IMPROVEMENT OF FIRE SAFETY IN ROOMS WITH EXISTING EXPANDED POLYSTYRENE ROOF INSULATION

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ABSTRACT

Expanded polystyrene (EPS) is used as a roof insulation material in energy efficient buildings. Organic nature of EPS makes it combustible and European Manufacturers of EPS provide several recommendations for its safe usage. Wide varieties of insulation tiles available in India at several price points are being employed by architects with EPS being the least expensive. Rooms with EPS based roof insulation constitute serious fire hazard. Surface treatment of EPS board with a mixture of gypsum plaster reinforced with bleached natural fibre/paper appears to be a promising combination towards mitigating fire hazard in existing rooms with EPS false ceiling enormously without compromising on room aesthetics.

INTRODUCTION

Expanded Poly Styrene (EPS) commonly referred as Thermocol has found wide range of applications in construction and packaging industries. With increasing awareness among the field experts and owners of the buildings to save energy at a low cost and due to the versatility in thermal insulation applications, there is an increase in EPS usage as roof insulation material in energy efficient buildings. Further, they have been found to have long life and are expected to retain their insulation properties for long periods even in environments with large and cyclic temperature variations [**1**]. EPS is a combustible substance and decomposes into its monomer Styrene, carbon monoxide, carbon dioxide and water upon combustion. EPS is manufactured with and without Fire Retardant (FR) additives. Hexa-Bromo Cyclo Dodecane (HBCD) is the only Fire retardant additive that is being employed as it meets the purpose at a dose as low as 0.7% (w/w). European Manufacturers of EPS [**2**] provide a summary of behavior of EPS in case of fire event. They provide several recommendations for its safe usage including its encapsulation and protective coatings. Interactions with local suppliers of EPS for roof insulation and building architects indicate recommended densities of EPS board are not being employed in existing buildings.

Currently wide varieties of insulation tiles of fire retardant nature are available at several price points and are employed by architects with EPS being the least expensive. Also the fire risk in rooms with existing EPS based roof insulation is of a serious concern and must be addressed with rigor. Complete replacement of EPS with fire retardant insulation tiles to improve fire safety may not become widely accepted as a solution since this will involve a high degree of capital investment. One approach would be to innovate a technique to treat existing roof material to improve the fire safety.

This paper is concerned with evolving solution for protecting existing EPS false roofing with application of a mixture of Plaster of Paris (POP) reinforced with bleached natural fibre or paper. This surface treatment, it is thought would mitigate fire hazard in existing rooms with false ceiling without compromising room aesthetics. Experiments conducted with pool fire of kerosene at 25kW (0.59 g/s at 43.2 MJ/kg) power level in 1 m^3 room show that the reinforced material is able to withstand the power without ignition. This is compared with the unprotected EPS material. The unprotected material is found to have a peak mass loss of 20%, which upon forced ignition at one of the shrunk portions made it completely burn. This, it is thought, could lead to rapid flame spread with a heavy smoke causing a disastrous fire if the material is left unprotected.

LITERATURE REVIEW

A wide range of techniques on EPS insulation are being suggested or followed by experts and organizations depending on the area of application of the roofing [**3**]. Although much work is carried in the line of improving the false roofing systems, efforts on improving existing false roofing present in industries, hotels and shop floors. A recently released report by CBRI (Central Building Research Institute) **[4]** presents a method for roof insulation to homes where in EPS sheets of 1 m × 0.5 m × 0.05 m size and density 18kg/m^3 is fixed directly on to the ceiling using bitumen primer. A 19 mm wire mesh is fixed below the EPS sheets and tied to the roof by means of GI wire. This is then coated with POP. The wire mesh is used to provide reinforcement to POP over EPS sheets. This is expensive and laborious approach in case of existing EPS roofs.

PROPERTIES OF THE EPS FROM LOCAL MARKET

Expanded Polystyrene (EPS) boards available in the local market and being used for the purpose of the false roofing systems in industrial shop floors, shopping malls, class rooms and office rooms are procured and analyzed. The material used in the study is found to have the characteristics shown in Table 1.

S.No.	Description	Data
1	Size	1 m × 0.5 m
2	Thickness	40 mm
3	Average weight	130 to 150 g
4	Density	6.5 to 7.5 kg/m^3

Table 1 Physical properties of EPS procured from the market

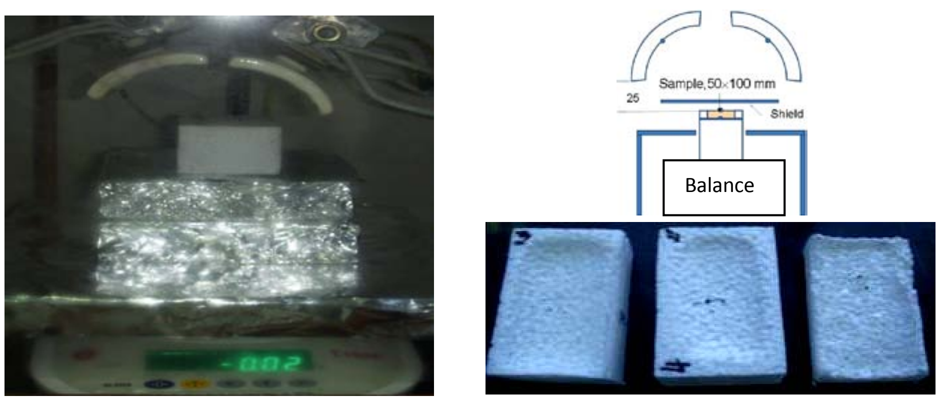
Thermal properties of EPS as found in literature are 0.04 W/m.K (conductivity), 15 kg/m^3 (density) and 1500 J/kg.K (specific heat) [**3**]. The data from literature indicates density is in the range of 11-30 kg/m^3 [**3**] while EPS available for false roofing in Bangalore market have densities in the range of 6 - 8 kg/m^3. These appear distinctly lower and therefore it is important to study the performance of this low density material.

EPS is usually ignited in two modes during a fire event – (a) due to point source of ignition – direct contact with local flame/high temperature source. EPS false roof normally hides ad-hoc wiring carried out after the statutory concealed wiring. The plenum created above the false roof is thus exposed to a fire hazard and (b) hot gases from fire in a compromised room. The response from EPS to heat depends on the temperature of ignition source. For hot gas temperatures of ~150°C, EPS tends to shrink/sublime/vaporize (as shown in Fig.1) leading to a less dangerous condition as its contribution to overall room fuel load is low. If EPS gets ignited due to a point heat source or hot gas streams with temperatures greater than 350°C then the condition is disastrous as EPS gets ignited. A rain of ignited liquid droplets will result which subsequently act as point sources of ignition causing accelerated damage and hampering evacuation activity too. EPS is treated with Hexa-Bromo-Cyclo-DoDecane (HBCD) to facilitate faster shrinkage protecting it from ignition. A cone calorimetric study [**3**] on reaction to fire from standard and Fire Retarded EPS reports that average and peak Heat Release Rates (HRR) are directly proportional to density (11 kg/m^3 to 30 kg/m^3) with FR variety having lower HRR.

The studies also report that EPS is a difficult material for cone calorimetric study because of the shrinkage properties.

EXPERIMENTAL STUDIES

EPS boards procured locally were subjected to a variety of fire tests including exposures low power flame heat sources like candle flame and LPG torch flames. They were also subjected to radiant heat in a horizontal configuration (twin ceramic heaters, 1000 W each) shown in Fig. 1. Volume reduction is found to be higher compared to mass reduction resulting in densification of EPS boards. Volume reduction rates for a heater surface temperature of 550 $^{\circ}$C is found to be 20% higher compared to 400 $^{\circ}$C.

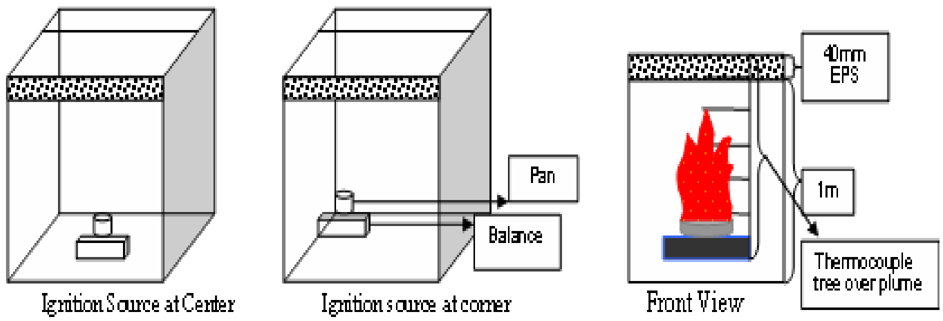


Heater Setup **80s (500 °C) 40 s (400 °C) 80 s (550°C)**

Fig. 1 heater setup and images of EPS after shrinkage

The experimental technique employed to study and compare both protected and unprotected EPS boards used for false roofing systems consisted of the following.

A test room of 1m^3 size is constructed using slotted angles of 39 mm × 2 mm c/s and is covered on three sides and on the top by a 0.19 mm GI sheet of 120 GSM leaving the floor and front side open for access to conduct experiment. Kerosene is used as fuel. Approximate size of fire base required for obtaining a temperature of about 150 °C in the vicinity of a 1 m high ceiling is determined for a flame elevation of about 2 times the fire base using Alperts correlation. Based on this, pool diameters of 181, 205, 225 and 240 mm dia. are chosen for study. Real time mass data is acquired to evaluate power levels using digital Balance (ESSAE , 0.1g LC, 600 g range) connected to data acquisition system (IOTech, Personal daq 56, 80 hz, 10 µV LC) to acquire mV data calibrated for mass loss. A thermocouple tree is constructed with 1 mm bead size type K thermocouple is used to obtain vertical, axial temperature profile of the pool fire. Tests were video graphed for analysis. The experiments



were conducted individually for both protected and unprotected sheets maintaining identical conditions.

Fig. 2 schematic of experimental arrangement

Characterization of the Ignition Source

Density and boiling point of kerosene used is determined to be 0.81 g/ml and 165°C respectively. Fig. 3 shows the images of pans used and a graphical representation of linear burning rate and power level versus pool dia. Obtained linear burn rate data is in the burn rate range indicated in burn rate range for kerosene pool fires [5].

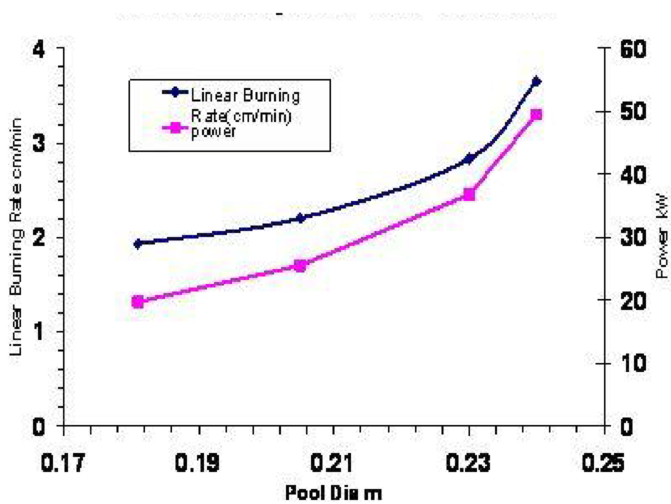


Fig. 3 linear burn rate of kerosene fire sizes and inset: tested pans

FIRE STUDIES

Experiments are conducted to test both the uncoated and coated EPS boards for the fire performance in $1m^3$ room maintaining the nominal atmospheric conditions. Two boards of equal sizes 1m×0.5m×0.04m were used in each case.

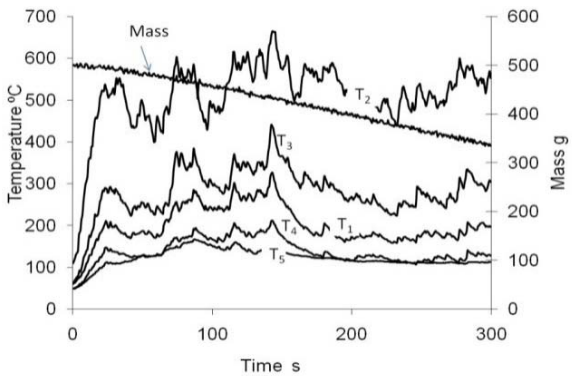
A pool fire of 205mm diameter with a power level of 25 kW is chosen as fires with a plume temperature of 500° – 600°C would be sufficient to burn the material. Fig 4 shows temperature histories recorded at 5 vertical locations for a pool fire of power 25 kW. Table 2 shows the power levels and predicted plume temperature from Alpert correlation [5] given below.

$$T_{pl} = T_{amb} + 16.9\left[\frac{(k_f.Q_f)^{2/3}}{(H_p - F_e)^{5/3}}\right]$$

Sl. No.	Pool Dia. mm	Area cm²	Fuel Mass Loss g/s	Linear Burn Rate cm/min	Mass Burn Rate g/m².s	Power Level kW	Predicted Plume Temp. °C
1	181	257	0.458	1.93	178	20	427
2	205	330	0.589	2.20	179	25	500
3	225	415	0.852	2.83	205	37	631
4	240	452	1.147	3.65	254	50	764

Table 2: Power levels and predicted (Alpert correlation) plume temperatures

Where T_{pl} is plume temperature (°C), T_{amb} is ambient temperature (°C), k_f fire location factor (m), Q_f fire heat release rate (kW), F_e Fire elevation (m), H_p target height measured from floor (m). The experiments were conducted in two modes, keeping the ignition source at centre and at the corner of the room.



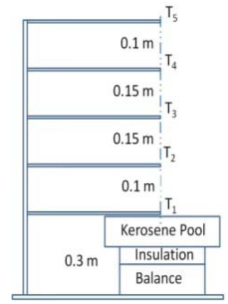


Fig.4: 205 mm φ pool fire temperature and mass profile; Right: TC tree

EPS COATING TECHNIQUES

Four techniques for applying gypsum on to the surface of EPS devised and tested.

(a) A 33% mixture of gypsum in water is prepared. A 45 GSM porous paper sandwiched between layers of gypsum coating is applied on to EPS surface. The board is air dried for ~4 hrs, before testing leading to a coating of about 1 mm adding 650 g to board (Mass addition of EPS 430%),

(b) Aqueous gypsum aggregate is cast on to EPS surface with uniform spreading without using hand. This improves surface finish with several options of colour and texture to contribute to aesthetics. Drying time is high,

(c) Thin consistency gypsum can also coated using spray pump and

Table 3: Coating cost for 1m × 0.5 m EPS board

S.No.	Material Description	Quantity	Cost Rs
1	Gypsum	500g	5
2	Paper 45 GSM	1	1
3	Labour	1	2
4	Total	1board	8

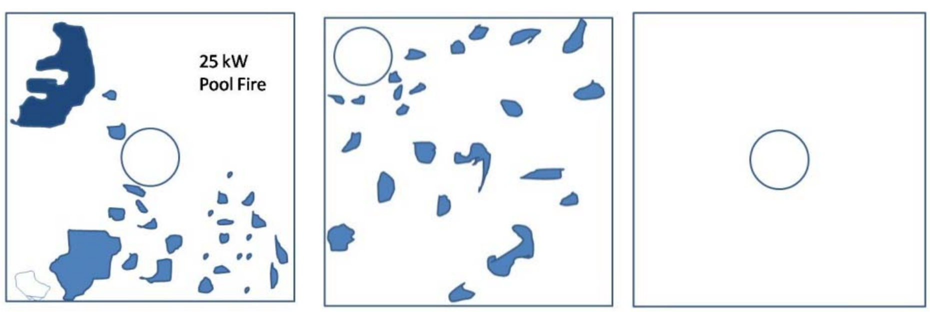
(d) Gypsum application with sponge roller is found to give thinner finish to the surface. Table 4 gives a comparison of test results from these techniques. The making cost of fiber reinforced gypsum coated EPS board of 40mm thickness is given in Table 3. With use of appropriate equipment cost can be reduced by 20%.

Table 4: Comparison of pool fire study of coated and uncoated EPS boards

Sample Description	Gypsum fraction %w/w	Average thicknes s mm	Layer loading g/m^2	25kW Fire Resistance min
EPS uncoated	Nil	40	-	hole in 18 s
EPS + Paper + Gypsum	86	41	809	30
Spray Technique	58	40.5	720	30
Sponge Roller	49	41	600	30
Pour- spreading	30	41	800	30

RESULTS AND DISCUSSION

Roofing is tested in 1 m^3 room with centre and corner fires. In both cases, the uncoated EPS started to vaporize creating holes of 0.05 m at 18 s which increased to a bigger size up to a diameter of about 0.4 m. The volume loss rate as observed from video is approximately to be at a rate of 0.01% per second. The coated EPS did not experience any volume loss till the end of the experiment, about 30 minutes from the start of ignition. Fig 6 shows the condition of the floor after experiment with the EPS uncoated boards at centre and corner locations.



Uncoated: Centre **Uncoated: Corner** **Coated Centre**

Fig. 6 schematic of floor after tests (dark regions show dripped material)

Dark regions were traced from images of actual experiment. It is seen that about 35% f floor area is compromised in both corner and centre cases of test while coated EPS shows extended safety.

a. Uncoated EPS **b. Coated EPS** **c. coated EPS**

Fig. 7 Images of EPS boards before and after pool fire test and c/s of EPS

Fig.7 shows comparisons of EPS surface conditions. The conditions (temperature and velocities) existing in tested configuration in the region just below the EPS surface is comparable to actual situations. Fig 7- c shows a section view of coating. Addition of color improved the aesthetics.

CONCLUSION

This study has been concerned with an approach to increase the fire retardency of commercially available EPS that has actually been already used in buildings. Experiments with coating thin layer of reinforced gypsum improves fire safety substantially in existing rooms with EPS insulation by retaining its integrity for over 30 minutes. The aesthetics can also be addressed with a marginal cost increase.

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