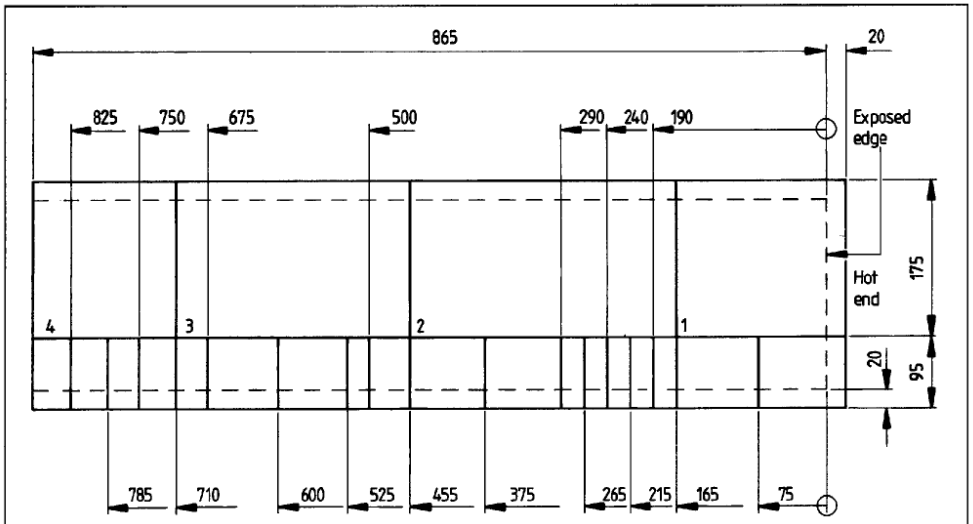
- BS 476: Part 6 – Test for fire propagation (heat release rate)
- Upon heating checking the temperature rise at different period of time
- The temperature rise
  - to certain extent co-relate to the heat release rate
- Total index I, Sub index i_1, i_2 and i_3
- No pass or fail criteria if testing the standard alone
- A supplement information if needs to classify to 'Class 0'

BS 476: Part 7 – Surface Flame Spread

- **BS 476: Part 7 – Surface flame spread**
  - **Under a specific heating condition, the flame spread distance and the time for such spread distance**
  - **The specimen should have an essentially flat surface for assessment**
  - **A radiation panel to provide radiation heat flux to the product tested surface**
  - **A pilot flame to ignite the specimen at the first minute of the test**

BS 476: Part 7 – Surface Flame Spread

- **Marking on the specimens to show the spread distance**



Distances from inside edge of specimen holder

All dimensions are in millimetres

Figure 7. Reference lines to assist surface spread of flame classification

Table 2. Classification of spread of flame

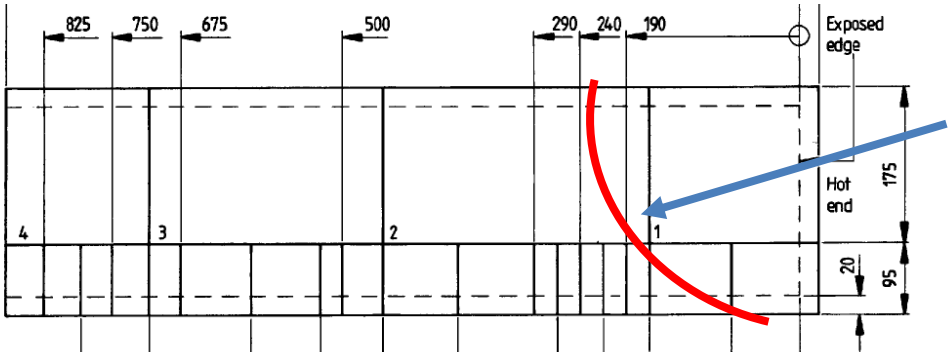
Classification	Spread of flame at 1.5 min		Final spread of flame	
	Limit	Limit for one specimen in sample	Limit	Limit for one specimen in sample
	mm	mm	mm	mm
Class 1	165	165 + 25	165	165 + 25
Class 2	215	215 + 25	455	455 + 45
Class 3	265	265 + 25	710	710 + 75
Class 4	Exceeding the limits for class 3			

Reaction to fire tests

- **Ref: RED – BS 476-7**

BS 476: Part 7 – Surface Flame Spread

- **Flame spread will be counted only if the flame front at the horizontal reference line was observed**



Flame spread distance record when flame front reach reference line position only

- **The specimen was orientated in horizontal direction**
  - **The flame spread is vertical (buoyancy?) or horizontal**
  - **The result for a tested flat surface represent the case in practice?**

BS 476: Part 12 - Ignitibility

- Using different fire source to ignite the material
- Ignition source from A to G
  - Ignition source ‘A’ - small flame simulating fault conditions in electrical equipment.
  - Ignition source ‘B’ is simulating a burning match.
  - Ignition source ‘C’ is simulating a cigarette lighter.
  - Ignition source ‘D’ is simulating burning crumpled newspaper.
  - Ignition source ‘E’ is simulating the flame produced by a flaming chip pan, three minutes after ignition of the cooking oil.
  - Ignition source ‘F’ is simulating a plumbers blow torch.
  - Ignition source ‘G’ is simulating a roofers torch.

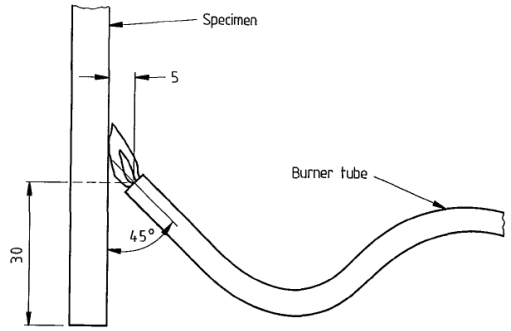
BS 476: Part 12 - Ignitibility

- **Purpose to find out:**
  - **Whether a sustained ignition (more than 10s or transient ignition (less than 10s)**
  - **Whether debris separates and whether it is flaming or glowing**
  - **Whether flaming reach any edge within 10s of the end of the flame application time**
  - **Whether flaming or glowing reaches any edge during application of the ignition source**

BS 476: Part 12 - Ignitibility

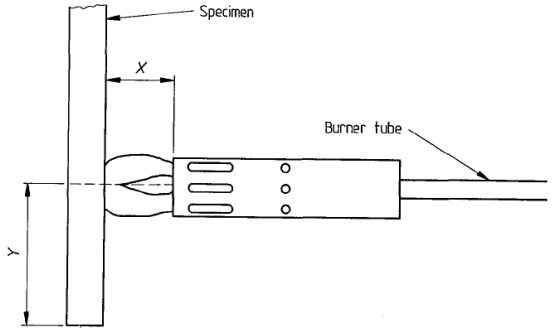
Different ignition methods

Face ignition

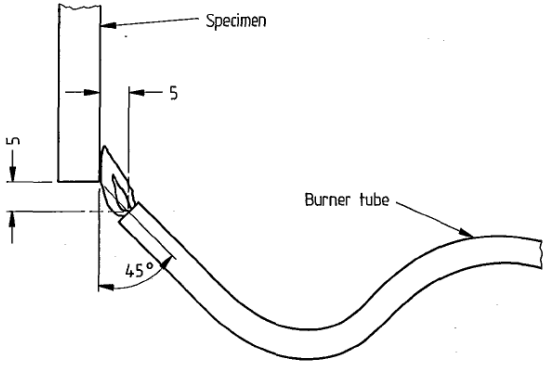


All linear dimensions are in millimetres.

(a) Sources A, B, C, D and E

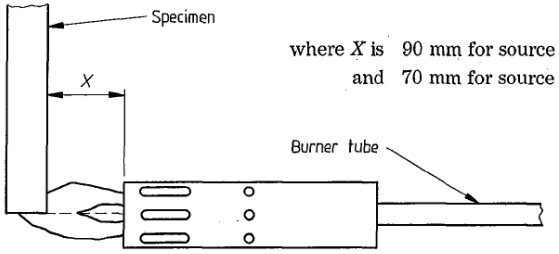


Bottom edge ignition



All dimensions are in millimetres.

(a) Sources A, B, C, D and E



where X is 90 mm for source F
and 70 mm for source G

Reaction to Fire tests: BS 476 Series

- Had been used in UK and HK for more than 20 years
- The tests considered the combustibility, flame spread and the ignitibility only
- No consideration about the smoke and toxicity generation during burning
- In case the material defined as non-combustible when tested to BS 476-4, it needs to conduct test to BS 476-6 and BS 476-7?

Section 3

Reaction to Fire Tests – BS EN 13501-1 series

Reaction to Fire tests: BS EN 13501-1 Series

- BS EN 13501-1: 2007 + A1: 2009
- For construction products excluding floorings and linear pipe thermal insulation:
  - Class A1: ISO 1182 and ISO 1716
  - Class A2: ISO 1182 and ISO 1716 or EN 13823 (SBI)
  - Class B to E: EN 13823 and ISO 11925-2
  - Class F: ISO 11925-2
- For flooring
  - EN 13823 replaced by ISO 9239-1

Reaction to Fire tests: BS EN 13501-1 Series

- **Table 1 extracted from BS EN 13501-1: 2007 + A1: 2009**

Table 1 — Classes of reaction to fire performance for construction products excluding floorings and linear pipe thermal insulation products

Class	Test method(s)	Classification criteria	Additional classification
A1	EN ISO 1182 [a] and	$\Delta T \leq 30$ °C; and $\Delta m \leq 50$ %; and $t_f = 0$ (i.e. no sustained flaming)	-
	EN ISO 1716	$PCS \leq 2{,}0$ MJ/kg [a] and $PCS \leq 2{,}0$ MJ/kg [b c] and $PCS \leq 1{,}4$ MJ/m^2 [d] and $PCS \leq 2{,}0$ MJ/kg [e]	-
A2	EN ISO 1182 [a] or	$\Delta T \leq 50$ °C; and $\Delta m \leq 50$ %; and $t_f \leq 20$ s	-
	EN ISO 1716 and	$PCS \leq 3{,}0$ MJ/kg [a] and $PCS \leq 4{,}0$ MJ/m^2 [b] and $PCS \leq 4{,}0$ MJ/m^2 [d] and $PCS \leq 3{,}0$ MJ/kg [e]	-
	EN 13823	$FIGRA \leq 120$ W/s and $LFS <$ edge of specimen and $THR_{600s} \leq 7{,}5$ MJ	Smoke production [f] and Flaming droplets/particles [g]
B	EN 13823 and	$FIGRA \leq 120$ W/s and $LFS <$ edge of specimen and $THR_{600s} \leq 7{,}5$ MJ	Smoke production [f] and Flaming droplets/particles [g]
	EN ISO 11925-2 [i]: Exposure = 30 s	$F_s \leq 150$ mm within 60 s	
C	EN 13823 and	$FIGRA \leq 250$ W/s and $LFS <$ edge of specimen and $THR_{600s} \leq 15$ MJ	Smoke production [f] and Flaming droplets/particles [g]
	EN ISO 11925-2 [i]: Exposure = 30 s	$F_s \leq 150$mm within 60 s	
D	EN 13823 and	$FIGRA \leq 750$ W/s	Smoke production [f] and Flaming droplets/particles [g]
	EN ISO 11925-2 [i]: Exposure = 30 s	$F_s \leq 150$ mm within 60 s	
E	EN ISO 11925-2 [i]: Exposure = 15 s	$F_s \leq 150$ mm within 20 s	Flaming droplets/particles [h]
F	No performance determined		

[a] For homogeneous products and substantial components of non-homogeneous products.
[b] For any external non-substantial component of non-homogeneous products.
[c] Alternatively, any external non-substantial component having a $PCS \leq 2{,}0$ MJ/m^2, provided that the product satisfies the following criteria of EN 13823: $FIGRA \leq 20$ W/s, and $LFS <$ edge of specimen, and $THR_{600s} \leq 4{,}0$ MJ, and s1, and d0.
[d] For any internal non-substantial component of non-homogeneous products.
[e] For the product as a whole.
[f] In the last phase of the development of the test procedure, modifications of the smoke measurement system have been introduced, the effect of which needs further investigation. This may result in a modification of the limit values and/or parameters for the evaluation of the smoke production.
s1 = $SMOGRA \leq 30$ m^2/s^2 and $TSP_{600s} \leq 50$ m^2 ; **s2** = $SMOGRA \leq 180$ m^2/s^2 and $TSP_{600s} \leq 200$ m^2; **s3** = not s1 or s2
[g] **d0** = No flaming droplets/ particles in EN 13823 within 600 s;
d1 = no flaming droplets/ particles persisting longer than 10 s in EN 13823 within 600 s;
d2 = not d0 or d1.
Ignition of the paper in EN ISO 11925-2 results in a d2 classification.
[h] Pass = no ignition of the paper (no classification);
Fail = ignition of the paper (**d2** classification).
[i] Under conditions of surface flame attack and, if appropriate to the end–use application of the product, edge flame attack.

Reaction to Fire tests: BS EN 13501-1 Series

- **Table 2 extracted from BS EN 13501-1: 2007 + A1: 2009**

Table 2 — Classes of reaction to fire performance for floorings

Class	Test method(s)	Classification criteria	Additional classifications
$A1_{fl}$	EN ISO 1182 [a] and	$\Delta T \leq 30$ °C; and $\Delta m \leq 50$ %; and $t_f = 0$ (i.e. no sustained flaming)	-
	EN ISO 1716	$PCS \leq 2{,}0$ MJ/kg [a] and $PCS \leq 2{,}0$ MJ/kg [b] and $PCS \leq 1{,}4$ MJ/m^2 [c] and $PCS \leq 2{,}0$ MJ/kg [d]	-
$A2_{fl}$	EN ISO 1182 [a] or	$\Delta T \leq 50$ °C and $\Delta m \leq 50$ % and $t_f \leq 20$ s	-
	EN ISO 1716 and	$PCS \leq 3{,}0$ MJ/kg [a] and $PCS \leq 4{,}0$ MJ/m^2 [b] and $PCS \leq 4{,}0$ MJ/m^2 [c] and $PCS \leq 3{,}0$ MJ/kg [d]	-
	EN ISO 9239-1 [e]	Critical flux [f] $\geq 8{,}0$ kW/m^2	Smoke production [g]
B_{fl}	EN ISO 9239-1 [e] and	Critical flux [f] $\geq 8{,}0$ kW/m^2	Smoke production [g]
	EN ISO 11925-2 [h]: Exposure = 15 s	$Fs \leq 150$ mm within 20 s	-
C_{fl}	EN ISO 9239-1 [e] and	Critical flux [f] $\geq 4{,}5$ kW/m^2	Smoke production [g]
	EN ISO 11925-2 [h]: Exposure = 15 s	$Fs \leq 150$ mm within 20 s	-
D_{fl}	EN ISO 9239-1 [e] and	Critical flux [f] $\geq 3{,}0$ kW/m^2	Smoke production [g]
	EN ISO 11925-2 [h]: Exposure = 15 s	$Fs \leq 150$ mm within 20 s	-
E_{fl}	EN ISO 11925-2 [h]: Exposure = 15 s	Fs ≤ 150 mm within 20 s	-
F_{fl}	No performance determined		

[a] For homogeneous products and substantial components of non-homogeneous products.
[b] For any external non-substantial component of non-homogeneous products.
[c] For any internal non-substantial component of non-homogeneous products.
[d] For the product as a whole.
[e] Test duration = 30 min.
[f] Critical flux is defined as the radiant flux at which the flame extinguishes or the radiant flux after a test period of 30 min, whichever is the lower (i.e. the flux corresponding with the furthest extent of spread of flame).
[g] **s1** = Smoke ≤ 750 % minutes;
s2 = not s1.
[h] Under conditions of surface flame attack and, if appropriate to the end use application of the product, edge flame attack.

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Reaction to Fire tests: BS EN 13501-1 vs BS 476

Class	Test required	
Non combustible	BS 476-4	Temp rise ≤ 50oC No sustained flame
Class A1	ISO 1182	Temp rise ≤ 30 oC Mass loss ≤ 50% No sustained flaming
	ISO 1716	PCS ≤ 2.0 MJ/kg for homogeneous or substantial components PCS ≤ 2.0 MJ/kg for external non-substantial component PCS ≤ 1.4 MJ/m^2 for internal non-substantial component PCS ≤ 2.0 MJ/kg for the whole product

Reaction to Fire tests: BS EN 13501-1 vs BS 476

Class	Test required	
Limited combustibility	BS 476-11 Or Class '0'	BS 476-6, Total index ≤ 12, sub index ≤ 6 BS 476-7, Class 1
Class A2	ISO 1182	Temp rise ≤ 50 °C Mass loss ≤ 50% Sustained flaming time < 20s
	ISO 1716	PCS ≤ 3.0 MJ/kg for homogeneous or substantial components PCS ≤ 4.0 MJ/m^2 for external non-substantial component PCS ≤.4.0 MJ/m^2 for internal non-substantial component PCS ≤ 3.0 MJ/kg for the whole product
	EN 13823	FIGRA ≤120 W/s and LFS < edge of specimen and THR_{600s} ≤ 7.5 MJ

Reaction to Fire tests: BS EN 13501-1 vs BS 476

Class	Test required	
Limited combustibility	BS 476-11 Or Class '0'	BS 476-6, Total index ≤ 12, sub index ≤ 6 BS 476-7, Class 1
Class A2	ISO 1182	Temp rise ≤ 50 °C Mass loss ≤ 50% Sustained flaming time < 20s
	ISO 1716	PCS ≤ 3.0 MJ/kg for homogeneous or substantial components PCS ≤ 4.0 MJ/m^2 for external non-substantial component PCS ≤.4.0 MJ/m^2 for internal non-substantial component PCS ≤ 3.0 MJ/kg for the whole product
	EN 13823	FIGRA ≤120 W/s and LFS < edge of specimen and THR600s ≤ 7.5 MJ SMOGRA ≤ 30 or 180m^2/s^2 and TSP ≤ 50m^2 or 200 m^2 No flaming droplets within 600s Or not flaming droplets last for 10s within 600s

Reaction to Fire tests: BS EN 13501-1 vs BS 476

Class	Test required	
Class 1-4 and/or Ignitibility	BS 476-7 and/or BS 476-12	BS 476-7, Class 1-4 BS 476-12, different ignition source, observation of flaming
Class B-D	EN 13823	FIGRA ≤120 or 250 or 750 W/s and LFS < edge of specimen or no specification THR_{600s} ≤ 7.5 or 15 MJ SMOGRA ≤ 30 or 180m^2/s^2 and TSP ≤ 50m^2 or 200 m^2 No flaming droplets within 600s Or not flaming droplets last for 10s within 600s
	ISO 11925-2 (exposure time = 30s)	FS ≤ 150 within 60s
Class E	ISO 11925-2 (exposure time = 15s)	FS ≤ 150 within 20s
Class F	No performance required	

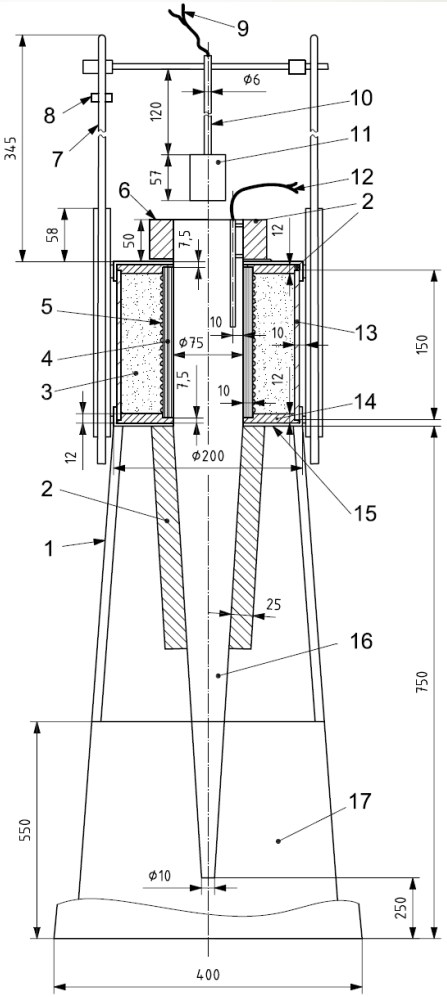
BS EN ISO 1182

- Checking of the combustibility of a material
- Specimens in a cylindrical form
  - 45 mm diameter x 50 mm (h)
- At least five specimens to be tested
- Specimens put into a tube furnace maintained at 750 ^{o}C
- Criteria for non-combustible given in BS EN 13501-1
  - Furnace temperature rise more than 30 ^{o}C
  - Mass loss more than 50% of the original dried mass
  - Flaming continuously for more than 10s during the test

BS EN ISO 1182

- **Furnace for ISO 1182**

- **Difference from BS 476-4**
  - **Specimen in cylindrical shape**
  - **Mass loss needs to be measured**
  - **The definition of stabilization at 750 ^{o}C are different**



Reaction to fire tests

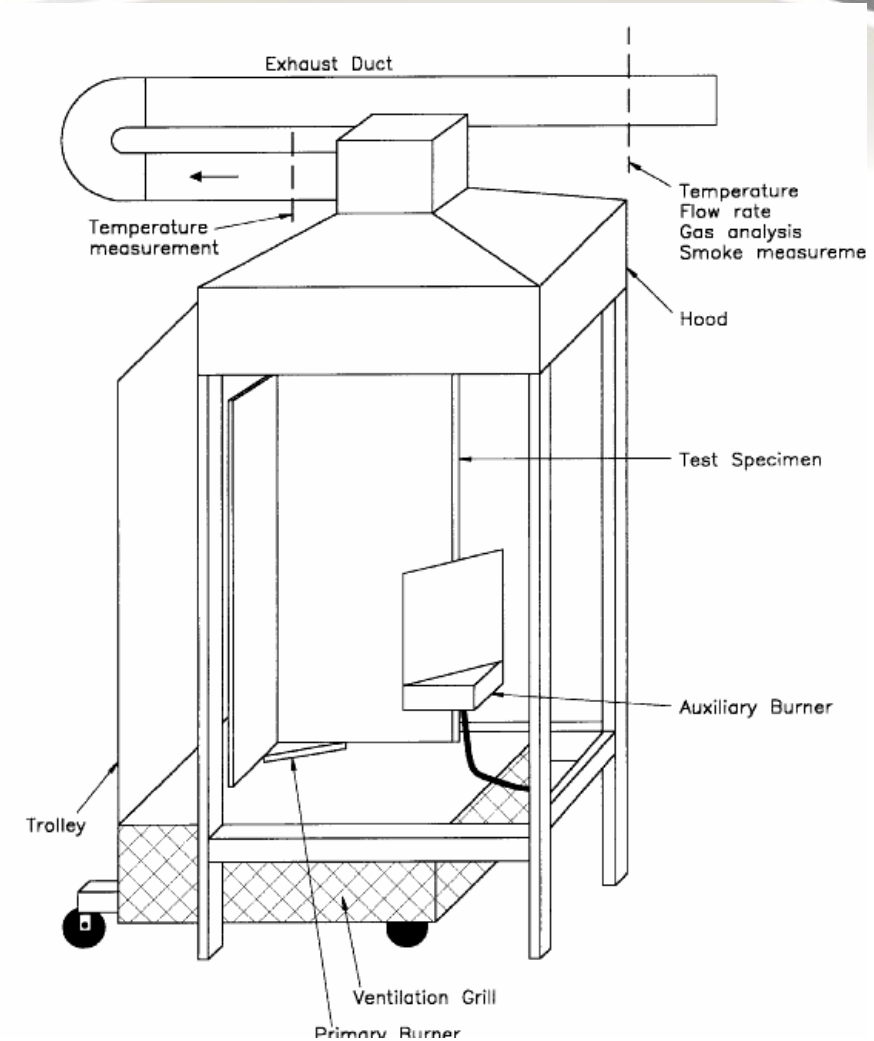
- **Ref:** Laboratorio de fuego – ISO 1182 (BS 476-4)

BS EN 13823 – Single Burning Item (SBI)

- A core test in the BS EN 13501-1 series
- An upgraded version of BS 476-6 and BS 476-7
- Flame spread in both vertical and horizontal directions are considered
- A corner config to be tested instead of just a flat surface
- The smoke generation and flaming droplets shall be considered as well
- Ignition source by gas burner
- More precise measurement in Heat Release Rate

BS EN 13823 – Single Burning Item (SBI)

- Fire Growth Rate Index (FIGRA)
- Total heat release rate over the first 10 minutes of the test (THR_{600s})
- Smoke Growth Rate (Simogra)
- Total smoke Production over the first 10 minutes (TSP_{600s})



Reaction to fire tests

- **Ref:** Laboratorio de fuego – SBI

BS EN 11925-2 – Small Flame Test

- Test method similar to BS 476-12
- One ignition source to be used only
- Six specimens to be tested
- Checking the ignitability of a material
  - Subjected to direct impingement of flames
  - Surface ignition
  - Bottom edge ignition
- Flame application
  - 15 s exposure time, total test duration 20 s
  - 30 s exposure time, total test duration 60 s

BS EN 11925-2 – Small Flame Test

- **Be careful the cutting direction of the specimens**
  - **Half of the submitted specimens shall be cut in direction of production**
  - **Another half of the specimens shall be cut in 90º to the direction of production**

Reaction to fire tests

- **Ref:** Laboratorio de fuego – ISO 11925

Fire Resistance vs Reaction to Fire

- **Fire Resistance is the ability of a system to resist the fire (the heating condition refer to standard fire curve) for a period of time (60 mins, 120 mins or 240 mins**
  - **The material to build the system need no to be non-combustible**
  - **E.g. Timber fire door, fire rated sealant**

- **Reaction to fire is the properties of a material when subjected to a specific heating condition (not refer to standard fire curve)**
  - **The material flame spread**
  - **The smoke generation**
  - **The heat release rate**
  - **Any flaming droplets**
  - **Or even the toxicity**

Fire Resistance vs Reaction to Fire

- **Fire Resistance and Reaction to Fire**
  - **Never substituting each other**

- **They are of equal importance**
  - **Fire Resistance product to prevent fire spread from one compartment to another**
  - **Reaction to fire properties of material prevent the flame spread, too much smoke/toxicity generation and the contribution of the material to the fire within a compartment**

Reaction to fire tests

- London fire: Grenfell Tower
- Importance of façade wall reaction to fire properties
- BS 8414 – Fire Performance of external cladding systems
- Practice in HK:
  - Material for façade cladding
    - Non-combustible

Reaction to fire tests

- **Non-combustible material used for façade cladding**
  - **All materials are non-combustible?**
    - **Coating on aluminum?**
    - **Insulation material – glass fiber, or even rockwool?**
    - **Fire sealant?**
    - **Weather sealant?**
- **When all the individual materials integrated to form a system, any influence to the overall performance?**
  - **Flame penetration through the façade**
  - **Aluminum soft and start to melt at 750 ^{o}C (temp for combustibility test)**
  - **How about if the material behind the façade is combustible?**
  - **Fire may reach the temperature exceed 1000 ^{o}C**

Reaction to fire tests

- **Façade design with the incorporation of combustible materials but well designed to meet the performance criteria**
  - **Allow innovative design**
  - **Confirm the reaction to fire performance meet the safety level**

- **Australia, Singapore, UK and EU required the façade to be tested to BS 8414-2**
  - **The behavior of a system may not be possible to predict from the materials' properties alone**
  - **Allow for innovative design, new materials for façade wall**

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Q and A Section

- **Thank you for your attention**