Proceeding Book

GO GREEN2015

INTERNATIONAL POSTGRADUATE CONFERENCE ON GLOBAL GREEN ISSUES

"Incorporating Green Approaches for Resilient Future"

7 - 8 OCTOBER 2015 | Dewan Kuliah Al-Khawarizmi

Universiti Teknologi MARA, Cawangan Perak
Kampus Seri Iskandar
32610 Seri Iskandar
Perak, Darul Ridzuan, MALAYSIA
Website: www.perak.uitm.edu.my/gogreen2015/
Email: gogreen2015@perak.uitm.edu.my

Universiti Teknologi MARA

FSPU Fakulti Senibina Perancangan Dan Ukur
Faculty of Architecture, Planning And Surveying

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Fakulti Senibina, Perancangan & Ukur
Universiti Teknologi MARA Cawangan Perak
Kampus Seri Iskandar
32610 Seri Iskandar,
Perak Darul Ridzuan, MALAYSIA
Tel: +605 374 2000
Fax: +605 374 2244

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Flame Retardancy Study Of Recycled Polymeric Foam Filled Composite Building Material

Syed Anas Bin Syed Mustafa[1], Rahmah Mohamed[2], and Lily Soraya Binti Amerudin[1]
[1]Faculty of Applied Science (FSG), Universiti Teknologi MARA (UiTM), Shah Alam, 40450 Selangor,
Email: ssyed_anas@hotmail.com
[2]Head, GREEN Polymer Research Group, FSG, UiTM, Shah Alam, 40450 Selangor,
Email: rahmahmd@salam.uitm.edu.my , greenkayangan@gmail.com

Abstract

Flame retardancy is an important fire safety element often emphasized by the construction sectors; It is utilized to prevent material ignition, and thus limit the effects of building fires. The preparation and characterization of Unsaturated Polyester Resin (UPR) composite systems filled with recycled Expanded Polystyrene (EPS) were systematically investigated. Core additives such as Flame Retardant (FR) and Antioxidant (AO) were added to the composite for imparting suitable characteristics to the composite. The result obtained via the comparison of the various composite systems studied had revealed that certain additives imparts higher flame retardancy levels than others, but each type of additives might had interacted with the polymeric matrixes differently. Thus, it could be concluded that the varying use of additives affects the systems' flame retardancy and thermal properties. Further in-depth studies of the polymeric composite may help in determining and confirming the actual mechanisms which these additives produces the effect on material's flammability.

Keywords: EPS, UPR, Thermoset Composite, Flammability, Thermal Properties

1.0 Introduction

Green Technology can be contributed by development of new materials using recycled plastic which served to impart some insulation and transparency/translucency qualities; these characteristics enables natural light transmission into buildings, and provides better energy efficiency by both reducing the artificial lighting and air conditioning needs during the day.

Unsaturated Polyester Resin (UPR) matrix composites have been used for many years in a broad technology fields such as naval construction, offshore applications, waterlines, and building construction. UPR is a chosen thermoset material due to its excellent processing ability; good cross-linking tendency, as well as mechanical properties upon cured. Studies had also been done to improve its thermal properties by incorporation of Expanded Polystyrene (EPS) into UPR with relevant diluents.

EPS sheet has been used as core material for sandwich core composite door shutter to replace wooden door shutters in building as applied by Vaidya, et.al. (2000). Gryshchuk (2002) deemed that UPR toughening to increase its impact performance is very important endeavour especially for building structures. It is in the light of this concern and more that this study was performed.

Thus, the preparation and characterization of recycled EPS filled UPR composite systems were systematically investigated. Core additives such as flame retardant (FR) agents, metal oxides and antioxidant (AO) for preventing aging were added to the UPR-EPS composite for imparting selected. Flame retardant functions to increase the resistance of a material to ignition and, once ignited, reduces the rate of flame spread via combustion suppression by acting either through the vapour phase or the condensed phase by chemical and/or physical mechanisms (S. Lu, 2002; F. Laoutid, et. al. 2009).

The use of a flame-retardant additive may prevent a small fire from becoming a catastrophe, to which most fires involving polymer composites often quickly evolved as it consume the volatile combustible material generated from the thermal degradation of polymers. Flame ignition itself depends on numerous variables such as oxygen availability, temperature, physical and chemical properties of polymer.

Most reactions of polymers with oxygen is exothermic, and if sufficient energy is available, would override the endothermic pyrolytic reaction and initiates flame spread. Flame spread; linear burning rate; or the rate of travel of a flame front under given conditions of burning, is a measure of fire hazard. The spreads of flame along the surface of a material can transmit fire. Building materials thus must meet the fire requirement designated by proper fire authorities before it can be utilised in construction industry.

Flame retardants can be incorporated into polymeric materials either as additives or as reactive materials. Additive types are widely used by blending directly into the polymeric material. Problems such as poor compatibility, leaching and reduced mechanical properties are often common drawbacks of additive FR. Reactive overcome these shortcomings by co-polymering the FR with the polymer itself, thus making the flame retardancy quality inherent to the material itself. The main concern and limitation however of this method is the toxicity due to use of halogenated monomers. (P.J. Burchill, 1996; Ewa Kicko-Walczak, 1999; C.M.C. Pereira, et. al. 2009; Terese E. Glodek, et. al. 2008).

This paper shall emphasise on the flammability and thermal characteristics of UPR/EPS composite system with varying organic and metal oxide FR additives with and without antioxidant inclusion. The aim of this work is to evaluate the thermal properties and fire resistance of varying percentage of these additives within the UPE-EPS composites.

2.0 Experimental

2.1 Materials and Method

The selected thermo-set matrix material used for fabricating these composite systems is UPR system, Reversol consisting of vinyl ester oligomers having density of 1.12 g/cc, viscosity of 450-600cps with 41-44% styrene content. Methyl Ethyl Ketone Peroxide (MEKP) and Cobalt solution used as initiator and promoter each, were supplied together with the UPE resin by Revertex Sdn Bhd. These ingredients are similar to materials used by Rashidan, et al. (2009).

The EPS or Styrofoam filler was obtained from waste material; Irganox, an antioxidant was supplied by Ciba Geigy; Phosphate Ester, Silesquioxane, and Melamine as flame retardants are supplied by Tina Organics (P) Ltd. Plasticizers & Allied Chemicals; Zinc Oxide and Tin Oxide solutions were supplied by Merck KGaA.

2.2 Composite Fabrication and Testing

Recycled EPS, fixed at 10% parts by weight (%wt) of UPR resin, was blended by utilizing a high speed agitation mixer until complete dissolution was attained. Gaseous contaminates present are eliminated from the mixture with vacuum suction, while solid contaminates are removed from the mixture after gravity settling for 24 hours.
Additives were then added to the mixture before the samples were prepared. The FR content was varied between 00%wt to 2.5%wt. Each FR are designated a code for distinction; Phosphate Ester is designated as FRA, Silesquioxane is designated as FRB, Melamine is designated as FRC, Tin Oxide is designated as FRD, and Zinc Oxide is designated as FRE.

The AO content was set to 0.5 grams for sample impregnated with organic FR additives but it is absent for sample impregnated with metal oxide FR additives. The MEKP and Cobalt solution usage was set to 2.5%wt and 1 drops respectively for every sample.

Compressive moulding process were done onto aluminium mould, where the mixture jellifies in the mould before any pressure was applied. Gelling time was set to be about 20 to 30 minutes. Once sufficient gel forms, low pressure press were applied for 1 hour at 70^{o}C to retain required shape, and complete curing were done by leaving the sample outside the mould for 24 hours at room temperature. These steps are similar to the process used by Rashidan, et al (2009).

This paper was produced from a study conducted via qualitative analysis of the manufactured samples. the flammability testing of the sample was subjected to the procedures underlined under the ASTM D635 standard. This particular standard utilizes prepared specimen size of 125 mm x 20 mm x 3 mm. A fixed distance of 75cm for combustion is used to complete flame propagation and the sample been placed to burn in horizontal position by using candle flame at room temperature. Linear burning rate were assessed from time taken to reach specified distance.

The samples with metal oxide FR additives were also tested via thermal probe to determine their thermal conductivity, thermal diffusivity and volumetric heat capacity. The thermal properties of samples was determined by use of a KD2 Pro Hand-held Thermal Probe which adheres to ASTM D5334-08 and IEEE Standard 422-03 as set by ASTM and IEEE.

3.0 RESULT AND DISCUSSION

3.1 Flammability Test

Table 1 shows the time required by the sample to burn for a fixed distance, as indicated as elapsed time (s); and the rate of combustion is shown by the linear burning equation, V(mm/s)

$$\text{Linear Burning Rate, } V = L/t$$

Where: L = the burn length, in millimetres between two reference marks (Length between the two is 75mm)
t = the time(s) (elapsed time the flame spreads across between the two reference mark)

Table 1: Linear burn rate comparison of different FR additive composition.

Sample Code	Additive in UPE/EPS Composite	Elapsed time(s)	Linear Burning (mm/s)	Linear Burning (mm/min)
F00	0.5%wt AO	510.6	0.147	8.813
FRA	2.5%wt FRA - 0.5%wt AO	812.4	0.092	5.527
FRB	2.5%wt FRB - 0.5%wt AO	709.8	0.106	6.340
FRC	2.5%wt FRC - 0.5%wt AO	627.6	0.120	7.170
FRABC	2.5%wt FRABC - 0.5%wt AO	805.2	0.093	5.589
FRD00	Similar to F00; AO absent	408.3	0.184	11.021
FRD 05	0.5%wt FRD	198.1	0.379	22.716
FRD 10	1.0%wt FRD	178.5	0.420	25.210
FRD 20	2.0%wt FRD	152.3	0.492	29.547
FRE 05	0.5%wt FRE	184.7	0.406	24.364
FRE 10	1.0%wt FRE	165.1	0.454	27.256
FRE 20	2.0%wt FRE	100.4	0.747	44.821

Based on the formulation as in designated code in Table 1, the linear burning rate decreases as a longer elapsed time is recorded. Each FR are designated a code for distinction; Phosphate Ester is designated as FRA, Silesquioxane is designated as FRB, Melamine is designated as FRC, Tin Oxide is designated as FRD, and Zinc Oxide is designated as FRE.

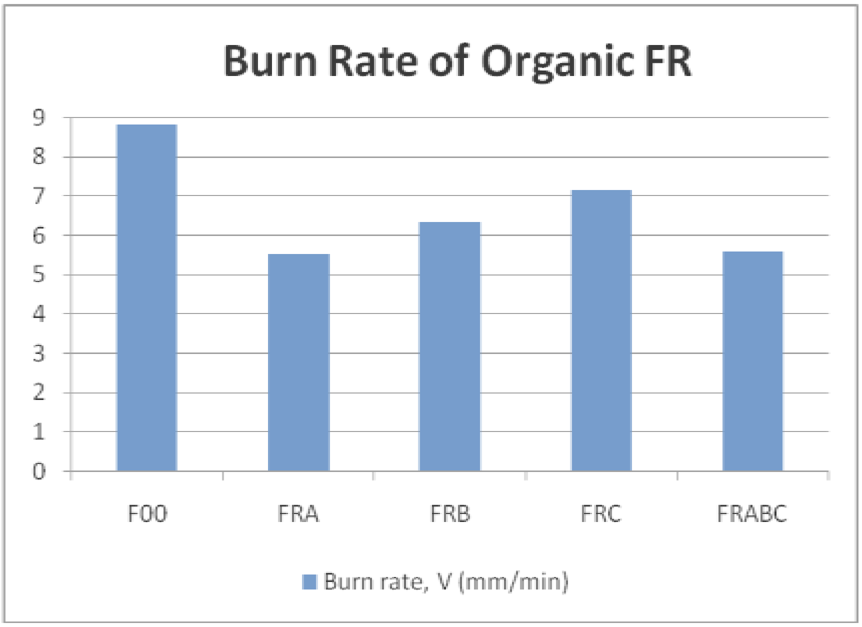

Figure 1: Linear burn rate comparison of different Organic FR composition.

As Table 1 and Figure 1 indicates, the burning time taken for the three types of organic FR shows how each affects the flame speed/burn rate either individually or in tandem. FRA shows the best performance as a flame retardant additive for the system at a 37.1% flame speed reduction; even an equivalent mixture of all three in the FRABC system was second best in relation to it. FRC, on the other hand, was the least efficient FR additive for this polymeric system, although it does boast a fair 18.6% reduction in flame speed.

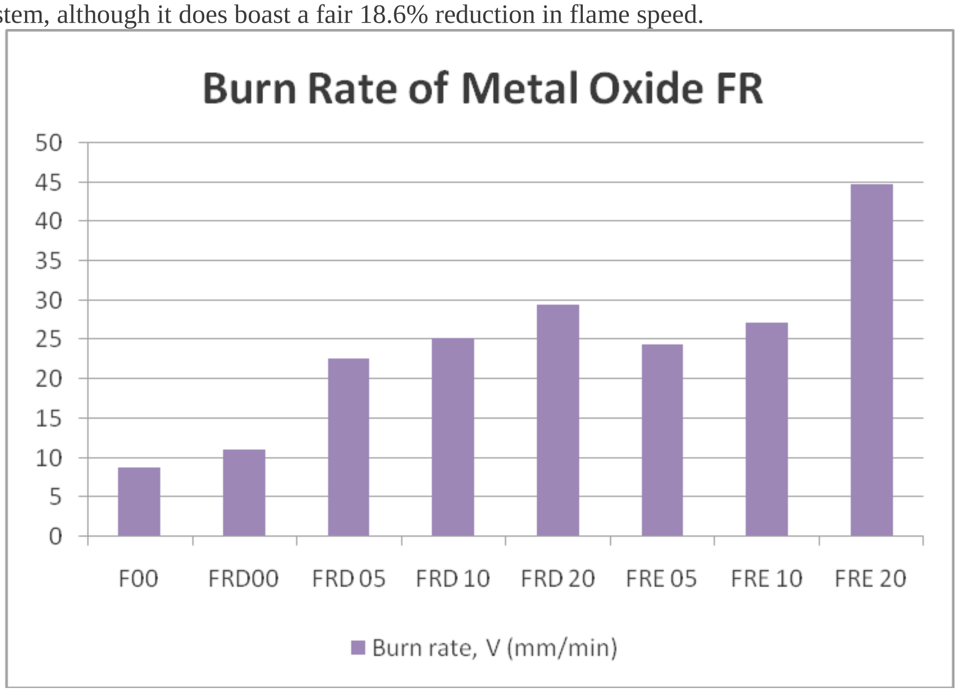

Figure 2: Linear burn rate comparison of varying Metal Oxide FR levels.

As shown in Figure 2, FRD and FRE however shows some failure in achieving flame retardancy effects for the polymeric system. Although the absence of AO may enable an easier ignition and faster flame rate as seen in the difference of F00 and FRD00, each increment of either material increases the flame speed as reported in Table 1 above. Introduction of either into the system triggers a doubling in flame speed, although subsequent amount only adds a small flame speed boost except the outlier of FRE 20.

A probable explanation is the manner which both organic and metal oxide FR was integrated into the polymeric system. Unlike the organic FR which often covalently bonded directly into the matrix, the metal oxide FR requires a suspension system to enable through mixing of the particle into the polymeric matrix. These suspensions usually utilizes relatively flammable solutions such as toluene which are counter-productive to the task expected of the additive. Until further study to determine this hypothesis, this shall be best to explain this data disparity.

3.2 Thermal Characteristics

Metal oxide FR testing for thermal tests were performed as the thermal probe instrument are only made available recently. This set were tested via thermal probe to determine their thermal conductivity, thermal diffusivity and volumetric heat capacity. These thermal characteristics are oft-considered qualities in green materials especially those involved in the construction industry. A low thermal conductivity, and the resulting thermal diffusivity, helps retain heat from dissipating against the end-users' needs.

Table 2: Thermal properties comparison of Metal Oxide FR.

Samples Code	Additive in UPE/EPS Composite	Conductivity, k, x10 W/m K	Diffusivity mm^2/s	Volumetric Specific Heat $MJ/m^3 K$
FRD00	UPR-EPS Mix.	1.930	0.096	2.008
FRD 05	0.5%wt FRD	1.900	0.094	2.030
FRD 10	1.0%wt FRD	1.720	0.089	1.921
FRD 20	2.0%wt FRD	2.800	0.089	3.134
FRE 05	0.5%wt FRE	1.810	0.090	2.006
FRE 10	1.0%wt FRE	1.240	0.091	1.368
FRE 20	2.0%wt FRE	1.470	0.098	1.505

The thermal conductivity indicated by Table 2 showed a minimum of 0.124 $Wm^{-1}K^{-1}$ as recorded by the FRE 10 sample, while the FRD 20 sample recorded the highest at 0.280 $Wm^{-1}K^{-1}$. Figure 3 below shows how increasing the amount of FRD/E decreases both thermal conductivity and volumetric specific heat before excessive additives reverses the trend.

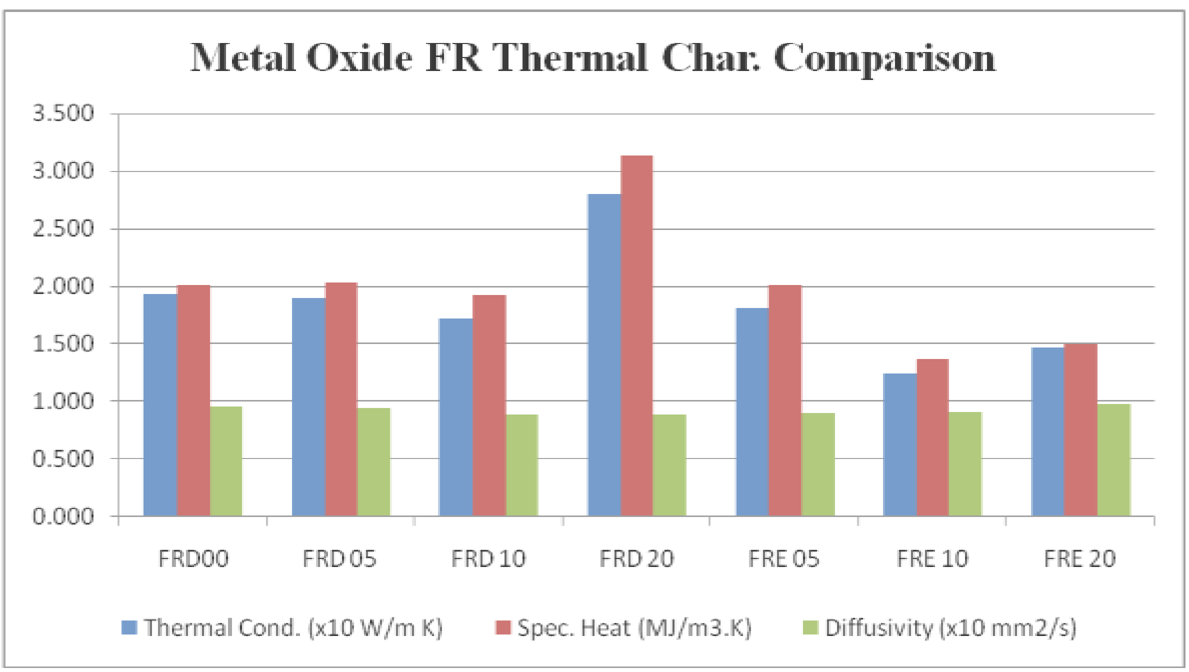

Figure 3: Metal Oxide FR thermal characteristic comparison.

In contrast, thermal diffusivity is a compound characteristic by the ratio of thermal conductivity to volumetric specific heat. This property measure thermal inertia in that how fast the material changes temperature due to its thermal conductivity and specific heat. In the construction industry, a material with low thermal diffusivity are preferable as the quality may indicates a material which could withstand changing environmental temperatures.
As such, FRD 10 had shown characteristic of a good green building material due to its relatively low thermal conductivity and specific heat give birth to its low diffusivity. This sample might be suitable for tropical climate such as in Malaysia.

Surprisingly, FRD 20 also sports a similar low diffusivity of FRD 10 despite its conductivity and specific heat are the highest of the set. This hypothetically makes FRD 20 a suitable alternative to FRD 10 for use in other type of climates where the temperature changes are faster or with more extreme temperature ranges.

All in all, the inclusion of metal oxide FR improves the thermal resistance quality of the polymeric system by lowering both thermal conductivity and specific heat until a certain threshold. This effect may occurs due to their metallic oxide nature, where the dispersed and trapped metal oxide particles might had created thermal barrier bubbles that acts similar to how air trapped in foams slows heat conduction. Further study are required to determine the validity of this hypothesis.

4.0 Conclusion

In conclusion, by utilising suitable FR that easily -assimilate with the polymeric system; the flammability, flame speed, and thus its fire hazard maybe reduced up to nearly 40%. Otherwise the effects desired may not be obtained and may even backfired due to the low capability of the additive to the system. Thus, FR compatibility should be a concern for its use.
In terms of the studied thermal characteristics, the inclusion of metal oxide FR had improved the thermal resistance quality of the polymeric system by lowering both thermal conductivity and specific heat until a certain threshold of 1.0%.

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