Characteristics of Palm Kernel Shell and Palm Kernel Shell-Polymer Composites: A Review

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Abstract- The peculiar characteristics of Palm Kernel Shell (PKS) may have corresponding effects on polymer mono composites and hybrid composites when used as filler in polymer matrices. This review paper relates Palm Kernel Shell (PKS), palm kernel shell-mono composites, and palm kernel shell hybrid composites in terms of identification, sampling, and analysis. The purpose was to establish the properties of palm kernel shells and their composites as documented by various researchers in a one-stop-shop document for use by current and future researchers. The accidental and judgmental sampling procedures were employed to sample documents that relate palm kernel shells and polymers. The study revealed that lignocellulos palm kernel shell properties, including lignin, cellulose, and hemicellulose might vary depending on the geographic location of the plant from which the shell is derived. Similarly, the mineral content of PKS, such as carbon, iron, Aluminum, potassium, silicon, phosphorus, oxygen, and cesium, among others, were found to vary. Other properties identified include solid density, porosity, specific gravity, specific heat capacity, moisture content, and angle of repose. The paper also observed that using PKS as a filler material in polymer composites could modify the properties of the filler and hence PKS/polymer composites. The paper concludes that PKS may be a good filler material when used in the development of PKS/oil palm mesocarp/polyethylene hybrid composites. Chemical treatment of the PKS particles may further enhance the characteristics of the evolved hybrid composite material.

Keywords: Composite materials, materials technology, palm kernel shell, polyethylene, polymer composites

1. Introduction

The lignocellular characteristics of Palm Kernel Shell (PKS), commonly referred to as Oil Palm Shell (OPS) or Oil Palm Kernel Shell (OPKS), as biogenic organic waste has been well established in the literature [1]. These characteristics have accustomed to the material the benefit of being used as a raw material for the development of composite materials, among others. For example, PKS may be used in the manufacturing of concrete as reinforcement [2]: fuel generation medium [3], cement production [4]; cutting tool development [5] and plastic polymer composite development [6]. Palm kernel shell is a waste product obtained after the processing of palm kernel. Palm kernel is enclosed in the shell. The shell is also enclosed in fleshy fiber, which contains palm oil. Thus palm kernel shell is obtained when the fibrous, fleshy fruit has been processed to obtain palm oil. Nevertheless, the shell can be obtained by
removing the fleshy fiber with the sole aim of reaching the shell without interest in the palm oil. By cracking the shell to get palm kernel nut, the shell is thus obtained. Various researchers have examined the properties of palm kernel shells to identify the suitability of the biomaterial in multiple applications. These interesting properties include porosity, moisture content, lignin content cellulose, and Nanocellulose fractions, solid density, and carbon content, among others [1]. One particular area which has found the application of PKS currently of intense interest is the plastic composite development studies. As a filler, PKS may modify and enhance particular desired properties [7] and reduce cost since they are waste material and, therefore, cheaply obtained [5]. Being a natural fiber, PKS have relatively low density, is environmentally friendly through quick and total degradation, abundant and therefore readily available [8].

In plastic composite development studies, PKS may be employed in mono-composite or hybrid composite manufacturing. Though few studies abound in these avenues of research, the addition of PKS in complete bio hybridization-plastic composite has been quite scanty [6, 9]. In the area of recycled sachet water polyethylene and vegetal oil palm mesocarp fiber (OPMF) and palm kernel shell (PKS) biogenic hybrid composite, it appears no studies have been carried out. Composites may be of intimately mingled or alternate layered type. In this work, the former technique has been investigated.

Generally, hybrid composites have full applications in engineering where the benefits of ease in manufacturing, strength-to-weight ratio, and low cost are required. Hybridization ensures joint properties, including impact strength, tensile strength, and compressive modulus, among others, which may be absent in mono-composite materials. Thus, hybrid materials are usually employed in designs where combinations of different fiber properties need to be used. Through innovative applications, hybrid composites have been of intense interest to researchers from antiquity. Recent studies have proved hybrid composites to be very efficient and of high-performance structural materials. The application of hybrid materials has also been fast increasing. For instance, hybrid material research has been deployed in the telecom industry, civil construction, marine applications, wind power generation, aeronautical applications, smart memory composites, and thermoplastic applications [10, 11]. This review paper relates to the latter, thermoplastic applications. It appears that the literature on palm kernel shell-thermoplastic hybrid composites is limited, though the research on other combination thermoplastic may abound. The paper presents a review of the palm kernel shell as a mono composite and hybrid composite filler material in plastic polymer materials technology. The objective is to identify the properties of palm kernel shell and its effects on the polymer matrix. And also to identify the type of plastic materials employed, assess the characteristics of developed composites; examine the various prospective applications of developed composites. As well as suggest leads to new research avenues to future researchers in plastic materials technology.

2. Characteristics of palm kernel shell
The oil palm fruit edible seed is described as a palm kernel. Palm fruit produces two types of oils that have different characteristics. The first of the oils, palm oil is obtained from the fibrous, fleshy outer part of the fruit: and palm kernel oil obtained from the edible kernel [12]. Palm kernel shell is the outermost part of the seed and therefore acts as a protector to the seed. The shell needs to be cracked before the edible part is released. The oil palm is believed to be originated from West Africa within the tropical rain forest of the continent. The Oil Palm (Elaeis guineensis) belt includes countries that lie within the equatorial belt, and these include Ghana, Nigeria, Togo, Cameroon, Cote d’Ivoire, Liberia, Sierra Leone, Congo, and Angola,
through Congo and Angola are in Central Africa. The shell is, therefore, a by-product of the production of palm kernel oil and palm oil from the seed of the palm tree. It is thick and brown/black wood-like in structure [13].

The process of obtaining palm kernel shell, which begins with the oil palm plant cultivation is well documented [14 -16]. It takes two to three years of new seedlings to mature into productive trees. The fruit bunch is directly attached to the grown tree with the fruits, also attached to spikes and spikelets which are connected to the stem of the bunch. By separating the spikes and spikelets from the bunch, the fruits could then be removed. Between 20 and 30 years, the fruit usually cultivated in small to large scale plantations are harvested. During the process, many waste products are generated. The empty fruit bunch, waste mesocarp fiber, and palm oil mill effluent, which may be applied as insecticide and pesticide, are some of the by-products of the seed production process. Before the seed is obtained, the hard stony shells need to be crushed into various shapes and sizes [14]. The shells may be of the “Dura” or “Tenera” type. Though Tenera has been designed as a hybrid breed to yield higher oil content, it has thinner shells. It is a hybrid of Dura (mother which has shells) and pisifera (father without shells). Dura has thicker shells, while pisifera has no shells [15, 16]. Oil palm fiber, empty fruit bunch (OPEB), and mesocarp fiber and PKS shells have several uses. The fibers may be used for weaving baskets and thermal energy generation. Palm kernel shells may be used for fuel heat generation, carbon activation for purifying water, concrete reinforcement in the building and construction industry, thermal insulation, and as filler in plastic composite manufacturing [1, 7].

Though West Africa is believed to be the roots of the oil palm tree, the plant is growing well in many tropical regions. By 2009, Indonesia was leading in the production of palm oil, followed by Malaysia and Nigeria in that order. Between 1994 and 2004, global production increased by more than 400%, reaching 8.66 million metric tons [17]. As of 2013, Malaysia was the largest producer and exporter of palm oil and PKS to Asian countries; China, and Singapore the largest importer of PKS; and Europe, followed by Ukraine. In the Middle East, Egypt is the largest import from Malaysia, followed by Qatar. Tanzania is the largest importer of PKS from Malaysia, with Benin and Algeria being the second and third respectively in Africa. Imports of PKS from Malaysia to North America and Oceania countries are also sizeable. For example, Mexico comes first with over half a million tons while Australia, Papua New Guinea, and New Caledonia import 11251.37t; 81.13t; and 18.81t, respectively [18].

Though vegetable fiber such as rice husk, bagasse, coconut shell fiber, groundnut shell, etc., have been utilized as filler in polymer composite development, the extensive and widespread production of PKS and consequential importation and exportation markets demands a particular interest in the areas of research concerning the commodity. In West Africa in general and Ghana in particular extensive utilization of the product appears to be relatively nonexistent: the first step is to investigate the properties and characteristics of the product to identify its possible applications in general and plastic materials technology in particular. Table 1 shows the properties of PKS, as determined by various researchers.
### Table 1: Properties of oil palm kernel shell

| Author(s)                                                                 | Property                                      | Values                  |
|--------------------------------------------------------------------------|-----------------------------------------------|-------------------------|
| Faudi et al. [8] (Textural characteristics, proximate and ultimate analyses of PKS) | Micropore surface area (m²g⁻¹)                | 0.20                    |
|                                                                          | Apparent density (gcm⁻³)                      | 1.47                    |
|                                                                          | Solid density (gcm⁻³)                         | 1.53                    |
|                                                                          | BET Surface area (m²g⁻¹)                      | 1.60                    |
|                                                                          | Porosity (%)                                  | 3.90                    |
|                                                                          | Lignin (%)                                    | 53.40                   |
|                                                                          | Cellulose (%)                                 | 29.70                   |
|                                                                          | Hemicellulose (%)                             | 47.70                   |
|                                                                          | Ash (%)                                       | 1.10                    |
|                                                                          | Volatile (%)                                  | 0.10                    |
|                                                                          | Moisture (%)                                  | 7.96                    |
|                                                                          | Carbon (%)                                    | 18.70                   |
| Fono-Tamo et al. [21] (Physicothermal properties of PKS)                 | Specific heat capacity (KJkg⁻¹K)              | 1.983 ± 0.01            |
|                                                                          | Specific gravity                              | 1.26 ± 17.4             |
|                                                                          | Bulk density (kgm⁻³)                          | 0.68 ± 0.05             |
|                                                                          | Thermal conductivity (w/mk phase change)      | 101.4 ± 0               |
| Okoroigwe et al., [34] (Bulk physical and chemical Characteristics of PKS) | Porosity (%)                                  | 28.00                   |
|                                                                          | Ash content (%)                               | 8.68                    |
|                                                                          | Moisture content (%)                          | 6.11                    |
|                                                                          | Bulk density (kgm⁻³)                          | 740.00                  |
|                                                                          | Lignin (%)                                    | 53.85                   |
|                                                                          | Cellulose (%)                                 | 6.92                    |
|                                                                          | Hemicellulose (%)                             | 26.116                  |
| Ikumapay&Akinlabi, [1] (Elemental composition of PKS at 20min (100cm)     | Carbon (w%)                                   | 60.70                   |
|                                                                          | Oxygen (w%)                                   | 38.00                   |
|                                                                          | Silicon (wt%)                                 | 1.00                    |
|                                                                          | Aluminium (wt%)                               | 0.10                    |
|                                                                          | Iron (wt%)                                    | not determined          |
|                                                                          | Ceasium (wt%)                                 | 0.10                    |
|                                                                          | Potassium (wt%)                               | 0.10                    |
| Dagwa et al. [32] (the elemental composition of PKS at 15min (150amplitude) | Carbon (wt %)                                 | 63.02                   |
|                                                                          | Oxygen (wt%)                                  | 36.04                   |
|                                                                          | Aluminium (wt%)                               | 0.43                    |
|                                                                          | Silicon (wt)                                  | 0.17                    |
|                                                                          | Phosphorous (wt%)                             | 0.17                    |
|                                                                          | Potassium (wt%)                               | 0.17                    |
|                                                                          | PH of PKS                                     | 4.41 ± 0.08             |
| Yacob et al. [33] (Elemental composition of PKS)                          | Carbon (wt%)                                  | 46.18                   |
|                                                                          | Oxygen (wt%)                                  | 45.08                   |
|                                                                          | Aluminium (wt%)                               | 3.47                    |
|                                                                          | Silicon (wt%)                                 | 5.25                    |
Table 1 shows that PKS mainly consist of carbon, oxygen, silicon, aluminium, iron potassium, and calcium and copper. PKS/ash may be used in energy generation, as a water purifier, like activated carbon and reinforcement product of metals, ceramics, and polymer developments as well as friction stir welding and processing. In whichever application of PKS/ash, the characteristic behaviour of the product depends on textural nature and the particular size of the particles. Thus macro-particles, micro-particles, and Nano-particles perform better in terms of effectiveness and efficiency in that order [1]. The angle of repose of PKS indicates that the material flows well and effortlessly in the pulverized state, and again the average compressibility index and Hausner ratio confirm the fair flowability of the material. This means that the smaller the particle size, the higher true density, compressibility index, powder porosity, and hydration capacity. The shape of pulverized PKS appears spherical using SEM photography, and the difference in elemental composition, as indicated in Table 1 could be attributed to the difference in PKS variety, soil type, and composition as well as the geographical location [7].
PKS ash contains a high fraction of silicon, which contributes to its high brittleness. The presence of a high percentage of iron (Fe) and aluminium (Al) is responsible for material strength. These attributes account for the material as an excellent reinforcement material for composite development and manufacturing in general, and plastic composites in particular [19]. As a lignocellular fiber, PKS has distinctive combustion characteristics through lower combustion and thermal reactivity as compared to empty fruit fiber (EFB) and oil palm mesocarp fiber (OPMF), both qualifying as fuel and energy generation source in Table 1 [20]. PKS is also a good insulator and behaves in consonance with its thermogravimetric characteristics [21].

3. Characteristics of palm kernel shell-polymer mono-composites

Lack of desired properties of conventional materials for materials technology relating polymer matrix composite manufacturing has called for the introduction of natural fiber as a fiber-reinforced material among researchers and industry players [1, 22]. In countries where agricultural activities are the mainstay of the economy, natural fiber as agricultural waste is abundant, creating environmental menace. One way by which ecological pollution can be reduced, if not curtailed, is the application of technology to convert waste into economic wealth. Fibrous agricultural waste available includes rice husk, bagasse, oil palm fiber, and oil palm shell, among others. The oil palm shell involvement as a material in Fiber Reinforced Plastics (FRP) has become prominent due to its peculiar characteristics and properties. For this reason, plastic such as polyethylene, natural rubber, polypropylene, polyvinyl alcohol, polyester, etc. have all been used as a reinforced matrix among plastic composite researchers [7, 22-26].

As a filler in High-Density Polyethylene (HDPE) composite, study results revealed a uniform dispersion of particulates and a single fiber pull out [27]. The results also revealed a marginal influence of shell on the melting and crystallization temperatures, though alkaline modification of particle surface reduced the melting and crystallization temperature. It is established that when up to an optimum 5% volume content of palm kernel shell particulates is used as filler in recycled polyethylene (RLDPE) matrix, composite hardness and tensile strength increased with shell content; and that these properties increased with decreasing particle size [6]. Scanning Electron Microscopy (SEM) of the composites also showed fair interfacial interaction between palm kernel shell particles and RLDPE composites. Treating the PKS particulates with NaOH directly impacted on the thermal properties of the composites. It was also established that increasing the loading of palm kernel shell particulates in Low-Density Polyethylene (LDPE) composites increased the tensile strength of the composite up to 10% but decreased upon further increase. Young’s modulus increased with increase in filler loading. However, elongation at break decreased with increasing filler loading. The study revealed that the tensile properties and Young’s modulus of PKS/LDPE composites enhanced with polyethylene co-acrylic acid (PEAA) as a compatibilizer but decreased in elongation at break and water absorption. Both PKS and PEAA enhanced compatibility and crystallinity of composites with improvement in interfacial adhesion and interaction.

A study by Daud et al. [7] showed enhancement in tensile strength, elongation at break, tensile modulus, cross-link density, and polymer-filler surface interaction. However, treating the palm kernel shell particulates with 3-aminopropyl trimethoxysilane (AMEO) coupling agent in palm kernel shell powder-natural rubber composites (PKS-NR). Though scorch time and cure time decreased, maximum torque increased when the silane was present as a coupling agent.
The use of a 3-aminopropyltriethoxysilane (APTES) coupling agent to modify the surface of palm kernel shell particulates also gives better tensile, flexural, and water absorption properties of palm kernel shell-polypropylene (PKS-PP) biocomposite. The coupling agent also positively influenced filler-matrix surface interactions, dispersion, and compatibility but reduced elongation at break. However, beyond 10% loading of PKS, tensile strength, and flexural strength reduced while Young’s modulus and water absorption increased continuously with increased loading [23].

A Sahari and Maleque [25] study yielded an increase of tensile strength and tensile modulus of unsaturated polyester when PKS was employed as filler. The study also yielded poor fiber pull-out, indicating unfavorable bonding at the filler-matrix interface. The study further yielded 30 vol % optimum of PKS concerning tensile strength and tensile modulus. Elongation at break enhanced with PKS content up to 20vol% while moisture content (water absorption) increased with increasing PKS content.

The effect of PKS particulates on Polyvinyl alcohol (PVA) was studied by Alias et al. [22]. PVA is a water-soluble synthetic polymer and biodegradable. Tensile strength and elongation at break reduced with an increase in PKS particulate weight content. However, tensile modulus increased up to 7:3 weight content of PVA and PKS, respectively. On the other hand, water absorption and water vapour transmission also increased as PKS loading increased. The biodegradability test indicated that PVA/PKS biocomposites degrade faster with PKS loading in terms of natural weathering and soil burial. Scanning Electron Microscope SEM micrographs showed that this behaviour of PVA/PKS composites is as a result of unfavourable adhesion between molecules and agglomeration with PKS particles as filler material. In a comparable study, the composites of palm kernel shell phosphorus alcohol (PKS/Epoxy/PVA) were characterized concerning tensile properties, impact, flexural, hardness strengths, and density. The results showed an enhancement of hardness and Young’s modulus when fiber volume fraction increased. Tensile strength was at a maximum when PKS content was 10% by volume.

Nevertheless, Young’s modulus and hardness were at minimum when fiber content was increased from 12% by volume. The study acknowledged the uniform bond between epoxy and PVA with small air spaces. The study also revealed that flexural strength dropped with the increase in epoxy content with the corresponding reduction in PVA content. The impact strength saw a significant increase when the ratio of epoxy to PVA got closer in the composites. In the characterization process, fiber volume was varied from 4 to 12 % at 2% intervals.

| Name         | Tm(°C) | Tc(°C) | ΔHf(J/g) | Xc(% crystallinity) |
|--------------|--------|--------|----------|---------------------|
| Unfilled System | 130.99 | 115.19 | 180.6582 | 196.8385            |
| EPK          | 134.39 | 117.13 | 127.4415 | 112.8431            |
| TEPK         | 133.17 | 115.95 | 105.8674 | 67.2911             |

Table 3: DSC analysis of LDPE/palm kernel shell (PKS biocomposites at different filler loading [26]

| Biocomposites | Tm(°C) | ΔHf(J/g) | Xc(% crystallinity) |
|---------------|--------|----------|---------------------|

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4. Characteristics of palm kernel shell-polymer hybrid composites

The development of hybrid biocomposites has evolved from incorporating two or more types of fillers into a single matrix [28]. The characteristic of hybrid composites is a sum of the specific fillers, the product of which combines the advantages and disadvantages of individual components. Thus by combining two or more fillers, the advantages of an individual component complement the disadvantages of the other. A balanced characteristic composite is therefore brought about, inherited from the weighted sum of the property constituents. For a hybrid composite, the original properties of the separate constituents are different from the property of the emerged material. When the original features of the individual components are still present within the composite and are, therefore, unchanged, the ensuing emerged material is classified as a nanocomposite [29]. It thus, presupposes that for biofiber composites, the characteristics of the hybrid composite depend mainly on fiber content, fiber orientation, fiber length, fiber/matrix bonding. The degree of mixing of fibers and matrix; the arrangement of both fibers; and the extent of failure strain of constituent fibers [28].

Hybrid fiber composites may be made of biofiber and synthetic fiber as fillers in a matrix or a combination of two natural fibers or fibers in a matrix. The matrix may be a plastic, metal, or ceramic. One advantage of hybrid composites is that they can be tailor-made or customized to suit specific purposes. For example, a material with high modulus but favorable brittle failure can be designed. Also, a material (strut member) with high initial modulus followed by limited yielding with accompanied little likely lowered load carrying capacity, could be created. There are two different methods by which hybrid fiber-reinforced materials or composites can be developed: One, intimately mingling with fibers; and two, laminating alternate layers of each composite type [11].

The tensile strength, flexural strength, impact strength, and hardness properties of PKS-PKF-Epoxy hybrid composites were reported by Olaitan et al. [30]. The study concentrated on the effect of PKS content on the composite and their mechanical properties, as indicated at the onset. The focus was to design a material suitable for a safety helmet. Palm kernel fiber (PKF) was selected to provide optimum properties (and balanced) as filler with the epoxy matrix. Generally, the composite with 6% PKS and 4% PKF offered the highest impact strength and therefore fit for the purpose. The average impact strength was 7.27J/mm²; hardness of 6.7 HRF; tensile strength of 21.55N/mm²; and flexural strength of 34.61N/mm². The epoxy resin used was Bisphenol-A-glycidyl. As a mono-composite of PKF-Epoxy, the 10% PKF

| Author             | Property       | TS(MPa) | EB(%)        | TM(GPa) | SP(%) | ST(min) | CT(min) | MT(dNm) |
|--------------------|----------------|---------|--------------|---------|-------|---------|---------|---------|
| Daud et al. [7]    |                | 20.82   | 923.33       | 3.091   | 345.83| 2.66    | 4.88    | 8.89    |
| Sahari & Maleque [25] |              | 20.1    | 285          | 8.5     | 105   | -       | -       | -       |

Table 4: Tensile properties with silane and curing technique
combination gave the optimum mechanical properties with the impact strength of 6.62 J/mm²; hardness of 6.9 HRF; tensile strength of 26.75N/mm² and flexural strength of 31.02 N/mm².

The physical and mechanical properties of recycled polyethylene, iron fillings, and palm kernel shell hybrid composite were investigated by Samotu et al. [19] at a 5wt% constant proportion of iron fillings. The purpose was to produce a new composite material suitable for a car bumper. The most important parameter in this regard was the impact strength-density ratio, with palm kernel ash varying from 5wt% to 20wt% at a 5% interval. Though most of the mechanical properties of the composite except hardness reduced with increased carbonized palm kernel shell (CPKS) content. The composite with 5wt% CPKS and 10wt% CPKS content were found to be the most favorable, with impact energy to density ratio of 0.26 and 0.19, respectively. In contrast, impact energy-reduced with an increase in CPKS content density increased.

Palm kernel shell filled in maleated polypropylene (PKS/PP) and palm kernel shell/Nanosilica-filled maleated polypropylene (PKS/Nanosilica/PP) hybrid composites were developed and characterized as two individual sets of composites. Characterization of the composites showed PKS/Nanosilica/PP matrix yielding a composite with enhanced tensile strength, impact strength, and tensile modulus than PKS/PP mono composite. Thermal analysis (DSC) also showed an increase in crystallinity when Nanosilica was added to the PKS/PP mono composite. However, the inclusion of inorganic Nanosilica in the mono composite reduced water ingestion into the composite. Comparatively, SEM analysis showed smaller empty spaces on the surface of the hybrid composite than the PKS/PP composite, attributed to enhanced interfacial adhesion and bonding, and better wettability between PKS filler and the matrix due to large interfacial surface area of SiO2 nanoparticles [10].

Abdul-Khalil et al. [31] have looked into the physical, mechanical, and morphological behaviour of OPS and seaweed composite film. Loading of OPS nanoparticles was varied from 0%, 1%, 5%, 10%, 20% and 30%. The 20% w/w yielded the maximum tensile strength of 44.8MPa and 3.13GPa Young’s modulus. Film hydrophobicity and percentage elongation at break, however, reduced to 47.30 and 2.10%, respectively. Beyond 20% PKS, tensile strength and by the hydrophobicity of the film reduced. The result was confirmed by the SEM analysis, which showed the absence of filler aggregation and void formation in the composite when less than 20% OPS nanoparticles were added. The study concluded that OPS Nano-particles are good material as a reinforcing material to enhance biopolymer-based material properties in biofiber hybrid development. The properties of palm kernel shells have, by no small means, contributed to the characteristic behaviour of the composite material [32-34].

5. Conclusion

The study has revealed that many researchers have investigated on palm kernel shell as a composite material. One of the major areas of interest is the polymer composite development. Though studies in this area are quite limited, polymers of interest include natural rubber, polypropylene, polyvinyl alcohol, polyester, polyethylene, and epoxy. The primary elemental composition of PKS is silicon, carbon, potassium, calcium, iron, aluminium, and oxygen. Silicon, copper, and phosphorous may also be present in PKS. In minor content of the elemental constituents may include rubidium, nickel, manganese, chromium, titanium. The element type and the quantity depends on the type of plant and the geographical location of the material. The significant properties of PKS that have been characterized are density, moisture properties, surface area, and thermal properties. Concerning PKS composite
characterization properties such as tensile strength, hydrophobicity, Young’s modulus, flexural strength, hardness, natural degradation, elongation at break and impact strength have been documented. Nanoparticles of PKS/ash perform better than micro and macro-particles in terms of textural characteristics. PKS application has been found in automobile construction, particularly for vehicle bumper construction and safety components such as helmets. It may also be used in the development of cutting tools in motor vehicle component machining. In addition to its use as polymer composite material, PKS may be employed in concrete reinforcement, energy generation, and water purification. Its application with oil palm mesocarp fiber and sachet water polyethene as an avenue to deal with environmental pollution may be a new area of research in the biofiber-plastic materials technology industry.

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