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Flammability properties of flame retarded natural fibre reinforced polymer composites: an overview

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Abstract

Natural fibre reinforced polymer composites are fast replacing the synthetic ones in some areas of the composite world. Light weights, non-susceptibility to corrosion, and eco-friendly benefits of natural fibre composites are some of its attractions. Natural fibres consist of three constituents namely; cellulose, lignin and hemicelluloses with the cellulose in major and are extremely responsive to flammability of natural fibers. For this reason, their applications have been limited to regions where fire is not of great threat. The incorporation of flame retardants (FR) during the fabrication of natural fibre composites can reduced their flammability potentials and enhance thermal stability. In this study, an overview of the types of flame retardants, standard fire performance tests, cone calorimeter flammability parameters and flammability of selected natural fibers was carefully done. The global trend in halogen free flame retardant selection was emphasized and it is clearly noted that fiber surface treatment and synergetic effect of metal hydroxides FR, and/or phosphorus and nitrogen based FR with Biobased FR may be the most effective

1. Introduction

Natural fibres being environmentally friendly and renewable in nature interests a lot of scientists, researchers and engineers for their use in polymer composite reinforcements. The type of fibre, fibre orientation, interfacial bonding and fibre aspect ratio are some common factors affecting the properties of natural fiber reinforced polymer composites (NFRPCs) which results in poor flame resistance, high water absorption and lower mechanical properties than synthetic fibers and thereby restricts their applications in various fields. The applications of NFRPCs are very numerous such as in sports, construction, automobile, and textile materials [1]. Surface treatment of natural fibres helps to improve the adhesion between the fibre surface and the polymer matrix which eventually results in improved physical and mechanical properties of the NFRPCs [2-4]. It is being believed that high cellulose in natural fibres provides chances of higher flammability while higher lignin content provides a greater chance of char formation during the burning of composites which creates a barrier for the mass transfer of heat [4-5]. The very purpose of flame retardants addition includes (1) improve their flammability resistance (2) help delay and obstruct fire propagation (3) inhibit flaming processes. A good number of flame retardant additives have been studied to improve flammability (fire reaction properties) of materials and there are many compounds from which flame retardant additives could be formulated.

This study aims at providing a brief overview of flammability and flame retardancy of natural fiber composites in a fashion that clearly defines the trend. It clearly highlighted on the types of flame retardants, standard fire performance tests, cone calorimeter flammability parameters and flammability of selected natural fibers.

2. Natural Fibres

The word natural implies a particular substance which exists naturally and not manmade. The word fibre is defined as a hair-like or thread like structure which has high aspect ratio (length to diameter ratio). These natural fibres are hair like materials that are continuous filaments which are similar to pieces of thread. They can be spun into filaments, thread or rope and can be used as a reinforcement component of polymer composites materials. It can also be pulped to make products such as paper or felt, [6]. Dunne et al. [7] reported that there are two major classifications of plant producing natural fibres: primary and secondary plants. The primary plants are those grown basically for their fibre content while the secondary plants are those where the fibre come as a by-product from some other primary uses. Sisal, cotton, jute, hemp, kenaf are examples of primary plants while banana, pineapple, oil palm, cereal stalks and coir are examples of secondary plants.

Table 1: *Physicochemical Properties of selected Natural Fibres, Sources.*

Type of fibre	*Origin*	*Density (g/cm^3)*	*Cellulose (%)*	*Lignin (%)*	*Hemicellulose (%)*	*Pectin (%)*
Oil palm	fruit	1.3	65	29	22.1	-
Jute	stem	1.3	58 - 63	12 - 14	21 - 24	-
Hemp	stem	1.48	57 - 77	3.7 - 13	14 - 22.4	0.9
Wood	stem	0.65	40 - 45	20 - 30	22	2 - 4
Flax	stem	1.5	64.1	2.0	16.7	-
Bagasse	stem	1.25	81	25.3	9.45	-
Sisal	leaf	1.37	65	9.9	12	10
Coir	fruit	1.2	32 - 34	40 - 45	0.15 – 0.25	-
kenaf	stem	1.5	31 - 57	15 - 17	21.5 - 23	-
Ramie	bast	1.51	68.6 - 91	0.6 – 0.7	5 – 16.7	1.9
Banana	stem	1.35	50 - 56	21 - 31	25 - 30	-
Henquen	leaf	1.3	77.6	131	3 - 8	-

3. Flame Retardant Compounds

Polymers and natural fibres are organic in nature and are very succetible to flaming if they are exposed to fire. Therefore, to extend their use in industries and ensure safety in their use environment, flame retardants are added at the manufacture stage in other to reduce their flammability characteristics. Flame-retardant systems can either be active or reactive in nature. The active flame retardants are not chemically bonded to the polymers or chemical materials used in the product but are mixed with other product materials during the product processing. These flame retardants maintain their chemical structure and are evenly dispersed throughout the product. They can also escape from their matrix through release to the air and accumulate in dust [11]. On the other hand, the reactive are chemically bonded to the polymers during polymerization, coupling or grafting processes and become an integral part of the product structure. The whole essence of incorporating flame retardants is to delay or to inhibit combustion [12].

There is health and safety regulation and restrictions on the use of halogen based FRs. Hull et al. [13] reported that mineral fillers, such as aluminum hydroxide (ATH), magnesium hydroxide, magnesium carbonate, or mixed magnesium/calcium carbonates and hydroxides and naturally occurring mixtures of huntite and hydro-magnesite are in heavy demand as sustainable, environmentally fire retardants. Depending on their nature, flame retardants can act in the condensed or in the gas phase through a physical or chemical process Nguyen [14]. Flame retardants (FR) can be further classified according to their mechanism of action into categories: Halogen based FR (ii) Halogen free FR (iii) Intumescent FR (iv) Biobased FR.

3.1. Halogen Based Flame Retardants (HBFRs)

There are theoretically four classes of chemical compounds that can be used as HBFRs: those containing fluorine, chlorine, bromine, or iodine. These halogens show their effectiveness in the increasing order as Fluorine< Chlorine < Bromine < Iodine, however, chlorine and bromine based flame retardants are commonly used. The very low thermal stability coupled with the difficult in processing fluorine and iodine compounds with commercial polymers makes brominated and chlorinated halogen flame retardant a better choice and most diversified class of retardants for flame inhibition, [15]. Aseeva and Daikon [16] reported that bromine and chlorine incorporated into a polymer chain by copolymerization, formed a reactive flame retardant that controls the flame temperature of a fire. They further reported that their effectiveness depends on the release of halogen in the form of radical or halogen halide at the same temperature range or below the decomposition temperature of the polymer. The major problem with halogen-based compounds is the release of smoke, containing corrosive, acidic and toxic gases that are serious health and environmental threats.

3.2. Halogen Free Flame Retardants (HFFRs)

Halogen free flame retardants are known to be eco-friendly and are intimately blended into the polymer during processing, but they do not chemically react with the polymer. A high mechanical stirring tool such as brabender mixer is used for blending. The substances are utilized at levels below about 20% of the polymer resin in order to enhance efficiency. HFFRs are very essential materials preferable in the condense phase of the burning process, [17]. The mode of action of HFFRs blended in composites is that they act as heat sink by releasing water vapour. They decompose endothermically giving out non-combustible volatiles, which performs a blanketing action in the flame. The blanket coating formed eliminates the formed heat and cools the substrate to a temperature below that which is needed to maintain combustion. Also, water is released into the flame where it impedes burning by diluting the flammable gases given out from the polymer matrix and preventing the access of oxygen to the gases in the composite surface. The relative low cost, easy to handle, non-toxicity and good anticorrosion properties of HFFRs makes them very attractive over the HBFRs class of flame retardants. Besides, their drawbacks such as poor thermal stability, low efficiency for loading up to 50% from the mass of the material and a decrease in the strength properties in sustaining their applications has raised serious concern, [18]. However, Hirschler [19], study have shown that HFFRs provides formulations that meet suitable standard test for many uses.

3.3. Intumescent Flame Retardants (IFRs)

Wikipedia defined the word intumescent as a substance that swells as a result of heat exposure, thus increasing in volume and decreasing in density. The mode of action of intumescent flame retardants is the formation of a voluminous, insulating protective layer through carbonization and simultaneous foaming [20]. They are used to protect combustible materials such as plastics or wood, and those like steel, which lose their strength when exposed to high temperatures, against the attack of heat and fire. The basic components of intumescent flame retardants are: (i) acid donors (e.g. ammonium polyphosphate), (ii) carbon donor (e.g. polyalcohol such as pentaerythritol, starch), (iii) spumific compounds; these are also known as blowing agents or gas evolving compounds. They produce large quantities of gas (e.g. melamine, urea) [4]. A synergetic effect such as combining ammonium polyphosphate (APP)/pentaerythritol (PER)/ with or without melamine acts both as the acid source and blowing agent during combustion. Nevertheless, there are shortcomings associated with the IFRs systems with polymers, such as; poor compatibility, thermal stability, moisture resistance and poor flame retardant efficiency at low IFR concentrations consequently leading to considerable decrease in mechanical properties. These shortcomings along with their actual level of toxicity need to be properly evaluated.

3.4. Biobased Flame Retardants (BFRs)

Biobased compounds generally refer to compounds that can be obtained from biological matter that can be found on earth. The identified most abundant elements include C, H, N, Ca, K, Si, Mg, Al, S, Fe, P, Cl, Na, Mn, Ti. It is worthy to note that some of these elements are known to have a flame retardant effect, [21]. Chemical composition is a key factor in considering the use of biomass for development of flame retardants. There are four main families of compounds and their derivatives that can be distinguished for this property: carbohydrates, proteins, lipids and phenolic compounds. The biobased compounds can be used directly or further modified to bring flame retardant functionalities. Carbohydrates consist of cellulose, starch and chitosan, and their derivatives, while lipids consist of lignin and tannins.

The improvement of the fire behavior of biobased flame retardants is essentially achieved through charring effect, which is created during combustion on the sample surface. The char generates a double positive influence: (i) on one side where carbon atoms constituting the polymer structure is fixed within the residue thus decreasing the amount of volatile fuel and therefore the amount of heat released by the combustion reaction; (ii) on the other side, it acts as a protective shield that slows down the heat transfer to the underlying polymer and modifies the kinetics of fuel diffusion to the flame.

Biobased flame retardants systems can be used as in one of the following modes (i) as intrinsic flame retardant system, (ii) in combination with traditional phosphorus or nitrogen flame retardant, (iii) after chemical modification and grafting into the polymer chain. Biobased compounds that has been used intrinsically include lignin, tannin, starch, chitosan and proteins and DNA [22]-23]. Combination of bio-based compounds with phosphorus and/or nitrogen has also been studied. Alongi et al. [24] reported a new flame retardant system containing a stable complex of cyclodextrinnano sponges (NS) and a phosphorous compound. The cyclodextrinnano sponges (NS) was synthesized from b-cyclodextrin a starch derivative. During combustion an intumescent layer was formed that enabled a decrease of peak heat release rate (pHRR) and total heat released (THR) measured by cone calorimeter. Réti et al. [25] used an intumescent composition with 10wt% - 30wt% starch in combination with ammonium polyphosphate (APP) in a polylactic acid (PLA) biopolymer. They obtained a V0 rating at the UL94 test and a 40% limiting oxygen index (LOI). De Chirico et al. [22] combined lignin with mono-ammonium phosphate and APP, aluminum hydroxide (ATH), melamine phosphate in a polypropylene (PP) matrix. The synergetic effects lead to increase in char yield and thermal degradation temperature and decreased the rate of heat release and the weight loss rate during combustion.

Biobased compounds have been chemically modified with phosphorylation being the most common. Numerous works dealing with phosphorylation of cellulose has been studied within the framework of textiles flame retardancy [26-27]. Similarly, phosphorylation and urea addition can be incorporated into lignin to enhance flame retardant properties. Zhang et al [28] prepared a urea-modified lignin (UM-Lig). This nitrogen containing lignin was combined with ammonium polyphosphate (APP) and used as a novel intumescent flame-retardant for PLA. The presence of the modifier (phosphorous, urea or melamine) accelerates the dehydration of biobased retardant and therefore promotes char yield and decrease the peak heat release rate (pHRR) and the total heat released (THR). Hu et al [29] carried out several studies involving the modification of chitosan with phosphorous pentoxide (P_2O_5) and nickel nitrate hexahydrate to give a nickel chitosan phosphate (NiPCS) and incorporated into polyvinyl alcohol (PVA) resin which reduced the pHRR and the THR accordingly and increased the char yield.

4 Fire Performance Tests and Flammability Parameters

4.1 Standard Fire Performance Tests

There are several laboratory test methods used for characterizing the flammability properties of composite materials and they are well established in these references, [30-31].

4.1.1 *Laboratory standard UL-94 test*

The under laboratory (UL) 94 test is perhaps the most frequently used small flame burner test. It provides an assessment of flammability for a variety of plastic materials intended for use in multiple applications. The UL 94 standard actually contains several test methods; the most commonly used test method is the 20 mm vertical burning tests (V0, V1 or V2). The test has two different types depending on sample's holding position: horizontal (UL94 HB) and vertical (UL94 V) tests and each test follows a specific standard for the testing procedure and set up. A typical test method case is the vertical burn method in which a test specimen bar of 13 mm by 125 mm with varying thickness is ignited while suspended 10 mm above a calibrated methane Bunsen burner. The flame is applied to a total of five test specimens twice for 10 seconds. The amount of burn time is recorded after each flame application for each test bar, [32]**.**

Figure 1 presents a schematic representation of the UL94 V set up. Pim Leonards [33] reported that in UL94-HB, a horizontal specimen subjected to slow burning on a burning rate <76 mm/min and for thickness < 3 mm whereas in UL94-V0, the specimen is in a vertical position as shown in Figure 1 and burning stops within 10 seconds and drips of particles are allowed as long as they are not inflamed. In another vertical test UL94-V1, the burning stops within 30 seconds on a vertical specimen and drips of particles are also allowed as long as they are not inflamed while in UL94-V2; the burning stops within 30 seconds on a vertical specimen but drips of flaming particles are allowed. Finally, for UL94-5VB and UL94V5VA; the burning stops within 60 seconds on a vertical specimen, no drips are allowed but plaque specimens may develop a hole and may not develop a hole respectively.

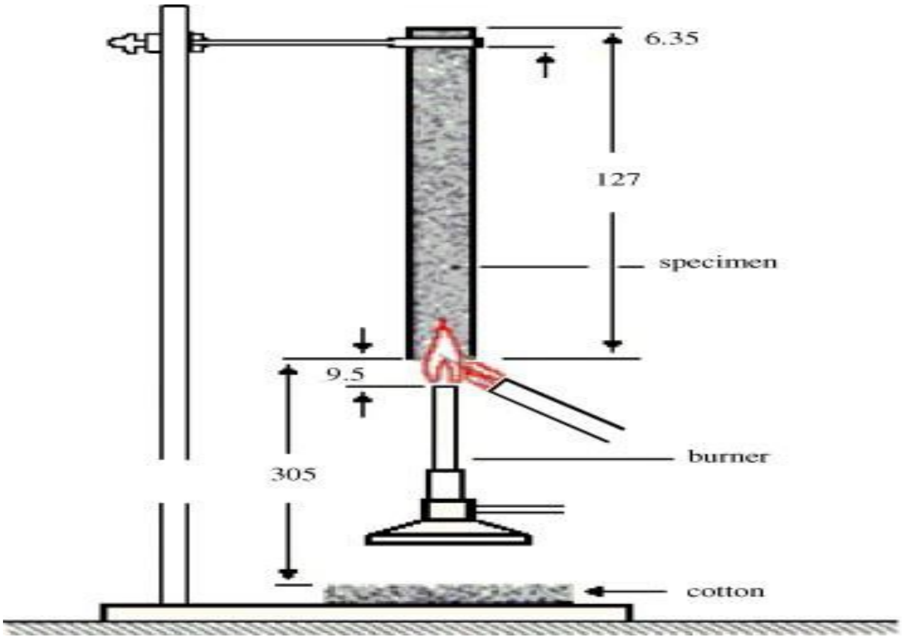

Figure1: Schematic representation of UL94-V [Source: Pim Leonards [33]

Table 2: *Standard ratings for UL94 vertical burning test* [34]

Rating	*Description*
UL-94 V-0	Flame must be out in 10 seconds or less. No glow beyond 30 seconds and no burning material can fall.
UL-94 V-1	Flame must be out in 30 seconds or less. No glow beyond 60 seconds and no burning material can fall.
UL-94 V-2	Flame must be out in 30 seconds or less, no glow beyond 60 seconds and burning material can fall.

4.1.2 *Limiting Oxygen Index (LOI)*

The Limiting Oxygen Index (LOI) represents the minimum level of oxygen it takes in an atmosphere to support flaming combustion. Polymers without flame retardants vary greatly in their ability to support combustion at normal atmospheric conditions and their relative resistance to burning depends on the chemical composition of each polymer. The LOI is a method of ranking the combustibility of polymers and it is very important for plastics used in aviation industry. Since air comprises about 20.95% (approx. 21%) oxygen by volume, any material with a limiting oxygen index less than 21% will burn easily and continuously in air. Conversely, the burning behaviour and tendency to propagate flame for a polymer with a limiting oxygen index greater than 21% will be reduced or even zero after removal of the igniting source. Self-sustaining combustion in any oxygen-nitrogen atmosphere is not possible if LOI > 100, indeed such values are not physically meaningful [35-36].

The LOI is measured by placing the samples in a flow of oxygen/nitrogen gas and increasing the concentration of oxygen until the sample will support combustion. The next lowest oxygen concentration is the value used as the index. The higher the LOI value, the higher the non- flammability of the material [37].

Nelson et al. [35] in their work tilted “A Dynamical Systems Model of the Limiting Oxygen Index Test” reported that oxygen index method describes the tendency of a material to sustain a flame. It has been used over years as the basis for systematic investigations into the relative effectiveness of different fire-retardants and fire-retardancy mechanisms. They described the limiting oxygen index (LOI), also called the critical oxygen index (COI) or oxygen index (OI), as in equation 1:

$$LOI = \frac{\phi(O_2)}{[\phi(O_2) + \phi(N_2)]} \quad \text{..........} \ (1)$$

where ϕ (O_2) and ϕ(N_2) are the minimum oxygen concentration and the nitrogen concentration in the inflow gases required to pass the "minimum burning length" criterion respectively.

4.1.3 Cone Calorimetric Test

The cone calorimeter test (CCT) is at present the most advanced method for assessing the reaction of materials to fire. The test gives the possibility to evaluate ignitability, combustibility, smoke production and production of toxic gases. It brings quantitative analysis to materials flammability by investigating parameters such as heat release rate (HRR), time to ignition (T_{ig}), total heat released (THR) and mass loss rate (MLR). The testing procedure and measurement observations are described in both ISO standard (ISO DIS 5660) and ASTM standards (ASTM E1354**).** The test is carried out by applying a constant external heat flux to 100 x 100 mm specimen under forced flaming conditions. If specimen thickness is less than 50 mm additional layers of insulation is usually required to fill out the depth and to hold the specimen securely in the holder [38]. This will allow the full surface of the test specimen to be exposed to a constant level of heat irradiance. The range of heat flux can vary between 0-100 kW/m^2, from a conical heater. At the early stage of the test, the surface temperature will increase rapidly and level off to a steady state [39].

Table 3: *Flammability characteristics of some natural fibre composites tested in the cone calorimeter* [4]

Sample (%)	*Heat flux (kW/m^2)*	T_{ig}*(s)*	*p-HRR (kW/m^2)*	*THR (MJ/m^2)*	MLR_{avg} *(g/s)*	Eh_c *(MJ/Kg*	*TSR (MJ/Kg)*	
BAF/PP	35	17	192.8	11.6	N/A	15.1	N/S	N/S
KF/PP-20%IFR	50	18	729	104.93	0.088	N/S	N/A	N/S
SAF/UP	50	15	459.2	508.4	0.093	27.7	13295.4	0.0411
HF/EX	35	55	754	63.1	NS	NS	2254	0.032
CFM/UP	50	68	571.8	182.1	22.2	18.5	7467.7	NS
WF/PP-APP/PER (30%)	35	20	311.6	79.5	0.029	NS	NS	NS
JF/PEHA-MMT	35	59	567.8	74.7	0.032	NS	NS	0.024
HF/EX-APP (15%)	35	46	259	34.4	NS	NS	938	0.05
FF/BP-ATH (25%)	50	15	559	48.3	NS	NS	NS	NS
SUGF/PBS	35	74	313	862	NS	19.3	NS	NS
WF/PP	35	15	757.9	123	0.039	NS	NS	NS
FF/EX	50	35	446	147	NA	NS	3977	NS

HF: Hemp fibre, EX: Epoxy Resin, CFM: Coconut Fibre Matt, UP: Unsaturated Polyester, SF: Sisal Fibre, WF: Wood Fibre, PP: Polypropylene, APP: Ammonium Polyphosphate, PER: Pentaerythritol, JF: Jute Fibre, PEHA: Poly 2-Ethyl Hexyl-Acrylate, MMT: Montmorillonite, FF: Flax Fibre, BP: Bio Polyester, SUGF: Sugar Cane Fibre, PBS: Poly (1,4 Butanediol Succinate), NS: Not Specified, NA: Not Assessed

4.2 *Fire Sensitivity Parameters*

4.2.1 Cone Calorimeter Flammability Parameters

Table 4 gives a summary of the important flammability parameters obtained from fire performance test especially as obtained from a cone calorimeter with their standard units. [40].

4.2.2 Heat Release Rate (HRR)

The HRR is solely a significant variable in defining phenomenon such as a fire hazard. It is assumed to be the driving force in any fire performance. It is defined as the thermal energy produced per unit surface when flammable decomposition products ignite and burn in the vicinity of the material in fire or heat flux [41]. Hapuarachchi, [40] reported that the amount of HRR defines the level of production of undesirable effects of fire and its products. This means that production of toxic gases, smoke and other types of fire hazards increase in parallel with the heat release rate.

Table 4: *Cone calorimeter flammability property parameters* [40]

Parameter	*Units*
Heat Release Rate (HRR)	KW/m^2
Peak Heat Release Rate (pHRR)	KW/m^2
Average Heat Release Rate (aHRR)	KW/m^2
Total Heat Released (THR)	KW/m^2
MARHE	kW/m^2
Effective Heat of Combustion (EHC)	MJ/Kg
Exhaust Flow Rate	m2/Kg
Specific Extinction Area (SEA)	m2/Kg
Mass Loss Rate (MLR)	g/s
Final Sample Mass	g
Time to Sustain Ignition	s
CO/CO_2 Production	g/s
Total oxygen consumed	g
Mass lost	g/m2
Carbon monoxide yield	kg/kg
Total smoke release	m^2/m^2
Total smoke production	m^2

Other variables correlated to HRR include The *Peak Heat Release Rate* (pHRR) which occurs rapidly and most times after ignition, and is usually a good indicator of maximum flammability of a material [42]. Another important HRR correlation variable indicator is the *Average Heat Release Rate (aHRR)*) which is the total heat released averaged over the total period and it is regarded as the most reliable measure of heat of contribution to a sustained fire.

4.3. Flammability Studies of Natural Fibre Composites

Natural fiber reinforced polymer composite is a promising material for various industrial and domestic products but its constituents; cellulose and polymer are highly flammable. To this end, efforts are seriously being expanded by researchers on a global scale to tackle this problem. Nadir et al. [43] investigated coir fibre reinforced polypropylene (PP) composite panel for automotive interior applications. In their study, mechanical, physical and flammability properties of the composite panels were evaluated. Four levels of coir fibre contents (40,50, 60 and 70wt%) were mixed with the PP powder and coupling agent,3wt% maleic anhydride grafted PP(MAPP) powder. The water resistance and the internal bond strength of the composites were badly affected by increasing coir fibre content. The result suggested that a mixture of 60wt% coir fibre, 37wt% PP powder and 3wt% MAPP is the optimal composite panel formulation for automobile interior application. Nural and Ishak [44] studied the fire retardant polyester composites from recycled polyethylene terephthalate (PET) waste reinforced with coconut fibre. The coconut fibres were pre-treated with NaOH followed by silane prior to inclusion into the resin. The untreated fibres composite was used as a control. Dricon as a phosphate type flame retardant was added to the composite to reduce flammability of the composite. The amount of Dricon was varied from 0 to 10wt% of the overall mass of resin. The burning properties and limiting oxygen index (LOI) of the treated and untreated composites increased with the addition of Dricon.

Ridzuan et al. [45] studied the effect of coupling agent and flame retardant on the performance of oil palm empty fruit bunch fibre (OPEFBF) reinforced polypropylene (PP) composite. Alkali treated and untreated OPEFBF were incorporated in PP with and without maleic anhydride grafted PP(MAPP) and magnesium hydroxide as flame retardant to produce the composite by melt casting method. The composites were characterized by mechanical and burning test along with scanning electron microscopy(SEM) and Fourier transform infrared (FTIR). The significant improvement in flame retardant property was at 60vol% of treated OPEFBF –PP composite with MAPP. The improved mechanical property was discussed by the development of encapsulated texture. Bharath and Basavarajappa [46] studied the flammability property of natural woven coconut tree leaf sheath (CLS) reinforced phenol formaldehyde (PF) composites. The CLS composites were prepared in both treated and untreated forms with volume fraction of 60wt% sheath and 40wt% of PF resin. CLS were chemically treated with 5% NaOH and composite panels were prepared using a hydraulic hit press at 1400^0C. The flammability of the composites was evaluated using the Underwriters Laboratory test (UL94) and Limiting Oxygen Index (LOI). The UL94 test showed a decrease in the mass loss and flame propagation rate for treated fibre as well as increase in resistance to flame. In LOI test, alkali treated composites required more oxygen than untreated ones to burn. Therefore, treatment of CLS fibre will improve the flammability of the composite used for construction and decorative purposes.

Table 5: *Applications of Selected Flame Retarded Natural Fibre Composites* [47-48]

Fibre	*Applications in building, construction and other fields.*
Wood fibre	Window frame, panels, door shutters, decking, railing systems, and fencing
Hemp fibre	Construction products, textiles, cordage, geo-textiles, paper & packaging, furniture, electrical, manufacture bank notes, and manufacture of pipes.
Oil palm fibre	Building materials such as windows, door frames, structural insulated panel building systems, siding, fencing, roofing, decking, and other building materials.
Rice husk fibre	Building materials such as building panels, bricks, window frame, panels, decking, railing systems, and fencing.
Flax fibre	Window frame, panels, decking, railing systems, fencing, tennis racket, bicycle frame, fork, seat post, snowboarding, and laptop cases.
Bagasse fibre	Window frame, panels, decking, railing systems, and fencing.
Stalk fibre	Building panel, furniture panels, bricks, and constructing drains and pipelines.
Sisal fibre	In construction industry such as panels, doors, shutting plate, and roofing sheets; also, manufacturing of paper and pulp.
Jute fibre	Building panels, roofing sheets, door frames, door shutters, transport, packaging, geo-textiles, and chip boards.
Kenaf fibre	Packing material, mobile cases, bags, insulations, clothing-grade cloth, soilless potting mixes, animal bedding, and material that absorb oil and liquids.
Cotton fibre	Furniture industry, textile and yarn, goods, and cordage
Ramie fibre	Used in products as industrial sewing thread, packing materials, fishing nets, and filter cloths. It is also made into fabrics for household furnishings (upholstery, canvas) and clothing, paper manufacture.
Coir fibre	Building panels, flush door shutters, roofing sheets, storage tank, packing material, helmets and postboxes, mirror casing, paper weights, projector cover, voltage stabilizer cover, a filling material for the seat upholstery, brushes and brooms, ropes and yarns for nets, bags, and mats, as well as padding for mattresses, seat cushions.

Hsiao et al. [49] compounded rice husk/polypropylene composite filled with graphene nanoplatelets and aluminum hydroxide (ATH) and magnesium hydroxide using a brabender plasticorder. The flammability and mechanical properties of natural fiber composites of different formulations were evaluated. The horizontal burning test results showed that plain 50wt% PP/rice husk composites demonstrated a horizontal burning rate of 36.08 mm/min. When flame retardant or nano-graphite was added to the composite, the burning rate reduced to 20 mm/min. On the other hand, a synergetic effect was observed when graphene nanoplatelets were used in conjunction with aluminum hydroxide (ATH) or magnesium hydroxide (MH). Horizontal burning rates were significantly reduced to a low value of 5.66 mm/min. The results of mechanical testing showed that adding graphene nanoplatelets not only improves the flame retardancy, the stiffness of the composites increases as well.

Conclusions

This paper explores the flammability properties of some natural fibre reinforced polymer composites. Natural fibre reinforced composites have found wide applications in industries as a result of their intrinsic properties such as biodegradability, light weight and eco-friendliness. Irrespective of these good properties, the high vulnerability of natural fibres and polymers to flame propagation has restricted their uses mainly under conditions where fire menace is impending. Current studies have shown that the incorporation of flame retardant additives in polymeric materials can lower the flammability properties and hinder the propagation of fire in the composite materials.

Flame retardant fillers equally act as heat barrier, limiting fuel or flame and therefore guard the composite surface from heat and air. The trend on flame retardant materials selection is moving away from halogenated to halogen free flame retardants using both inorganic and carbonaceous compounds. Further to this is to explore the use of biobased flame retardants systems either as intrinsic additive or reactive form with the polymer. We propose a green solution utilizing synergistic effects, multifunctional and integrated approaches of non-halogen FR (phosphorus or nitrogen-based FR) and chemically modified biobased flame as a sustainable flame retarded polymer system of our time and the near future for applications in areas such as automobile, aerospace, building and electronic packaging.

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