



# Advances and Development in Hybrid Polymer Composite: The Way Forward

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## Authors' contributions

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

This paper presents the unique and outstanding properties of hybrid polymer composite (HPC). The various classification of HPC based on the combination of matrices, fibres and fillers in use are brought to bear. The different techniques/methods employed in the production of hybrid polymer composites, ranging from hot press to cold press are being discussed. It is paramount to note that the production process of HPC from start to finish is not without some inherent and external challenges, such as agglomeration of fibre, fillers and weak interfacial adhesion between fillers and matrices. Chemical modification of fibre was identified as one of the ways of proffering solution to this drawback. This study also presents a wide range of the application of HPC as enumerated in this work. The degradation of HPC as a result of natural and accelerated weathering conditions such as ultra violet (UV) rays, heat caused by high temperature, rain and humidity was also discussed. The durability and lifespan of these HPC can be strengthened and prolonged through the use of intumescent and other additives. All of these can help in improving the resistance of HPC to adverse weathering conditions.

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## 1. INTRODUCTION

Over the years, lots of research has been carried out on polymer composite; but not so much work in the area of hybrid polymer composite. The reinforcement of polymer matrix with singular organic or inorganic fibres or fillers with the aim of improving their mechanical, physical, thermal and micro properties for application purposes is on the increase. Nevertheless, there is still room to improve their performance and all round qualities while targeting their specific areas of application. This is why the need to develop hybrid versions of polymer composite have become indispensable, in order to fill this gap.

A hybrid material is the unique outcome resulting from the combination of two or more materials of distinct properties [1]. Therefore, composites are multifaceted materials comprising of two or more relatively bonded constituents possessing distinct property and interface upon fusing together [2]. In hybrid composites, there exist more than one discontinuous phase known as the hybrid reinforcements embedded into a matrix or matrices referred to as continuous phase, which can be polymeric, metallic and ceramic by classification [2]. The interest of this review is the classification that is based on hybrid polymer composite. Hybrid polymer composites have a higher load bearing capability in different directions than composites made from single fiber or filler reinforcement. The matrix in this case, provides the platform for the load transfer by maintaining the direction and orientation of the reinforcing materials [3,4].

The area of application of a composite or hybrid polymer composite as well as the environment in which it will function, greatly determine the property choice of fibre or filler for reinforcement. The matrix to be used, the treatment process to be employed and the manufacturing technology are also of great consideration. The durability of hybrid polymer composites and its final product quality according to their classification is influenced by the aforementioned reasons [5]. Therefore, this study is aimed at highlighting the properties, classification, formulation treatment, application and degradation of HPC.

## 2. CLASSIFICATION OF HYBRID POLYMER COMPOSITE

Hybrid polymer composite may be classified into hybrid-polymer-matrix composite and hybrid

fibre/filler polymer composite. This is discussed below. Also, the polymer resin, fibre/filler and the processing technology in use is presented in Tables 1 and 2.

### 2.1 Hybrid-polymer-matrix Composite

This is a situation where more than one polymer matrix is used in the production of the hybrid polymer composite. These polymer matrices to be used and blended together at the discretion of the designer may include low density polyethylene (LDPE) high density polyethylene (HDPE), polypropylene (PP), polyethylene terephthalate (PET), and polystyrene (PS) – for thermoplastic polymers. For thermosets, they include epoxy, polyurethane, polyester. However, the need to have a good knowledge of the properties of the combining matrices in order to know their compactibility and mechanism of interaction within the designed composite cannot be overemphasized. The property information of each of these polymers is necessary before using them as matrices for hybrid polymer composite. In most cases, there is always the challenge of incompactibility and immiscibility of the polymers to be blended together. To tackle this challenge, a single-step direct electrospinning procedural method can be employed, where more than one polymer solutions are dissolved in a homogeneous solvent prior to fibre or filler addition. Another method is co-axial or co-electrospinning method, in which, polymers to be blended are dissolved in separate solvent prior to being electrospun by the same collector. This method is reported as being more efficient and encompassing, as it allows the encapsulation of the functional components as the core, or on the other hand acts as the coated shell around the hybrid polymer composite [6]. Table 1 presents the classification based on hybrid-polymer-matrix composite.

### 2.2 Hybrid-fibre/filler Polymer Composite

In this case, there can be more than one reinforcing fibre material in the hybrid polymer composite. These fibres can be natural or synthetic in origin. In some cases, a blend of natural-synthetic fibre is used as reinforcement in the hybrid polymer composite.

**Table 1. Hybrid-polymer-matrix composite**

Hybrid Resin	Fibre or Filler	Chemical treatment/ additive	Processing technology	Reference
Polystyrene/HDPE	None	None	Single screw extrusion	Jennifer and Elizabeth, 2018 [7]
Polypropylene/Polystyrene	None	None	Melt spinning	Dan et al., 2020 [8]
Poly (vinyl alcohol) 70%/Poly(lactic acid) 30%	None	None	Melt spinning	Tran et al., 2014 [9]
rHDPE/rPET	Rice Husk	None	Twin screw extruder and compression moulding	Chen et al., 2019 [10]
Polycarbonate/poly(methymethacrylate)	None	None	Electro- spinning	Cai and Huang, 2012 [6]
Poly-(N-isopropylacrylamide/methylmethacrylate)	None	None	Electro- spinning	Cai and Huang, 2012 [6]

**Table 2. Hybrid-fibre/ filler polymer composite**

Hybrid fibre	Resin	Chemical treatment/ additive	Processing technology	Reference
Bamboo/glass fibre	Polypropylene (PP)	MAPP	Injection moulding	Moe and Kin [80]
Pineapple/ sisal/glass fibre	polyester	Cobalt napthenate and MEKP	Hydraulic press	Mishra et al., [81]
Sisal/silk fibre	Unsaturated polyester	MEKP, Colbalt and napthenate	Hand layup	Noorunnisa et al., [82]
Basalt/hemp/GF/CF	Polypropylene (PP)	-	Hot press through mixing	Czigany [83]
Banana/GF	Polypropylene	MAPP	Twin screw extruder	Sanjay and Nayak [84]
Oil palm empty fruit bunch (OEFB/ GF)	Vinyl ester	-	Laminate resin transfer molding machine	Abdul et al., [85]
Kenaf/GF	Unsaturated polyester	-	Hand lay-up and cold press	Ghani et al., [86]
Kenaf/banana	Unsaturated polyester	NaOH and MEEK	Hand lay-up contact moulding	Akubueze et al., 2019 [12]
Cordenka/Jute	Polypropylene	-	Injection moulding	Tzounis et al., 2014 [13]
Glass/hemp/basalt	epoxy	-	Vaccum infusion	Eesae and Shojaei 2014 [14]

Similar to hybrid fibre polymer composite, two or more natural or synthetic (minerals) fillers are incorporated into a polymer matrix for hybrid composite production. The role of the filler in composites is usually tailored towards a specific function. Fillers which come in different grain sizes and aspect ratio are functions of shape to a great-extend, and these enhance the quality of composites. In most cases, these fillers act as additives and stabilizers. The use of fillers in most composite is cost effective. Some impart physical appearance such as colour and opacity to composites, as well as improved mechanical properties. Matrices that are filled or reinforced with fillers have less shrinking tendencies which help to sustain dimensional stability in composites. Examples of some filler are: calcined clay, calcium carbonate and titanium oxide ([www.foramfera.com](http://www.foramfera.com)) [11]. Interestingly, their inherent properties can be modified or improved upon. Table 2 presents the classification based on hybrid-fibre/filler polymer composite.

### **3. POLYMER COMPOSITE PROCESSING TECHNIQUES / METHOD**

As earlier mentioned, the processing or manufacturing technology employed in the production of polymer composite is one of the factors that influence its mechanical properties and durability. Basically, the choice of a processing technique is hinged on the type of matrices, the feed-form of the starting materials and the expected final form and application of the composite product [15]. Some processing technology which may be suitable for thermoplastics include hot pressing, hydraulic press, hydraulic compression moulding, hand lay-up, injection moulding, single or twin screw extrusion, two roll milling and cold press [16]. Similarly, resin transfer moulding (RTM) and sheet moulding compound (SMC) are more appropriate for processing thermoset matrices [17-20, and 21]. In some cases, a combination of more than one method is employed to achieve the task of polymer composite production. The factors of cost, availability, safety, convenience, energy consumption/economy, suitability and compatibility influence the choice of a particular combination of processing technique being used. Astrom [22] observed that the control of component moisture and the right processing parameters such as pressure and temperature, as well as the specific mechanical energy (SME) also greatly influence the final properties of the manufactured composite.

### **4. CHALLENGES AND DRAWBACKS IN HYBRID POLYMER COMPOSITE PRODUCTION**

Despite the advances in hybrid polymer composite, it is not without challenges. Some of the challenges encountered during the processing and production of polymer composite are: Prediction of optimum component mix ratio, agglomeration of fillers/fibres, improper interfacial adhesion, interphase link, geometric shape. The choice of appropriate combination of processing parameter for the compounding production process also greatly influences the final product quality of the composite [23,24]. Another contemporary critical challenge which has to do with finishing is the ability for researchers to adequately adopt and deploy a 3-dimensional print in the development and fabrication of polymer composite with high precision and customized complex geometry, aided by computer modeling software design. Cost is of essence in this case [79]. All of these challenges determine their life span, resistance to harsh weather condition, fire and area of application. It is also important to note that the inherent drawback of incompatibility between the hydrophilic nature of natural fibre and the hydrophobic nature of thermoplastic polymer matrices is of paramount concern. This gives rise to poor moisture resistance in polymer composite. This poor moisture resistance is due to the presence of polar groups such as hydroxyl group in natural fibre which causes fibre swelling. The presence of moisture negatively affects the processing and final quality of polymer composite [25-28].

In order to overcome most of these challenges, modification methods like surface or chemical treatment using alkaline (NaOH, KOH) silane, maleic anhydride poly polypropylene (MAPP) and lysine-based diisocyanate (LDI) are employed to narrow this gap of incompatibility [26,29-31]. Another drawback in natural fibre is their low degradation temperature compared to that of thermoplastic during processing and compounding [25,27].

### **5. MODIFICATION OF NATURAL FIBRES**

The shortcoming inherent in the mechanical and interfacial properties of natural fibres can be worked upon by subjecting the natural fibres to the appropriate modification method. This modification may be in form of chemical or physical method. In some cases, nano-technological technique is deployed [15].

## 5.1 Physical Modification

This involves the alteration of the surface and structural properties of the fibres with the aim of strengthening the fibre to have a better interfacial bonding with the matrix. Conventional methods like calendaring, stretching and thermo treatment are often being used in physical modification of fibres [32,76,77]. Da-Cunha et al. [32] reported that lignin which is one of the component compositions of natural fibre will become soft and tender thereby moving to the surface of the fibre when subjected to thermal treatment beyond its glass transition temperature. To be specific, kraft lignin will behave in this manner at 142<sup>o</sup>C, but will begin to degrade around 214<sup>o</sup>C. This heat treatment will generally increase the dimensional stability, hydrophobicity and crystallinity of the natural fibre. Interestingly, the popular wood panels in our offices and homes called medium density fibreboard (MDF) is a product of thermal treatment process at 180<sup>o</sup>C for 30mins in order to achieve minimal swelling capacity of MDF products [87,33]. Furthermore, Belgacem et al. [34] and Wakida and Tokino [35] reported that surface modification as a physical form of modification is geared towards improving the functional properties of natural fibres through discharge treatment. This can be carried out either through some of the following ways: corona discharge, sputtering and low temperature plasma. All of these methods are found to improve the interfacial bonding between hydrophobic matrix and hydrophilic natural fibre. In this case, plasma treatment technology is widely employed as it primarily leads to crystallization, etching, free radical formation polymerization and chemical implantation in natural fibre such as sisal and flax. Sputtering on the other hand mainly initiates surface roughness for better adhesion [36-38].

However, the type of discharge treatment in use, determine the nature of surface modification to be obtain. Carlsson et al. [39] reported the impact of oxygen and hydrogen plasma treatment on fibres from wood. Findings from the work show that oxygen plasma treatment opens up or predisposes the wood fibre to a higher degree of hydrophilicity while hydrogen plasma treatment minimizes the water absorption capacity of the wood fibre, thereby reducing the number of hydroxyl groups responsible for its hydrophilic property.

## 5.2 Chemical Modification

This method of modification employs the use of chemical agents to bring about changes within or

on the surface of a natural fibre. During this process of modification, hydrophobic functional groups are introduced into the fibre to minimize their hydrophilic properties. These methods of chemical modification can be grouped into 5 classes. Namely - oxidation, grafting, crosslinking, coupling agent treatment, and mercerization [87].

Oxidation as a chemical modification method entails the selective oxidation of either secondary or primary hydroxyl groups within a chain under moderate conditions. While grafting process has the capability of introducing functional groups like aldehyde, carboxyl and ketone into the cellulose chain of the natural fibre. All these carbonyl group play a functional role [87].

The use of coupling agent (CA) is one of the ways of carrying out chemical modification on the surfaces of particle fibre. The process introduces functional group on the fibre surface for better improved adhesion with polymer matrix. Saline and maleic anhydride are example of coupling agent. The molecules in coupling agent compose of alkoxy and organic functional group. The portion of the organic group bonds with the hydrophobic polymer matrix, while the alkoxy group covalently bond with the hydrophilic fibre or filler [40].

Crosslinking in polymer is initiated by an irreversible chemical change in form of condensation, addition and ring closure. In this case, the carbon atoms from different polymer chains within the polymer matrix are linked or tied together, transforming the viscous straight polymer into a network of insoluble gel. Similarly, the molecules within the amorphous region of the polymer matrix are prevented from sliding over one other. This however will reduce the melt flow index of the polymer matrix [41]. Furthermore, one of the basic functions of crosslinking is to enhance the dimensional stability of polymer composites, assisting it to withstand dry and wet cycle exposures. Chemical like formaldehyde is used for crosslinking [42]. Mercerization on the other hand, is the process by which natural fibres are subjected to alkalization in order to improve their cellulose content, fibre roughness for better adhesion with the polymer matrix. Some of the chemical used for this purpose are sodium hydroxide, potassium hydroxide and calcium hydroxide.

Muhammad et al. [88] chemically modified treated sawdust using 2-ethyl-hexyl methacrylate

( $C_{12}H_{22}O_2$ ). This compound works by interacting with the polar groups such as hydroxyl groups to form hydrogen or covalent bond that promote better adhesion within the wood polymer composite. The chemical reaction for this process is shown in Fig. 1.

Aside the type of treatment being employed which influences the successful outcome of a treatment process; other factors like concentration of chemical, contact (soaking) time and temperature also play crucial roles [89]. Some other chemicals that have been used for treatment are isocyanate, alkali, silane, peroxide. Alkali treatment is however a cheap and effective method. Despite the fact that increase in temperature easily initiates removal of noncellulosic components and fibrillation, caution on temperature control must be taken to prevent denaturing and deterioration of the natural fibre in order to preserve its mechanical properties [43-46].

## 6. APPLICATION OF HYBRID COMPOSITE

The application of hybrid composite over traditional conventional composite in engineering is on the increase due to its enhanced properties [47]. Some areas of application include automotive, aeronautics, biomedical, electronic, civil-structural, marine and military sector [90,91]. This is because several studies have

proven that hybrid composite have better performance properties than single phased materials in terms of flexural strength, tensile strength, corrosion resistance, low weight [48-53].

In the transportation industry, some components of cars, ships and aeroplanes are made from natural fibre composite (NFC) due to their excellent and durable properties. For instance, the rear and front door panel, as well as the parcel shelf of peugout 406 are products of (NFC). Similarly, the boot-lining, seat back and noise insulation panel of BMW 7 series are made from NFC, and a host of other automobile brands like Toyota, Audi, Volvo, Mitsubishi, Opel, and Rover have adopted NFC as part of the components used in the production of cars [54].

## 7. WEATHERING OF POLYMER COMPOSITE

Weathering is known to have great adverse effect on the life span and durability of all existing materials such as hybrid polymer composite. This generally leads to the degradation of exposed polymer composite over a period of time. Weathering processes can be initiated by the exposure of composites to natural environmental conditions. These conditions can also be simulated under an artificial accelerated setup, to create an atmosphere of weathering on composites.

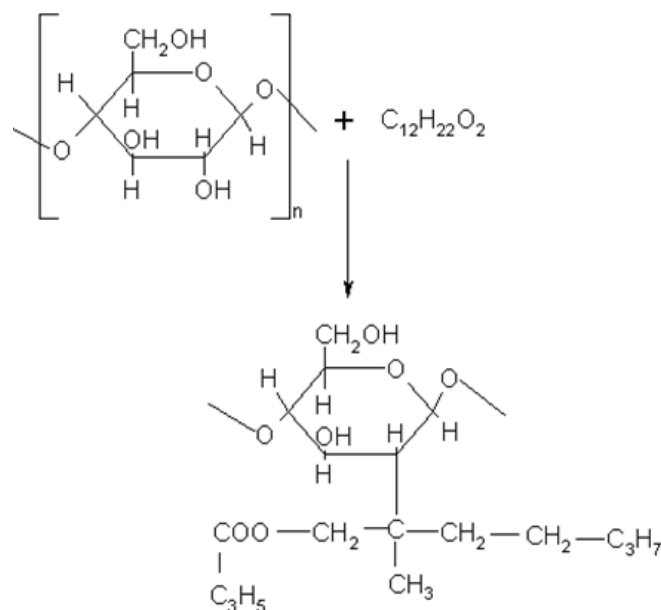


Fig. 1. Treatment of Cellulose in Sawdust with 2-ethyl-hexyl methacrylate

## 7.1 Natural and Accelerated Weathering Test

Natural weathering is a degradation condition of materials such as composite, initiated by environmental factors such as sunlight, water, heat freeze thaw and oxidation processes over a period of time, when exposed to weather. Adequate studies and information on the prediction of the lifespan of materials such as composites, with regards their natural aging or degradation period is known to be time consuming, cumbersome, and over a long term, cannot be relied upon for immediate result. This means that the analysis of the effect of natural weathering on composite materials is only suitable and practicable over short term exposure as expected. All of these short coming in natural weathering assessment led to the design and adoption of artificial or accelerated weathering laboratory equipment. The concept behind this artificial accelerated equipment is to simulate outdoor natural weathering conditions in an accelerated manner, where comparable long time degradation results can be predicted and obtained in short time, in relation to natural aging processes. There are some reservations that accelerated weathering results may not be totally extrapolated to reflect that of the natural outdoor degradation, in their various areas of application [55]. In order to reconcile this difference, Badji et al. [56] proposed correlations known as acceleration factor which is a ratio between natural aging time and artificial weathering time, to reflect the same effect for different materials. For instance, the natural deteriorating effect on neat polypropylene (PP) over a period of one year is equivalent to 250 h of its accelerated degradation exposure. While PP composite recorded 750 h equivalent degradation exposure for one year [57]. Similarly, Azwa et al. [25] observed that a minimum of 2 years natural exposure corresponds to about 400 - 2000 h accelerated weathering exposure. Furthermore, a comparative review by Friedrich [58], reported that, for an equivalent degradation effect in wood polymer composite, the expected natural exposure period is 7.4 times the artificial exposure duration.

In all of these, it is important to note that the equivalent of artificial weathering is not fix or constant universally, due to the following reasons- location of exposure, exposure conditions or factors, angle of inclination of exposure, the inherent property of the material under exposure and the exposure protocol and standard.

## 8. DEGRADATION AND EFFECT OF WEATHER ON POLYMER COMPOSITES

According to Rudi et al. [59] the reduction in performance and functionality of composite in tropical regions/countries like Nigeria and others is more severe. This is caused by harsh weather conditions. Generally, polymer and composites are vulnerable to colour change, change in mechanical and chemical properties, loss in weight and crystallinity and embrittlement due to degradation by weather [59,60]. Different biocomposites respond differently to the process of weather degradation owing to their difference in the polymer matrix and the reinforcing fibre specie, that forms the composite. However, scission in polymer chain leads to crack in polymer zones that are highly crystalline. Further studies have shown that, fibres with high lignin content in biocomposite promote discolouration and photobleaching. On the other hand, addition of antioxidant additive or mineral fillers such as talc and calcium carbonate assist in minimizing colour fading. Similarly, ultra violet (UV) stabilizers like zinc oxide, hindered amine light stabilizers (HALS) and titanium oxide are incorporated in composite to retain their colour and durability under long weathering effect [59,61]. The degradation of composite can be studied either by natural weathering or by artificial accelerated weathering. The later simulates the real natural weathering process. Azwa et al. [25] illustrates the UV degradation of natural fibre/polymer composite as presented in Fig. 2.

### 8.1 Thermal Degradation of Natural Fibre Polymer Composite

The thermal degradation of polymer composite in the presence of flame goes through 5 critical stages: heating, decomposition, ignition, combustion and propagation [25,62]. Since the operating temperature of most thermoplastics exceeds 200°C, as such, there is need to have a good understanding of the thermal properties of the reinforcing fillers or fibres before they are used as reinforcement in polymer composites [63]. Natural fibre polymer composite softens, buckles and deforms over time at temperatures of 100- 200°C, and decomposes at temperatures of 300-500°C when heated, will release smoke and toxic gases [25,64]. Generally, when polymer are exposed to high temperature heat, they produce volatile particles in form of smoke or soot, combustible and noncombustible liquid

and solid char, leaving behind a distorted shaped polymer material after reaching its melting temperature ( $T_m$ ). It is of great concern to note that, the liquid portion of the polymer that drops during burning can further fuel other sources of ignition [25,65]. Polymers like polyvinyl chloride (PVC) possess an inherent extinguishing property, though it produces gases that are irritable and toxic under high heat. Low or high density polyethylene and polyolefins which easily support combustion process through dripping of melted components can be improved by reinforcing them with natural fibre [25,66].

On the other hand, the chemical composition of natural fibres greatly influences their resistance. Dittenber and Ganagarao [26] alongside Suardana et al. [67] observed that high lignin content in natural fibre result in higher char formation, while high cellulose content leads to higher flammability. Hyas et al. [63] also asserts that high lignin content confers greater degree of thermal stability to wood fibre, while Muasher and Sain [61] opined that free radicals such as hydroperoxy, carboxylic acids and quinones are formed when the lignin component in natural fibres, absorbs ultra violet (UV) light. This will lead to yellow colouration in wood polymer composite due to photodegradation. Kader and

Mohammed [68], La Mantia and Morreale [69] and Fabiyi and McDonald [70] also observed that cellulose degrade gradually, due to their stability depending on the type and nature of the wood.

## 8.2 Biodegradability of Natural Fibre and Polymer Composite

Biodegradability is a natural process by which materials like natural fibre and polymer composite are degraded or broken by microorganism such as bacteria. Water retting and soil retting of natural fibre are employed in some cases to initiate separation of fibre bundles through partial biodegradation. Hanninen et al. [71] observed that over 50% of jute composite degrades naturally after 4 years of being covered up in the soil. Futhermore, the adoption and use of biopolymer for domestic and commercial is steadily gaining acceptability in order to gradually phase-out the use of thermosets and thermoplastics which pollutes the environment, and takes not less than 20 – 500 years to degrade, depending on the plastic polymeric material [78]. Examples of biopolymers from renewable sources are polylactide (PLA), cellulosic plastics, polyhydroxy alkanooates (PHAs) and starch plastics [72,73].

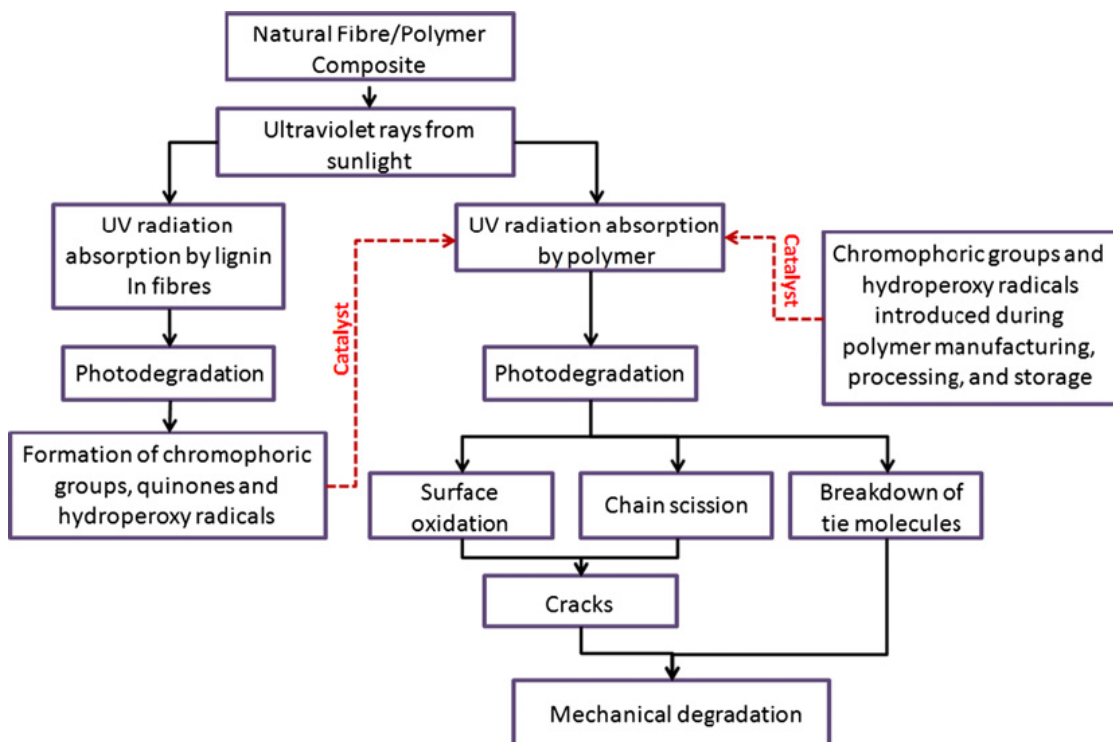


Fig. 2. UV Degradation of Natural fibre/Polymer Composite and its components [25]



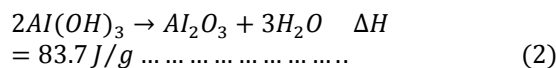
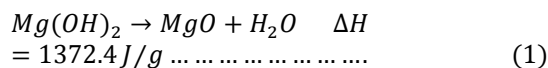
## 9. STRENGTHENING THE RESISTANCE OF NATURAL FIBRE COMPOSITE

The need to strengthen the thermal resistance capacity of natural fibre composite is of great necessity. This will enable them to function well under heat and fire attack.

### 9.1 Thermal and Fire Resistance of Polymer Composites

Aside moisture and UV effect, one other critical property requirement for the application of natural fibre composite in structural and building purposes, is its ability to resist flame and heat. This is why it is important to understand how resistive natural fibre polymer composites can be when exposed to fire, and how its properties can be improved in this area for safety purposes [23,25].

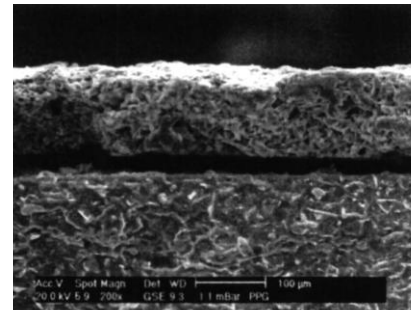
Compounds like magnesium hydroxide, aluminium hydroxide, ammonium polyphosphate and expanded graphite (EG) are good flame retarding materials with some appreciable degree of thermal stability. Though, magnesium hydroxide exhibit a higher thermal stability compared to aluminium hydroxide [23,62,65,74]. The equation and enthalpy of dissociation for  $Mg(OH)_2$  and  $Al(OH)_3$  are given in equation 1 and 2.



Also fibre ash and silica with high crystallinity from burnt natural fibre and coal when used as fillers in composite help to impact thermal resistance. Similarly, synthetic composites whose matrices are phenolic-based are excellent flame retarding materials, as they are known to have high oxygen index, low flame spread, less smoke, low heat release rate and high delay in ignition during thermal degradation [26]. Some other fire resisting materials and methods which can be incorporated or used as coating are intumescent, ceramics, glass mat, ablatives, phenolics, silicone and chemical additives [26]. Also natural fibres can be treated chemically to improve their thermal stability.

Interestingly, intumescent are passive fire protecting materials that swell when in contact with fire in order to protect the underlying composite material. Different compounds, materials, methods and procedures are employed to improve the thermal resistive

properties of natural fibre polymer composite (NFPC), thereby acting as a barricade to flame and fire propagation [23]. The scanning electron microscopic picture of the interface between the intumescent coating and the substrate for untreated polypropylene composite is presented by Duquesne et al. [75] in Fig. 3.



**Fig. 3. Scanning electron microscopic picture of the interface between the intumescent coating and the substrate for untreated polypropylene composite [75]**

There are two types of intumescent based on the nature of char formation. Namely- soft and hard char intumescent. Char formation help to build a protective core around composite, thereby preserving their structural integrity.

Soft char intumescent forms a light char derived from the chemical reaction of melamine, pentaerythritol and ammonium polyphosphate in the presence of a molten binding matrix such as styrene acrylates or vinyl acetate. Another form of soft char intumescent generally known as ablative coating has a substantial amount of hydrates which when heated decomposes to release water vapour, after which a cooling effect is experienced on the coated composite through the formation of a light char, having the nature of a microporous carbonaceous foam. This help to minimize the heat transfer process on a material from one point to another. On the other hand, hard char intumescent produces reasonable amount of char compared to the formal, having the capacity to exert substantial expansion pressure. This type of intumescent can be formed from graphite and sodium silicate, and is suitable for exterior or outdoor purposes like in plastic pipe [23].

## 10. CONCLUSION

The future of hybrid polymer composites holds unlimited possibilities, benefits and applications. This is because of the inherent unique property

and behaviour of the abundant natural materials in the world, not to talk of synthetic materials. To this effect, intense research work is been engaged and deployed in the modeling and fabrication of simple and complex customized polymer composite geometries, with high precision computer aided software. On the other hand, the study of the degradation process and life span of polymer composites is also of great interest and concern to researchers, as this will help in classifying polymer composites for indoor and outdoor applications, based on their resistance to environmental and weathering conditions.

## 11. THE WAY FORWARD

Since research is dynamic, particularly with endless possibilities and outcomes in the field of composite, there exist lot of gray and fallow areas that can be explored ranging from abundant natural materials, material modification, methodology and application. At discrete level, great volume of research is ongoing in the field of composite. The need for harmonious coordinated research collaboration amongst professionals from diverse fields is of necessity, if substantial unprecedented outcome and theories must be recorded in this field of research. Similarly, strong collaboration amongst industries, consumers, and academics must be established. Furthermore, the involvement of international organization in establishing research clusters with specific objectives and terms of references will go a long way in promoting quality research in the field of composite.

Since the idea behind “contribution to knowledge” in research is hinged either on choice of raw material, processing technology or area of application, it is paramount for research centres in each country to take advantage of the unique available raw materials, technology and application domiciled in their country, with the primary purpose of maximizing and processing the unique property of these materials, into reinforcing smart materials or matrices for composite products with suitable application.

It is obvious that the future of technology is artificial intelligence (AI). In line with this reality, there is need to also adopt and deploy AI in the production of hybrid polymer composite. This will assist in the choice and modification of natural fibre/matrices into “smart” materials such as Nitinol which changes its phase with temperature prompting movement. To be more specific, smart materials are intelligent multifunctional reactive unique kind of materials whose property and

responses can be controlled or temporarily altered as a result of changes in environmental factors such as pressure, moisture, temperature, stress, magnetic or electric field, light, pH and touch. Examples of smart materials are electroactive polymer (EAPs) and sensor. Others are camellion roofing sheet composite made from nano material which changes colour with temperature. Presently, bioplastic is gradually replacing petrochemical polymer due to its low CO<sub>2</sub> emission and renewability, though, its production is cost intensive.

Furthermore, AI can be deployed in the identification of defects and uneven distribution of filler/fibre in a polymer composite. This of course is critical to the durability and lifespan of HPC. In the failure analysis of structures in the construction industry, AI can also be used to predict the likely location or points where and when deflection and failure could occur due stress/load along the span of a building. Similarly, intense research work through the use of AI should also be engaged and deployed in the modeling and fabrication of simple and complex customized polymer composite geometries, in 3-dimensional print, with high precision computer aided software design.

All of these suggestions are aimed at improving the durability and lifespan of polymer composites. Some key areas where composites find concrete and enormous application are in the construction, automobile, electronics and medical industry.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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