POLYPROPYLENE/KENAF COMPOSITES AND THEIR PROPERTIES: ANALYSIS OF FIBRE LENGTH RETENTION IN TWIN SCREW COMPOUNDING/INJECTION MOULDING

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1 Introduction

With the increasing concerns about the sustainability issues, during the last decade natural fibres have been used by the researchers as replacements of glass fibres. In recent years, environment friendly natural fibres, such as kenaf, flax, sisal and jute, have been used in polymer composites manufacturing to get desirable thermal, mechanical and functional properties [1, 2]. Due to low density, high toughness and low energy consumption in fabrication, the current applications of these composites have been expanded to manufacturing of automotive and aircraft interior components [3].

A major limitation in exploiting the use of natural fibres is the poor adhesion between hydrophilic fibres and hydrophobic polymer matrix [4]. The limited thermal stability of natural fibres, which leads to degradation during processing beyond 200^{o}C, also restricts the mass manufacturing methods, such as injection moulding [5, 6]. The important aspect in making composites using natural fibres is to maintain high aspect ratio in order to achieve superior thermal, mechanical and functional properties. It is important to disintegrate fibre bundles into individual fibres without damaging them. Effective dispersion and distribution of fibres within the matrix material by avoiding agglomerates can create homogeneous composite with enhanced properties [7].

Properties also improve by the good interfacial bonding between fibre and matrix with more uniform fibre length distribution throughout the matrix. Fibre surface treatments, such as alkali treatment, silane treatment and matrix modification using compatibiliser are the most commonly used methods to improve the adhesion of fibres to matrix material [8, 9].

In this research, the first goal is to study the twin screw compounding behaviour of kenaf natural fibres with polypropylene matrix to obtain a homogeneous blend. Maleic anhydride grafted polymer has been used not only to modify fibres but also to achieve good interfacial bonding between the fibre and the matrix. The second goal is to understand the fibre dispersion and distribution within the composite by assessing fibre alignment and damage after each stage of processing during extrusion and injection moulding. Finally, the evaluation of thermal and mechanical characteristics of injection moulded products has been carried out to facilitate the effective use of kenaf natural fibre in composite applications.

2 Experimental Details

Polypropylene (PP) and maleic anhydride grafted polypropylene (MAPP) supplied by Clarient, New Zealand were employed as the polymer matrix and the compatibiliser, respectively. Kenaf bast fibre yarns supplied by Bruce Smith Limited, New Zealand were cut into required lengths before being used in compounding. Materials were dried before processing by using the parameters, shown in Table1.

2.1 Mixing approach

The addition of hydrophilic kenaf natural fibres to hydrophobic PP results in a composite with poor properties due to non-uniform fibre distribution and dispersion and an inferior fibre matrix interfacial bonding [10]. To resolve this issue MAPP was added during compounding as a compatibiliser (3 wt%). The limited thermal stability of most natural fibres leads to degradation during processing beyond 200°C [11]. Due to this behaviour of fibres, thermogravimetric analysis (TGA) was carried out to understand the thermal stability of kenaf and PP, Fig. 1. It shows extensive degradations of both the polymer and the fibres initiating around 250°C. The derivative thermogravimetry analysis (DTG) shows that the maximum degradation temperatures of PP and kenaf are shifted to higher temperatures of 325°C and 350°C, respectively.

2.2 Twin screw extruder compounding

Twin screw extrusion method is generally simple and cheap, which can be effectively used in large scale productions. Therefore, in this work, melt mixing approach, using intermeshing co-rotating twin screws, was employed to effectively mix the short natural fibres with PP matrix. Fully intermeshing twin screws provide narrow residence time distribution and hence provide uniform heat to most natural fibres by preventing degradation [12]. Co-rotating screws are effective in altering the direction of applied stresses through the use of different mixing elements, thus producing different mixing effects. The co-rotating twin screw configuration, as shown in Fig. 2, with L/D ratio of 40:1, was capable of providing optimum dispersive and distributive mixing required, in obtaining a homogeneous blend.

Eight blends were prepared using 30 wt% fibre of different fibre lengths, compounding methods and processing temperatures, Table 2.

Standard test samples were prepared using Boy 50A injection moulding machine to evaluate flammability and mechanical properties of the composites.

3 Results and Discussion

3.1Method of compounding

Compounding was carried out with die and without die, using twin screw extrusion, as shown in Fig. 3.

Samples were dissolved in hot Xylene to remove polymer in the compound. Extracted fibres were then observed through an optical microscope, and fibre lengths were analysed using ImageJ® software.

3.2 Compounding and injection moulding effect on fibre length distribution

Compounding long and short fibres shows that the length retention is high in the case of long fibre compounding but more even length distribution is achieved for short fibre compounding. Fig. 4 shows that there is negligible difference in fibre length retention after extruding long and short fibres. This is due to the fibre damage under high shear during the extrusion process, as shown under morphology analysis.

The other interesting observation is the effect of temperature on the fibre length distribution. The average length has significantly reduced at high temperature processing compared to that for low temperature processing, Fig. 5.

High temperature compounding and degradation has reduced the average fibre length causing low aspect ratios. In addition, the degradation leads to a decreased strength and hence increasing the fibre damage. The reduced viscosity of the melt mix and high shear dispersion of weaker fibres also result in damages, such as splitting, kinking and twisting, and thereby reduce the fibre length.

Fig.6 shows significant attrition rates at both stages of processing, which is expected to affect the mechanical properties. However, a significantly higher amount of fibre length reduction takes place during compounding or extrusion process, compared to that during injection moulding.

3.3 Morphology analysis

Fibre images were taken using optical microscopy, to evaluate the nature and amount of damage. When fibres are passed through more kneading elements under shear mixing, increased damage and breakage occur. This is more evident with the presence of fibre bending and twisting during extrusion process over compounding, as shown in Fig 7.

Mixing has improved during twin screw compounding due to displacement and shear deformation. This may cause fibre peeling, splitting and kinking, shown in the Scanning Electron Microscopy (SEM) image, Fig.8.

The use of high screw speed (150 rpm) with compatibiliser as an adhesion promoter increased the mixing performance during compounding. The absence of fibre pullout and less void content in the matrix further prove the existence of high compatibility and dispersion between immiscible components.

3.4 Fibre distribution after injection moulding

Alignment of fibres in the final product is a key factor in determining the thermal and mechanical properties of the composite. In this regard, alignment was determined using optical microscopy, which also showed dispersion of fibres, thereby giving information on morphology.

During injection moulding, cross and axial mixing ensures homogeneous distribution of fibres. All the fibres entangle and tend to turn around themselves during mixing due to the shear force generated within the barrel. This causes additional damages to long fibres compared to those in short ones, and the resultant composite fibre length is nearly the same in both cases. This can be noticed from the optical micrographs, shown in Fig. 9.

4. Thermal properties

4.1 UL-94 V Standard test

Fire retardance is an important characteristic of a composite in a range of applications, such as aerospace and transportation. The UL-94 V standard test (ASTM D3801) is used to assess this property. Dripping phenomenon is an indication of the tendency for fire growth, which is one of the most important characteristic effects in fire proof materials. Visual observations of Fig. 10 carried out using long and short fibre composites showed a delay in dripping time of the composites (41 and 47 seconds for long and short fibres, respectively) after ignition as compared to that for pure PP (12 seconds).

Generally, natural fibres are expected to act as heat sources in composites; however, the results obtained in this study are quite interesting. Although increased burning rate has been observed in long fibre composites compared to those with short fibres, both of them performed better than pure PP. The performance of short fibres may be attributed to the presence of more uniform and homogeneous blend. The addition of compatibiliser creates better interfacial bonding which acts as a barrier to the flowability of PP and reduces the effect of dripping.

Kenaf fibre compounded composite forms more stable layer of char after the fully burnt state, which is absent in pure PP. When the fibres are uniformly distributed within the matrix, the burning fibre char formation creates a barrier between the burnt and unburnt material. This barrier formation further inhibits fire growth by reducing volatiles and oxygen content present in the fire boundary.

4.2 Cone Calorimeter test

Cone calorimeter test is a small scale standard test method (ASTM E1354) for quantitatively characterising and comparing flammability properties. Materials are forced to burn under constant external heat flux to evaluate the principal fire properties, such as peak heat release rate (PHRR), heat release rate (HRR), total heat release (THR), mass loss rate (MLR) and smoke release rate (SRR), which can take place in real life fire scenario.

Heat release rate of compounds was analysed under cone calorimeter at a heat flux of 50 kW/m^2 using compounded and extruded samples, Fig.11.

It appears that the processing condition did not make much difference in the overall thermal behaviour (time to burn off), although the peak heat release rate of the neat polymer is significantly higher than those of compounded or extruded samples. Even though kenaf fibre composites ignite earlier than pure PP, the formation of floating char layer tends to protect the outer layer exposed to fire and thereby reduces the speed of fire growth.

5. Mechanical properties

Tensile, flexural and charpy impact tests were carried out following the standard test procedures [ASTM D638, ASTM D790 and ASTM D6110] to evaluate the mechanical performance of the compounds, shown in Fig.12.

The kenaf/PP composites show reasonable improvements in tensile and flexural properties over PP irrespective of the compounding method. However, the impact property of the composites was lower than that of neat PP although extrusion tended to improve the behaviour.

The significant increase observed in tensile and flexural moduli and strengths of composites compared to pure PP can be attributed to the homogeneous blend obtained through twin screw compounding with the presence of a compatibiliser. This provides an enhanced interfacial bonding between the fibre and the matrix.

The reason behind the drop in impact properties may be due to the low strength and degradation of fibres during shear processing under twin screw extrusion and injection moulding. On the other hand, even though the fibres were initially dried, the high water absorption tendency of kenaf natural fibre tends to swell the fibres and thereby create micro-damages, which could be a significant parameter when material is subjected to impact loads.

Conclusions

Compounding of 30 wt% kenaf natural fibre with PP has been carried out in a co-rotating twin screw extruder and analysed the fibre length distribution after compounding and injection moulding. It has been found that considerable amount of fibre damage takes place during the extrusion process and there is no significant improvement in properties with long fibre composite compounds.

Kenaf compounded composites tend to increase the fire control behaviour by reducing the dripping phenomenon and heat release rate compared to those for neat PP. This is potentially due to the homogeneous blend obtained by twin screw compounding and the ability of formation of char when kenaf fibre undergoes combustion. Furthermore, the addition of compatibiliser significantly improves the overall strength and stiffness of the composite with homogeneous dispersion of fibres within the matrix.

Acknowledgments

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Table 1: Material drying parameters

Material type	Manufacturer	Drying temperature [^oC]	Drying time [hrs.]
PP	Samsung	80	> 12
MAPP	Dupont	80	> 12
Kenaf	Weitex	70	> 40

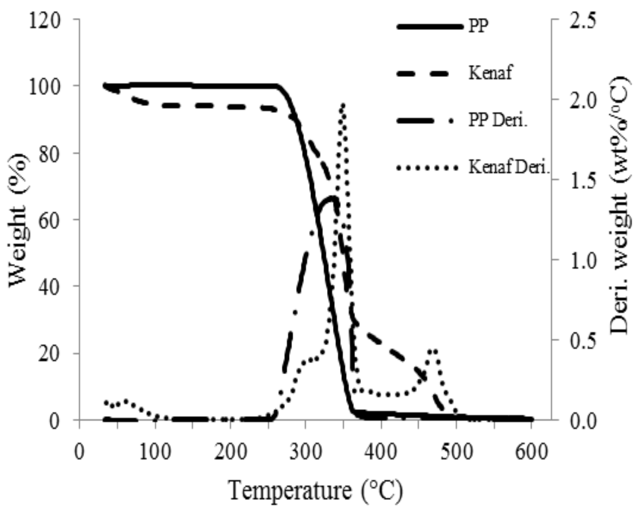


Fig. 1. TG and DTG curves of PP and Kenaf

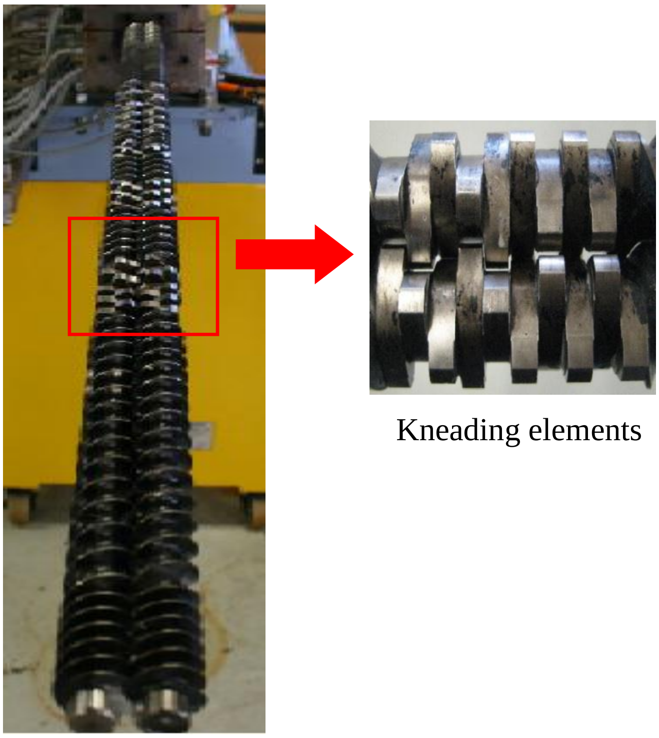


Fig. 2. Fully intermeshing co-rotating twin screw used in extruder compounding

Table 2. Polymer and fibre blends

Designation	Compounding method	Fibre length (mm)	Process temp. [^{o}C]
KeLC	Compounded	7.5	180
KeHLC	Compounded	7.5	220
KeLE	Extruded	7.5	180
KeHLE	Extruded	7.5	220
KeSC	Compounded	2.5	180
KeHSC	Compounded	2.5	220
KeSE	Extruded	2.5	180
KeHSE	Extruded	2.5	220

Ke–Kenaf, C–Compound, E–Extrude, L–Long, S-Short, H-High Temperature

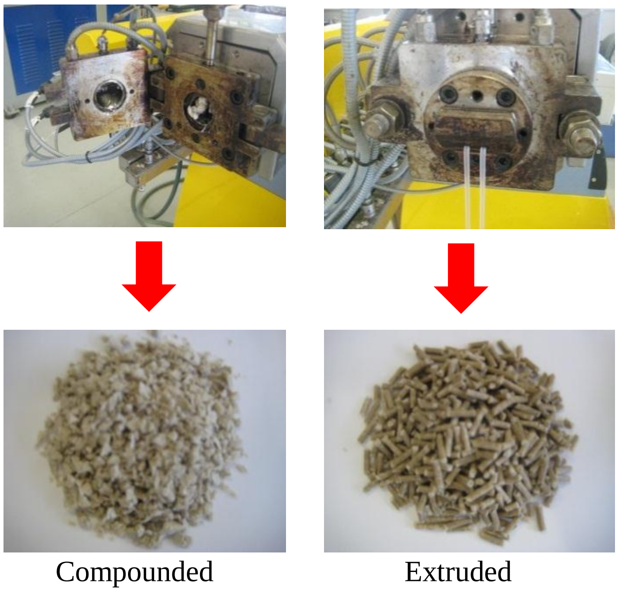


Fig. 3. Two different blends obtained during twin screw compounding

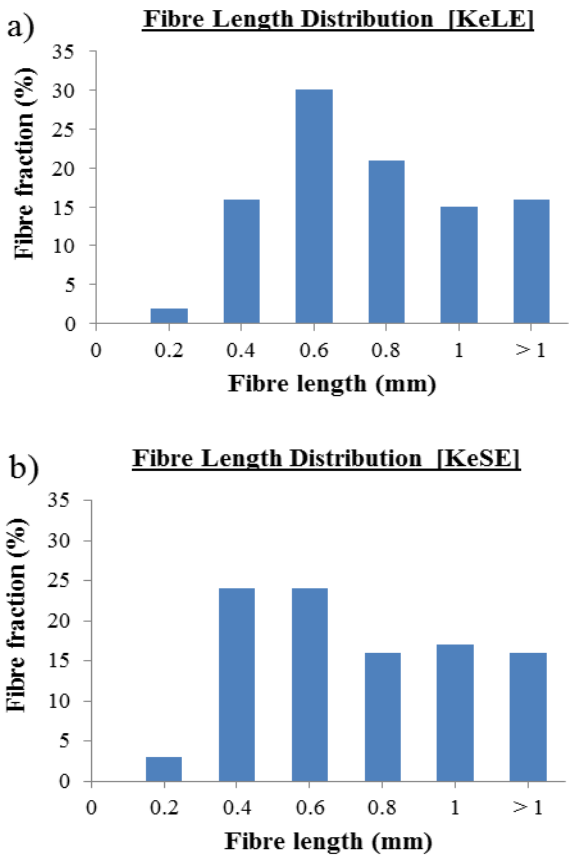


Fig. 4. Fibre length distribution after extrusion a) long fibres b) short fibres

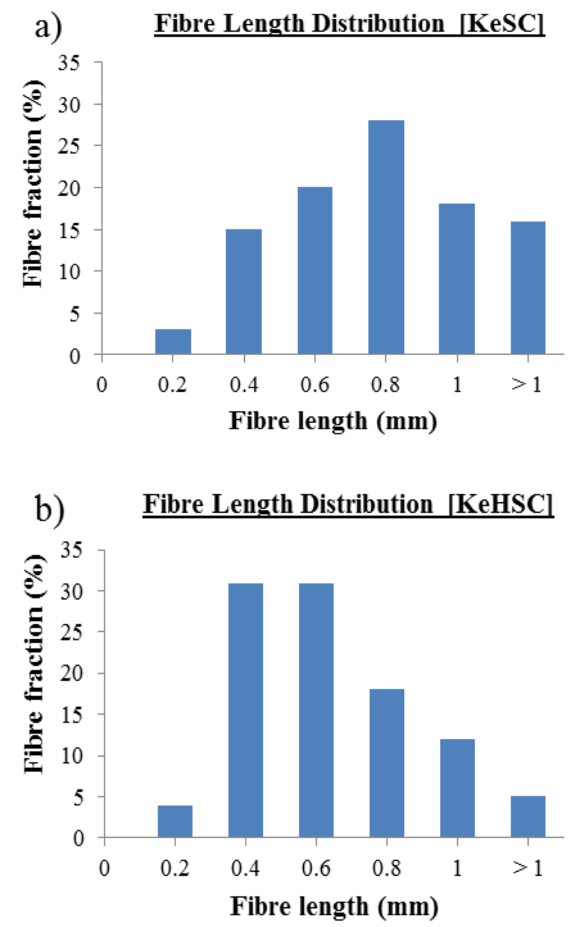


Fig. 5. Fibre length distribution after compounding a) low temperature b) high temperature

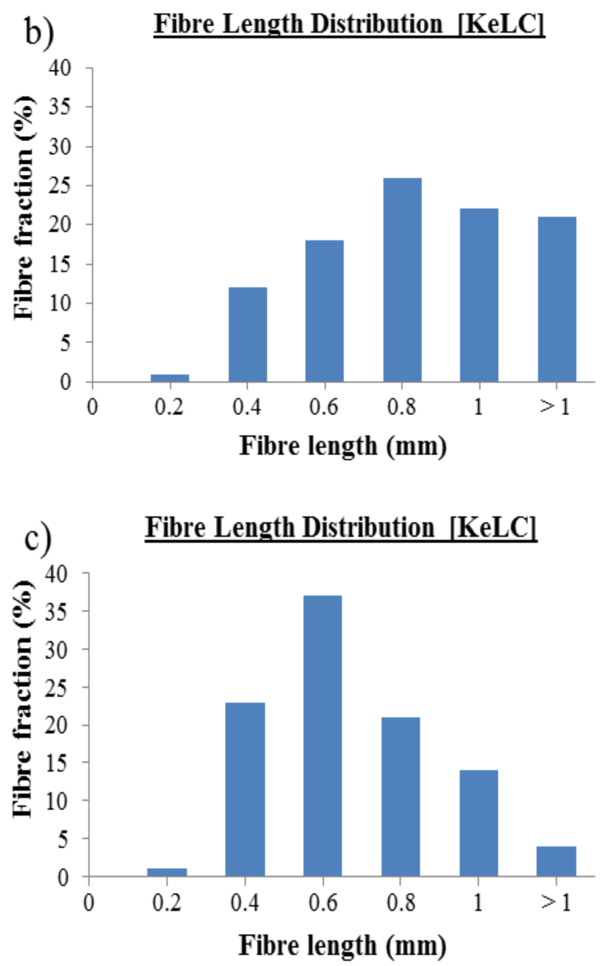
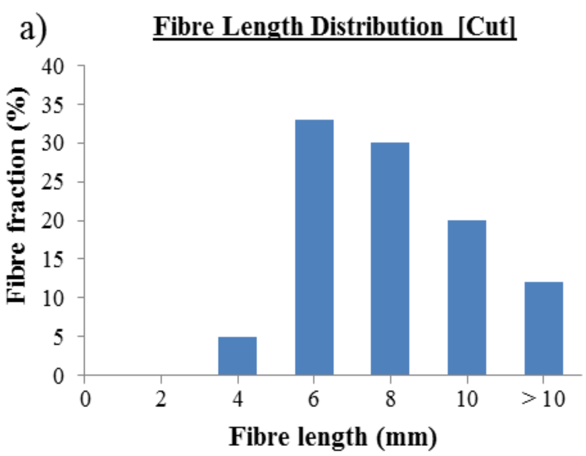


Fig. 6. Fibre length distribution for KeLC: a) initial b) after compounding c) after injection moulding



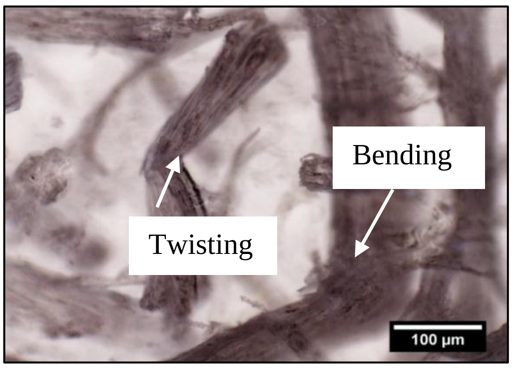


Fig. 7. Optical microscopy image of fibre damage during processing

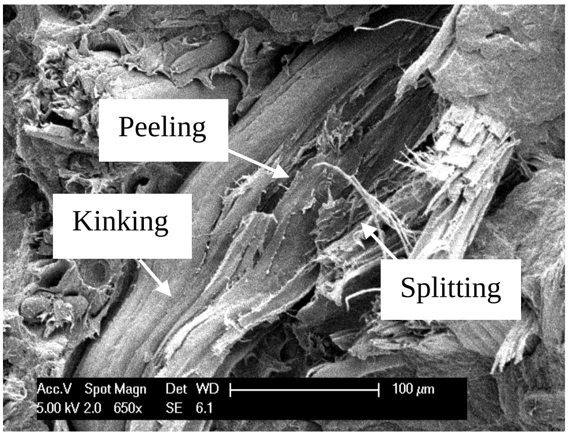


Fig. 8. Composite morphology analyses

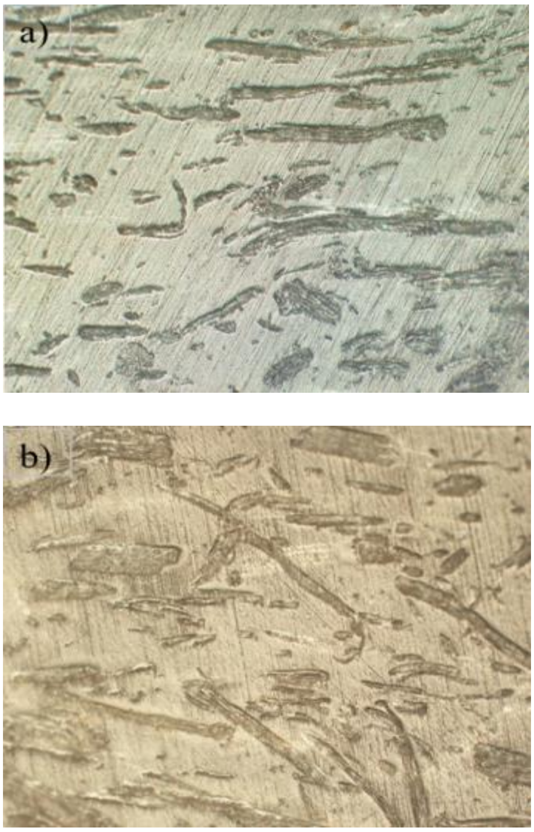


Fig. 9. Fibre dispersion and distribution on surface during injection moulding a) long b) short

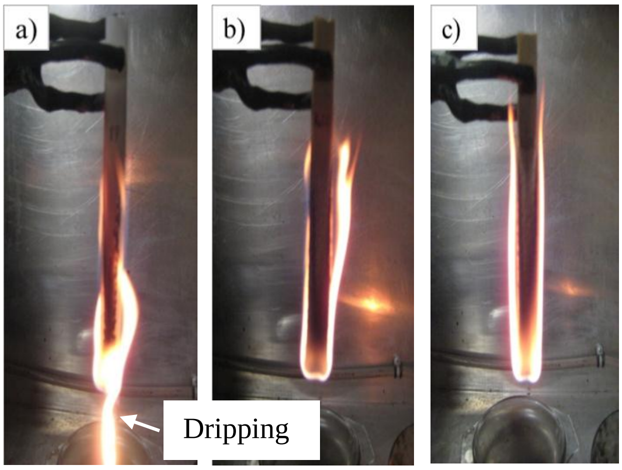


Fig. 10. Digital pictures of UL-94 V test: a) PP b) KeLC c) KeSC

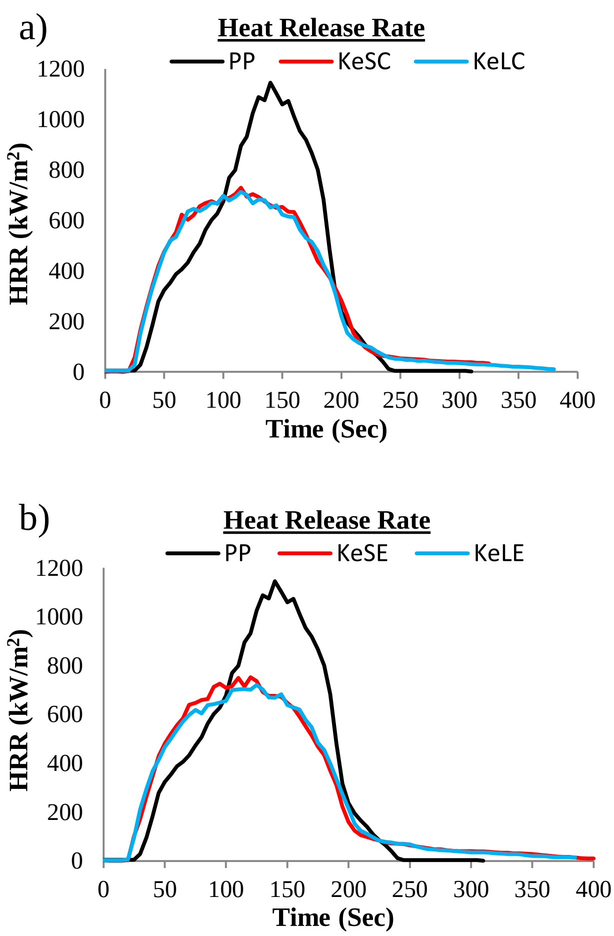
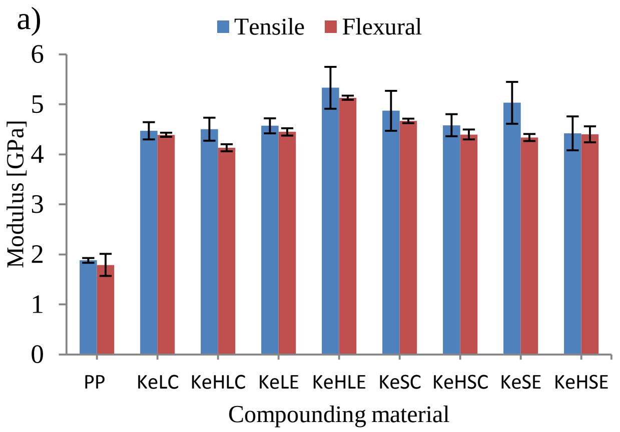


Fig. 11. Heat release rate of composites a) compounded b) extruded



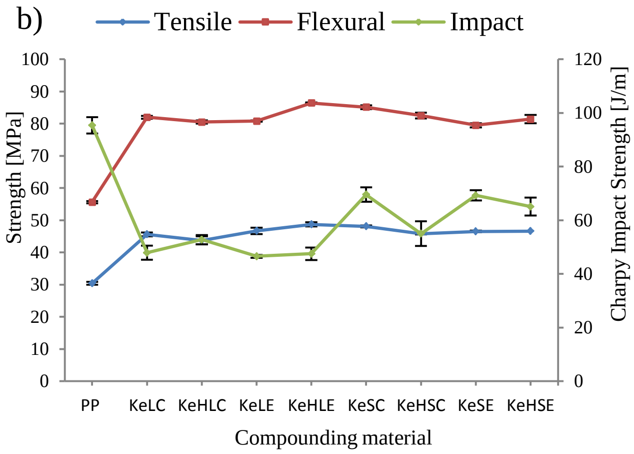


Fig. 12. Mechanical properties of kenaf fibre composites a) modulus b) strength

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