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The Effective Parameters for Reaction-to-fire Properties of Expanded Polystyrene Foams in Bench Scale

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ABSTRACT

Fire behaviour of different types of expanded polystyrene (EPS) was studied with the use of ISO 5660 cone calorimeter test method. The roles played by specimen density and thickness on fire performance of the foam were examined. The relationship between the fire properties of specimens, such as total-heat-release and heat-release-rate, with their densities and thicknesses was determined. The thickness of specimens played two contradictory roles on fire behaviour of specimens. On the one hand, due to rapid melting the specimen received less heat energy relative to the calibrated level and hence the ignition was delayed. On the other hand, the available mass for combustion reactions increased, which resulted in higher heat and smoke release (both total and rates). This should be carefully considered in interpretation of fire test results of EPS foam in predicting its fire risk. It was revealed that both average and the peak-of-heat-release-rates were directly dependent on density of the foam and increased with it. A good repeatability for heat-release-rate was obtained in this method, but this was not held for ignitability of specimens. The results showed that time-to-ignition cannot be a characteristic value to make distinction between the standard and fire retarded types of EPS in cone calorimeter test, but peak-heat-release-rate values can be well utilized for this purpose.

Key Words:

expanded polystyrene;
fire behaviour;
heat release;
smoke;
cone calorimeter.

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INTRODUCTION

Expanded polystyrene (EPS) foam has found many applications in building construction, because of its low thermal conductivity, light weight and good physical properties. EPS is vastly used as thermal insulation, permanent forms for concrete (like insulated concrete form or "ICF" system) and core of sandwich panels. Many attempts have been made on physical and mechanical properties of EPS. For instance, Gnip et al. [1-3] studied water absorption, tensile strength, and compressive creep of EPS. Doroudiani et al. have investigated the relationships between processing, structure and some mechanical properties of EPS and the effects of foam density on its strength and tensile modulus [4-6].

However, using EPS foams in buildings can increase the fire risk. Therefore its reaction to fire should be well understood and proper fire safety precautions must be taken into account. Reaction to fire is defined by EN 13501-1 [7] as "response of a product contributed by its own decomposition to a fire to which is exposed under specified conditions". Heat-release-rate (HRR), total-heat-release (THR), effective-heat-of-combustion (EHC) and smoke density are the most important reaction-to-fire properties of materials, which should be considered. These properties are very important to characterize the fire performance of a material for fire safety design of buildings.

The fire performance of EPS products has been tested by some researchers with both small and full-scale test methods [8-11]. The full scale tests are expensive and not available to many researchers or code authorities. Therefore, testing on a small scale like cone calorimeter test method is much more interesting. However, it is important that all the effective parameters should be well recognized and quantified; nevertheless it may lead to faulty interpretations. Studying previous works on the fire performance of EPS [10-14] does indicate that some important parameters, like density and thickness of foam have not been taken into consideration. Scudamore et al. [10] have reported the fire performance of EPS with cone calorimeter, though his investigation includes the results of only a few tests on EPS foams and the roles of density and thickness of the specimens which have an important influence on fire behaviour of EPS, have not been covered. Collier et al. [11] have reported only one cone calorimeter test result for EPS, which is obviously different with the results of Scudamore et al. A comparison of their results on fire retarded (FR) and standard (N-FR) type of EPS is shown in Table 1.

Characterization of smoke in EPS combustion of both standard and FR-EPS have been investigated by Rossi et al. [15]. The results showed that the fire retardant additives somewhat modify the characteristics of EPS combustion and composition of the smoke. Jovanovic et al. have conducted tests on combustion of gases and the toxicity of EPS at high temperatures [16].

In this work, the fire performance of standard and FR types of EPS foams has been investigated by ISO 5660 cone calorimeter in Fire Laboratory of Building & Housing Research Center (BHRC). In order to obtain more accurate results, the number of test specimens was increased. The influence of density and thickness of specimens on fire behaviour of the foams, which was not considered by previous published works, has also been investigated.

EXPERIMENTAL

Materials

Standard and FR-EPS blocks were provided from commercial sources. The physical, mechanical and

Table 1. Comparison of results obtained by Scudamore et al. [10] and Collier et al. [11].

Fire parameter	Heat flux (kW/m^2)	Fire retarded-expanded polystyrene		Standard expanded polystyrene	
		Ref. [10]	Ref. [11]	Ref. [10]	Ref. [11]
TTI (s)	20	NI	No data	NI	193
	30	77	120	73	78
	40	40	No data	28	No data
	50	24	37	18	26
PHRR (kW/m^2)	20	NI	No data	NI	295.5
	30	238	193.4	299	319.7
	40	321	No data	394	No data
	50	379	305.6	407	507.3
Av. SEA (m^2/kg)	20	NI	No data	NI	1255
	30	1461	1351	1317	1261
	40	1334	No data	1200	No data
	50	1297	1394	1346	1174

TTI: time-to-ignition; PHRR: peak-heat-release-rate; Av. SEA: average-specific-extinction-area.

thermal properties of samples were tested according to EN and ASTM standards, before fire tests. Test results on all samples satisfied the ASTM C578:2001 [17] and EN 13163:2001 [18] requirements.

Test Method and Equipment

The tests were carried out according to ISO 5660-1:2002 test method with an FTT Dual Cone Calorimeter apparatus, made in England. The design of the apparatus is based on the oxygen consumption theory [19-22].

RESULTS AND DISCUSSION

The obtained results are presented in Tables 2-4 and Figures 1-9. It is quite clear that the results obtained from only few specimens cannot accurately describe the fire performance of EPS.

The Foam Density Effect

Density of EPS foam has a considerable influence on its properties, including its fire performance. By increasing the density of the material, the available

Table 2. Cone calorimeter results for FR-EPS specimens at 35 kW/m^2.

Specimen No.	1	2	3	4	5	6	7	8	9
ρ, nominal (kg/m^3)	11						14		
ρ, measured (kg/m^3)	10.4	10.4	10.8	10.8	11.5	11.5	13.0	13.2	15.4
ρ, average (kg/m^3)	10.9						13.9		
TTI (s)	95.00	168.00	470.00	76.00	202.00	70.00	571.00	126.00	97.00
FO (s)	360.00	348.00	667.00	258.00	360.00	486.00	725.00	300.00	341.00
Av. HRR (kW/m^2)	69.30	42.10	61.50	65.30	52.80	44.60	63.10	74.10	76.10
PHRR (kW/m^2)	142.30	172.50	173.60	180.30	147.50	155.70	105.30	205.50	258.20
T PHRR (s)	100.00	175.00	505.00	78.00	207.00	75.00	580.00	135.00	110.00
Av. MLR$_{(10-90)\%}$ (g/m^{2}s)	2.72	2.17	1.10	2.62	1.61	1.58	1.25	2.55	3.09
Av. EHC (MJ/kg)	35.26	19.05	34.76	40.06	30.70	39.26	40.78	31.50	28.08
THR (MJ/m^2)	18.70	9.20	13.60	12.90	9.70	18.60	14.10	13.20	18.50
Specimen No.	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ρ, nominal (kg/m^3)	18			20			30		
ρ, measured (kg/m^3)	17.3	17.5	18.4	20.2	21.5	20.4	31.2	31.7	29.95
ρ, average (kg/m^3)	17.7			20.7			31.0		
TTI (s)	90.00	83.00	70.00	70.00	159.00	63.00	74.00	144.00	39.00
FO (s)	346.00	403.00	500.00	490.00	348.00	254.00	325.00	394.00	234.00
Av. HRR (kW/m^2)	119.50	86.70	72.30	82.70	114.80	99.42	131.70	146.60	158.68
PHRR (kW/m^2)	264.10	242.70	185.00	213.40	232.80	245.41	299.80	235.84	281.70
T PHRR (s)	110.00	90.00	75.00	80.00	204.00	69.00	80.00	184.00	52.00
Av. MLR$_{(10-90)\%}$ (g/m^{2}s)	3.95	3.72	2.66	3.22	5.65	5.10	7.20	6.50	8.40
Av. EHC (MJ/kg)	39.59	34.64	34.42	34.10	29.79	32.09	30.50	30.91	26.27
THR (MJ/m^2)	28.90	27.10	30.10	34.00	22.20	19.50	33.50	37.20	30.90

TTI: time-to-ignition; FO: flame out; Av. HRR: average-heat-release-rate; PHRR: peak-heat-release-rate; T PHRR: time-to-peak-release-rate; Av. MLR$_{(10-90)\%}$: average-mass-loss-rate between times of 10% and 90% of mass loss; Av. EHC: average-effective-heat-of-combustion; THR: total-heat-release.

mass for combustion reactions increases and therefore more intensive combustion is expected. The effect of density was studied with testing of fire-retarded (FR) type specimens with different densities (10-31 kg/m^3). The thickness of the samples was around 40-50 mm. They were tested at a heat flux of 35 kW/m^2. The results are given in Table 2.

Time-to-ignition (TTI)

Time-to-ignition of the specimens did not show any obvious dependency on density of the foams in the examined range. An extensive range of 39-571 s was obtained for all specimens. The time-to-ignition of specimens 3 and 7 showed a considerable deviation from other results. With omitting the data of these two specimens from the results, the range of 39-202 s is obtained for time-to-ignition of EPS with about 90% probability (16 of 18 specimens), which then, the average value is about 102 s. The obtained standard deviation for this data is 43.7.

The repeatability of time-to-ignition (r) in the standard test method [19], in the range of 5 s to 150 s, is presented as follows:

$$r = 4.1 + 0.125\ TTI \quad (1)$$

By considering 102 s as an average value for time-to-ignition, a repeatability of r = 16 s is obtained according to eqn (1), while the test results are much wider. Still if we consider only the results for a specific density, again the obtained range of time-to-ignition of EPS specimens is wider than the repeatability, which is achieved from eqn (1). The reason for this behaviour, and also the reason of notable deviation of time-to-ignition of specimens 3 and 7 with respect to other specimens, is due to the complexity of ignition phenomena of EPS. EPS is thermoplastic foam, which melts at about 100ºC and recedes away heat source, once exposed to high temperatures. Furthermore, as the fire-retardant additives are added only in a slight percent (less than 0.5% by weight), therefore the absence of a retardant in evolved gases, adjacent to ignition source at an instant, may allow the gases to start combustion and release enough energy to persist burning. In conjunction to this, the venting condition of the test method should be also considered, in which fresh air constantly (with a rate of 24 L/s) mixes with evolved gases. These can affect the ignition of specimens in an unpredictable manner. Hence, a wide range of time-to-ignition results may be obtained for EPS specimens. This behaviour is unlike the rigid thermosetting polymeric foams, such as polyurethane (PU) foam. For rigid PU foam, time-to-ignition of 5 s was obtained for many specimens with densities in range of 20-55 kg/m^3 at 35 kW/m^2 [23].

Total-heat-release (THR) and Average-effective-heat-of-combustion (Av. EHC)

The total-heat-release data of EPS specimens with different densities are presented in Table 2. As it can be observed, an increase in density results in higher total-heat-release, which is due to the increase of available mass for combustion. The repeatability of the data is presented in the standard test method [19] in the range of 5-720 MJ/m^2 as follows:

$$r = 7.4 + 0.068\ THR \quad (2)$$

The obtained mean total-heat-release for six specimens with ρ_{av} = 10.9 kg/m^3 (specimens 1-6) is 13.78 MJ/m^2. Considering this mean value and using eqn (2), a range of 5.44-22.12 MJ/m^2 is achieved for r (based on mean value). The obtained values show an acceptable repeatability in comparison with this range.

The graph of the average-heat-of-combustion of the specimens versus density is shown in Figure 1. This figure demonstrates that this property is nearly independent of density of the foam in the examined

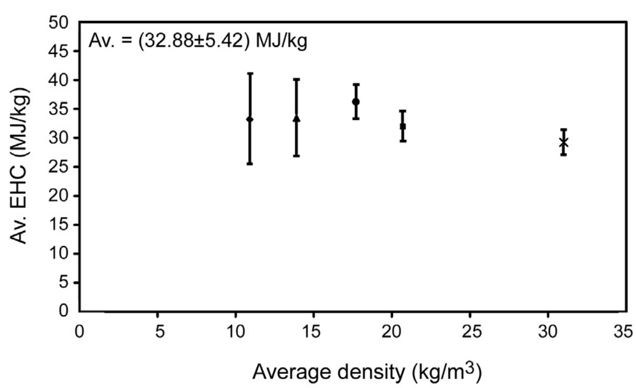
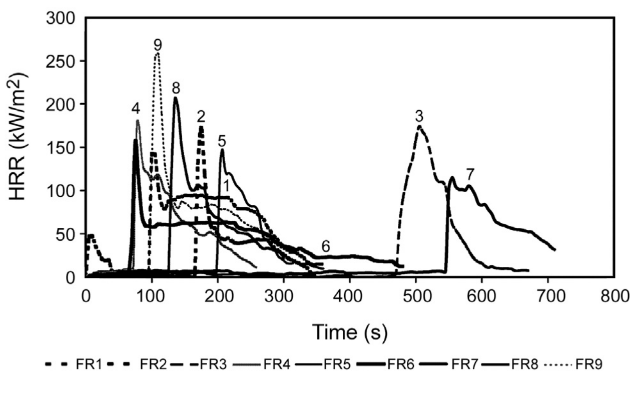


Figure 1. Average-effective-heat-of-combustion (Av. EHC) for FR-EPS of different densities at 35 kW/m^2.

range (10-31 kg/m^3). The average amount obtained from all specimens is 32.88 MJ/kg with standard deviation of 5.42. It should be noted that this result may not be valid for an unventilated condition, which can cause less effective-heat-of-combustion due to reduction of oxygen concentration and incomplete combustion.

Heat-release-rate (HRR)

The heat-release-rate graphs of fire-retardant type specimens are depicted in Figures 2a and 2b. The specimens 3 and 7 were ignited considerably later than the other specimens, as explained in "Time-to-ignition (TTI)" section. The graphs of average heat-release-rate and its average peak (Av. PHRR) versus density of EPS specimens are shown in Figures 3 and 4. The results illustrate that both average and peak heat-release-rate values ascend with increasing density. The main reason is that the available combustible mass, and as a result the mass loss rate



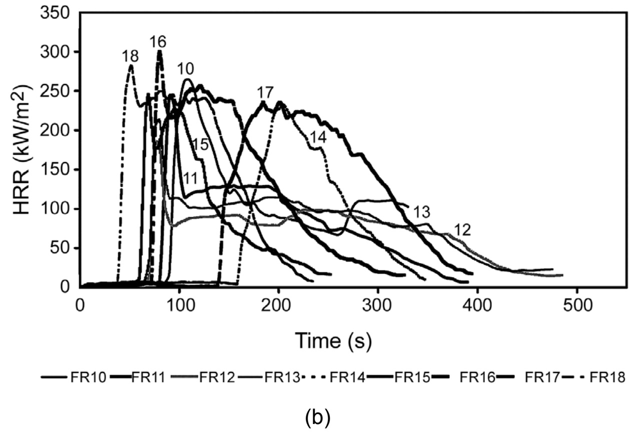


Figure 2. Heat-release-rate for FR-EPS specimens with different densities (a) and (b).

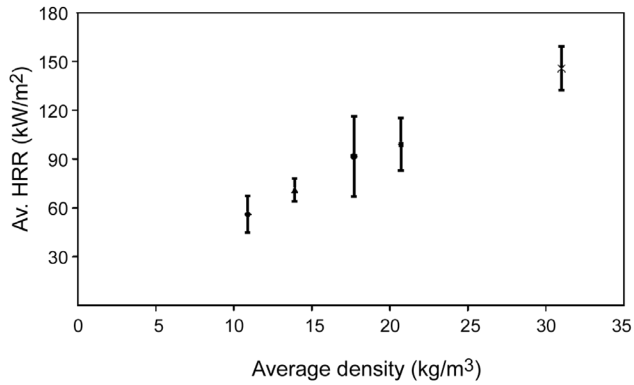


Figure 3. Relationship between average-heat-release-rate (Av. HRR) and density for FR-EPS at 35 kW/m^2.

(MLR), increase with density and consequently heat is released with more intensity. The relation of average mass-loss-rate between timing of 10% and 90% of mass loss testifies this matter (Figure 5). The relation between average-heat-release-rate and density of specimens, in range of 10-31 kg/m^3, can be depicted as follows:

$$Average - heat - release - rate = 4.39\rho + 9.83 (R = 0.9177) \quad (3)$$

In which average-heat-release-rate and ρ are in kW/m^2 and kg/m^3, respectively, and R is correlation coefficient. It can be seen from data depicted in the figures and eqn (3) that both average and peak-of-heat-release-rate are dependant on density of the foam and increase with it.

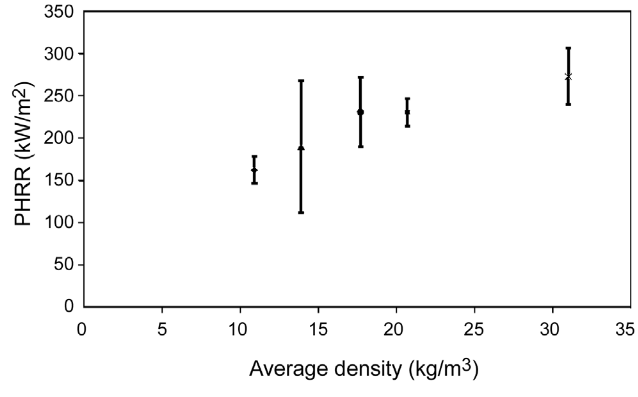


Figure 4. Relationship between peak-of-heat-release-rate (Av. PHRR) and density for FR-EPS at 35 kW/m^2.

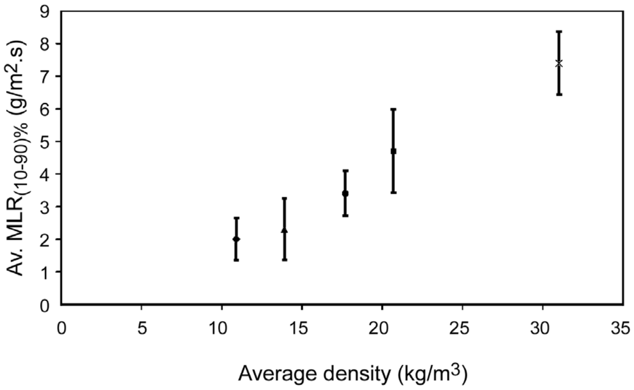


Figure 5. Average-mass-loss-rate (Av. $MLR_{(10-90)\%}$) versus density for FR-EPS specimens at 35 kW/m^2.

If a specified short range of density is considered, a good repeatability for peak-heat-release-rate is achieved. The repeatability of peak-heat-release-rate is presented in the standard test method [19] as follows, in the range of 70-1120 kW/m^2:

$$r = 13.3 + 0.131 \ PHRR \quad (4)$$

The obtained mean peak-heat-release-rate for six specimens 1 to 6 with ρ_{av} = 10.9 kg/m^3 is 161.99 kW/m^2. Considering this mean value and using eqn (4), a range of 127.5-196.5 kW/m^2 is achieved for r, which is wider than the range of experimentally obtained values (142.3-180.3) and reveals the acceptable repeatability of peak-heat-release-rate values for EPS with cone calorimeter test method.

The Effects of Thickness

Thickness of specimens is another parameter which can affect the fire behaviour of EPS. This was investigated by testing four fire-retarded specimens (numbers 19-22) with different thicknesses at a heat flux of 35 kW/m^2. The results are depicted in Table 3. As it can be observed from the results, time-to-ignition considerably increases with increasing thickness of the foam; so its values for the specimens with thicknesses of 21 mm and 40 mm are 47 s and 159 s, respectively. This is due to the kind of thermal behaviour exhibited by EPS. This thermoplastic foam softens and shrinks at temperature of about 100ºC. This happens very fast under fire test conditions in which temperature is much higher than this value. Hence, once the test has started, the specimen melts and recedes away heat source. This causes the material receiving lower heat energy than the calibrated testing quantity. For example, if an EPS foam specimen with 40 mm thickness is tested at 35 kW/m^2 radiation level, once the test is started, the specimen melts and recedes away the cone. In this condition, the

Table 3. Cone calorimeter results for EPS specimens of different thicknesses.

Specimen No.	19	20	21	22
ρ (kg/m^3)	23.80	24.30	21.90	21.50
t (mm)	10.50	20.60	30.60	39.90
TTI (s)	49.00	47.00	63.00	159.00
FO (s)	270.00	160.00	271.00	348.00
Av. HRR (kW/m^2)	32.10	124.50	90.20	114.80
PHRR (kW/m^2)	157.00	294.60	230.60	232.80
T PHRR (s)	54.00	56.00	94.00	204.00
Av. Spec MLR (g/m^2s)	0.91	4.38	3.07	3.84
$\dot{q}''_{180}$ (kW/m^2)	36.40	79.50	102.30	119.30
$\dot{q}''_{300}$ (kW/m^2)	26.80	51.40	68.70	88.20
THR (MJ/kg)	7.30	14.10	19.40	22.20
Av. EHC (MJ/kg)	35.36	28.39	29.39	29.79

TTI: time-to-ignition; FO: flame out; Av. HRR: average-heat-release-rate; PHRR: peak-heat-release-rate; T PHRR: time-to-peak-heat-release-rate; Av. Spec MLR: average-specific-mass-loss-rate; $\dot{q}''_{180}$: average-heat-release-rate, 180 s after ignition; $\dot{q}''_{300}$: average-heat-releas-rate, 300 s after ignition; THR: total-heat-release; Av. EHC: average-effective-heat-of-combustion;

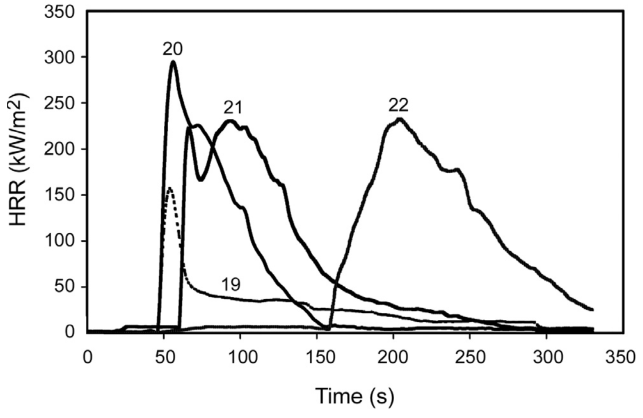


Figure 6. Heat-release-rate (HRR) curves for FR-EPS specimens with different thicknesses at 35 kW/m^2.

distance of surface of the produced liquid film with bottom of the cone is about 65 mm. The measured heat flux at this distance is about 20 kW/m^2, which is much lower than the calibrated level. Therefore, the received heat flux to EPS foam specimens is reduced with increasing thickness and the ignition occurs with delay. Similarly a delay can also be seen in time-to-peak of heat-release-rate (Table 3). Lukas [24] has discussed the heat flux measured at different positions from the cone heater inside a sample holder.

However, in contrary, the available combustible mass increases with increasing thickness of the specimens. This results in rising of heat-release-rate, which can be seen in its average values at 180 s and 300 s after ignition. It should be noted that, as the specimen No 20 was ignited faster than the thicker specimens, and the duration of test (according to End of Test criteria of ISO 5660) was shorter; hence the value of its average heat-release-rate was higher than specimens No 21 and No 22 (Figure 6).

In other words, we are faced with two phenomena when the thickness of EPS foam specimen increases:

-The specimen recedes away heat source and hence receives less heat relative to the calibrated one,

-The available mass for combustion reaction increases with thickness.

The first phenomenon causes time delays in ignition-dependant events (like time-to-ignition and time of peak-heat-release-rate) and also, relatively, in decreasing the mean value of rates that have a relation with time-to-ignition (like, average heat-release-rate). The second phenomenon results in increasing fire products (heat and smoke) and mean rates of events in a determined time after ignition (total-heat-release, TSR, $\dot{q}''_{180}$, $\dot{q}''_{300}$, etc.).

These effects on fire performance of EPS foam have not been considered in other research works [10-14], while these parameters are very important and should be taken into account in evaluating the fire behaviour of EPS foam products, when evaluated with cone calorimeter or other tests with similar conditions. This can be the case for other thermoplastic foams, as Vanspeybroeck et al. [25] reported for polyurethane flexible foam. They found that a decrease in heat flux (down to 40%) occurs with increasing distance from the conical heater, as a consequence of melting specimens. Hence they concluded that cone calorimeter test results were dependent on a large extent on the thickness and the melting behaviour of the foam samples.

Type of EPS

The fire performance of standard and fire retarded types under cone calorimeter test condition was evaluated. Three standard types and three fire retarded EPS specimens were tested. All the specimens had a density of nearly 17 kg/m^3 and thicknesses of about 46 mm. The results are given in Table 4 and discussed as the followings:

Table 4. Fire test results for standard and FR-EPS specimens at 35 kW/m^2*.

Specimen type	ρ (kg/m^3)	TTI (s)	Av. HRR (kW/m^2)	PHRR (kW/m^2)	Av. EHC (MJ/kg)	THR (MJ/m^2)
Standard	16.5±0.67	77.67±9.3	89.9±19.4	310.5±15.0	30.3±1.2	24.5±0.9
FR	17.7±0.59	81.0±10.0	92.8±24.1	230.6±40.9	36.2±2.9	28.7±1.5

(*) The obtained results are given as mean value ± standard deviation.
TTI: time-to-ignition; Av. HRR: average-heat-release-rate; PHRR: peak-heat-release-rate; Av. EHC: average-effective-heat-of-combustion; THR: total-heat-release.

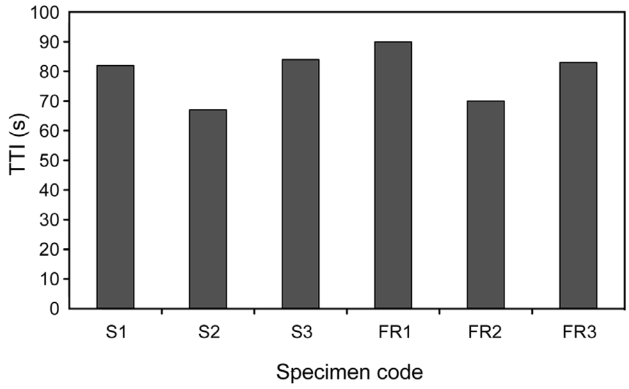


Figure 7. Time-to-ignition for FR and N-FR EPS specimens at 35 kW/m^2.

Time-to-ignition

Time-to-ignition of the specimens is depicted in Figure 7. These data do not follow any special pattern and are relatively scattered, as discussed in "Time to Ignition section (TTI)". This shows that time-to-ignition is not an appropriate characteristic for recognizing standard and fire retarded types in cone calorimeter test. This is not dealt with properly in earlier works. Scudamore et al. [10] have reported a time-to-ignition of 73 s and 77 s for standard and fire retarded types, respectively, under a heat flux of 30 kW/m^2. Collier et al. [11] have reported 78 s for standard and 120 s for fire retarded type samples in the same radiation level. There are obviously considerable differences between their results. The outcomes of both works have been obtained from few tests in comparison to this investigation.

Total-heat-release and Average-effective-heat-of-combustion

As it can be observed from the results presented in Table 4 and Figure 8, there is no meaningful difference between total-heat-release and average-effective-heat-of-combustion values of standard and fire-retarded types. The reason is that both types are fully combustible and completely burn when they are exposed to a sufficient external heat source and oxygen concentration, which both exist in cone calorimeter test condition.

Heat Release Rate

Heat-release-rate curves for standard and FR types are shown in Figure 9. As it is discussed in previous parts of the paper, peak-heat-release-rate value depends upon density of the foam. For the tested range of density (about 17 kg/m^3), average peak-heat-release-rate values are equal to 310.5±15.0 kW/m^2 and 230.6±40.9 kW/m^2, which were obtained for standard and fire-retarded types, respectively. All the values of standard type specimens were greater than 294 kW/m^2, but the maximum obtained value for fire-retarded specimens was 264 kW/m^2. Because of the presence of flame retardants like hexabromocyclododecane (HBCD), which causes quenching effects and induces disorder, heat release rate decreases in fire-retarded samples. This practically lowers the rate of fire growth in foam in relation to standard type EPS.

Scudamore et al. [10] have reported heat-release-rate values equal to 299 kW/m^2 and 394 kW/m^2 at

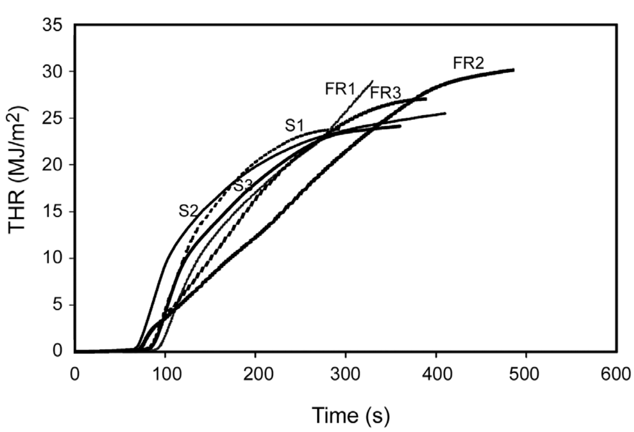


Figure 8. Total-heat-release for FR and N-FR EPS specimens at 35 kW/m^2.

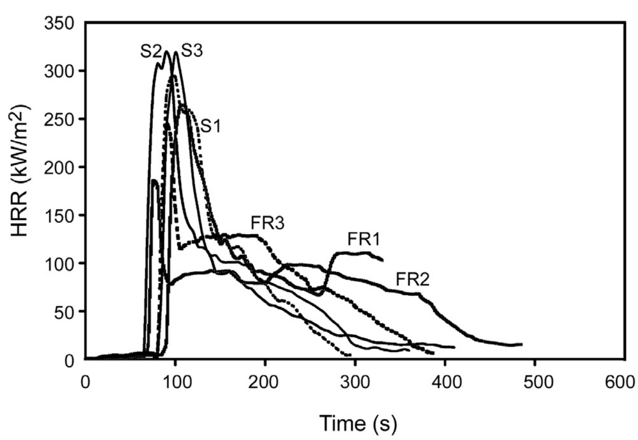


Figure 9. Heat-release-rate (HRR) curves for FR and N-FR EPS specimens at 35 kW/m^2.

30 kW/m^2 and 40 kW/m^2 radiation levels, respectively, for standard EPS. For fire-retarded type EPS, they also have reported 238 kW/m^2 and 321 kW/m^2 at 30 kW/m^2 and 40 kW/m^2 heat flux levels, respectively. Collier et al. [11] have reported peak-heat-release-rate of 320 kW/m^2 for standard type and 193 kW/m^2 for fire-retarded, both at 30 kW/m^2. Their results are approximately close to those reported in this article.

CONCLUSION

Tests were carried out on fire behaviour of EPS foams with cone calorimeter. The influences of density and thickness of specimens and type of foam were investigated. Important results are:

- The given data for fire behaviour of EPS in some technical documents [10-14] are based on a few numbers of test results and without considering the effects of density and thickness of specimens. Our results showed that these matters considerably influence the results and have to be taken into account.

- It was shown that both average heat release rate and peak of heat release rate directly depend upon density of foam and increase with it. However, good correlations could not be achieved with simple regression method, which is due to complexity of combustion reactions and behaviour of material at high temperature.

- The thickness of the specimen has two contradictory effects on fire performance of EPS. On the one hand, because of fast melting behaviour of the specimen, it receives less heat energy relative to the calibrated level. On the other hand, the available mass for combustion reactions increases. The first effect appears in delayed timing events (like, time to ignition and T peak heat release rate) and the second one results in increasing combustion products and the rates of happenings (like, time-heat-release, TSR, $\dot{q}''_{180}$ and $\dot{q}''_{300}$). This behaviour of EPS makes it a difficult material for evaluation of its fire performance and fire risk with cone calorimeter. For example, as a fire protective coating (like thermal barrier required by International Building Code [26]) is essential for its application in buildings; this may result in melting of EPS before exposing to fire. Hence, it is possible in a real fire that a thicker EPS product does not ignite or shows a less contribution to fire growth, at least in initial stages of fire.

- Peak heat release rate is the most important fire property of EPS that can be used for distinguishing between standard and fire-retarded EPS samples with cone calorimeter test method. The density of the foam should be also considered for this purpose. For example, the peak heat release rate of FR specimens with a density around 30 kg/m^3 may reach 300 kW/m^2, but with densities less than 15 kg/m^3, it is around 170-180 kW/m^2 and rarely reaches a maximum value of 200 kW/m^2. Time-to-ignition of standard and fire-retarded types cannot be reliably used for distinguishing between standard and fire-retarded types. It is even possible to see a shorter time -to-ignition for an fire-retarded type than standard one, because of complexity in material behaviour and combustion reactions.

- Based on the mean values obtained for 6 specimens with similar densities (about 11 kg/m^3), a good repeatability was obtained for total-heat-release and heat-release-rate in comparison with the given equations in the standard test method, but this was not true for time-to-ignition. The repeatability of time-to-ignition results of EPS foam specimens are much wider than the equation given in the standard test method.

NOMENCLATURE AND ABBREVIATIONS

Av. EHC	: Average-effective-heat-of-combustion (MJ/kg)
Av. SEA	: Average-specific-extinction-area (m^2/kg)
Av. Spec MLR	: Average-specific-mass-loss-rate (g/m^{2}s)
FO	: Flame out (s)
$MLR_{(10\text{-}90)\%}$	: Mass-loss-rate between times of 10% and 90% of mass loss (g/m^{2}s)
PHRR	: Peak-heat-release-rate (kW/m^2)
$\dot{q}''_{180}$	: Average-heat-release-rate, 180 s after ignition (kW/m^2)
$\dot{q}''_{300}$	: Average-heat-release-rate, 300 s after ignition (kW/m^2)

r	: Repeatability
R	: Correlation coefficient
t	: Thickness of specimen (mm)
T PHRR	: Time-to-peak-heat-release-rate (s)
THR	: Total-heat-release (MJ/m^2)
TTI	: Time-to-ignition (s)
ρ	: Density (kg/m^3)

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