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Flame retardancy study of recycled expanded polystyrene filled polymeric building material

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Abstract
Flame retardancy is an important characteristic in the flame and fire safety field to both prevent and limit the effects of material ignition and flame consumption. The preparation and characterization of Unsaturated Polyester Resin (UPR) filled recycled Expanded Polystyrene (EPS) composite systems were systematically investigated. Additives such as organic nanocrystal (ONC) and silica aerogel powder were added to the composite for imparting suitable characteristics to the composite. The result obtained from comparing the current study against its predecessor reveals that Liquid Natural Rubber (LNR) is significantly more flammable than Styrene Butadiene Rubber (SBR), but aerogel utilization can negate this effect. It can be concluded that the use of additive could also affect its flame retardancy and thermal properties. Further studies of the materials could be done in determining and/or confirming the actual mechanisms to which ONC and aerogel produces this effect on flammability.

Keywords: Flame Retardancy, Polystyrene, Recycled Composite, Thermal Characteristics Unsaturated Polyester

1. Introduction

Unsaturated Polyester (UPE) matrix composites had been used for many years in broad technology fields such as naval construction, offshore applications, waterlines, and building construction. UPE is an economical thermo-set material which is widely used due to its excellent processing ability; good cross-linking tendency, as well as mechanical properties once cured. Expanded Polystyrene (EPS) sheet has been demonstrated by Vaidya *et al.,* (2000) for use as core material for sandwich core composite door shutter to replace wooden door shutters in building [1]. Studies had been done on the use of EPS incorporated Unsaturated Polyester Resin (UPR) composite fabricated with relevant diluents. Gryshchuk (2002) asserts that unsaturated polyester resin toughening is very important for increasing its impact performance especially for structures and building purposes [2].

Flammability are often defined as the capability of a material sustaining a flame when it is ignited. Flammability poses an ever-present concern in fire safety and prevention; where reducing the flammability of materials, or inversely, increasing its flame retardancy are a priority to help prevent fires by both hardening them against ignition and reduces the flame spreading once it does occur. The preparation and characterization of UPR filled recycled EPS composite systems have been systematically investigated. Additives such as ONC and silica aerogel powder were added to the UPR-EPS blend for imparting suitable characteristics to the composite. The effect of differing weight percentage of additives on the thermal properties and flammability of the material hence forth were determined. The fabricated composites undergoes linear flame propagation test to determine the level of its flammability.

The use of rubber as a toughening agent with UPE had been investigated by both Bonnia (2012) and Redzuan *et al*. (2013) [3, 4], and the use of aerogel in paint for increasing its thermal insulation and flammability capabilities had also been performed by other researchers such as Erdem Cuce (2014), Papadopoulus (2005) and Ossama (1996) [5, 6, 7]. An integration of nanocrystal and aerogel to the UPE/EPS blend were found to lower the thermal conductivity of the material, which is a favourable characteristic required for insulating panels products. From our previous paper, S. Anas *et al.* (2012), we found that the thermal conductivity, k value had reduced by more than half upon adding the additives as prescribed [8]. This paper hence forth shall emphasize on comparing the flammability of various UPR/EPS composite systems impregnated with some selected additives by evaluating the changes in flame propagation speed as effect of the additives utilized.

2. Experimental

2.1 Materials and Method

The selected thermo-set matrix material used for fabricating these composite systems is the Reversol P9780 UPR resin, consisting of vinyl ester oligomers with an average density of 1.12 g/cc; viscosity of 450-600Cps; with a 41-44% styrene content. The EPS or Styrofoam filler was obtained from waste material. 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. This paper was produced by applying an analytical quantitative methodology where the sample produced are subjected to repeated testing on its flammability via ASTM D635-10 standard, and measurement of its thermo-physical properties via a KD-2 Pro thermal probe and a digital densitometer.

2.2 Composite fabrication and testing

Recycled EPS, fixed at 10% parts by weight (%wt) of UPR resin, was blended utilizing a high speed agitation mixer until complete dissolution was attained. This enables the gaseous and solid contaminates present to be easily eliminated from the mixture via gravity settling for 24 hours.

Additives were added before the samples were prepared pouring the mixture onto an aluminium mould. The additives such as ONC content was added at specific quantities as a percentage of blend weight. The process was followed by adding 3%wt of MEKP initiator and suitable amount of cobalt as accelerant to cure the EPS/UPE composite. Gelation time was set to be about 5 minutes. Once fully gelled, complete curing were done under warm compression for 1 hour at a relatively constant 70^{o}C temperature.

The produced sample were then tested by using ASTM D635-10 standard, where samples were lit while suspended in a horizontal position to which flame characteristic and propagation speed were noted. The samples were also subjected to thermo-physical measurements via a KD-2 Pro thermal probe and density determination via a digital densitometer.

3. Result and Discussion

The additives utilized across the samples are elastomers (SBR or LNR), antioxidant (AO), flame retardant (FR), silica aerogel (Ag) and organic nanocrystal (ONC). Table 1 shows the time required for burning the samples at the fixed distance, indicated as elapsed time (s), and the rate of combustion is shown by the linear burning formulation, V (mm/min) in equation 1.

$$\text{Linear Burning, } V = 60L/t \quad (1)$$

Where

L= the burn length, in millimetres between reference marks (100-25=75mm)

t = the time(s) (elapsed time from the 25mm to 100mm reference mark)

Both Table 1 and Fig 1 shows a few key trends; an integration of elastomer into the system promotes flame propagation; a composite utilizing SBR is shown to be more flame retardant compared to the group utilizing LNR; and the use of aerogel and ONC additives have mixed effect on flame propagation speed.

Table 1: Comparison of combustion elapsed time in different additive systems

Additive in UPE/EPS Composite (Per 100% weight mixed UPE/EPS)	Designation	Elapsed time, t (s)	Linear Burning, V (mm/min)
20%wt SBR - 0.5%wt AO	S1	85	52.94
20%wt SBR - 0.5%wt AO - 0.5%wt FR	S2	105	42.86
4%wt SBR - 0.5%wt AO	SA1	511	8.81
4%wt SBR - 0.5%wt AO – 2.5%wt FR	SA2	814	5.53
4%wt SBR - 0.5%wt AO - 5%wt FR	SA3	1433	3.14
4%wt LNR - 0.5%wt AO - 5%wt FR	L1	542	8.30
4%wt LNR - 0.5%wt AO - 5%wt FR - 0.2%wt ONC	L2	617	7.29
4%wt LNR - 0.5%wt AO - 5%wt FR - 0.2%wt Ag	L3	1196	3.76
4%wt LNR - 0.5%wt AO - 5%wt FR - 0.2%wt ONC- 0.2%wt Ag	L4	698	6.45

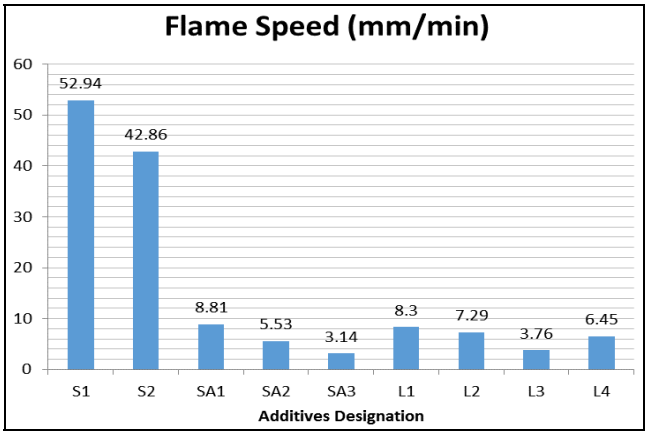

Fig 1: Flame propagation speed for all systems

Going by the set definition of flammability, a faster flame propagation speed correlates to better flammability or lower flame retardancy of a material. Hence, a 75% reduction of SBR content had reduced the flame speed by 80% as shown by comparing sample S1 and SA1 of similar content. This could also be inferred that excessive amount of elastomer might be a preferred fuel for the flameas shown by how slightly the flame retardant tempers the flame propagation speed at higher elastomer content; at 20wt% SBR and 5wt% FR only reduces the flame speed by only 19%, whereas at 4wt% SBR, similar additions reduces the flame speed by a significant 64%.

Comparison between sample SA3 and L1 which differs only on the type of elastomer used, it is inferred that SBR is the more flame-retardant of the two. This is shown by monumental increase in flame speed reported from the L1 sample despite using similar flame retardant amount. This phenomena could be attributed to the different chemical composition between the two elastomers as resulted from the manufacturing processes.

The addition of aerogel and ONC into the composite systems had some effects on the flammability of the materials. The aerogel integrated L3 sample shows significant reduction in flame speed (55% reduction), while the ONC integrated L2 sample report slight reduction (12% reduction). The L4 sample containing both shows value slightly above the expected average of the L2 and L3 (actual speed of 6.45mm/min against the expected 5.53mm/min).

The significant reduction imparted by aerogel might be inferred to be attributed to its inherent Silicon (Si) based

composition which also serves as a thermal insulating material. Silica as a mineral is fairly resistant to ignition and burning which might inhibit flame propagation. The excellent thermal insulating properties of aerogel were found to inhibit flame propagation by shielding the more flammable contents from the high temperature and heat necessary for ignition.

In order to further determine the suitability of utilizing these additives systems, these additive systems should be investigated based on another avenue, namely their effects upon the thermo-physical properties of the resultant material. The chosen measured thermo-physical properties are their thermal conductivity, thermal diffusivity, volumetric specific heat, and overall density.

Table 2: Comparison of thermal properties of different additive systems

Samples	Conductivity W/m.K	Diffusivity mm2/s	Volumetric Specific Heat MJ/m3.K	Density g/cm3
UPR/EPS (L0)	0.165	0.093	1.764	1.221
L1	0.099	0.092	1.112	1.230
L2	0.090	0.089	0.983	1.217
L3	0.254	0.122	1.810	1.205
L4	0.227	0.102	1.657	1.240

Table 2 suggested that adding only the flame retardant as in L1 reduces the thermal conductivity and specific heat, thus maintaining the diffusivity which is the ratio of conductivity to specific heat. Diffusivity is an important ratio in due part to a higher value denotes a material which transfer heat better than retaining it, and maybe suitable for certain applications.

Introducing ONC into the system as in L2 reduces all three thermal properties. Adding aerogel instead such as L3 increases them instead. Finally, adding both additives into L4 balances the two systems preceding it. The results shows that aerogel enhances specific heat capacity as is expected of a material commonly used as a heat insulator, despite going against the same notion by also increasing its thermal conductivity as well. It could be theorized that this is caused by the silica within the cured material, which as a material, has a fairly good thermal retention. With its minute particle size and proper dispersion across the material, this in turn helps enhance heat transfer through the prompt heat adsorption of adjacent aerogel particles across the material.

The slight thermal properties reduction effect of ONC might be explained by its proposed use as an Infra-Red (IR) radiation reflector. IR radiation generated by a heating source were reflected from the sample surface and thus not absorbed by the material, which in turn reduces the amount of heat that could be measured. This reduction was then manifested as a reduction in the specific heat and thermal conductivity.

Density was also affected by the additives system as shown above. Inclusion of FR which was used in liquid form might had increased the density by due of the denser liquid integrated. Both ONC and aerogel however might had reduced the density by having some of material volume displaced by the suspension solvent used to integrate either additive into the material.

Aerogel is also quite significantly the least dense additive used, hence explaining further density reduction upon its integration. However, the integration of both additives had slight increased the density instead, which may be caused by an undetermined mechanism or reaction to enable the integration, thus requiring further study.

Despite all explanations given, these descriptions were merely deductions that are interpolated and concluded from the inherent properties of the material and additives used. In short, further studies are required to fully determine whether the proposed explanations given are true or another different mechanism are at work.

4. Conclusion

It could be concluded from the results that incorporation of SBR instead of NR reduced the flammability of the composite; significant reduction in flammability could also be brought by reduced amount of SBR. The increase in FR used proved to inhibit flammability while the use of additives such as ONC and aerogel have some mixed effects on flame retardancy; the incorporation of aerogel reduces flame retardancy significantly compared to ONC. The integration of aerogel also improves volumetric specific heat while reducing overall density. ONC integrations have slight effect on overall thermal properties. Combining both additives however produces slightly optimized properties. Further research is required to determine and confirm the proposed explanation of the result.

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