Available online at
www.ijacskros.com

Indian Journal of Advances in Chemical Science

Indian Journal of Advances in Chemical Science 3 (2014) 109-112

Fire Behaviors of Polyurethane Foams

T.S. Raghu[1]*, T.M. Kotresh[1], R. Indushekar[1], K. Murugesh Babu[2]

[1]Defence Bioengineering and Electromedical Laboratory, Bengaluru - 560 093, Karnataka, India. [2]Department of Textile Technology, Bapuji Institute of Engineering & Technology, Davangere - 577 001, Karnataka, India.

Received 9th September 2014; Revised 24th October 2014; Accepted 25th November 2014

ABSTRACT

The effect of using flame retardant (FR) additives in polyurethane (PU) foam has been investigated using a cone calorimeter at 30 kW/m^2. Peak heat release rate was found to increase for normal foam as compared to FR foam. Carbon dioxide was found lower for FR PU foam, whereas carbon monoxide yield was found to be very high as compared to PU foam. Smoke toxicity, as indicated by the index of combustion completeness, was found to be higher for PU FR as compared to PU foam.

Key words: *Cone calorimeter, Flammability, Heat flux, Heat release rate, Polyurethane flame retardant foam.*

1. INTRODUCTION

Foams either in combination or in their individual forms, have found a large number of applications in industry and in daily life. Polyurethane (PU) foams are widely used in many commercially established applications such as mattresses, automotive and furniture cushions and carpet backing. Flexible PU foams are extensively used due to their superior cushioning, ease of handling and physical properties. Seat cushion design of a military fighter aircraft is gaining importance in light of the sustained missions that may have the aircrew in their seats for more than 15 h [1]. The use of foam certainly enhances the sitting comfort, but this is coupled with the significant disadvantage of its flammability. The composition and weight of conventional seat materials used in public transport vehicles (passenger aircraft, trains, buses, etc.) contribute a major part of the hazards affecting passenger survival in fires [2].

The flammability of urethane foams can be considered from three viewpoints, (1) fire hazard, or the extent to which the material represents a danger to life and property; (2) fire damage, or the extent to which the behavior of the material in a fire contributes to financial loss and, (3) fire protection, or the extent to which the material reduces hazard and damage to other materials in the system [3].

Fire hazards of foams can be minimized by incorporation FR agents into the foam, i.e., reactive and non-reactive type. Reactive type and halogen containing FR additives are found to be eco-friendly as compared to other agents, since these compounds participate in the foaming reactions with foam and become part of the polymer and combustion proceeds via a free radical mechanism. Phosphorus compounds are effective flame retardants for oxygen-containing polymers and functions in a condensed phase and promote char formation [4], which provides a protective barrier for less accessibility to oxygen reduces the heat release rate (HRR). Hence in this present study, an attempt has been made to study the fire behaviors of foam containing both halogen and phosphorous compound as FR agent.

2. EXPERIMENTAL

2.1. Materials

In the present study, commercially available PU foam and FR PU foam were used. The details of foams are given in Table 1.

2.2. Cone Calorimeter

A cone calorimeter that operates on the "oxygen consumption" principle [5] and made by Fire Testing

Table 1: Details of PU foams.

Foam type	Density (kg/m^3)	Thickness (mm)
PU foam	32	25
PU FR foam	32	25

PU=Polyurethane, FR=Flame retardant

*Corresponding Author:
E-mail: meetraghu2004@rediffmail.com,
Phone: +91-9481480534

Technology Limited UK was used in the testing of samples as per ISO 5660. Foams were tested at 30 kW/m^2 of heat flux.

2.3. Preparation of Foam Sample

Samples of size 100 mm × 100 mm × 25 mm and 200 mm × 200 mm were cut from the continuous sheets of PU foam. A single layer of aluminum foil with its shiny side toward the sample was used to wrap the foam. The wrapped sample was secured in the sample pan with a sufficient backing of ceramic wool blanket (60 kg/m^3 density) over the ceramic block. A retainer frame was placed around this assembly and hence that only 88 cm^2 of the top surface of the foam sample was exposed to the radiating conical heater. The optional wire grid was not used in the present study.

3. RESULTS AND DISCUSSIONS

3.1. Ignition Time

The values of ignition time (t_{ig}) of the foams 30 kW/m^2 of heat flux considered in the present study are given in Table 2. It is seen that the ignition time increases for the FR treated foam as compared to normal foam even though the density is constant. This is attributed to foam containing different chemical constituent with the same density. Hence, the use of FR agents reduces the life-threatening and hazardous effects from the fire to a little extent as compared to normal PU foams [6].

Table 2: Ignition time and related parameters.

Parameters	PU foam	FRPU foam
Initial mass m_1 (g)	8	8.2
Mass lost m_2 (g)	6.68	4.76
% mass lost=m_2/m_1×100	83.5	58.04
Ignition time t_{ig} (s)	16	25
PHRR (kW/m^2)	317.97	284.93
Av HRR (kW/m^2)	105.2	68.2
THR (MJ/m^2)	18.69	11.04
TOC (g)	12.71	7.68
Av MLR (g/s)	8.98	12.74
Av CO (kg/kg)	0.06	0.17
Av CO_2 (kg/kg)	2.2	1.72
Index of combustion, Av CO/Av CO_2	0.027	0.098
Flash over propensity, t_{ig}/PHRR	0.050	0.087
Number of tests conducted	4	3

Av HRR=Average heat release rate, THR=Total heat release, TOC=Total oxygen consumed, Av MLR=Average mass loss rate, Av CO=Average CO yield, Av CO_2=Average CO_2 yield, PHRR=Peak heat release rate, HRR=Heat release rate, PU=Polyurethane, FR=Flame retardant

3.2. Heat Release

3.2.1 Heat release rate

Figure 1 shows the heat-release rates of PU foams, the HRR curve shows a sharp peak, followed by a drop in HRR, with the subsequent rise in HRR spread over a period. The initial peak in HRR in case of PU foam is attributed to surface pyrolysis [7], but the same phenomena is shifted over a period of time in case of FR foam as compared to PU foam and the drop is associated with the char formation was rapid in case of FR foam compared to PU foam. This is attributed to strong char formation in the case of FR foam acts as a strong barrier and reduces the accessibility oxygen for burning results in a rapid reduction in HRR at the end of the test. Nature of char formation by the PU and FR foam was shown in Figure 2a and b. Figures differentiate the stability of the char formed due to FR nature of the foam as compared to normal foam.

3.2.2. Peak heat release rate (PHRR)

PHRR and t_{ig} are believed by many fire scientists to be the major detriment of the onset of flash-over propensity for furniture in the real fire situation [8]. It can be seen that FR foam drastically reduces the PHRR vis-à-vis that of PU foam. As seen from the Table 2, mass loss rate was higher for the PU foam compared to FR PU foam. The enhanced mass loss rates offer more fuel per unit time resulting in a higher heat output.

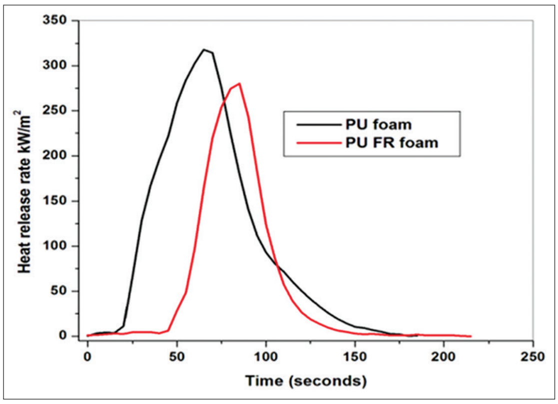

Figure 1: Heat release rate curves.

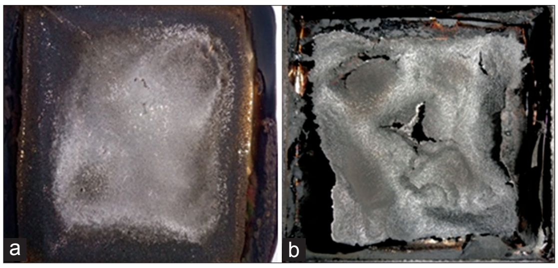

Figure 2: Stability of char formed, (a) polyurethane (PU) foam, (b) PU flame retardant foam.

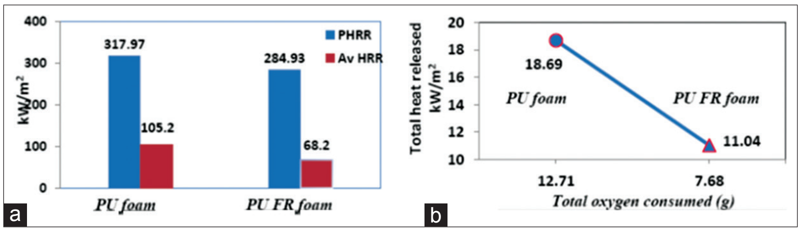

Figure 3: (a) Peak heat release rate and average heat release rate, (b) total heat release versus total oxygen consumed curves of foams.

Reduction in PHRR was due to decreased heating rate in case of FR foam leading to the formation of surface char as shown in the Figure 3a.

3.2.3. Average heat release rate (Av HRR) and total heat release (THR)

Av HRR values for foams are given in Figure 3a. As can be seen, the Av HRR values depend upon the PHRR values. In addition to this, THR and total oxygen consumed (TOC) were also drastically reduces for FR foam and found to be linearly correlated as shown in Figure 3b. These results depend on the amount of fuel load exposed to particular heat flux and strong protective barrier formation in the case of FR foam reduces the oxygen required for combustion resulting in reduced heat release from the foam.

3.2.4. Carbon dioxide (CO_2) and carbon monoxide (CO)

CO is the most common toxic gas in fires, but there are numerous published reports of the combined actions of CO when accompanied by another toxic gas, such as CO_2, HCN, HCI, and HF. Among the various combinations of toxic gases, the combination of CO and HCN, CO_2 has most often been studied because of the similarities in their narcotic actions [9]. The effect of FR agent has a major impact on the yield of CO_2 and CO is shown in Figure 4. CO_2 yield was found to decrease for the FR PU as compared to PU foam, but the CO yield was found to 190% higher for FR PU than that for PU foam. This has a major impact on the smoke toxicity, found to be higher FR PU as compared to PU foam. Increase in CO liberation is due to the FR additives used in the foam.

4. CONCLUSIONS

The present work attempts to study the effect of FR agent on the burning behavior of foam at a heat flux of 30 kW/m^2. The present works are also of practical utility for design and develop the foams according to a degree of fire safety required in various applications, such as seats of automobiles, aircrafts and trains. The following conclusions are drawn from the study.

- The ignition time (t_{ig}) for the FR foam was increased as compared to PU foam and is due to FR nature of the foam decreases the rate of heating of the sample to reach to its ignition temperature
- HRR, PHRR, Av HRR, THR and TOC parameters were found to decrease for FR PU as compared to PU foam. This is attributed to fuel load available per unit area of the material and the strong char formation in the form of protective barrier reduces the accessibility of the oxygen for combustion
- Mass loss rate and MLR ratio were found to be lower for FR foam, resulting from the strong defensive mechanism involved in combustion of FR PU compared to PU foam
- CO_2 yields for FR PU was lower vis-à-vis of PU foam and the reduction is an indicator of suppression brought by FR agent, but CO yield for FR PU foam was increase about 190% than that for PU foam. Hence, smoke toxicity of PU FR was higher compared to PU foam.

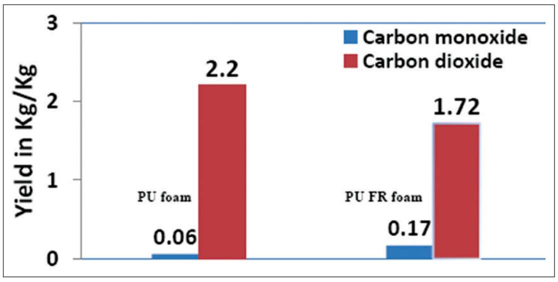

Figure 4: CO and CO_2 yield (kg/kg) of foams.

5. REFERENCES

1. C. Perry, T. Nguyen, S. Pint, (2002) Evaluation of proposed seat cushions to vertical impact, ***SAFE Journal,* 30(3):** 197-207.
2. H. H. Spieth, E. L. Trabold, (1981) Methodology for fire hazard analysis of multilayer seat constructions, ***Textile Research Journal,* 51:** 202-216.
3. J. Green, (1996) Mechanisms for flame retardancy and smoke suppression - A review, ***Journal of Fire Sciences,* 14:** 426-442.
4. C. J. Hilado, (1968) Flame retardant urethane foams, ***Journal of Cellular Plastics,* 4(9):** 339-344.
5. V. Babrauskas, (1993) Ten years of heat release research with the cone calorimeter In: Y. Hasemi, (Ed.), ***Heat Release and Fire Hazard,*** Tsukuba, Japan: Building Research Institute, pIII-1.
6. T. M. Kotresh, R. Indushekar, M. S. Subbulakshmi, S. N. Vijayalakshmi, A. S. Krishna Prasad, (2006) Evaluation of commercial flame retardant polyester curtain fabrics in the cone calorimeter,

***Journal of Industrial Textiles,* 36(1):** 47-58.
7. T. M. Kotresh, R. Indushekar, M. S. Subbulakshmi, S. N. Vijayalakshmi, A. S. Krishna Prasad, K. Gaurav, (2005) Evaluation of foam/single and multiple layer Nomex fabric combinations in the cone calorimeter, ***Polymer Testing,* 24:** 607-612.
8. T. M. Kotresh, R. Indushekar, M. S. Subbulakshmi, S. N. Vijayalakshmi, A. S. Krishna Prasad, V. C. Padaki, A. K. Agrawal, (2006) Effect of heat flux on the burning behavior of foam and foam/Nomex III fabric combination in the cone calorimeter, ***Polymer Testing,* 25:** 744-757.
9. Y. Tsuchiya, (1986) On the unproved synergism of the inhalation toxicity of fire gas, ***Journal of Fire Sciences,* 4:** 346-354.

Bibliographical Sketch

Raghu TS, working as a research fellow in DEBEL DRDO, and registered for Phd. Under VTU in the year 2012, working in the area of design and development of protective clothing's for services. He has completed his M tech in textile technology from VTU in 2009-10. Later joined DEBEL DRDO Bangalore and has got 3-4 years of experience in evaluation of Flammability and related parameters for various assemblies used in services. He has worked in the field of antimicrobial coatings on to the high performance textiles. He has filed one Indian patent and communicated two papers to international journals.