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FIRE IN BIOCOMPOSITE



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FROM THE EDITOR

Fire safety is a crucial aspect of material design, and the development of fire-resistant biocomposites has gained significant attention in recent years. Biocomposites, composed of natural fibers or particles embedded in a polymer matrix, offer a sustainable alternative to traditional composites and provide unique advantages such as reduced environmental impact and improved mechanical properties. However, the inherent flammability of some natural fibers poses challenges to their widespread use. Ensuring biocomposite fire performance meets or exceeds industry standards is also a challenge. Researchers have explored various strategies to enhance the fire resistance of biocomposites without compromising their desirable properties, including the incorporation of flame retardants, fiber treatments, modification of the polymer matrix, optimization of the fiber-matrix interface, and polymer formulations to enhance the fire resistance of biocomposites. By understanding the fire behavior of biocomposites, testing methodologies, and implementing effective fire retardancy strategies, these materials hold great potential for a wide range of applications where both ecological sustainability and fire safety are paramount.

FIRE PROPERTIES OF NATURAL FIBER COMPOSITES



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Application of natural fiber reinforced polymer composite (NFRP) materials has seen a dramatic increase over the last five decades because of impressive mechanical, thermal, and physical properties. As these materials have diverse applications in aerospace, construction, maritime, electronic and automobile industry, the increased demand for these materials is evident. Despite their many benefits, natural fiber composites also come with a set of shortcomings and the most notable of which are the poor fire properties. When a natural fiber composite gets exposed to high temperatures, decomposition of the material along with release of heat, smoke and toxic volatiles are imminent leading to potential structure failure (Figure 1). Chemical constituents of plant fibers principally cellulose, hemicellulose, lignin, pectin and wax. The main structural component is cellulose which is highly crystalline. The flammability of fibers is influenced by their crystallinity, as a high concentration of levoglucosan, produced

during the thermal decomposition process, intensifies their combustibility. In contrast, highly oriented fibrils slow down the pyrolysis process and thus decrease flammability. Hemicelluloses decompose between 200 and 260°C, releasing non-combustible gases like CO₂. Lignin decomposes between 160–400°C, with different bonding conditions dictating the temperature range. Lignin affects the degradation pathway of cellulose, promoting dehydration and char formation. Bast fibers rich in lignin, such as flax and hemp, have been found to exhibit lower rates of heat release compared to leaf fibers like cabuya and abaca. However, it has also been found that the surface impurities or chemicals of the fiber can affect its flammability. One study (1) suggested that lignin content has a negligible effect on heat release rate, likely due to sodium salts on the fiber surfaces. This limitation has curtailed some applications of the natural fiber composites but ongoing research is aimed at improving the fire properties of these materials.

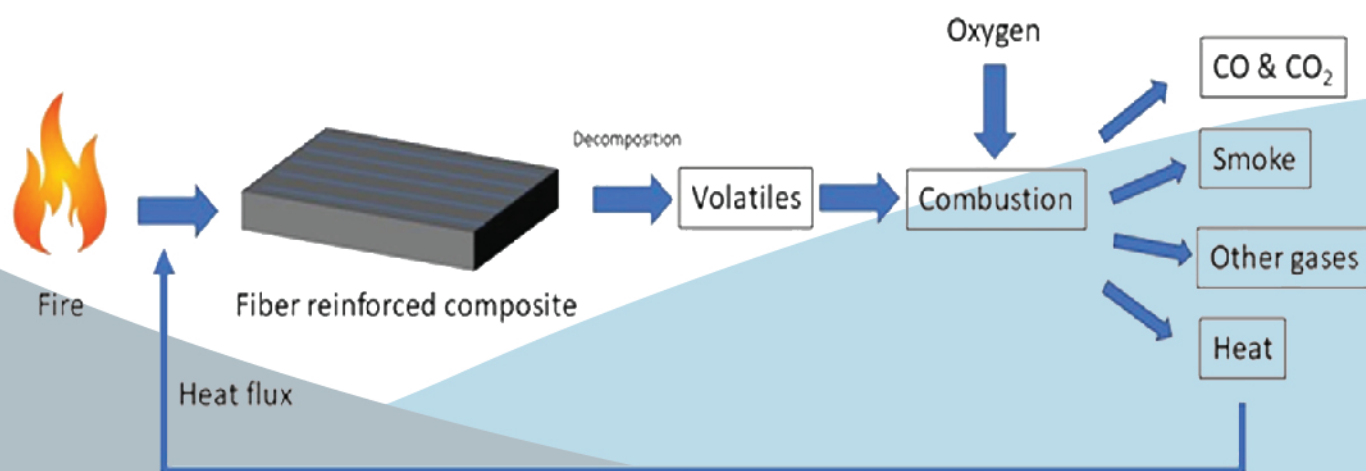


Figure 1: Mechanism of thermal decomposition of polymer composites

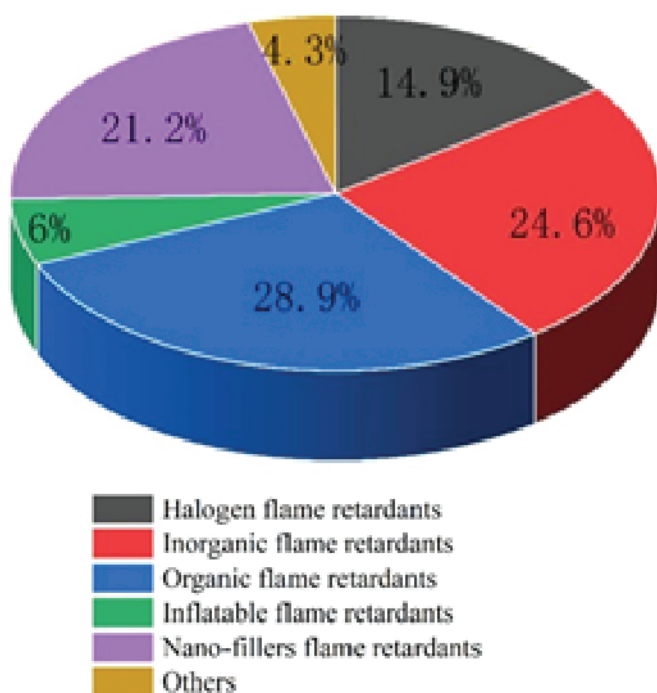
Fire properties of natural fiber composites can be identified by their reaction to fire and fire resistance properties such as heat release rate, time to ignite, flame spread rate and oxygen index (2). "Time to ignition" refers to the minimum time required for a combustible material to ignite and sustain flaming when exposed to heat. It is a crucial property of composites with organic resins. Ignition typically occurs when the composite's surface is heated to a point that triggers thermal decomposition. Various factors, like temperature, oxygen availability, and the material's properties, influence this ignition time. Ignition times are measured via cone calorimetry. A cone calorimeter is an invaluable tool for examining the fire reaction properties of materials using the oxygen consumption method under external irradiance. It allows for precise analysis under flaming conditions and offers the flexibility of horizontal and vertical orientations of the cone heater. However, it does face limitations in not addressing certain physical phenomena like in-depth absorption, heat distortion, or the change in material properties during burning. Despite these drawbacks, it still provides crucial insights into the decomposition and burning of various materials. Heat release rate (HRR) is considered the most crucial fire reaction property, as it provides information on the burning rate, consumed mass, and production of smoke and other combustion products. However, research into the impact of material orientation on fire performance in a cone calorimeter environment has been limited. The Limiting Oxygen Index (LOI) is a measure to determine the flammability of composite materials. Essentially it refers to the lowest concentration of oxygen required to maintain a flame. LOI is an important parameter to effectively measure a burning material's ease of self-extinguishment. However, this test doesn't mimic a realistic fire environment, limiting the LOI's ability to accurately quantify a material's fire reaction

behavior. While LOI is used to compare the combustibility level of different polymer composites, it shouldn't be used as the exclusive quantitative metric to measure fire resistance.

The fire resistance characteristics of natural fiber composites are determined by the changes in chemical compositions and microstructural differences. Fire resistance property of the composites can be enhanced by minimizing the cellulose content, increasing crystallinity and lowering the degree of polymerization. Furthermore, the application of various coatings and flame retardants such as ceramic, intumescent, silicone, phosphorus, ammonium polyphosphate, phenolic, ablative, and glass mats can also bolster the fire resistance of these natural fiber composites. Proportion of various flame retardant materials have been shown in figure 2. Flame retardants have been reported to have improved the fire resistance of natural fiber composites. First, they minimize the intensity of fire by diluting the combustible organic material (3). Moreover, they act as heat sink by reducing the overall temperature of the composite. These retardants can decompose endothermically and produce water or any non-combustible products having high specific heat capacity to lower the temperature. Heat release rate (HRR) can also be reduced by the flame retardants and thereby slowing down the combustion process of composites. Finally, by enhancing the aromaticity of the polymer matrix, flame retardants facilitate the decomposition of composites into a carbon-rich char. This layer of char slows down the conduction of heat into the composites and reduce the emission of flammable gases. Table 1 shows use of various flame retardants to improve fire resistance characteristics of natural fiber reinforced composites.

Table 1: Application of flame retardants in nature fiber composites

| Fiber | Polymer | Fire retardant material | Rating achieved in UL-94 | LOI (vol%) | Ref |
|--------|----------------------------------|--|--------------------------|------------|------|
| Hemp | Epoxy resin | Phosphorus | V-0 | 32 | (4) |
| Bamboo | Polylactic acid | Combination of Ammonium polyphosphate and Silicon-Phosphorus aerogel | V-0 | 37.2 | (5) |
| Bamboo | Polylactic acid | Combination of Ammonium polyphosphate and Silicon-Nitrogen aerogel | V-0 | 37.0 | (6) |
| Bamboo | Polylactic acid | Combination of Ammonium polyphosphate and Isopropyltriisostearoyl titanate-Silicon | V-0 | 36.4 | (7) |
| Bamboo | High Density Polyethylene (HDPE) | H ₂ Ti ₂ O ₃ ·H ₂ O nanotubes (TNT) | - | 19.7 | (8) |
| Wood | Polypropylene | Ammonium polyphosphate and Silica | - | 28.9 | (9) |
| Kenaf | Polypropylene | Ammonium polyphosphate | V-0 | - | (10) |

**Figure 2:** Proportion of representation of different types of flame-retardant polymer material (11)

Fiber reinforced polymer composite materials present significant health risks when involved in fire. Composites in produce dense, toxic smoke filled with combustion gases, soot particles, and fiber. Immediate exposure is reported to cause impaired judgement, eye irritation, and severe coughing. Long-term effects may include organ damage and cancers. These hazards are primarily attributed to ultra-small fiber fragments and toxic fumes from the burning composite materials. While immediate health problems from smoke inhalation are known, long-term hazards are less understood, requiring further research to comprehend their potential impact fully.

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CONVENTIONAL BIOCOMPOSITES: ITS FIRE PROPERTIES



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Nowadays, conventional biocomposites namely plywood, particleboard, fibreboard and so on are still relevant due to its demand in the market especially for furniture and interior applications. Unlike polymer-based composites, conventional biocomposites mostly are made from lignocellulosic (wood and non-wood) elements as their main constituent compared to the binder or matrix. As the constituents are dominant by the lignocellulosic elements, conventional biocomposites are susceptible to fire and combustion and become one of the crucial challenges in the wood and wood-based industries [1]. In their study, wood species, moisture content, density, heat exposure time, wood permeability and porosity are some factors that will determine the fire behavior.

Wood originally consisted of cellulose, hemicellulose, and lignin is a fuel source and has relatively low ignition temperatures, which indicates easy to get burn at lower temperatures. As reported by Östman [2], the absorbed water in any wood sample begins to evaporate at approximately 100 °C, followed by a thermal softening process between 180 to about 300°C and finally thermal degradation of the individual constituents. Hemicellulose decomposes at a lower temperature (180–350 °C), while cellulose degrades at a relatively higher temperature (275–350 °C). When wood or biocomposite is in contact with fire, it undergoes pyrolysis. Wood pyrolysis or known as thermal degradation, is a complex process and occurs in a narrow zone over the exposed surface of wood samples when

they are subjected to thermal decomposition in an oxygen free atmosphere [3]. The layers formed by wood pyrolysis are shown in Figure 1. The rate of combustion and heat release from wood is based on the pyrolysis rate of cellulose and the reactions of pyrolysates with air. The combustibility of wood and wood-based products can be delayed by fire retardant treatments. As reported by previous studies, wood fire retardants are applied by high pressure impregnation, integration of chemicals into the glue system, surface treatments, the addition of nanocomposites during manufacturing or chemical and physical modification [1,4-5].

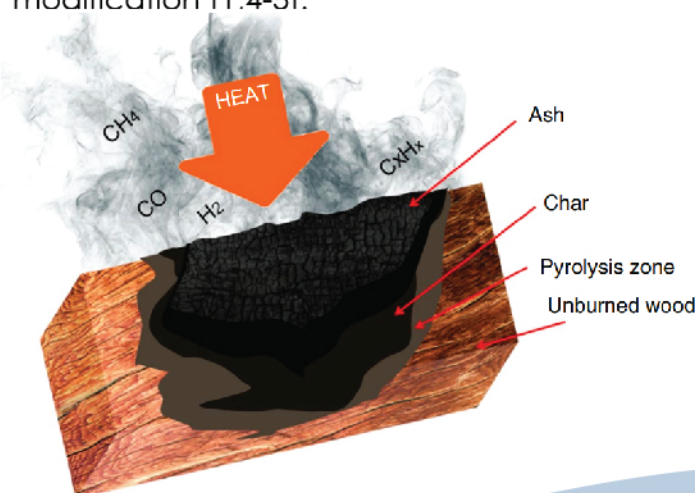


Figure 1: Different layers from wood pyrolysis [1]

Compared to polymer-based composites, conventional biocomposites treated with fire retarded are less reported recently. Harada et al [6] studied the fire performances of 28–30mm thick wood-based composites namely plywood, particleboard, and medium density fibreboard (MDF) using ISO 834-1 fire resistance test standard. This study was done due to the usage of thick

wood-based composite as construction materials for walls and floors. In their finding, only few types of wood-based fulfilled the insulation properties specified in the Building Standard Law of Japan. Meanwhile, the time to ignition and initial total heat release of plywood, particleboard and MDF using cone calorimeter test were affected by the surface layer density rather than the average density. Apart from that, Lee et al [7] evaluated the flammability properties of wood-based panels (particleboard, MDF, hardboard, plywood, and laminated flooring) and gypsum particleboard using a cone calorimeter. In their finding, among the wood-based panels, the time to ignition of MDF and laminate flooring was the shortest and longest, respectively. However, the time to ignition of gypsum particleboard could not be measured because gypsum is a nonflammable material. They also concluded that gypsum particleboard with high content of wood-particle could be considered as a replacement for wood-based panels due to the superior fire-retardant properties.

Table 1 tabulates the studies on fire retardants in conventional biocomposites. In this report, only three types of biocomposite are involved namely MDF, particleboard and plywood. The properties of MDF can be improved using flame retardant chemicals such as multi-walled carbon nanotubes, phosphoric acid, monoammonium phosphate, diammonium phosphate, borax, boric acid [8-9]. In a study Gürü et al [10], fly ash powder was used as fire retardant material. In their study, the pistachio shells particles were bonded using urea formaldehyde and the fly ash was used at up to 20 mass % of total mass. Findings show that the maximum flame temperature of control board (without fly ash) was 795 K and the value decreased to 568 K with the addition of 20 mass % fly ash. This indicates that, instead of chemicals or mineral agents, fly ash which is waste raw material with low operating cost can be one of alternative fire-retardant material and used in the composite particleboard as a flame retarder.

Table 1: Studies on fire retardants in conventional biocomposites

| Type of Biocomposite | Wood/ Non-wood elements | Adhesive | Fire retardant material | References |
|---------------------------|-------------------------------|-------------------|--|-----------------|
| Medium density fibreboard | Wood fibre | Urea formaldehyde | Multi-walled carbon nanotubes | Dineshkumar [8] |
| | Pine and Beech fibres (mixed) | Phenolic | Phosphoric acid, monoammonium phosphate, diammonium phosphate, borax, boric acid | Ayrlmis [9] |
| Particleboard | Pistachio shell particle | Urea formaldehyde | Fly ash | Guru [10] |
| | Poplar wood particle | Soy protein-based | Soy protein-based adhesive | Zeng et al [11] |
| Plywood | Aspen veneer | Silicone-based | Silicone-based adhesive | Wang et al [12] |

In another study done by Zeng et al [11] used soy protein-based adhesive as an alternative of fire-retardant material for particleboard. It works as an effective manufacture approach of non-formaldehyde adhesive with Limited oxygen index (LOI) and UL-94 test value of 28.7% and V-1 rating, respectively. Wang et al [12] used silicone-based adhesive (SI) as a fire-retardant material and compared to polyurethane-based (PU) adhesive. Findings revealed that the SI/plywood exhibited a greater fire-resistance and reaction-to-fire performance (in terms of ignitability) as

compared to the PU/plywood. Therefore, silicone adhesives can be a potential replacement to PU adhesives to improve the fire resistance without disturbing the presence of the composite. As a conclusion, conventional biocomposites have low fire tolerance thus there are a need to consider the usage of fire-retardant materials to improve their fire properties. Apart from using synthetic fire retardant, waste material could be an alternative fire-retardant, and there are several approaches to modify the adhesive and act as fire retardant materials.

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SYNERGISTIC EFFECT BETWEEN IONIC LIQUIDS AND CONVENTIONAL FLAME RETARDANTS IN POLYMER COMPOSITES

Ahmad Adlie Shamsuri

The synergistic effect, also known as synergy, is a phenomenon in which the combined effect of two or more substances, processes, or factors exceeds the aggregate of their individual effects. In other words, when multiple elements interact or cooperate, they produce a result that is more significant, potent, or advantageous than would be anticipated based on their individual contributions. Certain substances may have a synergistic effect when combined in chemical reactions. By combining two materials with individual flame-retardant properties, for instance, it may be possible to create a material with a significantly higher flammability resistance [1]. The synergistic effect in the context of polymer composites refers to the augmented or improved properties demonstrated by the composite material in comparison to its constituents or components. Polymer composites consist of a polymer matrix reinforced with filler materials like fibres, particulates, or additives. When the polymer matrix and reinforcement interact synergistically, composite materials with superior mechanical, thermal, electrical, or other specific properties can be produced.

Ionic liquids are substances that consist solely of ions, which are electrically charged atoms or molecules (Figure 1). Ionic liquids consist of cations (positively charged ions) and anions (negatively charged ions), as opposed to traditional liquids, which are typically composed of neutral molecules. Due to their singular composition, ionic liquids exhibit a variety of intriguing properties and have garnered considerable interest in a variety of fields. Ionic liquids have shown promise as flame retardants in polymer composites due

to their unique properties and ability to increase the fire resistance of materials by decreasing their flammability. When incorporated into the polymer matrix, they can inhibit the combustion process and the propagation of flames, thereby reducing the overall fire risk. Moreover, flame-retardant ionic liquids may reduce smoke and toxic gas emissions during a fire [2]. They can prevent the emission of volatile organic compounds and other hazardous by products, making the polymer composite more fire-resistant.

When combined with other flame-retardant additives or fillers, ionic liquids may produce synergistic effects [3,4]. Combining ionic liquids with other flame-retardant agents, such as phosphorus-based compounds or nanofillers, can further improve the composite's overall fire performance [5]. The synergistic effect between ionic liquids and conventional flame retardants in polymer composites can be attributed to several mechanisms that work together to enhance the overall fire retardancy of the material. One mechanism involves the improved dispersion of fillers within the polymer matrix [6]. Ionic liquids can act as dispersants, promoting the even distribution of conventional flame-retardant fillers, such as phosphorus-based compounds or metal hydroxides. This improved dispersion increases the availability and accessibility of the flame-retardant agents throughout the composite, leading to a more efficient fire protection system.

Furthermore, the presence of ionic liquids can facilitate surface modification of the filler particles. The interaction between the ionic liquid and the filler surface can lead to the formation of a protective coating or layer [7], which acts as a barrier against heat and flame propagation. This coating inhibits the release of volatile components from the filler, delaying the onset of combustion and reducing the flammability of the composite. Ionic liquids also contribute to the formation of a stable and robust char layer during the combustion process. The decomposition of the polymer matrix generates char, which acts as a physical barrier against heat transfer and oxygen diffusion [8]. The presence of ionic liquids promotes the formation of a dense and cohesive char layer, which enhances the overall fire resistance of the composite. In addition, ionic liquids can release flame-retardant gases or radicals upon exposure to heat or flames. These gases or radicals can chemically interfere with the combustion process by scavenging free radicals, inhibiting chain reactions, or diluting the combustible gases. This mechanism further

suppresses the combustion process and reduces the flammability of the composite.

Ionic liquids are known for their high thermal stability, which makes them capable of withstanding elevated temperatures during a fire. By maintaining their integrity, they provide continuous flame retardancy and contribute to the overall thermal stability of the composite [9]. Finally, the presence of ionic liquids can help suppress gas-phase reactions that contribute to flame spread and smoke generation. They can inhibit the degradation of the polymer matrix and reduce the release of volatile organic compounds and toxic gases [10], resulting in reduced smoke density and toxicity during a fire event. The combination of these mechanisms and the synergistic interaction between ionic liquids and conventional flame retardants lead to significantly enhanced fire retardancy in polymer composites. By leveraging the unique properties of ionic liquids and their compatibility with conventional flame retardants, researchers and engineers aim to develop safer and more fire-resistant materials for various applications.

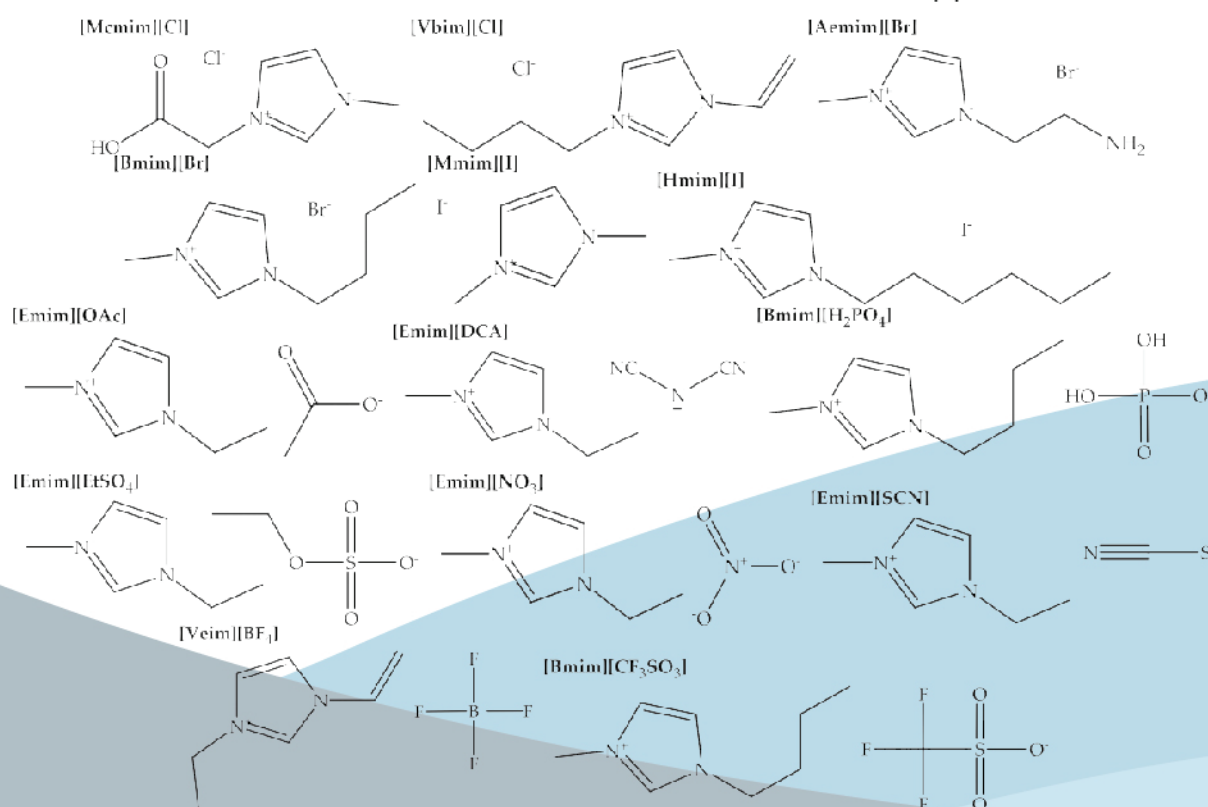


Figure 1. Examples of ionic liquids [11].

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HYBRID SANDWICH BIOCOMPOSITE STRUCTURE: FIRE SMOKE TOXICITY

Ayu Rafiqah Shafi & Khalina Abdan



The investigations on flammability behaviour of pure matrix with different wt% bio-epoxy and some prototype sandwich composites were done using cone calorimeter device in University of Queensland, Australia and its findings were recorded. Since the information on fire smoke and toxicity test for jatropha bio-epoxy and the hybrid palm/carbon/glass fiber composite was limited, the results would be elaborated more on the comparison and fire reaction between the specimen designs. The cone calorimeter experiment set up represented similar situation during a fire situation. It has many advantages with which the fire situation of a material could be studied and understood through sensors inside the cone-shaped tunnel. Thus a prevention or improvement could be made to make the fire situation controllable and less critical. In this cone calorimetry test, a sample of 100 mm × 100 mm with a thermally thick thickness, which was around at least 6 mm (as in figure 1.0), was ignited to burn, then its heat released in function of weight loss is measured and products emitted as gases are detected by sensors in the cone calorimeter.

In table 1 is the experimental plan for the cone calorimeter testing. It is divided into two sections, one; test of fire smoke toxicity behavior of pure matrix at different wt% bio-epoxy only. Two; test of fire smoke toxicity reaction of hybrid sandwich composites with three different combinations including aramid core in the middle of the specimen. Later in this chapter, another experimental plan was shown in table 4.11 for determining critical heat flux and time to ignition. Research-

ers suggested that more layers in the skin of composite structure will reduce the peak of heat release rate and smoke toxicity also would be decreased (Kotresh et al., 2005). Many studies were carried out in the 90's and early 2000's in fire calorimeter test as seen in references in Mouritz's article (Mouritz et al., 2006). Most of the cone calorimeter test were about synthetic products at that time. Since early 2010's, developing and biocomposite became popular

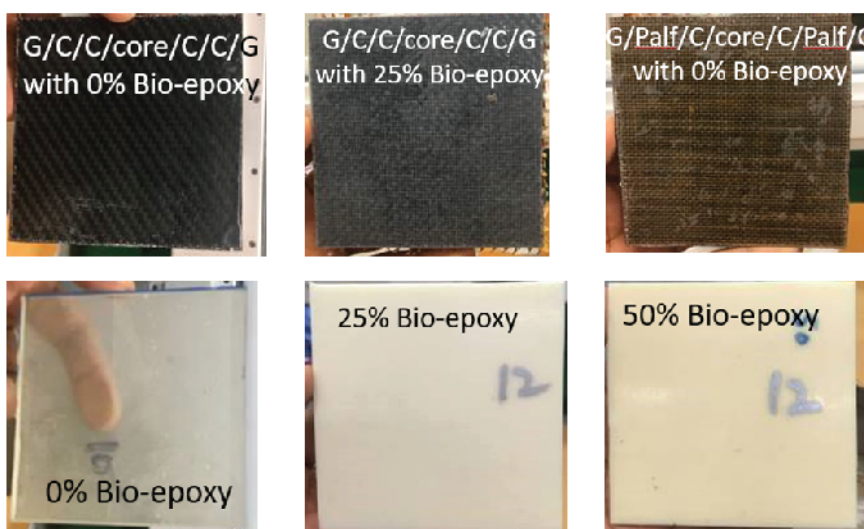


Figure 1.0: Specimen of pure matrix with different wt% of bio-epoxy, and sandwich structures with different combination. All specimens had dimension of 100 mm × 100 mm × 7.2 mm

and more of the research articles were about the synthesis, characterisation, performances evaluation of the biocomposite etc. This was due to proliferative fabrication of fully synthetic composite products and it became very common when manufacturers were looking for lightweight products with very high performance characteristics. Since then, awareness of reducing carbon footprint to environment had increased as airplanes which utilised as much as 80 % of composite materials, were left in its graveyard after its service period without being able to be recycled, reused or itself decompose.

Table 1: Experimental set up for cone calorimeter testing.

| Sandwich structure configuration | Cone Calorimetry | | Critical Heat Flux |
|---|----------------------|----------------------|--------------------|
| | 35 kW/m ² | 75 kW/m ² | |
| G/C/C/core/C/C/G 0% bio-epoxy | √ | √ | √ |
| G/C/C/core/C/C/G 25% bio-epoxy Hybrid | √ | √ | √ |
| G/P/C/core/C/P/G 0% bio-epoxy Pure Matrix Block | √ | √ | √ |
| 0% bio-epoxy Pure Matrix Block | √ | √ | √ |
| 25% bio-epoxy Pure Matrix Block | √ | √ | √ |
| 50% bio-epoxy | √ | √ | √ |

Firstly, the fire smoke toxicity test and analysis were carried out on the specimens of pure matrix only, followed by specimens of matrix/reinforcement in further subsection. The results could be compared of pure matrix to be the baseline results and whether reinforcement has impact or not during the combustion process. Gas chromatography-mass spectrometry (GCMS) results is interesting as it could be used to determine the content of the compound emitted into the air as pyrolysis occurs, differs with combustion in which the chemical reaction of the specimen happened with the presence of oxygen molecules.

Gas chromatography-mass spectrometry (GCMS) results in table 2 provided the major compounds in specimen of pure matrix with 0, 25 and 50 wt% bio-epoxy. These compounds became volatile from solid polymer when given external heat as process of pyrolysis. To ensure reliable data, quality of volatiles detection was selected for above 85 % only. Pure synthetic matrix had all the synthetic compounds such as benzyl alcohol, benzene and a majority of BPA in it. For specimen of 25 and 50 wt% bio-epoxy, presence of acid compounds were found, mainly due to blending jatropha bio-epoxy into the matrix. Since jatropha bio-epoxy was a type of fatty acid, results in table 2 had confirmed the content of the matrix. However, in 25 wt% bio-epoxy matrix, only a small portion of acid was found, and probably was due to limited dispersion of the bio-epoxy, and the small quantity of the specimen used during pyrolysis. Compared to 50 wt% matrix, three types of acid compounds were found, up to 9 % of the total mass. Generally, the matrix consisted of bisphenol A (BPA) which was up to 79 % for fully synthetic matrix, followed by 63 % and 60% for 25 and 50 wt% bio-epoxy matrix.

Table 2: Compounds found in GCMS result on pure matrix.

| Specimen | Compound name | Compound formula | Quantity (mg) (%) | Retention time (s) |
|--------------------------|---------------------------------|-------------------|-------------------|--------------------|
| Pure Matrix 0 wt% BE | Benzyl Alcohol | $C_6H_5CH_2OH$ | 4660 (8) | 29 |
| | Benzene | $C_{10}H_{14}$ | 1033 (2) | 33 |
| | Phenol (BPA) | $C_{15}H_{16}O_2$ | 41677 (79) | 44 |
| | Others | - | 5085 (11) | |
| | Total weight | | 52455 | |
| Pure Matrix 25 wt% BE | Benzyl Alcohol | $C_6H_5CH_2OH$ | 7664 (9) | 25 |
| | Benzene | $C_{10}H_{14}$ | 2980 (3) | 33 |
| | Phenol (BPA) | $C_{15}H_{16}O_2$ | 54570 (63) | 44 |
| | Decanedioic acid (Sebacic acid) | $C_{10}H_{18}O_4$ | 874 (1) | 50 |
| | Others | - | 21369 (24) | |
| | Total weight | | 87457 | |
| Pure Matrix 50 wt% BE | Benzyl Alcohol | $C_6H_5CH_2OH$ | 4994 (4) | 28 |
| | Benzene | $C_{10}H_{14}$ | 5450 (5) | 33 |
| | Phenol (BPA) | $C_{15}H_{16}O_2$ | 70684 (60) | 44 |
| | Dodecanoic acid (Lauric acid) | $C_{12}H_{24}O_2$ | 4515 (4) | 48 |
| | Decanedioic acid (Sebacic acid) | $C_{10}H_{18}O_4$ | 3318 (3) | 50 |
| | Undecanoic Acid (Fatty acid) | $C_{11}H_{22}O_2$ | 1776 (2) | 50 |
| | Others | - | 28858 (22) | |
| | Total weight | | 116598 | |

* Compound formula was taken from source:

<https://webbook.nist.gov/> and <https://pubchem.ncbi.nlm.nih.gov/>.

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CHARACTERISATION OF WOVEN KENAF/POLYESTER REINFORCED POLYLACTIC ACID HYBRID COMPOSITES



MOHD AZLIN BIN MOHD NOR
March 2023

Chair: Prof. Dato' H Ng Paik San, PhD
Faculty: Institute of Tropical Forestry and Forest Products (INTROP)
Programme: Doctor of Philosophy
Field of Study : Biocomposite Technology

Growing concerns about the disposal of petroleum-based products and the demand for high-strength materials have stimulated interest in the use of biodegradable materials with higher strength for the production of hybrid composites. The objective of this study is to determine the mechanical, thermal, morphological and flammability properties of woven kenaf/polyester reinforced polylactic acid hybrid composites. The composites were fabricated by the hot-press method. The effects of different fibre contents and stacking sequences were examined.

The first and second phases focused on the characterization of woven polyester-reinforced polylactic acid and woven kenaf-reinforced polylactic acid composites. The characterization focused on the effects of different fibre contents on both composites. Increasing the polyester fibre content in the composites resulted in the highest improvement in tensile and impact strength of the composites. For the woven kenaf/PLA composites, the results show that the addition of woven kenaf improved tensile properties by 47%. In the third and fourth phases, the effects of different fibre contents and stacking sequences of the hybrid composites were investigated. The sample with 4 layers of woven polyester and 1 layer of woven kenaf (S4) showed a significant percentage increase in tensile strength and elongation at break among the hybrid composites. However, the higher composition of woven kenaf in the hybrid laminated composites exhibited better flexural properties.

The addition of woven polyester in the composites improved the thermal stability and degradation of the composites. In terms of flammability, the result shows that the addition

of kenaf fabric was responsible for the high char yield and extended the burning time of the hybrid composites. The S5 sample with 4 layers of woven kenaf and 1 layer of woven polyester also shows the optimum viscoelastic properties such as storage modulus and loss modulus among the hybrid composites.

In summary, the optimum composition for woven kenaf / polyester / PLA hybrid composites was determined for the S5 sample. All data were statistically analysed using a one-way analysis of variance and showed significant differences between the results. Overall, based on the results, these hybrid composites are suitable for use in non-load-bearing applications such as car headliners and door panels properties.

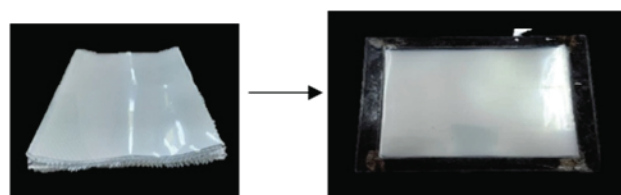


Figure 1: a) Layered woven fabric and film
b) Layered woven fabric and film in a mould

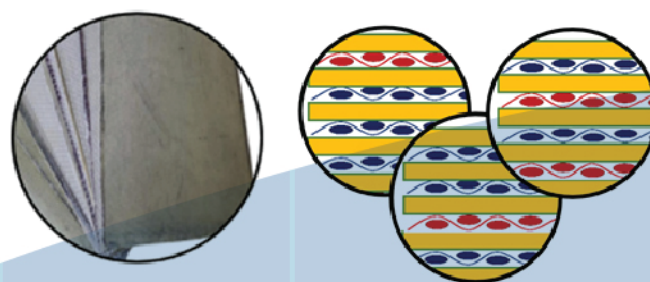


Figure 2: a) Hybrid laminated composites
b) Layering sequences

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CHARACTERIZATION AND PROPERTIES OF MISWAK (SALVADORA PERSICA L.) FIBER-REINFORCED POLYLACTIC ACID BIOCOMPOSITES



NUR DIYANA BINTI AHMAD FAZIL

June 2023

Chair: Professor Khalina Abdan, PhD

Faculty: Institute of Tropical Forestry and Forest Products (INTROP)

Programme: Master of Science

Field of Study: Bio composite Technology

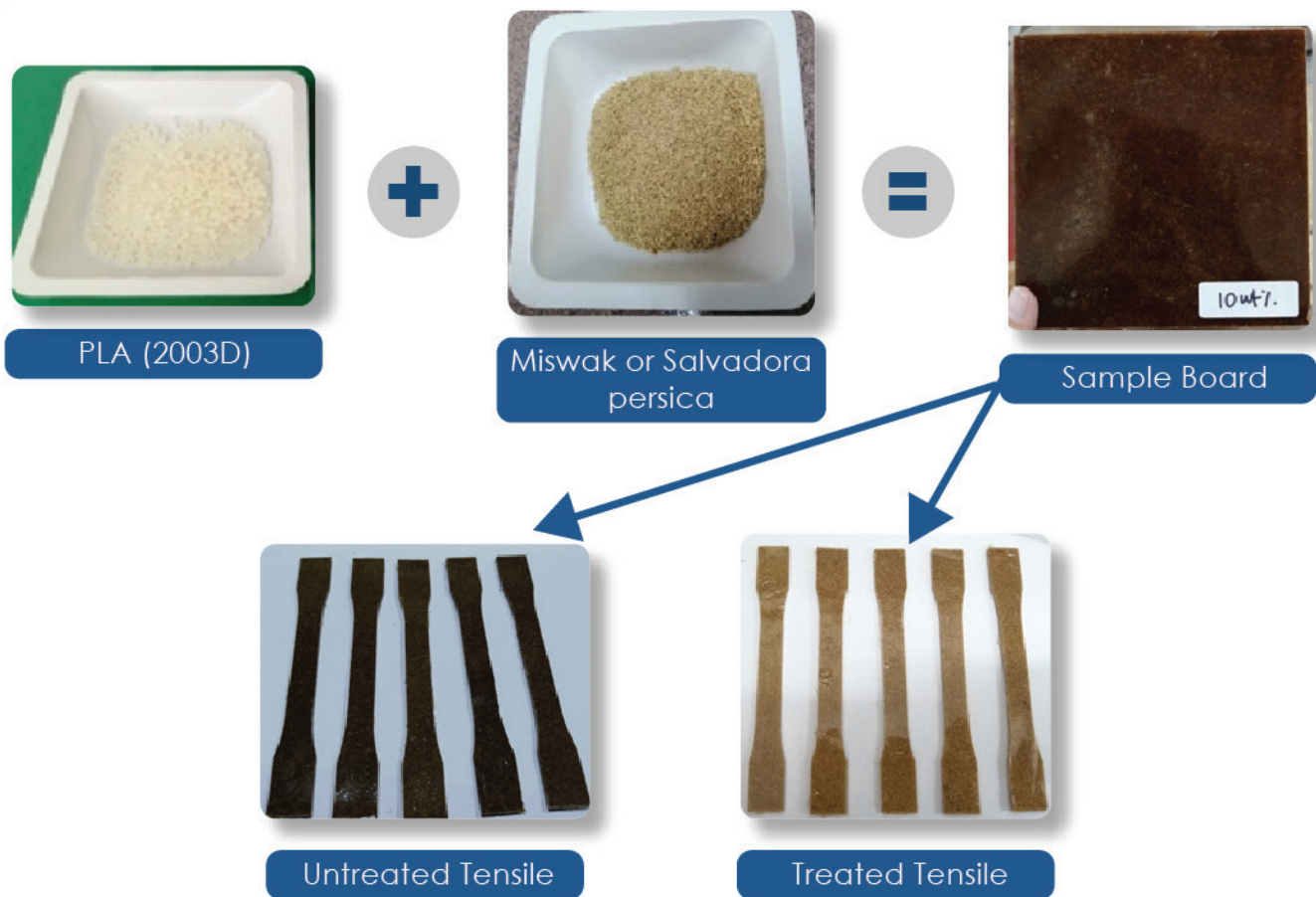
In this study, composite boards from PLA reinforced with miswak fibers (MF) were made. Sodium hydroxide (NaOH) was used as solvent to treat miswak fiber prior incorporate with PLA. Different fiber loadings ranging from 10 to 30wt.% for miswak fiber, whilst from 0.5 to 3% concentration of NaOH were used to treat the fiber. Basic characterizations were carried-out for both untreated and NaOH-treated fibers. The effects of both untreated and NaOH treated miswak fibers in PLA matrix were examined using FTIR spectroscopy, surface morphology, tensile, thermal stability, and dynamic mechanical properties. The comparison between PLA/MF and PLA/treated MF composite properties were also discussed.

The physical properties of miswak fiber revealed the fiber was found to be low in molecular weight in FTIR analysis as the number of obvious peaks are less than 5 peaks and low in the aspect ratio as it value was lower than 10. Based on the surface morphology analysis, residual content was revealed for the untreated miswak fiber surface, while the NaOH treated miswak fiber revealed smooth and clean fiber surface. In TGA analysis show the thermal stability of fiber was increased from 88°C for untreated miswak fiber to 96°C for NaOH treated miswak fiber as resulted from the fiber treatment.

Composite board of PLA/MF were successfully produced by incorporating 10 to 30wt.% of miswak fibers in PLA matrix. The addition of miswak fiber seems has increased the density

of the board and decreased the board tensile property. The surface morphology of board seems affected by showing non-homogeneous and void surface. FTIR spectroscopy shows typical semi-crystalline polymer for all PLA/MF boards. The thermal stability of PLA/MF board also found lower than neat PLA board. The Tg for PLA was 59°C and decreased to the range of 56 °C - 59°C for PLA/MF board.

Composite board of PLA/MF were also successfully produced by incorporating 0.5 to 3% of NaOH concentration of miswak fiber into PLA matrix. Like composite board with untreated miswak fiber, the addition of NaOH treated miswak fiber seems not affect the FTIR peaks of the board due to little amount of miswak fiber. However, reduced effect on tensile property was observed. The presence of NaOH treated miswak fiber seems to affect the surface morphology of the composite board as image illustrated more homogeneous and cleaner surface resulted of improve interfacial adhesion between fiber and matrix. The thermal stability of PLA/NaOH treated miswak fiber possessed higher than PLA/untreated miswak fiber. The Tg range of PLA/NaOH treated miswak fiber was recorded from 59°C to 63°C. The storage modulus and tan delta of PLA/MF recorded to improve with the addition of treated miswak fiber and better than PLA/untreated miswak fiber.



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FLAMMIBILITY TESTER UL94 & LIMITED OXYGEN INDEX (LOI)



By: **Muhamad Azri Bin Mejan**
Science Officer
Laboratory of Biocomposite Technology, INTROP

UL94-AVH Chamber



1. Machine Descriptions

UL94 examines the combustions characteristics (after flame, after glow) by burner (H-5025 UL Tirrill Burner) when test specimen combusts in chambers with internal volume of 0.85m³. The chamber was prepared with internal light to facilitate the observation process and the exhaust fan to eliminate the combustion gases.

The device is equipped with Specimen Moving System to facilitates the separation of the specimen and protect the machine user from the poisonous gas. It also equipped with Burner Moving System in order to comply with all the testing standards.

Year: 2018

- a. UPM Staff/Student = RM180/sample
- b. IPTA/IPTS = RM210/sample
- c. Agency/Private Company = RM300/sample

2. Standard

- a) Horizontal burning test: UL 94HB (ASTM D 5048 or ISO 10351)
- b) Vertical burning test: UL 94 V-0, V-1, or V-2 (ASTM D 3801, IEC 707, or ISO 1210)

Limited Oxygen Index (LOI)



1. Machine Descriptions

The FESTECC LOI (Limited Oxygen Index) tester detects the minimum oxygen concentration required during specimen combustion. The oxygen analyzer in this equipment is adapted Paramagnetic Type, which has a precise, long life, low error rate, and high dependability.

2. Standard

- a) ASTM D 2863, ISO 4589-2, NES 714

Year: 2018

- a. UPM Staff/Student = RM200/sample
- b. IPTA/IPTS = RM235/sample
- c. Agency/Private Company = RM335/sample

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