INFLUENCE OF FIBERGLASS MESH ON FLAMMABILITY OF EPS USED AS INSULATION OF BUILDINGS

by

Qiang XU[a], Cong JIN[b], Gregory J. GRIFFIN[c], Jordan HRISTOV[d], Dejan B. CVETINOVIĆ[e], and Yong JIANG[f*]

[a] School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing, China
[b] School of Computer Science and Technology, Nanjing University of Science and Technology, Nanjing, China
[c] School of Civil, Environmental and Chemical Engineering, RMIT University, Melbourne, Australia
[d] Department of Chemical Engineering, University of Chemical Technology and Metallurgy, Sofia, Bulgaria
[e] Vinča Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia
[f] State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei, China

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Different scale tests to explore the influence of fiberglass mesh on the fire behavior of expanded polystyrene (EPS) have been conducted. Micro scale combustion calorimeter to measure the heat release rate per unit mass, heat release capacity, and the total heat release of EPS and as well as the fiberglass for milligram specimen mass has been used. Cone colorimeter bench scale burning tests with the EPS specimens and EPS-fiberglass compound specimens have been carried out. The heat release rate per unit area, ignition times, and the derived minimum igniting heat fluxes were determined. Comparative burning tests on the fire spread tendency of EPS and EPS-fiberglass compound specimens have been carried out. It was established that the fiberglass mesh stabilizes the EPS fire as a wick fire due to the adherence of the melting polystyrene adheres to the fiberglass mesh and this causes an upwards fire spread.

Key words: *insulation, EPS, flammability, fiberglass mesh, fire safety*

Introduction

Exterior insulation finishing systems (EIFS) are of a general class of non-load bearing building cladding systems that provides an exterior wall with an insulated, water resistant, finished surface in an integrated composite materials system. The EIFS are now widely applied in North America, Europe, the Pacific Rim, and many other areas around the world. The producers of EIFS performed by Industry Manufacturers Association (EIMA) define two classes of EIFS: class polymer based (PB) identified as PB EIFS and polymer modified (PM) identified as PM EIFS. The first group (PB EIFS) uses EPS adhering to the substrate with a fiberglass mesh embedded in a base coat, while the second one (PM EIFS) is based on extruded polystyrene (XPS).

The construction industry of China also applies the high energy efficient wall systems for residential buildings (in accordance with a building code issued in 2001 by the Ministry of

* Corresponding author, e-mail: yjjiang@ustc.edu.cn

Building of China) and now the installation of EIFS to resident and office buildings is compulsory [1]. In accordance with this directive, both PB (EPS) and PM (XPS) EIFS are commonly used in China but many deadly fires occur within such layers where the EIFS are the main fire loads. Moreover, due to design of the insulation panels and their positions at the building façades the fire spread is facilitated which increases the risk of fire spread especially in cases of tall (tower-type) buildings [2]. Among many origins of such fires, for instance, are an illegal firework show (on February 9th, 2009) when a thermoplastic insulation of a 32-story building in Beijing's Central Business District was ignited and burnt.

Insulations, such as EPS and XPS, are the main materials which can catch fire in the sandwich structures of EIFS. In the EIFS design the reinforced layer consisting of a fiberglass mesh embedded in a cementitious adhesive is applied onto the surface of the insulation manually (with a trowel). The fiberglass meshes used have different apertures, somewhat like window screening (the common case with 5.25 mm × 5.25 mm mesh aperture as it s commented further in this article). A common feature appearing in fire is the melt-drip effect of the insulation material and auxiliary materials of composition which also contribute to the fire spread.

The fire behavior of EPS has been studied over an extended period of time [3]. The earlier investigations focused on the initial stage involving gasification and pyrolysis of EPS [4]. The gasification kinetics studies have been focused on evaluation of gaseous products released during the combustion process [4-6] when the ignition has been caused by hot metallic particles [7, 8]. The flammability of EIFS is a function of the organic material load in the insulation [9]. A predictive model of the fire response of glass reinforced plastic sandwich panels has been formulated by Galgano *et al.* [10] while the flammability of EPS has been studied in [11-14].

The fiberglass used to reinforce the plastics, named as glass reinforced plastics (GRP), is at the focus of various fire studies addressing the flammability or improved fire resistance of GRP. In this context, cone calorimeter tests with GRP [15, 16] have been used to predict the fire behavior of these materials and to verify the recommendations of ISO 9705 tests [17].

The present work addresses the effect of fiberglass mesh on the fire behavior of EPS in tests performed in a micro scale facility. The contribution of fiberglass mesh to EPS fire spread in large scale fire tests is commented too.

Experimental methods

Materials

The fiberglass mesh has high mechanical strength, good cohesion and can adhere with EPS firmly. Fiberglass alkali-resistant meshes (covered by alkaline resistant latex) are commonly used as necessary structural and reinforcement materials in EIFS. The specifications of the fiberglass mesh used in the reported research study are:
- material: E-glass,
- color: white,
- nominal mesh size: 5.25 mm × 5.25 mm,
- construction: plain weave,
- unit weight: 125 g/m^2, and
- coating: Alkaline-resistant latex.

The EPS specimens – 1000 mm × 1200 mm and with density of 12.5 kg/m^3 were taken from 48 mm thick EPS panel. The EPS was white, contained no flame retardant, and had a limiting oxygen index (LOI) of 20.3% (as measured by ASTM2863).

Facilities

Tests at three scales were arranged, namely:

– Micro scale thermogravimetry (TG) tests were conducted to get measure the pyrolysis process for the EPS and fiberglass.
– The flammability of EPS and fiberglass were tested by micro scale combustion calorimeter (MCC) according to ASTM 7309-13. The attachment of molten polystyrene to fiberglass was observed by SEM.
– The influence of fiberglass mesh on the ignition and flaming of EPS was determined by bench scale cone calorimeter tests according to ISO 5660. No-ignition cone tests were conducted to measure the shapes of molten polystyrene with and without fiberglass mesh.

The role of fiberglass mesh in fire spread of EPS was assessed using fire growth tests representative of real fire scenarios.

The micro scale thermal and flammability analysis of EPS and fiberglass were conducted with TG/DSC and MCC [18, 19]. The thermal analysis was carried out by means of simultaneous thermal analysis (STA), using a Netzsch STA 449C TG-DSC which applies TG and differential scanning calorimetry (DSC) to the EPS and fiberglass specimens under a nitrogen atmosphere. A heating rate of 20 K/min to a maximum temperature of 600 and 1400 °C for EPS and for fiberglass, respectively, was used with a gas flow rate of 75 mL/min. The specimens were contained in an Al_2O_3 crucible without lid. The micro scale flammability analysis with MCC was conducted using a Type MCC-2 at the VTT Technical Research Centre of Finland. The equipment was from Govmark Organization, Inc., Farmingdale, N.Y., USA, and operated to the ASTM standard test method D7309-13, *Method A* [20]. According to the MCC2 data sheet [21], this calorimeter was developed by the Federal Aviation Administration. The heating rate used was 10, 20, 30, 50, and 100 K/min.

Both the ignition and the burning bench scale tests of the EPS and EPS-fiberglass-mesh composite specimens were carried out using a cone calorimeter (Fire Testing Technology Limited, East Grinstead, UK) in accordance with ISO5660 [22], at the State Key Laboratory of Fire Safety Science of China. The cone calorimeter uses the oxygen consumption method to determine heat release rates of burning specimens. The cone specimens were cut as 100 by100 mm square samples. All test specimens were oriented in the horizontal direction with the standard pilot operating. Specimens were placed in an edge frame sample holder as allowed in the standard. The edge frame holder reduces the test surface area to 0.0088 m^2, and this is the area used in calculations. The specimen inside the holder was supported horizontally on a load cell and exposed to a set external heat flux with irradiance level of 25, 35, and 50 kW/m, respectively. Ignition is promoted using a spark igniter. The nominal exhaust system flow rate for all tests was 0.024 m^3/s.

Three kinds of specimens were prepared for cone calorimeter tests: EPS, EPS with one-layer of fiberglass mesh, and EPS with two-layers of fiberglass mesh. The mesh was applied onto one surface of the EPS for the one-layer-mesh specimens, while meshes were attached to both surfaces of EPS for two-layer-mesh specimens.

The facilities and the test procedures for the large scale burning tests are described in section *Fire Spread Tests*.

Test results and analysis

Micro scale TG and MCC results

The TG curves shown in fig. 1 are related to the EPS behavior where the decomposition of EPS was considered as one-step reaction and occurred between 340 and 470 ºC and

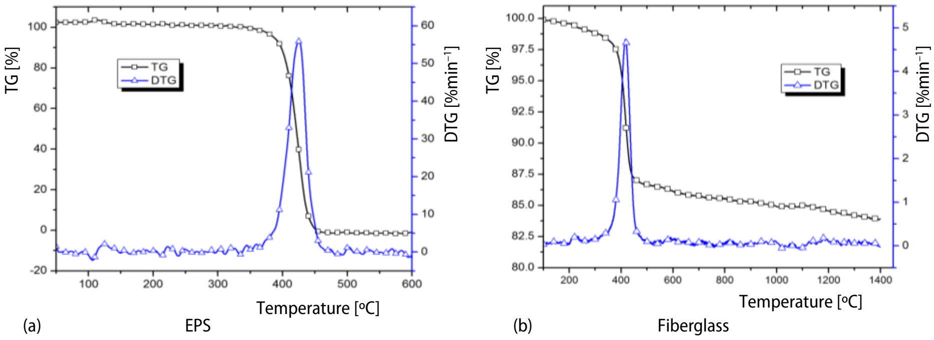

Figure 1. The TG mass loss temperature curves
(*for color image see journal web site*)

the peak mass loss rate was at 425 ºC. Most of the gases released are flammable and contribute to combustion process of EPS [23]. The main decomposition process for fiberglass occurred between 310 and 490 ºC. Total mass loss was about 17% and the peak mass loss rate was at 417 ºC . The main mass loss could be attributed to the decomposition of the latex coating material.

The MCC curves are shown on fig. 2, while the relevant data are summarized in tab. 1. The fiberglass exhibits a quite low, Q_{max}, compared with EPS at all heating rates applied. The ratio of Q_{max} for fiberglass and EPS was about 3.2%, 4.1%, 3.8%, 5.2%, and 3.9% at heating rates of 10, 20, 30, 50, 100 K/min, respectively. At the same time, the ratio for total heat release (THR) was about 5.2%, 6.7%, 6.6%, 6.7%, and 4.6%, respectively. Futher, the fiberglass demonstrates lower temperature corresponding to Q_{max} than that of EPS at any heating rate (the difference are of about 30.9 ºC), 33.1 °C, 27.1 °C, 33.3 °C, and 27.5 °C lower than that of EPS and this effect could be attributed to the earlier decomposition of coating material as it was demonstrated by the TG tests.

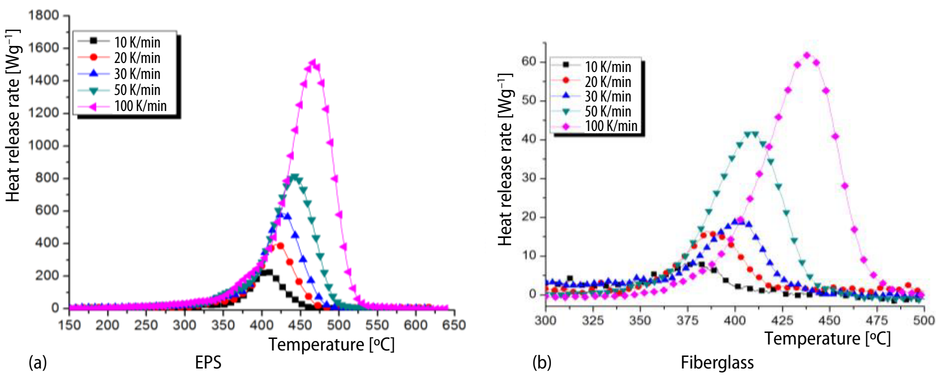

Figure 2. The MCC heat release rate temperature curves
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The data sheet of the MCC2 provided by Govmark® Organization Inc. [20] correlates the derived property, namely: the heat release capacity (HRC) obtained from the MCC tests to the LOI from the flammability of plastics tests of Underwriters Laboratory (UL94). According to the criteria published in this data sheet [20] the plastic material is considered as flammable in the following cases: if the measured HRC is above 400 J/gK, the material continues to burn

Table 1. Data obtained from MCC

Sample label	HRC [$Jg^{-1}°C^{-1}$]	Q_{max} [Wg^{-1}]	THR [kJg^{-1}]	T_{Qmax} [°C]
EPS_MCC_10	1516.6	253.1	38.4	406.4
EPS_MCC_20	1185.3	395.1	32.8	419.1
EPS_MCC_30	1018.4	509.2	33.3	427.2
EPS_MCC_50	975.0	812.5	34.4	441.9
EPS_MCC_100	947.1	1578.5	39.4	466.3
Fiber_MCC_10	48.0	8.0	2.0	375.5
Fiber_MCC_20	48.3	16.1	2.2	386.0
Fiber_MCC_30	38.2	19.2	2.2	400.1
Fiber_MCC_50	50.4	42.0	2.3	408.6
Fiber_MCC_100	36.0	62.0	1.8	438.8

Q_{max}- maximum heat release rate per unit mass,
T_{Qmax}- temperature of Q_{max}

after a short time exposure to a small flame, which indicates *LOI* below 21%, and the material exhibits a UL 94 horizontal burning (HB) rating, which means a slow burning (< 76 mm/min) on a horizontal specimen: for a specimen of < 3mm thickness where burning stops before a distance of 100 mm has been reached [23, 24]. The relationship between HRC and *LOI* can be described as [20]:

$$LOI = \frac{125}{\mathrm{HRC}^{1/4}} \tag{1}$$

The calculated *LOI* of EPS varied from 20.0% to 22.5% (ASTM2863 test result is 20.3%), while that of fiberglass varied from 46.9% to 51.0% based upon eq. (1) and the MCC data summarized in tab. 1. Thus, EPS was classified as flammable and HB according to the UL94 rating.

According to [20], materials with a HRC below 150 J/gK will not ignite after short time exposure to a small flame and will have a *LOI* > 35%. Thus, the fiberglass with very low HRC, see tab. 1, and a calculated *LOI* of 46.9% to 51.0% would be considered as a non-ignitable material and can be classified as V0, that is: burning stops within 10 seconds on a vertical specimen and drips of particles allowed as long as they are not flaming) [23]. The MCC tests revealed that some of the coating material from the fiberglass mesh could burn and consequently the HRR would be limited.

Bench scale cone calorimetric test results

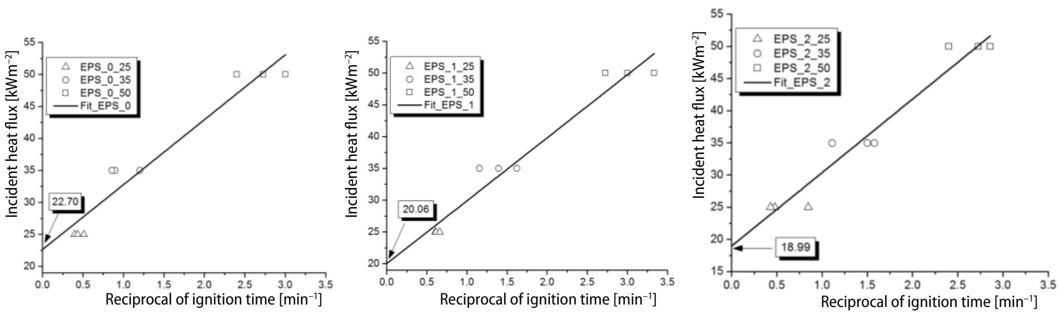
The data obtained from the cone calorimeter tests are summarized in tab. 2. The labeling methods for the specimens are: material layers of fiberglass mesh, incident heat flux test, and serial number. For example, EPS_0_25_A is the first specimen without fiberglass mesh tested under 25 kW/m^2 incident heat flux.

As it could be expected the ignition time is proportional to incident heat flux applied. The material ignition properties were derived by the method of Janssens [24] by plotting the incident heat flux against the reciprocal ignition time, see fig. 3. The tests revealed that the minimum heat fluxes required for ignition of EPS specimens were: about 22.70 kW/m^2 for EPS, 20.06 kW/m^2 for EPS with one-layer of fiberglass mesh, and 18.99 kW/m^2 for a specimen with

Table 2. Cone Calorimeter results

Label	IHF [kWm^{-2}]	Fiber	t_{ig} [s]	*p*HRR [kWm^{-2}]	t_{pHRR} [s]	THR [MJm^{-2}]
EPS_0_25_A	25	No	118	418.7	174	19.5
EPS_0_25_B		No	152	402.1	198	18.6
EPS_0_25_C		No	139	587.5	179	14.2
EPS_1_25_A		1	99	462.0	154	19.8
EPS_1_25_B		1	98	478.8	154	20.6
EPS_1_25_C		1	91	464.5	146	20.9
EPS_2_25_A		2	110	441.0	169	19.5
EPS_2_25_B		2	71	376.5	124	23.3
EPS_2_25_C		2	140	439.3	183	20.8
EPS_0_35_A	35	No	67	557.0	106	16.0
EPS_0_35_B		No	70	499.7	112	16.1
EPS_0_35_C		No	50	487.4	90	17.8
EPS_1_35_A		1	43	522.8	93	20.4
EPS_1_35_B		1	52	518.0	102	20.3
EPS_1_35_C		1	37	487.1	86	19.7
EPS_2_35_A		2	54	512.7	108	20.7
EPS_2_35_B		2	38	453.5	99	21.2
EPS_2_35_C		2	40	469.4	101	21.0
EPS_0_50_A	50	No	25	506.4	65	16.4
EPS_0_50_B		No	20	572.2	66	17.2
EPS_0_50_C		No	22	539.4	62	17.0
EPS_1_50_A		1	22	581.0	69	20.5
EPS_1_50_B		1	18	611.9	68	20.2
EPS_1_50_C		1	20	558.3	70	20.9
EPS_2_50_A		2	21	617.4	66	17.8
EPS_2_50_B		2	22	462.2	82	20.5
EPS_2_50_C		2	25	564.8	76	20.8

IHF-incident heat flux, t_{ig}-time to ignition, pHRR-peak HRR per unit area, t_{pHRR}-time to pHRR



(a) EPS without fiberglass mesh (b) EPS with one-layer of fiberglass mesh (c) EPS with two-layers of fiberglass mesh

Figure 3. Determination of the minimum heat flux required for ignition of EPS specimens

two-layers of fiberglass mesh. Thus, the fiberglass mesh behavior in the ignition process of EPS is of primarily importance.

The cone calorimeter test of EPS used a piloted ignition procedure. It was observed that the specimen initially melted and shrank thus forming a flammable pool of melt material which consequently was ignited. The pool shape varies and it is affected mainly by the geometry imposed by the fiberglass mesh design. From the data summarized in tab. 2 it is possible to calculate the average value of the incident heat flux shown graphically in figs. 4 and 5.

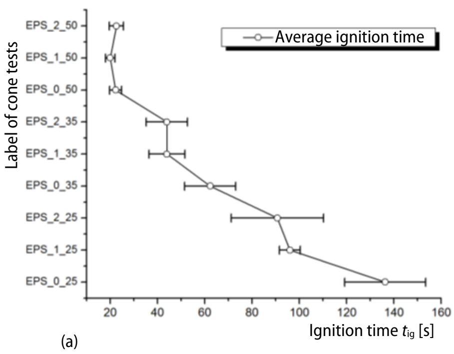


Figure 4. Average of t_{ig}

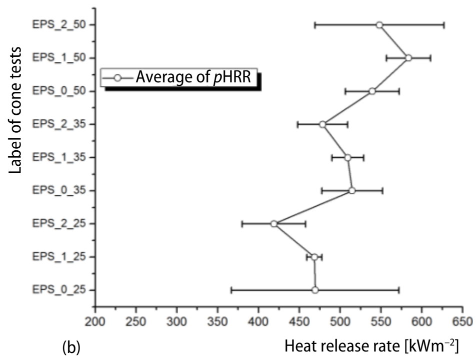


Figure 5. Average of *p*HRR

Further, at 25 kW/m^2 and 35 kW/m^2 incident heat fluxes the specimens with fiberglass meshes demonstrated shorter average ignition times, t_{ig}, than the ones without meshes. However, where higher accident flux of 50 kW/m^2 was applied such differences was not detected, fig. 4. In addition, the fiberglass mesh has no obvious effect on the *p*HRR since the average of *p*HRR does not vary significantly, see fig. 5. The EPS samples with two fiberglass layers demonstrated lower average *p*HRR values under all incident heat fluxes applied. This could be attributed to the upper fiberglass mesh which blocks a part of the incident heat flux directed to the underlying EPS and also prevents the escape of combustible volatiles from the melted pool polystyrene.

When 25 kW/m^2 and 35 kW/m^2 incident heat fluxes were applied to specimens with fiberglass meshes shorter average values of $t_{p\mathrm{HRR}}$ were observed, shorter than in cases with specimens without meshes. However, when a 50 kW/m^2 incident flux was applied the behavior was just the opposite, see fig. 6, and this, to some extent, could be attributed to faster release of combustible gases from the basic insulating material.

For the average THR, the values corresponding to specimens with fiberglass meshes are higher than data corresponding to specimens without meshes. This effect could be attributed to the existence of more flammable gases from the fiberglass mesh. Moreover, the THR increases with the increase in the incident heat flux because the variations in t_{ig} – the t_{ig} are larger at low incident heat flux which is attributed to the large amount of flammable gases escaping from the samples prior to the ignition point. The average values of THR of all 27 samples tested was established at 19.14 MJ/m^2 (σ = 2.28 MJ/m^2).

The effective heat of combustion (EHC) was calculated from the specimen mass and the THR data, see fig. 7. The average EHC calculated for EPS is 24.99 MJ/kg^1, which is lower than the data provided in other sources [25] while the data for EPS_1 (30.72 MJ/kg) and EPS_2 (58 MJ/kg) is in agreement with them. Futher, the EHC of the specimens with fiberglass mesh is significantly higher than that of EPS specimens. The EPS material after melting adheres onto the fiberglass mesh and the effective combustion area increases and consequently the rate of pyrolysis gas released is increased, too.

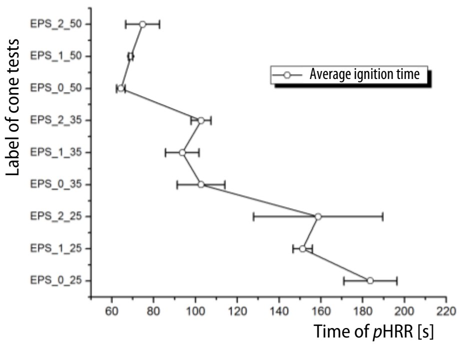


Figure 6. Average of $t_{p\mathrm{HRR}}$

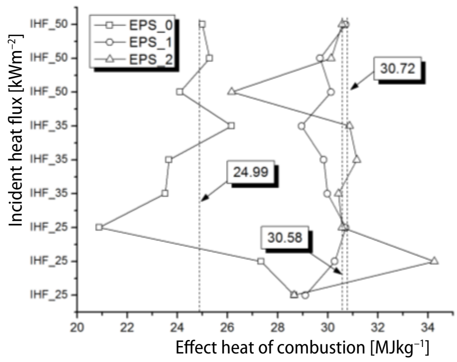


Figure 7. The EHC

According to the results of the TG analysis, the total mass loss of the fiberglass at temperatures within the range of 50 to 1400 ºC was about 17%. This mass loss is mainly due to burning of the coating latex material as well as contributed by volatiles released by the sandwich core. The average mass of a specimen of fiberglass mesh in the cone calorimeter tests was about 1.25 g. According to the MCC experiments, the average heat generated from the pyrolysis gases released by the fiberglass was 2.1 kJ/g. The heat generated from one-layer of fiberglass mesh was about 0.446 kJ while for samples with two-layers it was about 0.893 kJ.

The average mass of EPS was about 6.03 g and the average combustion heat, as measured by the MCC was about 35.66 kJ/g. In addition, when the EPS was completely burned the heat generated was established at 215.0 kJ. If the pyrolysis gases of fiberglass were completely combusted, the contribution of fiberglass to the combustion heat would be 0.21% for a single-layer and 0.42% for a double-layer. This indicates that the physical behavior of the samples under fire, such as the expansion of effective burning area and the wicking action [26] of the glass fibers, are the main factors affecting the flammability of the EPS specimens.

Fire spread tests

Two special burning tests were arranged to study the fire spread behavior of EPS samples. For the first test the experimental apparatus and a burning procedure are shown by fig. 8. The temperature of the flame was measured with self-made K type thermocouples. Nine thermocouples were used and spaced horizontally at 100 ± 0.9 mm intervals (labeled from A to I). The distance from the tip of thermocouples to the upper surface of the EPS sample was 10 mm.

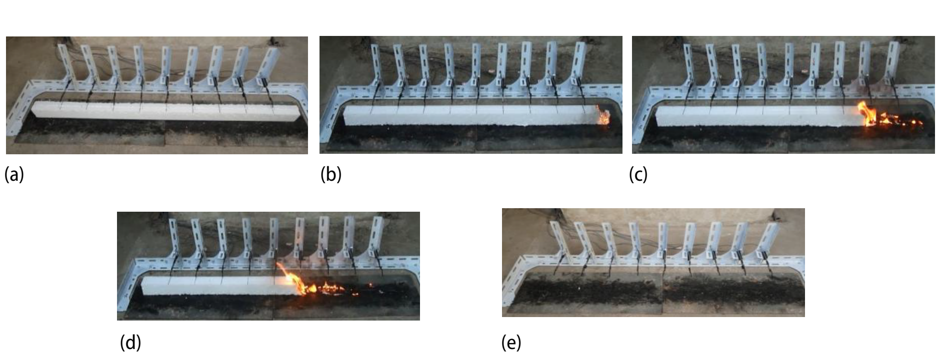


Figure 8. Experimental apparatus and burning procedure

The line of 9 tips was projected over the horizontal center line of the EPS sample. The sampling rate of data acquisition equipment was 50 samples per second. Two groups of experiments were conducted. One group focused on tests with EPS panels only (labeled as EE). The second group of tests used EPS panels with fiberglass mesh embedded (labeled as EFE).

In the EE group, the panels were cut to three sizes, 1000 × 48 × 10, 1000 × 48 × 20, and 1000 × 48 × 30 (length × height × width, the unit is mm). Two EPS panels of the same size were put together and formed the test samples of 1000 × 48 × 20, 1000 × 48 × 40, and 1000 × 48 × 60, which were labeled as 20-EE, 40-EE, and 60-EE, respectively.

In the EPS group, panels with embedded fiberglass mesh (of the same size as in group EE) were labeled as 20-EFE, 40-EFE, and 60-EFE, respectively (the numerical indicator corresponds to indicators used for the samples of the EE group).

Three horizontal tests were performed for each size of sample for a program of 18 tests. The sample was ignited with a gas torch at one end. The burning process for EPS (the temperature history curves are shown in fig. 9) developed in four consequent stages in four stages: melt/dripping with thermal decomposition, ignition, combustion, and flame propagation. The observed burning process was that demonstrated by the beads forming the EPS, that is: initial shrinking first shrank and melting, followed by burning. The molten material of EE samples would slump more than that observed for EFE samples, where some of the molten material in the EFE was supported by the fiberglass mesh. The fiberglass mesh does not burn, but it works as a wick for melted plastic material [26], as well as its surface would turn black and fragile.

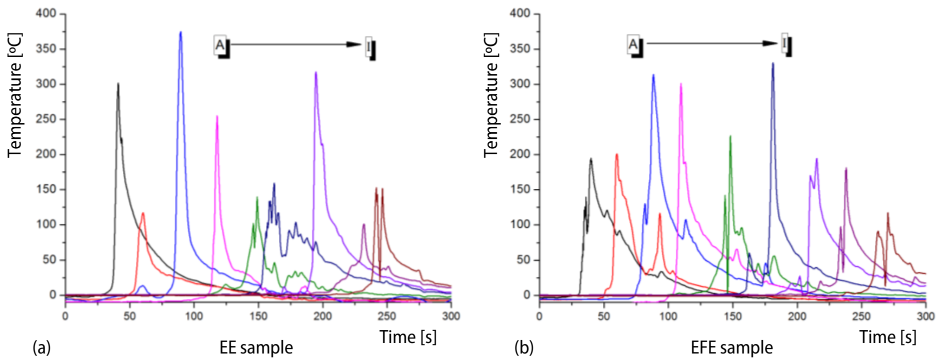


Figure 9. Temperature curves of flame propagation
(*for color image see journal web site*)

The peak temperature fluctuation of the EE samples was more than that of the EFE samples. The flame spread speed of EFE samples was lower than that of EE samples, as it is shown by the data summarized in tab. 3. The fiberglass mesh appears to have a stabilizing effect on the combustion of the EPS.

Table 3. Average velocity of fire spread [mms^{-1}]

Sample	A-B	B-C	C-D	D-E	E-F	F-G	G-H	H-I	V	σ
20-EE	4.8	5.6	5.0	4.3	5.6	5.1	3.1	6.5	5.0	1.01
40-EE	4.6	4.9	6.6	4.1	4.0	4.5	3.9	2.1	4.3	1.25
60-EE	5.1	3.4	3.5	3.3	7.5	3.1	2.7	9.4	4.8	2.44
20-EFE	3.3	3.8	3.5	4.3	3.5	2.7	4.1	3.8	3.6	0.50
40-EFE	3.1	3.5	5.1	3.7	3.0	3.7	3.3	5.1	3.8	0.83
60-EFE	5.0	3.5	4.9	2.6	2.9	3.5	3.6	4.3	3.8	0.88

In the second test larger scale burning experiments were carried out. The test was conducted with either two-layers of EPS panel 1000 × 600 × 20 (height × width × thickness, the unit is mm), or with EPS panels with one-layer of embedded fiberglass mesh. The EPS panels were ignited with a gas torch at the left side as shown by figs.10 and 11. The photos in fig.10 are serial images of EPS panel fire. It is clear that the fire spreads downwards but left the upper half of the panel almost unburned (nearly 39.3% of the panel was burnt). It could be observed that as the EPS started to be heated the melting begins and the melt dislodge from the panel, dropping to the floor and therefore removing burning droplets from the upper part of the panel. In contrast, as shown in fig. 11, for the tests conducted with fiberglass mesh embedded in the panel, the fire spread across the entire panel (nearly 95.1% was burnt). An upwards propagation of fire was observed an in this case some of the burning EPS adhere to the mesh thus allowing the flames to ignite EPS further up the panel.

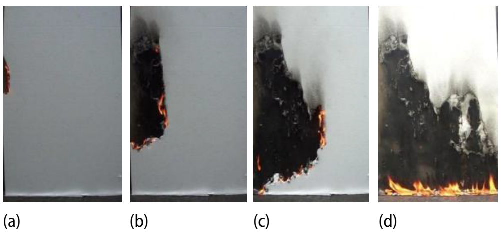


Figure 10. Burning of EPS

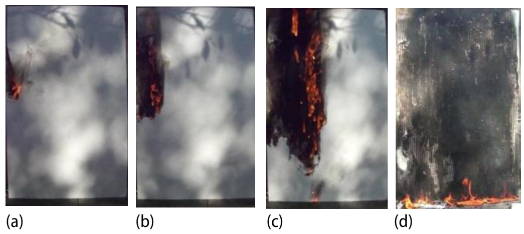


Figure 11. Burning of EPS with fiberglass

The SEM images (shown by fig. 12) were taken for fiberglass using a Type JEOL-JSM-6380LV SEM. The fiberglass samples were taken before and after burning. The attachment of EPS remains to the burnt mesh is illustrated clearly in SEM images. This is evidence of the formation of wick combustion.

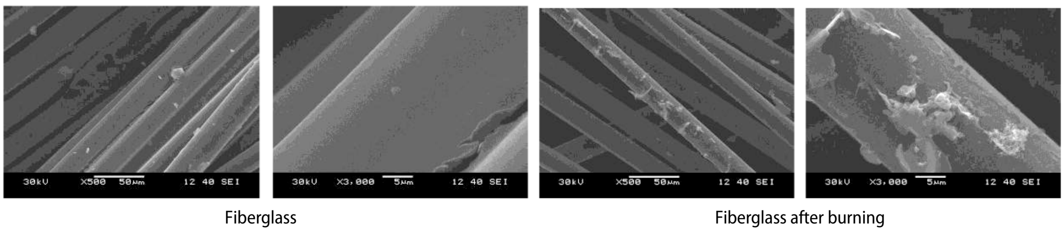


Figure 12. The SEM photos of fiberglass

Conclusions

This study provides information for a deeper understanding of the fiberglass mesh effect on the fire behavior of EPS panels.

The cone calorimeter tests reveal that the effect of the fiberglass mesh on the ignition characteristics of EPS is significant mainly when lower minimum heat fluxes are required to ignite, that is related to shorter ignition times. The EPS material after melting adheres onto the fiberglass mesh and the effective combustion area increases and consequently the rate of pyrolysis gas released is increased, too. The large initial effective combustion area and the wicking effect are the main contributions of the fiberglass meshes to the fire behaviour of EPS composites. Moreover, the large scale combustion experiments demonstrated that the fiberglass mesh stabilizes the combustion process due to the formation of melted pools and the consequent wicking effect.

Vertical burning tests were not conducted with the cone calorimeter, thus the effect of fiberglass mesh on EPS combustion under such conditions but this draws future experiments.

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