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Review Article
Composition, Characteristics and Socioeconomic Benefits of Palm Kernel Shell Exploitation-An Overview

Omolayo M. Ikumapayi and Esther T. Akinlabi

Department of Mechanical Engineering Science, University of Johannesburg, Auckland Park Kingsway Campus, 2006 Johannesburg, South Africa

Abstract
Intensive research has increased the creation of new biomaterials with specific engineered properties. It is on record that a large amount of these biomaterials waste are generated by the processing of palm oil that invariably causes an environmental problem. This review study sheds light on various applications that palm kernel shell (PKS) has been used for in the recent years and applications that could also be considered in the near future. It has been reported that tropical belt of Africa, Asia and Brazil are the highest producers and exporters of palm oil across the globe and by implication the most producers of the PKS. The PKS as a biomaterial waste product got after the processing of palm oil has been extensively utilized in the various form of applications for both technical and environmental benefits varying from additive, energy production, reinforcement, aggregation, water purification and as well as a composite matrix. It was observed that great use of this waste product is prominent in the structural components, automotive parts as well as water detoxifier. The PKS-powder has been characterized in this review through the use of Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray (EDX) analysis. The milling was done with the aid of digital Vibratory disc milling machine for 0, 10, 15 and 20 min. Zero min was taken to be when it was sieved with a 300 µm ASTM standard sieve. It was established in the study that the duration of the milling affects volume, surface area, particle size, pore size distributions, micro structure and some other mechanical properties as well as the morphology of the powder. The particles size got reduced from 300 µm to average diameter of 200 nm. The variations in elemental compositions of palm kernel shell powder from as they were affected by milling. The micrographs revealed that there was a tremendous reduction in grain size from 300 µm to about 200 nm.

Key words: Biomass, palm kernel shell, reinforcement, waste product, SEM-EDX, palm oil, biomaterials, composite matrix

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Corresponding Author: Omolayo M. Ikumapayi, Department of Mechanical Engineering Science, University of Johannesburg, Auckland Park Kingsway Campus, Johannesburg, 2006, South Africa

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Palm kernel Shell (PKS) also referred to as Oil Palm Kernel Shell (OPKS) and Oil palm Shell (OPS) in literature are highly lignocellulosic biogenic waste generated from the processing of crude palm oil[1]. This is the shell parts that remained after the nut has been removed and after crushing in the palm oil mill and is obtained as residual waste in the extraction of the kernel from the nut. Oil palm is cultivated in plantations of about two to three decades rotational farming followed by removal and replanting[2,3]. Its moisture content is low which has been reported to range between 11-13%. In the year 2001 alone the estimated value of 3.06 million metric tons was produced by Indonesia and Malaysia. The PKS is the hard part that enclosed the nut of palm kernel fruit (Fig. 1) that houses the palm kernel seed of the palm tree (Elaeis guineensis)[4]. The PKS can be obtained by crushing into sections then separating to remove the palm seed during the processing of palm kernel oil. During the process of removing or extracting ripe, fleshy and fresh fruit from the bunches at the mills, residues and waste are generated in form of solid and liquid. These residues and waste include fibres, empty fruit bunches (EFB), shells and liquid waste in form of sewage (palm oil mill effluent (POME)) with several uses, these include prevention of the fibres from insect and pest attack, also in weaving baskets and most especially for domestic use as a means of energy generation during cooking. The PKS has proven to be the first choice of biomass waste after which EFB pellet, followed by the wood chip, then sawdust pellet, shredded EFB[5,6]. Researchers have established that the palm kernel shell has estimated value of about 34.5% of a single ripe, fresh fruit[7,8]. From the estimated value of 34.5% PKS from a single fruit, one can see that the disposal of these biomass waste will continue to pose major environmental problems[9]. Figure 1a and b showed the palm kernel fruits and the Palm Kernel Shell, respectively and Fig. 1c shown the pulverized PKS.

REVIEW PALM KERNEL SHELL

Palm kernel shell (PKS): The Agro-waste (PKS) was obtained locally as shown in Fig. 1b and pulverized into powder as shown in Fig. 1c and this was then characterized using SEM-EDX.

Vibratory disc milling machine (VDMM): Milling operation was performed using a digitalized vibratory disc milling

Fig. 1(a-c): (a) Palm kernel fruits, (b) Palm kernel shell and (c) Pulverised PKS

Table 1: Vibratory disc milling machine specification

Property	Specification
Dimension	740×740×950 mm
Number of bowls	2
Capacity per bowl	200 g
Feed size	< 15mm
Motor	380V/50 Hz, 1.5 KW
Motor speed	940 rpm

Table 2: Variable in elemental composition as analyzed by EDXS

			Elemental composition at different milling times			
	Element (%)	0 min (1 mm)	0 min (100 µm)	10 min (100 µm)	15 min (100 µm)	20 min (100 µm)
PKS-P	C	64.4	61.7	62.4	62.8	60.7
	O	34.1	37.4	36.9	36.6	38.0
	Si	0.9	0.4	0.6	0.4	1.0
	Al	0.2	0.1	0.1	0.1	0.1
	Fe	0.2	0.2	nd	nd	nd
	Ca	0.1	0.3	nd	0.1	0.1
	K	0.1	nd	nd	nd	0.1

nd: Not detected

machine (Model 2MZ-200). The milling was carried out for 5, 10 and 20 min by charging 40 g of the powder sample into each bowl. The machine has specification as presented in Table 1.

Scanning electron microscope (SEM): The SEM and EDX were coupled together which was used to determine micro structures of the samples which revealed its morphology, composition and particle surface crystallography information. The SEM-EDX analyses were conducted at the University of Johannesburg, South Africa (A TESCAN model, type VEGA 3 LMH). The micrographs of different milling time are presented in Fig. 2.

Energy dispersive x-ray spectroscopy (EDXS): The elemental composition of both milled and unmilled palm kernel shell powders were analyzed by the use of SEM-EDX machine. The variation in the trend of the composition of each element present was monitored at different milling time. Table 2 showed the results of the EDXS when compare at different milling time.

Properties of PKS: The PKS has unique properties that made it useful for different applications. Different researchers have carried out different findings on the properties of PKS and to know the best suitable applications. The textural characteristic, proximate and ultimate analysis of PKS have been presented in Table 3, 4 and 5.

Thermal properties: Table 4 presented the summary of physico-thermal properties of the pulverized palm kernel shell[11].

Table 3: Textural characteristics, proximate and ultimate analyses of PKS[10]

Properties	Values
Micropore surface area ($m^2\ g^{-1}$)	0.20
Apparent density ($g\ cm^{-3}$)	1.47
Solid density ($g\ cm^{-3}$)	1.53
BET surface area ($m^2\ g^{-1}$)	1.60
Porosity (%)	3.90
Proximate analysis (wt, %)	
Ash	1.10
Volatile	0.10
Moisture	7.96
Carbon	18.70
Structural analysis (wt, %)	
Lignin	53.40
Cellulose	29.70
Halocellulose	47.70

VARIOUS APPLICATIONS OF PKS

PKS has been used extensively in the various application which has been categorized into three sections based on their usage.

PKS as concrete reinforcement, aggregate and additive: This aspect of review centred on the use of PKS as an aggregate as well as an alternative substitute as shown in Table 6, this encompasses using Palm kernel Shell Concrete (PKSC) as Low Weight Concretes (LWC)[13-16]. It was concluded that the uniform distribution of PKS particle is the significant factor that responsible for the improvement in strength and it enhances the improvement of wear property of the recycled polyethylene matrix composite[17,18], this assertion was also in agreement with the studies carried out by the following researchers[19-21]. Nevertheless, its utilization has spanned to concrete reinforcement especially in the construction industry, this usage has been modernized and modified with other

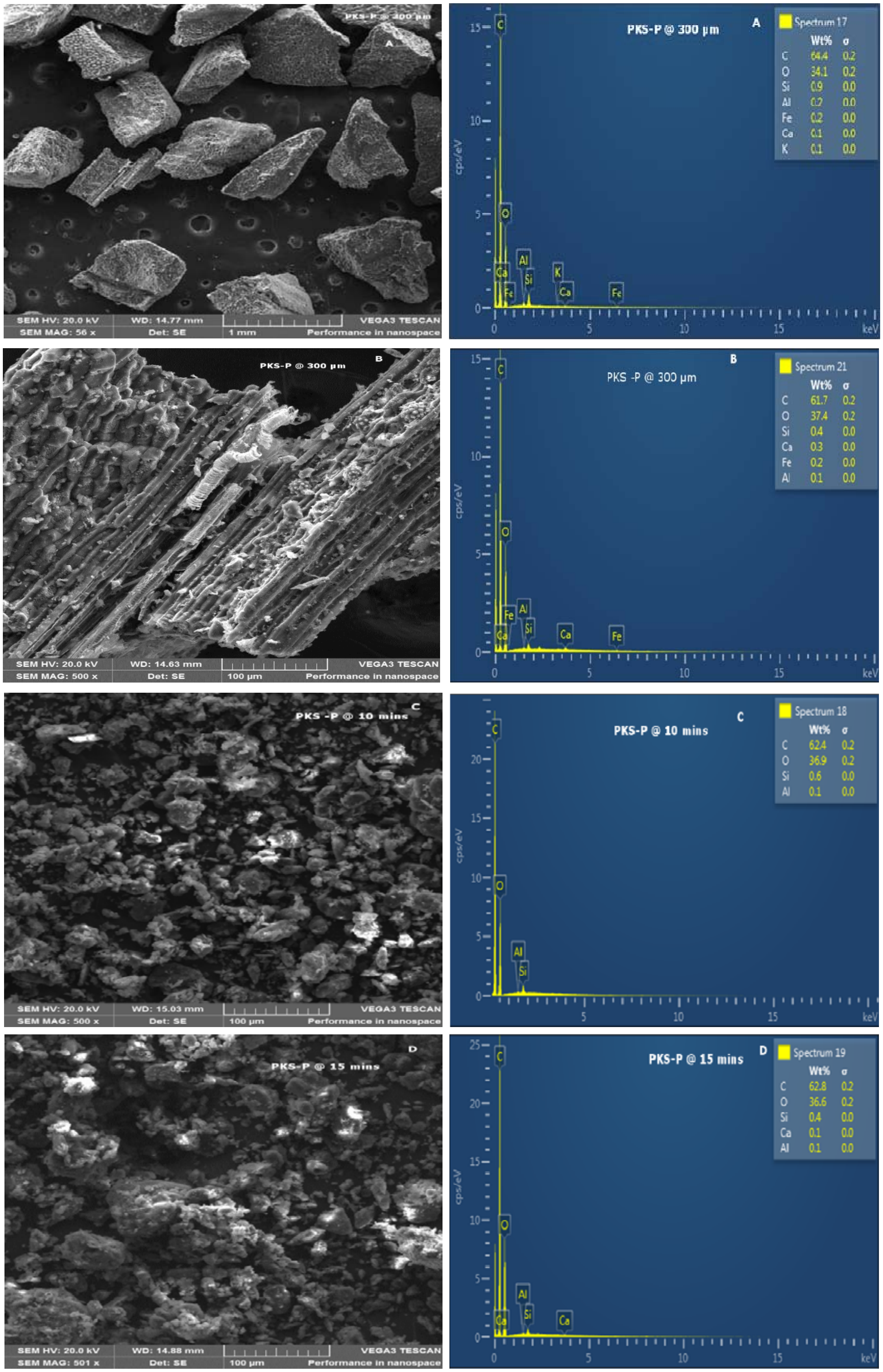

Fig. 2: Continue

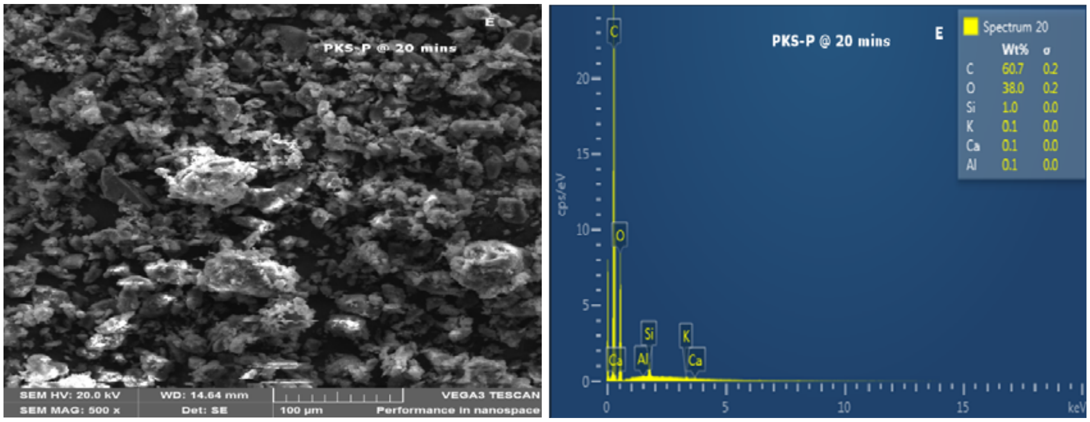

Fig. 2: SEM Micrographs of palm kernel shell powder (PKS-Ps) at 500x SEM MAG at different milling time of 0, 10, 15 and 20 min. The EDX that shows elemental compositions at different milling time is placed side by side with the micrographs

Table 4: Physico-thermal properties of pulverised PKS[11]

Properties	PKS particles
Specific heat (KJ kg^{-1} K)	1.983±0.01
Specific gravity	1.26±0.07
Bulk density (kg m^{-3})	560±17.4
Thermal conductivity (W/m K)	0.68±0.05
Phase change (°C)	101.4

Data are presented in Mean±SD

Table 5: Bulk physical and chemical characteristics of palm kernel shell[12]

Property	Parameters	Values	
		Ar	db
Physical	Porosity (%)	28.00	650
	Ash content (%)	8.68	-
	Moisture content (%)	6.11	-
	Bulk density (kg m^{-3})	740.00	9.24
Structural	Hemicellulose (%)	26.16	
Carbohydrates	Lignin (%)	53.85	
	Cellulose (%)	6.92	

Ar: As Received and db: Dry basis)

additives like the production of admixture with Portland cement to produce better concrete or purely PKS concrete[22,23].

PKS as water purification: This aspect of review centred on the use of Palm kernel shell as Activated Carbon (AC) in the treatment of water to remove pollutants as shown in Table 7. Various authors have worked on different methods varying from proximate analysis, elemental analysis, solid and apparent densities analysis, lignocellulosic content analysis, BET surface, Microphoto, Functional groups, textural characteristics, surface chemistry and composition of AC in order to remove impurities in the body of water to be treated using AC from PKS[38,39]. These impurities come in form of lead ions, copper ions, Hexavalent chromium, nickel, dyes such as Basic Blue 9 and Methylene Blue and other pollutants such as Phenol, 4-chrologuaiacol (4CG), 2, 4, 6-tricholorophenol (TCP) and iodine[40,41].

PKS as energy/fuel production: Palm kernel shell which generated renewable energy has been receiving great attentions nowadays as a means to meet energy demand[6,44]. Palm kernel shell has been recognized as biomass product as a result of its small size and high calorific or heat energy value as summarised in Table 8. After the processing of oil palm fruit, PKS will be separated and kernel oil will then undergo further distilled process[45]. It has been established that PKS has made debut entrance into biofuel resource for t he production of biomass product. Europe, Japan and Korea have established that PKS as renewable energy conform to country energy regulation[46,47]. The PKS has been characterized for its awesome utilization in the generation of bio-energy and also in its great potential feedstock for biochar, bio-oil as well as biogas production[48,49]. Figure 3 showed different ways in which biomass waste product can be converted to renewable energy[50,51].

To further buttress on the usefulness of PKS, the world renowned country for the exporter of PKS will be used for market trend. Malaysia which was renowned for oil palm agriculture in the world and is presently the world's largest exporter of palm oil and as such has been presented as case study for PKS markets[37,61-64]. It was on record as shown in Fig. 4 that exportation quantity of PKS markets from Malaysia to other foreign countries as at year 2013 was a great

Table 6: Summary of the present study on PKS as concrete reinforcement, aggregate and additive

References	Focus	Contribution(s)/conclusion(s)
Alengaram *et al.*[1]	Comparison between OPKSC and NWC with regards to strength, bond and fracture ability	It was concluded that OPKS and cement matrix has proven to be weaker in terms of bonding compared crushed granite and cement matrix. It was also established that 10% increase of silica fume further improved the sum total of OPKSC mechanical properties
Afolalu *et al.*[2]	HSS cutting tools were carburized at different temperatures of 800,850,900 and 950°C with holding time of 60, 90 and 120 min, respectively	It was found from the experiment carried out that cutting tool carburized at holding temperature and time of 800°C and 90 min has the lowest cutting weight loss, volume and wear rate of 0.002 g, 0.00026 cm^3 and 5.476×10-10 cm^2 with maximum wear resistance of 1.83×109
Yusuf and Jimoh[4]	PKS has been used for road concrete construction	The authors concluded from their findings that it is cheaper to use PKS concrete for all levels of traffic road construction than using asphaltic and normal concretes
Fono-Tamo *et al.*[11]	Production of PKS based particle boards which were compounded with other additives like sawdust was the focal point	It was established that Standard particle boards were manufactured by the admixture of PKS and sawdust as a base material
Alengaram *et al.*[13]	Comparison of Normal Weight Concrete (NWC) with the structural behavior of Palm Kernel Shell Concrete (PKSC)	(1) It was established that the beam of PKSC was higher than NWC in terms of moment capacity (2) With testing for failure mode, PKSC beam proved ductile while NWC beam proved brittle (3) As a result of ductility of PKSC beam under constant load, the deflection in the PKSC beam was higher than that of NWC beam which was brittle and prone to failure without prior warning
Alengaram *et al.*[14]	Different seizes of PKS have been used with other aggregates to produce concrete	(1) It was concluded that the smaller size gave higher density while the larger size of PKS gave higher toughness (2) It was also affirmed that a mixture of different aggregates produced higher compressive strength
Ibhadode and Dagwa[24]	Using PKS to develop asbestos-free friction lining	(1) Manufacturing parameters and optimal friction materials were achieved by the use of taguchi optimization technique (2) It was established that PKS is a good substitute for asbestos
Osei[25]	Replacing concrete made of Poland cement and crushed granite with concrete made of pozzolana and PKS	(1) It was concluded that PKS and Pozzolana can potentially be used as an alternative replacement of Portland cement and crushed granite respectively to produce cheaper lightweight concrete (2) Pozzolana and PKS exhibited similar influences on the density and work ability of concrete both of which reduced as the pozzolana and PKS contents increased
Mahmud *et al.*[26]	Varying sand content and incorporate mineral admixtures to improve mechanical properties of PKSC	The results of this study confirmed that appropriate mixture of sand to cement in ratio 1:6 together with mineral admixtures have awesome effects on the mechanical properties as against previous studies
Olanipekun *et al.*[27]	Analysis of cost and strength characteristics of concrete produced with crushed PKS and granular coconut Shell as alternative means for conventional coarse aggregate	It was concluded that coconut shell concrete has higher compressive strength than palm kernel shell concrete of the same proportion. Also, it was established that coconut shell concrete produced has a cost reduction of 30% while palm kernel shell concrete has about 42% cost reduction
Oyedepo *et al.*[28]	The study used 20% each of CSA and PKSA for reinforcement in cement and compare their compressive strength after 28 days	This research has shown that PKSA and CSA can be used as an alternative replacement for cement concrete which will reduce production cost as well as environmental pollution caused by PKS and also enhance the reduction in the use of cement as concretes
Ekwueme *et al.*[29]	Carbonization of PKS at various temperatures at times interval was the area of focus. The carbonized PKS was then sieved through 100 and 150 µm mesh	(1) It was concluded that the smaller the filler particle size the better the reinforcement, this was as a result gotten where 100 µm performs better than 150 µm during reinforcement of natural rubber (2) There should be moderation in the carbonization temperature. The optimum carbonization temperature was gotten to be 600°C
Afolalu *et al.*[30]	HSS cutting tools were subjected to different mechanical tests such as impact, toughness for both carburized and un-carburized samples	(1) It was concluded that cutting tool carburized with PKS has higher impact/toughness value of 24J as against the control sample with 17J (2) Impact strength was progressively increased with increase in carburizing temperature and holding time which enhances improvement in impact strength of the carburized tool over the un-carburized sample
Khankhaje *et al.*[31]	A comparative study on the effect of using two different sizes of oil palm kernel shell (OPKS) and cockleshell (CS) to serve as an alternative replacement for the natural coarse aggregate to improve the properties of pervious concrete pavement	It was concluded that pervious concrete containing CS showed better properties than those of incorporating OPKS Apart from that, strong relationships between density, void content, permeability, compressive strength values indicated that they can be used as a pervious concrete quality control tests for prediction of properties of pervious concrete pavement before placement in the field
Muntohar and Rahman[32]	Oil Palm kernel shell was used to produce shell crete block	This research revealed that the compressive and flexural strength of the shell crete reduced by the increment in the amount of PKS in the mixture. It was also showed that a Large amount of PKS content in the shellcrete absorbed water easily and subsequently lower its density
Adebayo[33]	The focus was to compare the effects of PKS in lattice blocks and Concrete with reference to crushed stone aggregate	The results revealed that laterite blocks reinforced with pulverized PKS at the optimum ratio of (1:4) (PKS: Laterite) were 15% stronger than ordinary plain laterite blocks. It was further revealed that crushed stone aggregate with PKS to form concrete blocks lower in strength by about 50%. It was therefore, concluded that PKS cannot be used as a replacement for crushed stone aggregates in concrete.
Nwaobakata and Agunwamba[34]	The focus here is on the use of palm kernel ash (PKA) as filler during hot asphalt mixing	The results revealed that PKA has improved and better fatigue and also permanent deformation characteristics which also showed a reduction in moisture susceptibility. The addition of 3% PKA has greatly improved asphalt concrete behaviors and eventually in the production of more durable mixtures that will give higher resistance to distress
Ishola *et al.*[35]	The focus in on the production of Brake pad using non-asbestos organic (NAO) which is PKS	Non-asbestos organic (NAO) based PKS brake pad was successfully developed via compressive molding by varying the particle sizes of PKS
Mgbemena *et al.*[36]	Focus here is using PKS develop brake lining which is non-asbestos friction materials	It was established that PKS based Brake friction lining produced high wear high than the Original Equipment Manufacturer (OEM) Lining Materials and that the PKS based Brake friction lining showed better thermal stability when compared to OEM
Dagwa *et al.*[37]	Characterization of pulverized PKS was to determine its suitability for composite materials formulation	This research concluded that PKS can be used as a filler in the production of the polymer composite. This was established by various characterizations conducted among which was SEM which revealed that PKS powder had a spherical shape, EDX analysis revealed that pulverized PKS had a high carbon content of about 63 wt %, XRD pattern revealed that pulverized PKS was more of amorphous material with traces of microcrystalline material

Table 7: Summary of the previous works on PKS as a water purifier

References	Focus	Contribution(s)/Conclusion(s)
Fuadi et al.[10]	AC was produced from PKS and use as an adsorbent to remove pollutants from the aqueous phase	It was established from the review that AC produced from PKS has been used extensively to remove heavy metal, dyes, paints and other pollutants from the body of waste water
Okoroigwe *et al.*[12]	This article focuses on the way PKS can be used for both reinforcement as well as water purification	The characterizations results of PKS gotten by the use of x-ray diffraction (XRD) and x-ray photo-spectrometry (XPS) showed that PKS possessed some surface elements, crystalline materials and morphological qualities that qualified PKS as a good material fillers in construction as well as adsorption industries
Garcia *et al.*[42]	Production of AC from PKS was established which was used to remove colorants from the body of water with the help of activating agent called $ZnCl_2$	It was established that after 4 h contact time, about 90% adsorptions has been achieved. It was then concluded that Palm oil mill waste biomaterials can be efficiently used to remove colorants in the body of waste-waters
Muhammad *et al.*[43]	Activated Carbon produced from PKS was used to remove impurities such as zinc ion and cadmium ion from the aqueous solutions. The analysis was achieved by the use of Redlich–Peterson isotherms, Freundlich and Langmuir	In this research, three corrective models were employed in studying activities of AC produced from PKS, they were the modified extended Redlich–Peterson (MERP) and the modified extended Langmuir (MEL), as well as modified extended Freundlich (MEF). It was revealed that binary isotherm could be best described by the model called the modified extended Langmuir

Table 8: Summary of the present study on PKS as energy/fuel generation

References	Focus	Contribution(s)/Conclusion(s)
Rahman *et al.*[6]	Pyrolysis of PKS was characterized and to be used for washing medium and pre-treatmnet process	The energy content in char was seen to increase as the ash content became lower. The presence of ash, which acts as a catalyst, promotes secondary reactions during pyrolysis and is thus considered a significant contributor to high water fractions in the organic liquid yield
Okoroigwe and Saffron[48]	The focus here is on Bioenergy generation via PKS	The findings showed that pyrolyzed PKS has higher percentage of Carbon content and moderate hydrogen value and as such high heating value. It was established that PKS has greater potential to supply sustainable renewable energy to developing countries
Ugwu and Agbo[52]	PKS was carbonized and pulverized to produce Briquettes	It was established that PKS briquettes produced higher amount of calorific value than that produced from both the charcoal and sawdust and that such briquettes generated can be utilized for cooking and ironing of clothes
Yacob *et al.*[53]	PKS has been utilized here to serve as chemical activated carbon in order to produce Microwave-induced with larger surface area	In the process of using PKS as chemical activated carbon to produce Microwave, the characterization was carried out by the aid of Fourier Transform Infrared (FTIR) and other analysis were adopted to determine it effectiveness such as Thermal and Nitrogen gas adsorption Methods
Mohamad *et al.*[54]	This study focused on the use of PKS as steam gasification for hydrogen production at the temperature of 700°C in the presence of catalysts called Ni/BEA and Fe/BEA at 5% each	Steam generation from PKS was used to establish the effects of steam to biomass (S/B) and that of calcination temperature on product gas distribution and it was concluded that the catalytic activity decreases with increasing calcination temperature. Also, the product generated which is Co and CH_4 tend to increase with the increase in the ration of
Ninduangdee *et al.*[55]	The Characterizations and Combustions behaviours of Palm Kernel Shell (PKS) and Empty Fruit Bunch (EFB) were investigated using Thermogravimetric analyzer	It was observed that EFB exhibits tremendously higher combustive and thermal reactions than PKS as a result of reduction in burnout and ignition temperatures as well as lower activation energy
Obi[56]	The Focus here was on how to form a composite briquette with the PKS and sawdust by using the binding agent which was cassava starch	It was established that everlasting briquettes composite can be produced from the mixture of ground PKS and that of Sawdust in the ratio 50:50. It was concluded that a relaxed density of 0.48 g cm^{-3}, a compressed density of 0.84 g cm^{-3}, compaction ratio of 1.41 and relaxation ratio of 1.76 was achieved as well as durability rating of an amount of 73.40% and water resistance time was gotten to be 4.09 h
Febriansyah *et al.*[57]	The focus here was to replace fossil fuels with a well-designed and robust biomass stove made of PKS	It was concluded that the biomass stove made of PKS performed excellently well under the following features height of 25 cm, burner air opening at 75% with a combustion chamber diameter of 20 cm. It was established that mean combustion temperatures was gotten to be 682.59°C and overall efficiency of the biomass stove made of PKS was 66.63%
Lai *et al.*[58]	The study investigated how PKS pellet can affect the strength and process parameters	It was concluded that PKS powders can be pelletized to moderately porosity without binders which was expected to be utilized in the pelletization selection conditions for efficient and effective gasification
Bazargan *et al.*[59]	The focus here was how to generate briquettes/pellets from compacted PKS biochars	It was recorded that the calorific value derived from the compacted PKS biochars was so high and exceeding normal values for biomass
Fono-Tamo and Koya[60]	Pulverized PKS was evaluated to enhance its diversification from waste and determine its elemental composition, physical properties as well as thermal properties to exploit its utilization in engineering and eco-friendly environment	It was established that PKS could be diversified from waste to combustion fuel and other useful biomaterial composite utilization

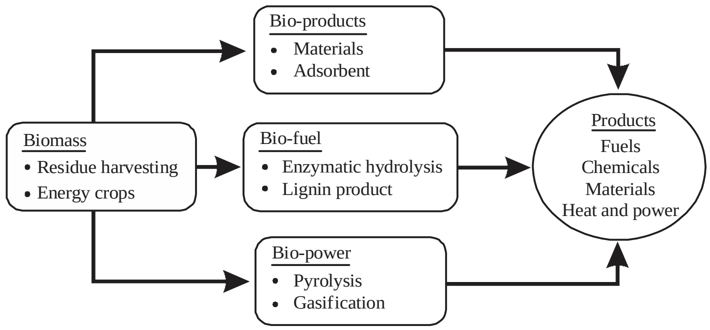

Fig. 3: Energy generation from biomass waste product

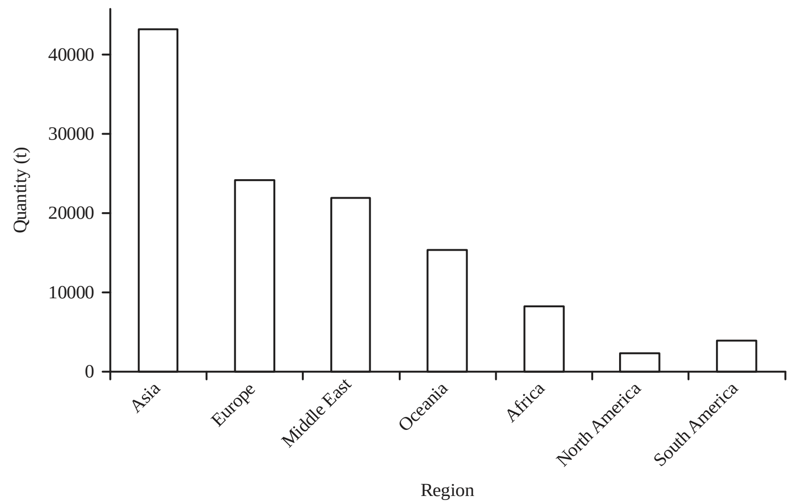

Fig. 4: PKS Importation by continents from Malaysia in the year 2013

success[64]. It was recorded that Asia country has the highest importation of PKS from Malaysia with total volume of 43,245.171 t next to it was Europe with total volume of 24,010.323 t after which was Middle East with total volume of 21,891.449 t.

It was further established as shown in Table 9, that at as 2013, the exportation of PKS to Asia countries from Malaysia revealed that China has the total volume of 10,588.966 t of PKS while Singapore recorded the second highest of PKS exportation from Malaysia with a total of 7,917.701 t[65].

Bring this PKS market to Africa countries, Fig. 5 shown that Tanzania has the highest volume of importation of PKS from Malaysia with a total of 2,879.03 t and Benin recorded half of Tanzania values with a total of 1,400.68 t as at year 2013. It was established that Algeria importation of PKS top three highest in Africa with a total of 1,077.74 t while Cameroon and Mozambique countries imported least with the same value of PKS importation[65] of 22.40 t.

In Europe it was observed that Russia country has the highest Importation of PKS from Malaysia with a total volume of 9,737.20 t as evidence in the Table 10, Ukraine recorded the second highest importer of PKS from Malaysia with a total of 8,887.40 t while Netherland imported least value at 2013 with a total volume of 20.75 t[65].

In the Middle East, Fig. 6 revealed that Egypt had imported a total volume of 10,539.45 t of PKS in the year 2013 which was observed to be slightly lower than the amount imported by China (2nd Largest Importer of PKS as at 2013 from Malaysia). It was also recorded that Iran climbs the top two of the largest importer in the country of the Middle East which recorded 3,399.29 t. Qatar, on the other hand, had the lowest importation of PKS from Malaysia with a total quantity[65] of 6.86 t.

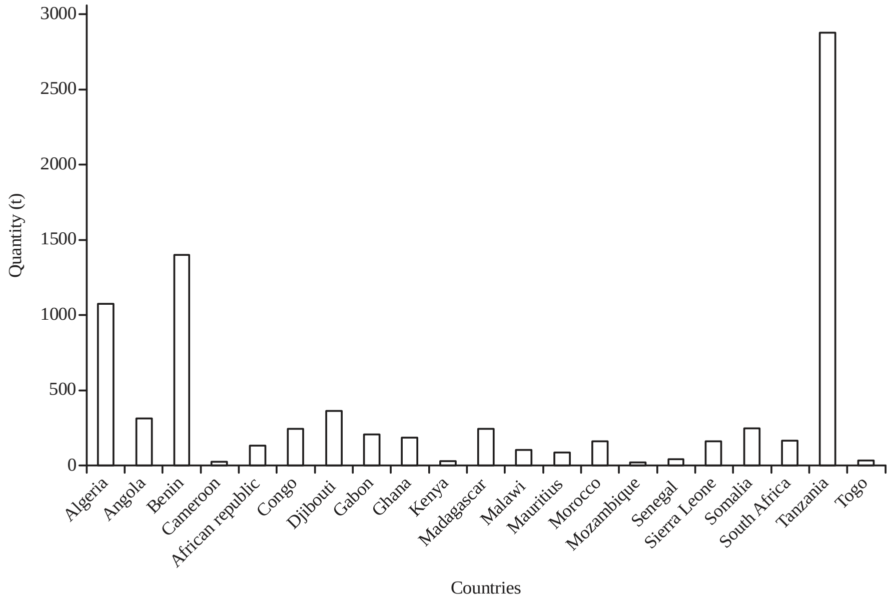

Fig. 5: Statistical data of PKS Imported by Africa Countries in 2013

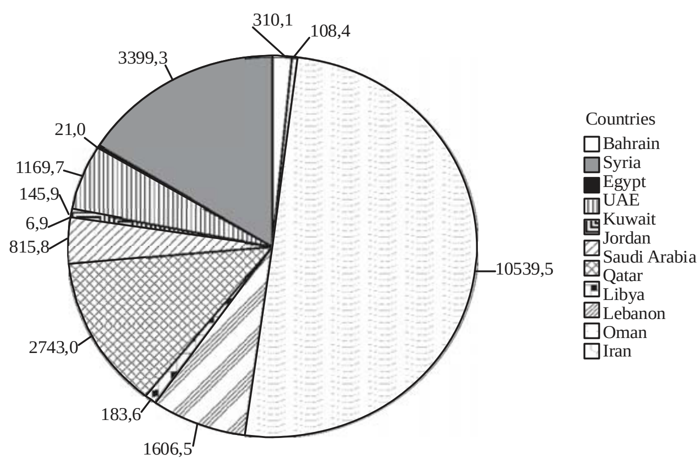

Fig. 6: Statistical data on PKS exported by Malaysia to Middle East Countries in 2013

Table 9: Statistical data of PKS exported to Asia country in year 2013

Countries	Quantity (t)
Thailand	43.97
China	10,588.97
Taiwan	508.84
Indonesia	5.68
Japan	2,348.44
South Korea	2,737.22
Kyrgyzstan	431.48
Bangladesh	2,111
Brunei	1.08
Sri Lanka	525.11
Hong Kong	340.26
Singapore	7,917.70
Kazakhstan	841.94
Vietnam	10.00
Pakistan	2,500.31
Philippines	1.26
India	398.89

As shown in Table 11 with reference to Oceania countries in PKS markets, Australia has the highest Importer of PKS from Malaysia with a total quantity of 11,251.37 t followed by New Zealand which has a total volume of 3,880.77 t and New Caledonia imported least value of PKS with an amount of 18.81 t[65].

In North America, it was on record as at 2013 as shown in Fig. 7 that Mexico top the list of the country with the highest value of PKS importation from Malaysia with a total of 512.72 t, it was observed that importation in North America does not vary too much. Nevertheless, it has been recorded that the Dominican Republic and the Bahamas behaved indifferently, in both cases, the importation of PKS was 224 t and 1.80 t, respectively[65].

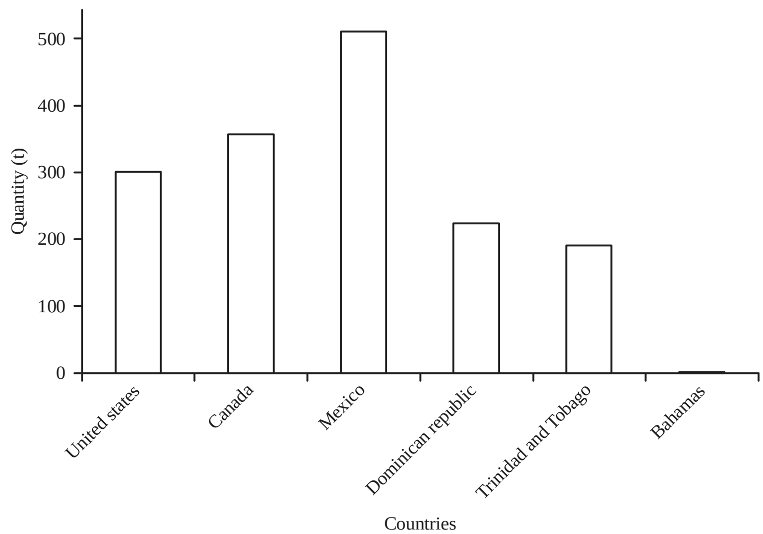

Fig. 7: PKS imported by North America countries in the year 2013 from Malaysia

Table 10: Statistical data of PKS exportation by Malaysia to Europe in 2013

Countries	Quantity (t)
Georgia	411.44
Lithuania	21.40
Poland	85.26
Turkey	3234.34
Bulgaria	644.00
Denmark	117.40
Latvia	82.80
Netherlands	20.75
Slovenia	21.76
Croatia	23.74
Hungary	79.95
Romania	642.88
Ukraine	8887.40
Russia	9737.20

Table 11: PKS imported by Oceania Countries in the year 2013 from Malaysia

Countries	Quantity (t)
New Caledonia	18.81
Papua New Guinea	81.13
Fiji	23.85
New Caledonia	18.81
Australia	11251.37

CONCLUSION

After the extensive reviews and experimentation of palm kernel shell. It was revealed by EDX analysis, that the main constituents of PKS-powder are carbon, silicon, aluminium, iron, calcium, potassium and oxygen.

Aside being used as filler, additives, reinforcement in building applications, energy generation, activated carbon and water purifier. PKS ash can also being use in the reinforcement of polymers, ceramics and metals matrices composites especially during friction stir welding and processing.

SIGNIFICANCE STATEMENT

Palm kernel shell powder/ash has been used for several applications. It has been established that the performance, efficiency and effectiveness of palm kernel shell/ash in any applications be as reinforcement, fillers, activated carbon, water purification, additives as well as energy generation depend whether is in form of nano-, micro- and macro-particles. In this review study, Palm kernel shell powder was studied to determine its usefulness in the area of surface engineering such texture and surface modification and functionalization. In our previous article, PKS powder was used as carbon additive in the manufacturing of HSS cutting tools used on lathe machine, in this study the end result performed higher than the control tool imported abroad. This was one of the reasons that propelled this study into using it for reinforcement in Friction Stir Processing (FSP) which no one has used both in matrices and hybrid composites, this will be used after it has been heat treated to optimum calcination temperature to form ash. PKS Ash has been proven significance in the field of Engineering where they use it abundantly for reinforcement in concretes and polymers, water purifiers and energy generation as fuel.

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