EFFECTS OF FLAME RETARDANCE ADDITIVES ON THE MECHANICAL AND FIRE PERFORMANCE OF NATURAL FIBRE COMPOSITES

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ABSTRACT

The incorporation of sustainability is becoming increasingly important in manufacturing practices worldwide. This includes the development of natural fibre composites with mechanical and flammability characteristics suitable for structural interiors. Composites manufactured from kenaf fibres and polypropylene (PP) were investigated as to their suitability as materials for the interiors of buildings, aircraft and such-like. Natural fibres like kenaf act as fuel sources during combustion, and hence, flame retardants are added to the mix. In the present study, the ammonium polyphosphate (APP)-based flame retardant Budit® 3167 was used to address this issue. Limited studies exist on how the inclusion of APP influences the composites' mechanical properties. Hence the main objective of this research project was to evaluate the effect of adding Budit 3167 on both mechanical and flammability properties of kenaf-PP composites. Kenaf-PP composites were manufactured with various fibre weight percentages, with and without Budit 3167. The composites were subjected to different experiments to assess their mechanical and flammability behaviour. It was found that Budit 3167 not only improved the flammability properties of the composites, but also the tensile and flexural moduli due to the flame retardant behaving like a particle reinforcement. However, weak interfacial bonds arising from the addition of Budit 3167 led to a decrease in mechanical strength, providing a basis for further investigation. It was concluded that kenaf-PP composites with Budit 3167 show good potential as a sustainable alternative for structural interiors.

KEYWORDS

Kenaf-polypropylene composites, APP flame retardant, Budit® 3167, mechanical properties, fire performance.

INTRODUCTION

There is growing interest in the use of natural fibre reinforcements in polymer composites. The traditional composites that are synthetic fibre-based with a thermoset matrix are difficult to recycle after their designed service life (Rai and Jha 2004). Recent developments in natural fibre composites have influenced its use in structural and infrastructural applications. For instance, natural fibre composites have been used to develop load-bearing elements such as beams and multipurpose panels. The attraction of using natural fibre composites in beam development is driven by the lower density of natural fibres, lower cost and environmental benefits (Ticoalu et al. 2010). Natural fibre composites offer high specific strength, high specific stiffness, low weight, recyclability and renewability. However, there are concerns around their structural strength and stiffness, as well as flammability requirements for the material. Past studies such as Sobczak et al. (2012) on natural fibres have shown that they possess comparable specific mechanical properties to synthetic alternatives, indicating reinforcement potential. However, natural fibres represent an additional fuel source for combustion (Ohlemiller et al. 1993; Chai et al. 2012), and therefore, natural fibre composites have been known to perform poorly in flammability testing. In order to satisfy flammability requirements, a potential solution is the incorporation of flame retardants. Various studies have been carried out using a wide range of flame retardants applied to natural fibre composites, showing positive results (Jeencham et al. 2010; Suppakarn et al. 2009). However, there has been a lack of studies on how the inclusion of flame retardants within natural fibre composites affect the composites' mechanical and structural properties.

This paper describes a final year undergraduate research project in mechanical engineering which examined how the inclusion of flame retardants affects the mechanical and flammability properties of natural fibre composites. The project focused on evaluating composites constructed with kenaf as the fibre reinforcement and PP as the matrix. MAPP and APP-based Budit 3167 have been used as the compatibiliser and flame retardant, respectively.

The work began with research and experiments to determine optimal processing procedures and parameters for the manufacture of the composites. Once determined, composites were manufactured with and without the flame retardant, and experiments were conducted to evaluate the performance of the composites. An important aim of the project was to determine if there is a relationship between the input materials for the natural fibre composites, when evaluated for their mechanical and flammability properties.

Project Objectives and Outline

Table 1 presents an overview of the project. The main objective was to evaluate how the inclusion of an APP flame retardant affects the mechanical and flammability properties of kenaf-PP composites. This was broken down into the following aspects:

- To evaluate the effects of various kenaf fibre weight percentages as a reinforcement for a PP matrix, with MAPP as a compatibiliser to improve interfacial bonding.
- To assess the mechanical and flammability properties of the kenaf fibre-PP composite.
- To evaluate the effects that an APP flame retardant has on a kenaf-PP composite's mechanical and flammability properties.
- To test various compositions of kenaf and PP, while keeping MAPP and APP fixed. This was to assess whether these have any relationship to the mechanical and flammability properties of the composite.

Table 1 Project overview

	Description	Main Processes	Blends (wt%) (with nomenclature)
Stage 1: Determination of machinery	Establishing fibre length retention of the available extruders	Extrusion, soxhlet extraction, fibre length analysis	30% kenaf; 4% MAPP; 66% PP
Stage 2: Setting the control standard	Creation of specimens without flame retardants	Extrusion, injection moulding	0% kenaf; 0% MAPP; 100% PP (K0)
			25% kenaf; 4% MAPP; 71%PP (K25)
			30% kenaf; 4% MAPP; 66% PP (K30)
			35% kenaf; 4% MAPP; 61% PP (K35)
Stage 3: Adding the flame retardant	Addition of APP-based Budit 3167 flame retardant to the specimens	Extrusion, injection moulding	0% kenaf; 0% MAPP; 30% APP; 70% PP (K0F)
			25% kenaf; 4% MAPP; 30% APP; 41% PP (K25F)
			30% kenaf; 4% MAPP; 30% APP; 36% PP (K30F)
			35% kenaf; 4% MAPP; 30% APP; 31% PP (K35F)
Stage 4: Testing and analysis	Determination of mechanical and flammability properties of the specimens	Tensile, flexural, Charpy impact, drop tower impact, vertical burn and cone calorimeter testing	All injection moulded blends
Stage 5: Analysis of composite's mechanisms	Further evaluation of the composites to better understand their mechanisms	Scanning electron microscopy and differential scanning calorimetry	All composite blends and the constituent materials

MANUFACTURE OF TEST SPECIMENS

To study the effects of a flame retardant on the composites' mechanical and flammability properties, a control standard first needs to be set by manufacturing specimens without the flame retardant. Specimens manufactured with the addition of the flame retardant can then be compared to the standard. Four constituent materials were used for the production of the test specimens, as shown in Table 1. The parameters selected for the compositions were based off the best results, as identified in the literature review, to achieve desirable properties. Two independent parameters were isolated for the production of the test specimens. These were the flame retardant and MAPP content, set to 30 wt% (El-Shekeil et al. 2012) and 4 wt% respectively. Test specimens with kenaf fibre loadings of 25 wt% and 35 wt% were also manufactured.

Materials Procurement

The Moplen HP400L polypropylene was supplied by Lyondell Basell Australia. This PP is a moderate melt flow homopolymer, designed for injection moulding applications. Its characteristics are summarised in Table 2.

Table 2 Characteristics of Moplen HP400L PP

Density (g/cm^3)	Melt flow index (g/10min)	Tensile modulus (GPa)	Flexural modulus (GPa)	Impact strength[A] (kJ/m^2)	Softening temperature[B] (ºC)
0.9	5.5	1.3	1.4	3.0	155

[A]Notched Izod impact test; [B]Vicat softening temperature

Jute-Bangladesh Ltd. supplied the kenaf fibres. The characteristics of kenaf are shown in Table 3. The maleic anhydride grafted polypropylene, TP Licocene PP MA 6452, was purchased from Clariant International Ltd. This grade of MAPP is specially formulated for natural fibre composites reinforced in PP. The ammonium polyphosphate based flame retardant, Budit® 3167, was manufactured by Budenheim Ibérica Comercial. It is an intumescent mixture, optimised for use with PP and PE. Budit 3167 has a decomposition temperature above 250ºC and a bulk density of 0.47 g/cm^3, as per the technical data sheet.

Table 3 Characteristics of kenaf fibres (Akil et al. 2011)

Density (g/cm^3)	Tensile strength (MPa)	Tensile modulus (GPa)	Tensile elongation (%)	Cellulose content (%)
1.44	930	53	1.6	45 – 57

Material Preparation

Before the constituent materials could be compounded together using an extruder, a degree of preparation was required. In general, the finer the constituent materials, the better the opportunity for mixing. This leads to a more homogeneous material. The PP came in a large granular form and therefore, to achieve better dispersion, it was outsourced to be professionally granulated into fine particles. The kenaf came in a yarn form and thus, needed to be processed into a more suitable state. The kenaf yarns were firstly cut using a LabTech Scientific pelletiser into lengths between 20 – 30 mm. These fibres were then taken and fine cut using a Webner granulator with a fine mesh, achieving lengths between 3 – 4 mm. The flame retardant and MAPP both came in fine particle forms which were directly usable.

Natural fibres are prone to moisture absorption. Moisture content greatly affects the performance of natural fibre composites, lowering their mechanical properties. With the intention of producing a natural fibre composite with good mechanical properties, drying the kenaf fibres prior to compounding was a critical stage in the manufacturing process. The kenaf fibres were dried overnight at 80°C prior to extrusion. A moisture analysis showed that the moisture content decreased from 11.0% to 3.3%. In general, increasing the fibre content significantly increases the composite's stiffness and strength but also increases the moisture content uptake (Lee et al. 2013). The moisture content at a given relative humidity can have a great effect on the performance of natural fibre composites, lowering its mechanical properties (Helwig and Paukszta 2000). The moisture content and rate of accumulation is directly related to the ambient relative humidity and therefore, drying the natural fibres prior to processing is a significant step (Robertson et al. 2013).

Extrusion

The constituent materials were first premixed by hand and then intensively mixed with the use of a high speed mixer, set to 21 Hz and turned on for periods no longer than 2 minutes at a time. It was critical that the speed and duration did not exceed these parameters as MAPP is prone to melting. The constituent materials were compounded using a LabTech Scientific co-rotating extruder with kneading blocks. The temperature profile utilised started at 165°C near the hopper, and ended at 185°C near the die, increasing in steps of 5°C. It was essential to heat up the materials gradually due to the poor thermal conductivity of PP. This allowed heat to conduct into the material without first degrading the exterior. The temperature profile was also not to exceed the kenaf fibre degradation temperature, identified as around 200°C. Only the temperature of the die exceeded this limit. It was set to 210°C to lower the pressure build up in this area. With the entire extruder set to a speed of 185 rpm, residence time was generally short for all areas (especially in the die), reducing the risk of degradation. It was also ensured that the melt temperature did not exceed 185°C at any point within the extruder. The extrudates were cooled on a conveyor belt with fans and pelletised using a LabTech Scientific pelletiser. The pelletised

extrudates were dried overnight at 80°C prior to injection and compression moulding, adhering to best practices to achieve desirable properties for the specimens produced.

Injection Moulding

Specimens manufactured via an injection moulding process may not produce the best properties, as the extrusion processes are known to reduce the kenaf fibre length. However, this process is representative of how many structural interior components are currently produced and thus, will allow the results to be more applicable to the manufacturing industry. Various types of specimens were injection moulded at 180°C using a Procan CT injection moulder. Specimens compliant with a range of standards were created for tensile, flexural, impact, vertical burn and cone calorimeter testing. A strict procedure was followed in order to prevent contamination.

Compression Moulding

Another method of producing parts for structural interiors is through compression moulding. This process is less common due to factors such as lower production rates and larger inconsistencies. However, compression moulding requires smaller capital investment and therefore, is at times utilised for the production of low quantity, non-critical parts where it is not feasible to manufacture costly injection dies. Even though one of the benefits of compression moulding is fibre length retention, the pelletised extrudates were utilised for the purpose of comparison. Specimens were produced for the drop tower impact test using a 10 tonne hydraulic press and a customised die.

EXPERIMENTAL METHODOLOGY

A wide range of experiments, tensile, flexural, Charpy impact, drop tower impact, vertical burn and cone calorimetry, were conducted on the test specimens manufactured. This was done to evaluate the performance of and to gain a clearer understanding of how the inclusion of an APP flame retardant affects the composites' mechanical and flammability properties. All the test specimens were conditioned at 23°C and 50% humidity for a minimum of 72 hours prior to testing, in accordance with ASTM International standard D618-13: Standard Practice for Conditioning Plastics for Testing. Due to the random orientation of the kenaf fibres, the composites were assumed to be isotropic materials. To simplify analysis, the direction of injection moulding was ignored. In addition, differential scanning calorimetry (DSC) and scanning electron microscopy (SEM) analyses were also conducted to better understand the mechanisms behind the composites' behaviour. However, due to space limitations, only the flexural, Charpy impact, vertical burn and some of the cone calorimetry results are discussed in the present instance.

Flexural Test

Flexural tests were carried out in accordance with ASTM D790-10: Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials. Dog bone test specimens manufactured through the injection moulding process were tested on an Instron 1185 universal testing machine with a 1 kN load cell. Five specimens of each blend were tested, with the crosshead speed set to 13 mm/min.

Charpy Impact Test

Charpy impact tests were carried out in accordance with ASTM D6110-10: Standard Test Method for Determining the Charpy Impact Resistance of Notched Specimens of Plastics. Bar specimens manufactured through the injection moulding process were prepared using a notch cutter and tested on a Charpy impact machine. Five specimens of each blend were tested.

Vertical Burning Test

Vertical burning tests were carried out in accordance with Underwriters Laboratories flammability standard UL94: Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances. Bar specimens manufactured through the injection moulding process were held vertically and the bottom ends exposed to a laboratory Bunsen burner flame at 45°C. Each specimen was ignited for a period of 10 seconds. If the flame self-extinguished, the specimen was ignited an additional time for 10 seconds. The time taken for the flame to extinguish was recorded. If the flame did not self-extinguish, the test was terminated after 60 seconds. This is because such a specimen has essentially failed to meet any of the ratings. The events during the burning process were also documented, in particular, whether there was burning char, glow or falling material. The aim

was for the specimens to achieve the highest rating, UL94 V-0. To achieve this, the flame must self-extinguish in 10 seconds or less, no glow beyond 30 seconds and no material should fall.

Cone Calorimeter Test

To better understand the flammability characteristics of the composite blends manufactured, cone calorimetry tests were carried out in accordance with ASTM E1354-13: Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter. The 100 mm diameter injection moulded specimens were tested on the FTT cone calorimeter. Utilising a heat flux of 50 kW/m^2, the cone calorimeter was able to determine important burn properties such as the ignitability, heat release rate (HRR), mass lost rate and development of smoke and other by-products. This test method is based on the observation that the net heat of combustion is directly related to the amount of oxygen required for combustion. Three specimens of each blend were tested. To increase accuracy, the required measurements were inputted individually for each specimen. Furthermore, every specimen underwent a calibration process prior to testing.

RESULTS AND DISCUSSION

Flexural Tests

The flexural tests determined the flexural modulus and maximum flexural stress of the composite specimens. These are summarised in Figures 1 and 2, while Figure 3 shows the legends for these and later figures that present results for composites with and without the fire retardant.

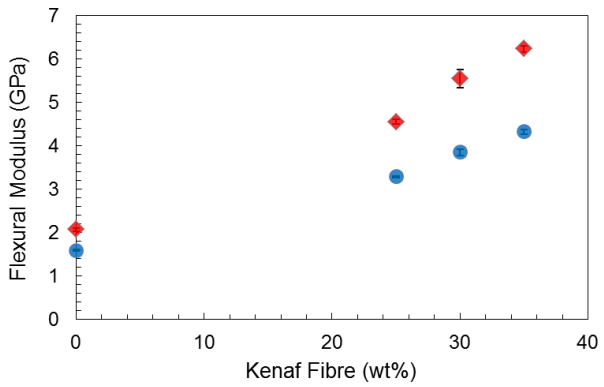

Figure 1 Flexural modulus vs fibre content

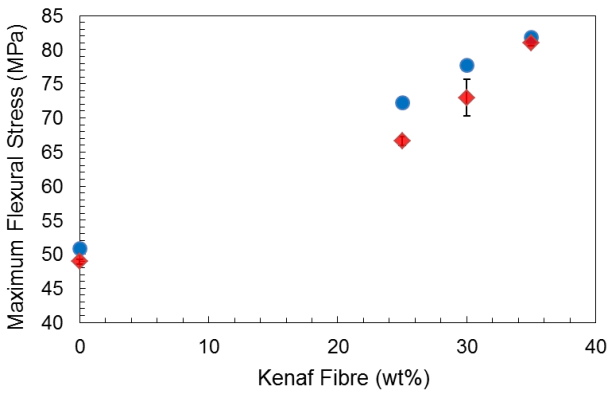

Figure 2 Maximum flexural stress vs fibre content

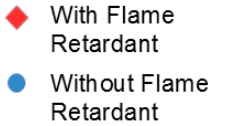

Figure 3 Legend for figures-1

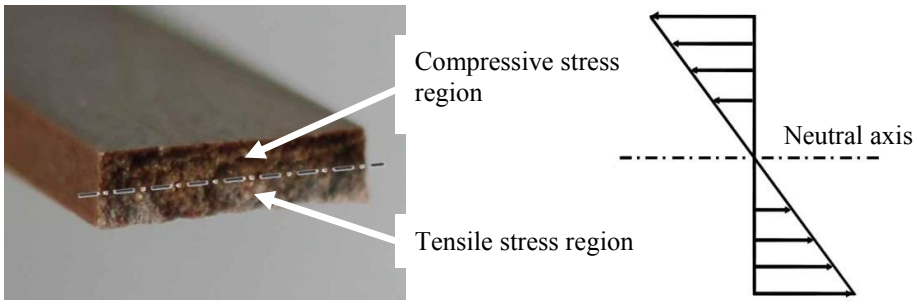

Figure 4 Flexural fracture surface showing two distinct regions

The following trends can be observed from the flexural tests:
(i) Increase in the composites' flexural properties, in terms of both flexural moduli and maximum flexural stress, as kenaf fibre loading increases;
(ii) Addition of the flame retardant increases the composites' flexural moduli between 38.7% to 44.2%;
(iii) Addition of the flame retardant decreases the composites' maximum flexural strength between 1.6% to 7.7%.

Kenaf fibres have superior mechanical properties compared to PP; hence the increase in both flexural modulus and maximum flexural stress with increasing fibre content. Adding the flame retardant further increases the flexural modulus, as the flame retardant acts like a particle reinforcement within the elastic region of the test, and

also, more PP is displaced. However, with regard to the maximum flexural stress, specimens without the flame retardant have better properties. The flexural test consists of both tensile and compressive components, as shown in Figure 4. Within the tensile part of the specimens, the weak bonds between the flame retardant and PP break in the plastic region of the test, resulting in the creation of micro voids and thus reducing the cross-sectional area able to withstand the imposed loading. (This isn't the case in the compressive part of the specimens). However, as the fibre content increases, this difference between the specimens without the flame retardant and those with the flame retardant is reduced. This is because the increased fibre percentage is able to withstand more of the load, thus compensating to some extent the loss of bonding between the flame retardant particles and the matrix, and also the micro voids created. In addition, the amount of PP is also reduced with increasing fibre fraction.

Charpy Impact Tests

The results from the Charpy impact test (Figure 5) show one distinct trend; the large reduction in impact resistance
with the addition of the flame retardant. This decrease in impact resistance is primarily due to the displacement of 30 wt% PP resulting from the addition of flame retardant particles. PP is the primary constituent material providing the composites with ductility and is therefore effectively responsible for the composites' impact resisting properties.
The effect of the flame retardant on the composites' ductility is highlighted in the flexural (and also tensile) tests. Prior to adding the flame retardant, the composite specimens do not fracture before 5% flexural strain. However, after adding the flame retardant, the kenaf blend specimens fracture at a flexural strain between 2.0% to 2.7%.

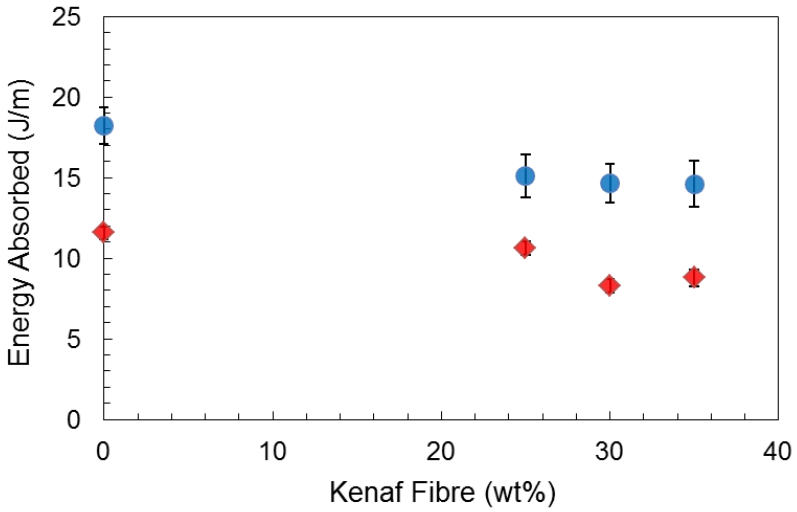

Figure 5 Charpy impact test results

The flame retardant particles act as reinforcements within the elastic region and thus, increase both the tensile and flexural moduli of the composites. This increase in tensile and flexural moduli correlates to a decrease in impact resistance of the composites. The flame retardant particles are essentially brittle materials, thus the large reduction in impact resistance once they are added. When the kenaf fibres are added, MAPP is used to enhance the interfacial bonding between the fibres and the PP, resulting in more effective load transfer. This explains why the drop in impact resistance between the specimens with and without kenaf fibre loading is less significant, when there is a PP reduction between 25 wt% to 35 wt%.

Vertical Burning Tests

The effect of kenaf fibre loading and the addition of the flame retardant on the composites' self-extinguishing abilities are summarised in Figure 6. The two horizontal lines indicate the benchmarks the worst performing specimen is required to be under for the blend to achieve the rating given by the line. The results show that the addition of the flame retardant significantly improves the composites' self-extinguishing fire properties. All the specimens without flame retardants failed to self-extinguish in less than 60 seconds and therefore, did not meet any of the UL94 ratings. Furthermore, burning material fell from all these specimens during the vertical burn test as shown in Figure 7, a very undesirable trait. The specimens with flame retardant performed much better, with only one blend, K25F, failing to achieve a UL94 rating. The Budit 3167 flame retardant is designed for PP.

Hence the fact that blend K0F passed the highest rating, with no specimens igniting during any of the tests, is not surprising. Blend K30F performed extremely well, with the worst specimen self-extinguishing in 9 seconds and therefore, also achieving the highest rating of UL94 V-0. Based on the poorest performing specimen self-extinguishing in 26 seconds, blend K35F achieved the second highest rating of UL94 V-1. Even though blend K35F did not pass with the highest rating overall, it should be noted that there were some specimens within this blend that, independently, would have achieved the UL94 V-0 rating. This variation is likely to be due to factors such as human error, for instance, and inconsistent burning and re-ignition times. Ignition occurs when there is a sufficient level of heat energy transferred to the specimens (Helwig and Paukszta 2000; Babrauskas and Peacock 1992). The UL94 vertical burn test stipulates that each specimen shall be ignited for 10 seconds, allowed to self-extinguish, then re-ignited for another 10 seconds. There is no mention of a wait period between when the flame self-extinguishes and re-ignition, and therefore, it was assumed to be instantaneous. This led to problems when the specimens did not cleanly self-extinguish, resulting in inconsistent re-ignition times. If specimens do not conduct sufficient levels of heat energy required for ignition, they will not ignite. During the down time before re-ignition, heat energy dissipates from the specimens. Therefore, if re-ignition is not instantaneous, heat energy is lost. The second period of ignition will build upon the existing levels of heat energy, and in most cases, induce ignition within the specimens. The variation in the results suggests that there is a fine line between the amount of heat energy required for some specimens, and the total amount of heat energy available in 20 seconds of ignition. As such, the loss in heat energy during the down time is likely to be influential.

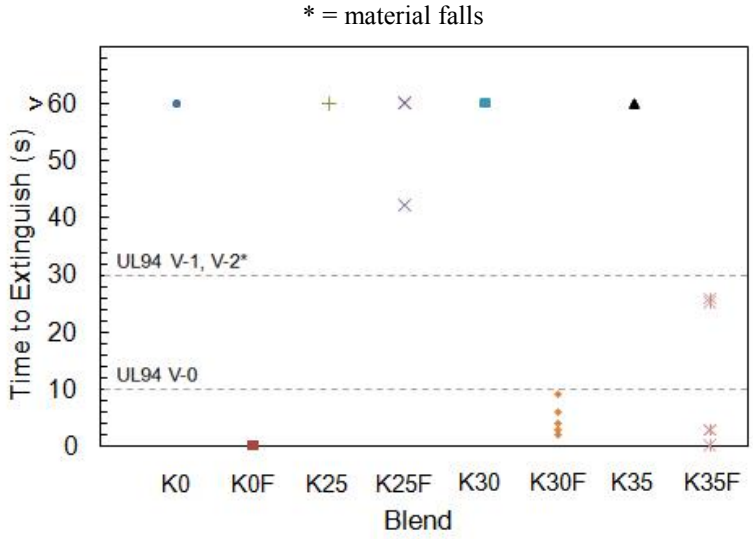

Figure 6 Extinguishing times of all specimens in the vertical burn test

Figure 7 Material falling

Cone Calorimeter Tests

The cone calorimetry analysis determined the effect of kenaf fibre loading and the addition of the flame retardant on the composites' flammability-related properties. Numerous flammability characteristics were evaluated from the cone calorimetry test, some of which are discussed here. The heat release rate (HRR) results are illustrated in Figures 8 and 9. (Figure 10 shows the legend for these and other figures where composite blends are plotted against time as the independent variable). These two figures show two distinct trends once the flame retardants are added. The first is that the composite blends have a reduction of more than 50% in their peak HRRs. The second is that HRRs around 200 kW/m^2 are sustained for longer durations.

It is clear from Figure 8 that the composite blends form two separate groups, with the point of difference attributable to the addition of the flame retardant. Even though the peak HRRs of the blends containing flame retardants are lower, a moderate HRR was sustained for a longer duration and therefore, it is difficult to justify which is preferred. Calculation of the area under the HRR curves for each blend gives the total heat released (THR), providing a means of direct comparison, as shown in Figure 11. A large reduction in the THR is seen for the kenaf fibre blends once the flame retardants were added. This is because 30 wt% of PP, a combustible constituent, has been displaced by the flame retardant. The APP based flame retardant also has various flame retarding mechanisms which lower the HRR and thus, the THR (Xu et al. 2013). An inconsistent trend is seen for the blends without kenaf fibres, K0 and K0F. The THR of K0, the non-flame retardant blend, is actually lower than the blend with the flame retardant, K0F. Upon inspection of the events during the tests for K0, it was found that significant dripping occurred. This means a loss of material, explaining the inconsistent trend and

large variation in data. Due to this factor, data relating to blend K0 should be viewed with caution. The results of time to ignition (TTI) are summarised in Figure 12. These results show that the TTI increases for the kenaf blends once the flame retardants are added. This is due to the flame retarding mechanisms of the Budit 3167 flame retardant. Subject to high levels of heat, the flame retardants' first mode of action is the release of non-combustible gases. These gases form a blanket, preventing the access of oxygen to the composite (Xu et al. 2013) and therefore, delaying the TTI.

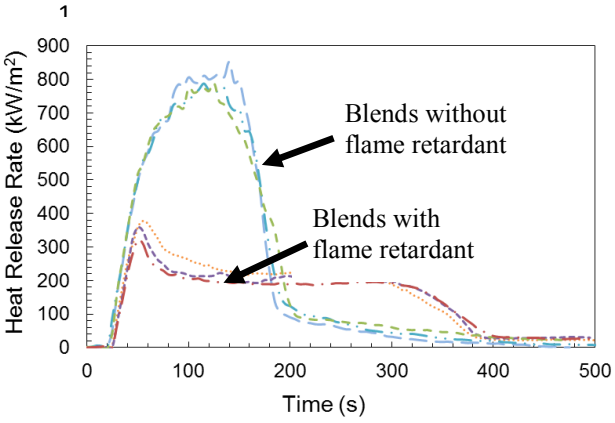

Figure 8 HRR of blends with kenaf fibres

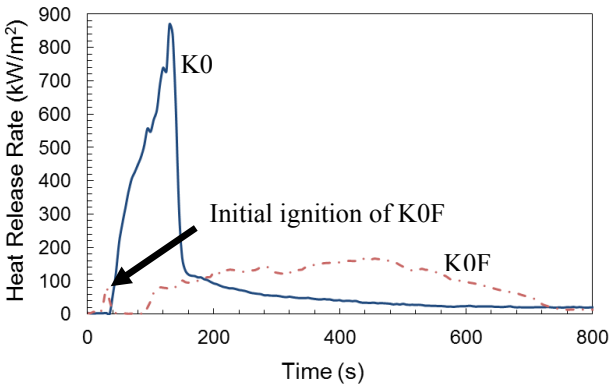

Figure 9 HRR of blends without kenaf fibres

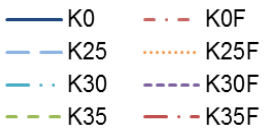

Figure 10 Legend for figures-2

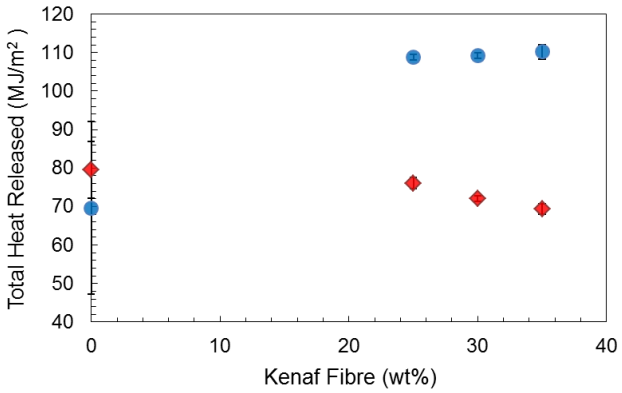

Figure 11 Summary of total heat released

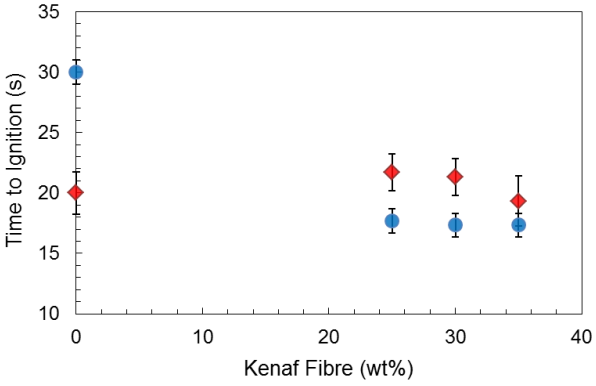

Figure 12 Summary of ignition times

The TTI decreases significantly once kenaf fibres are added to the composites without flame retardants. This is due to the poor thermal stability of natural fibres such as kenaf, inducing ignition. This trend is reinforced by a study conducted by Kozlowski et al. (Kozłowski and Władyka-Przybylak 2008). Kenaf fibre blends have lower TTIs than neat PP, even with the addition of flame retardants. This highlights the significance of the kenaf fibres' poor thermal stability on the overall composite.

The results for the blends without kenaf fibres reversed the trend that the addition of flame retardants increases the TTI. Once flame retardants are added to the pure PP blend, the composites' TTI decreases significantly. This is due to the flame retardants' second mode of flame retarding action, the formation of a char layer (Xu et al. 2013). During the initial stages of heating, heat energy is transferred to the surface of the composites quickly. The rate of heat transfer between the heat source and the composites' surface is much greater than the composites' ability to conduct the heat towards its interior. Coupled with the flame retardants, this forms a char layer. This char layer prevents both heat and oxygen from accessing the interior of the composites. This observation is reinforced in a study conducted by Su et al. (2012).

Another important flammability characteristic of the composites is the production of smoke and other gases. This is because most fire related deaths are due to the inhalation of combustion gases and particulates (Price et al. 2001). The smoke production rates (SPR) of the composites are shown in Figures 13 and 14. Once the flame

retardants are added, the SPR results show two distinct trends. The first is the reduction of the SPR peaks and the second is that SPRs around 0.035 m^2/s are sustained for longer durations, similar trends to those of the HRRs.

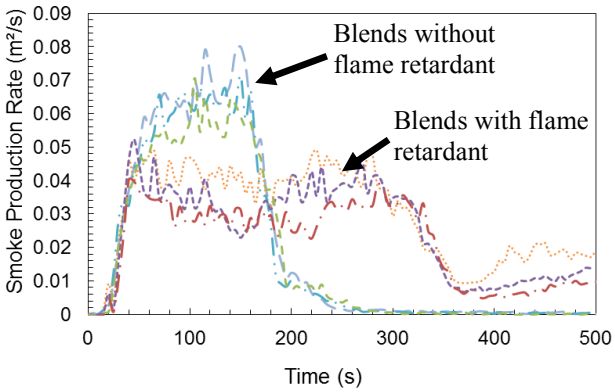

Figure 13 SPR of blends with kenaf fibres

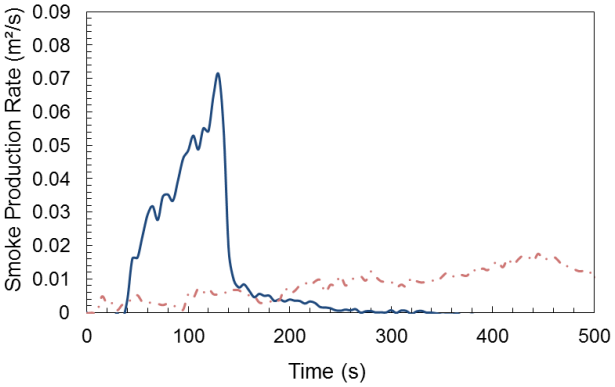

Figure 14 SPR of blends without kenaf fibres

Like the HRRs, two separate groups are formed, with the point of difference attributed to the addition of the flame retardant, as shown in Figure 13.Calculation of the area under the SPR curves gives the total smoke production (TSP), providing a means of direct comparison, as shown in Figure 15. An increase in the TSP is seen with the addition of the flame retardants, a trend opposite to that of the THR. This is due to the flame retardants' first mode of action, the release of non-combustible gases. The FTT cone calorimeter measures smoke production by utilising a light extinction method within a controlled duct and these gases affect the measurements. The TSP increases significantly once kenaf fibres are introduced to the composites. This is because of the volatile organic compounds within the kenaf fibres. When kenaf plants are living, they contain sap and other volatile hydrocarbons within their cells. These remain in the kenaf fibres unless a process has been carried out to remove them (Ismail et al. 2010). The kenaf fibres utilised had not undergone any process to remove the volatile organic compounds and therefore, the presence of these volatile organic compounds within the kenaf fibres explains the increase in TSP.

CONCLUDING REMARKS

Through the experimental results obtained, the following conclusions are drawn for the kenaf - PP composites evaluated:

- Budit 3167 flame retardant of 30 wt% improves the composites' tensile and flexural moduli; however, it reduces the composites' tensile, flexural and impact strengths.
- Budit 3167 of 30 wt% improves the kenaf - PP composites' flammability properties.
- Increases in kenaf fibre loading results in better tensile and flexural properties; however, they lead to decreases in impact properties of the composites.
- Increases in kenaf fibre loading results in a decline in flammability properties of the composites.
- No clear relationships were observed between the mechanical and flammability properties of the composites.

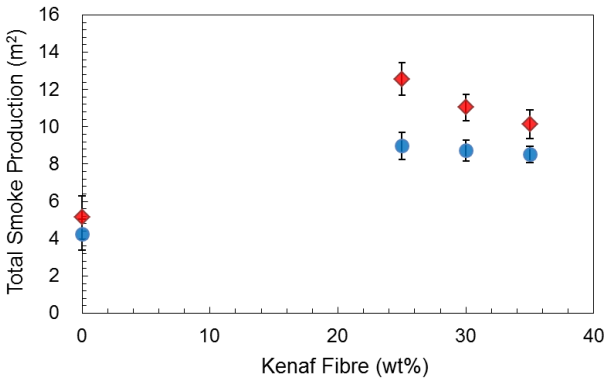

Figure 15 Summary of total smoke production

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