

Short Review on the Use of Oil Palm Shell in Concrete and Activated Carbon

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Abstract

Oil palm is known as *Elaeis guineensis*, found in Africa, South East Asia and China. Oil palm shell is used to prepare activated carbon because of high carbon content, high surface area, highly developed porosity and low price. During the physical activation, carbonization occurs in order to create porosity in the raw material. Literature review indicated that carbon material was impregnated with chemical agents such as phosphoric acid, potassium hydroxide, sulphuric acid, sodium hydroxide and zinc chloride in chemical activation process. Experimental results showed that the obtained activated carbon was used in hydrogen storage purpose, supercapacitor, gases and liquid phase adsorption process. On the other hand, oil palm shell was used in manufacturing lightweight concrete because of lighter and will not produce toxic substance. The bulk density and compressive strength of oil palm shell-based concrete were 500 - 600 kg/m³ and more than 25 MPa, respectively.

Keywords

Activated Carbon, Oil Palm Shell, Concrete, Activation, Carbonization

1. Introduction

The United States Department of Agriculture estimated Malaysia's 2019 palm oil production was at 20.5 million metric tons [1], up 4 percent from year 2018 and it is the second prime palm oil producing country in the world. In a study, it predicted to increase every year involving 4.4 million hectares of cultivating area [2]. Palm oil mills produce crude palm oil and oil palm kernel as well as vast quantities of remains such as oil palm fibre, shell and empty fruit bunches [3]. Such as 19 million tonnes' crop residues contain empty fruit bunch, fibre and shell from per year of production [2]. It is projected that more than 4.56 million

tonnes of palm shell as left-over is generated yearly [4]. And this is just oil palm shell (OPS) causing from handling of palm oil production which interjects 5.5% to the overall solid waste. Thus, using OPS as an aggregate can be considered as ecologically desirable in order to fully utilize waste materials appearing as by-products from other industries [5]. In operation of turbines for electricity OPS has been customarily used as solid fuels for steam boiler [6] and to envelop the surface of the roads in the areas where it is planted [7]. It was also converted to bio-oil through pyrolysis process for energy [8] and densified into briquettes. It was also used in the production of charcoal and activated carbon. Researchers have been investigating the capability of OPS as structural lightweight aggregate for more than twenty years. Among the countries in the world, Indonesia, Malaysia Thailand and Nigeria have oil palm industry as one of their main agricultural based industry. Yearly production of the crude palm oil by Malaysia is over 7 million tonnes [9]. Palm oil production over the world is shown in **Figure 1**.

One of the major downsides of this process is the amount of solid waste generated during the palm fruit processing. For example, Malaysia, Indonesia, Thailand and Nigeria produce over 8 million tons of oil palm shell (OPS) in a year [11].

In construction of building load bearing ability such as dead load is vital in design stages. Lightweight concrete is normally exercised to solve this problem. Two main advantages designers may expect while applying lightweight aggregate concrete: reduced dead load weight and high thermal insulation, both are important in minimizing earthquake impact. In lightweight concrete, functional design and architectural expression of forms can be achieved easier than in any other avenue [12]. Currently, architects, contractors and engineers have recognized the essential financial side and associated gains offered by lightweight concrete. Nevertheless, different features of lightweight aggregate and concrete required departures from ordinary practice to suit the purpose of design [13]. Such as, lightweight aggregate concrete can be used as part of a building structure

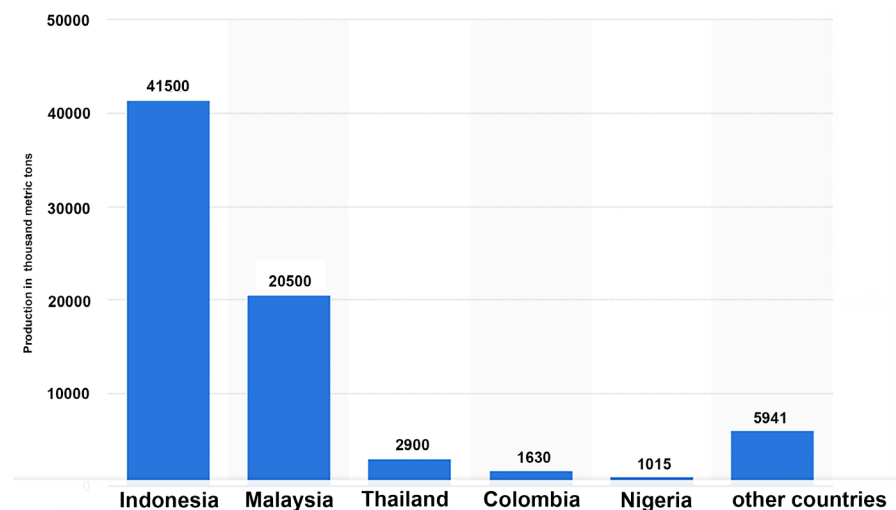


Figure 1. Leading producers of palm oil worldwide from 2018/2019 [10].

in slab, wall and column. And in its creation, the employment and reutilizing of solid waste material especially from agro-industry are very meaningful [6]. Replacement of agricultural wastes and industry based wastes into worthwhile materials has not only eco-friendly benefits, but may also safeguard the natural resources. Agricultural waste materials have good possibility or benefit to be generated back to advantageous material, suitably decreasing problems related to solid waste instead of only reducing the waste production.

Activated carbon has very unique properties such as high surface area and high porosity, which increases adsorption capacity. Porous materials [14] could be divided into three categories (Figure 2), namely microporous (less than 2 nm), mesoporous (2 - 50 nm) and macroporous (greater than 50 nm). Activated carbon could be produced by using several raw materials including watermelon peel [15], banana peel [16], orange peel [17], lemon peel [18], tea [19], coconut shell [20], waste tire rubber [21], durian shell [22], rambutan [23], pine cone [24], grape [25], papaya seed [26], mango [27] under physical or chemical activation process. As reported, global activated carbon market size about USD 4.72 billion in 2018 [28] due to increasing demand in water treatment, food processing air and gas purification applications [29]. Oil palm shell was used to prepare activated carbon due to high carbon content, high surface area, highly developed porosity and low price. It is known as *Elaeis guineensis*, found in Africa, South East Asia and China. Palm oil and palm kernel oil were produced from oil palm fruit. Palm oil was used in candle, soap, cosmetic, biofuel and lubricating greases while palm kernel oil was employed in ice cream, margarine, bread, chocolate.

In this work, oil palm shell was used to prepare activated carbon and concrete. The obtained activated carbon was employed in wide applications as discussed here. The properties of oil palm based concrete were explained and compared with other raw materials well.

2. Literature Survey

2.1. Oil Palm Based Concrete

Oil palm shell (OPS) is not frequently consumed in the building construction industry but is regularly curbed as wastes generated from agricultural bases [30].

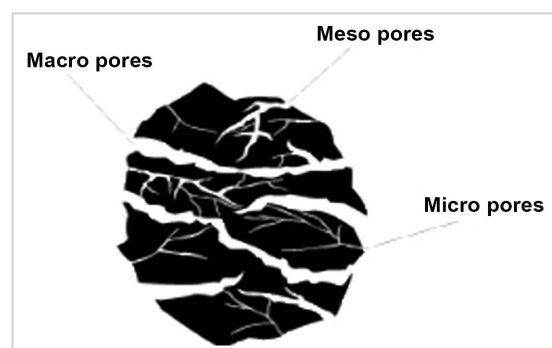


Figure 2. Three groups of pores are distinguished based on IUPAC definitions.

Numerous proposals focusing on minimizing traditional building material costs have been deliberated by using such kind of agro-wastes with the pursuit of affordable housing system for both the rural and urban populations of Malaysia and other developing countries. In countries where abundant agricultural wastes are discharged, these wastes can be used as potential replacement material in construction industry [31] [32]. One such choice is OPS which has the prospective to be used as substitute coarse aggregate in concrete [13]. Oil palm solid wastes are produced in abundant in the factories and is mostly burned by the orthodox process and it contributes to air pollution [33]. Consequently, these remainders are becoming costly to fix by fulfilling the requirements of environmental regulations imposed by Department of Environment. Efforts are underway to improve the use of these by-products through the development of various products with added values. One of the alternatives to dispose these wastes would be the consumption of palm shell (OPS) into building materials. Green issues are becoming more important at this age and needs to be addressed in all possible aspects of life, therefore the buildings are not exempted. On the other hand, construction materials have significant impacts on the Green Building Rating (GBR). Three of the vital factors to be mentioned which make concrete less eco-friendly are: a) carbon monoxide emission during the process of cement production, b) the amount of energy we offer to it, c) natural resources used such as water, aggregate and fillers are extensively used in the creation process of concrete.

Lately a number of researches [32] [34] have been conducted to utilize these palm shell wastes in manufacturing lightweight concrete. OPS are the hard stony endocarp but are lightweight and naturally sized. Once they adjoin in the concrete matrix, they will not infect or percolate to produce toxic substances due to the rigid surfaces of organic origin. In addition, OPS are lighter than the conventional coarse aggregate so the resulting concrete will be lightweight [35]. OPS replacement coarse aggregate is able to attain the strength of more than 17 MPa [34], which is a necessity for structural lightweight concrete as per ASTM (ASTM C330). Lately, OPS concrete compressive strength has attained more than 25 MPa [36]. The bulk density of OPS is in the range of 500 - 600 kg/m³ [6]. It was noticed that partial replacement OPS concrete density varies in the range of 1700 to 2185 kg/m³. Thus, it can be used as a better replacement of coarse aggregate to generate structural lightweight concrete. To realise the potential of OPS in concrete applications, Harimi and co-workers [37], who has evaluated the daily normal temperature of house wall surface by using OPS based lightweight concrete as building material, informed that OPS concrete walls temperature was always lower than the outdoor temperature. Nevertheless, the study only evaluated the interior surface temperature of the wall and concentrated on the architectural aspect. Even though OPS lightweight aggregate concrete has been effectively made in the past, most of the researchers focused on structural lightweight concrete purpose and the highest 28-day compressive strength of about 48 MPa [38]. Previous studies have used only around 15% to 18% OPS of volume fraction from total volume of OPS based lightweight concrete to produce high compress-

sive strength. OPS concrete seems to be inexpensive compared to the normal aggregate concrete. The shape of OPS shape can be angular or polygonal based on the breaking arrangement of the nut and its oil color differs. The attributes of the OPS are such that the OPS has the density identical to the other lightweight aggregates whereas its weight is about 60% less as measured against the usual coarse aggregates [39] [40] [41]. Furthermore, OPS have Los Angeles abrasion value about 1/5th of normal coarse aggregates [42]. Consequently, such characters and properties make OPS aggregates endurance to wear and low impact and crushing values makes them compatible to shockwave [4]. Shell thickness of OPS too is similar to coconut shell and flakiness index is about three times higher than crushed granite [39].

2.2. Oil Palm Shell Based Activated Carbon

The preparation of activated carbon under different physical and chemical activation conditions was reported by many researchers. Researchers have observed that porosity of charcoal could be developed under carbonization stage. Selection of lower or higher carbonization temperature causes a significant effect on the samples. Basically, there are two groups of activation process, namely physical activation [under steam and carbon dioxide] and chemical activation [phosphoric acid, K₂CO₃, KOH, ZnCl₂, sulphuric acid]. This process plays an important role in order to enlarge pore volume, diameter of pores and porosity of activated carbon [43]. **Table 1** shows the activated carbon has been successfully produced by using various raw materials under physical and chemical activation. Highlighted results were provided based on literature review.

In this work, activated carbon produced by using oil palm shell as raw material. Activated carbons obtained could be used for hydrogen storage purpose. Because of these carbons have many advantages including high surface area, inexpensive materials, highly pore microstructure, light weight and stable for large scale production. Zhao and co-workers [55] reported that the produced carbons have surface area of 3508 m²/g, micropores volume of 1.1 cm³/g. Outstanding storage capacities of hydrogen were 6.8% and 2.86% at 4 MPa and 1 bar respectively.

On the other hand, removal of copper ions by using activated carbon was studied. Gulnaziya and co-workers [56] found that high adsorption capacity at pH 5 if compared to pH 3 and in the presence of complexing agent such as malonic acid, boric acid. Other researchers such as Muzakkir and co-workers [57] study removal of zinc ion, lead ion and copper ions by using activated carbon. The best conditions such as pH (pH 6), absorbent dosage (0.5 g) and contact time (45 minutes). Good removal of lead ion (100%) if compared to zinc (79%) and copper ion (81%). The best kinetic model is pseudo-second order model. Removal of chromium ions by using chitosan coated activated carbon was reported by Saifuddin and co-workers [58]. Adsorption capacity was 154 mg Cr/g and fittest well Langmuir model.

Table 1. Production of activated carbon and highlighted results.

Raw material	Physical activation	Chemical activation	Highlighted results
Palm tree branches	<ul style="list-style-type: none"> 700 °C for 1 hour under steam 	<ul style="list-style-type: none"> At 500 °C for 2 hours Activating agent: Phosphoric acid and K₂CO₃ 	<ul style="list-style-type: none"> SEM: The highest development of pores could be observed as the concentration of phosphoric acid was increased [44]. pH: The highest percentage removal of Cr (VI) ions was observed at pH 2.
Olive wastes	<ul style="list-style-type: none"> 573 K for 3 hours under steam 	<ul style="list-style-type: none"> 1073 K for 1 hour Activation agent: Phosphoric acid and potassium hydroxide 	<ul style="list-style-type: none"> BET: 1375 m²/g and 466 m²/g for the activated carbon impregnated with KOH and phosphoric acid, respectively [45]. Activated carbon impregnated with KOH has the highest micropore volume (0.52 m³/g), mesopore volume (0.3 cm³/g) if compared to phosphoric acid. Adsorption of indigo carmine supported Freundlich model, and pseudo-second order kinetic equation.
Oak sawdust	<ul style="list-style-type: none"> 500 °C for 5 minutes 	<ul style="list-style-type: none"> 500 °C for 35 minutes Phosphoric acid 	<ul style="list-style-type: none"> Carbon yield (29.4%), moisture content (4.6%) and ash content (6.6%) for the activated carbon impregnated with phosphoric acid were reported [46]. The Langmuir adsorption of phenol (99 mg/g) and nicotinic acid (99 mg/g) for the activated carbon impregnated with phosphoric acid was highlighted.
Rice straw	<ul style="list-style-type: none"> 400 °C for 4 hours 	<ul style="list-style-type: none"> Tube furnace at various temperature (650 °C, 750 °C and 850 °C) KOH 	<ul style="list-style-type: none"> The highest carbon content could be observed for the activated carbon prepared at 850 °C (80.46%) if compared to 650 °C (66.18 %) and 750 °C (70.92%). The highest surface area (1048 m²/g), total pore volume (0.64 cm³/g), micropore volume (0.0436 cm³/g) and mesopore (0.568 cm³/g) could be seen in activated carbon produced at 850 °C [47].
Prawn shell	<ul style="list-style-type: none"> 800 °C for 3 hours 	<ul style="list-style-type: none"> 800 °C for 1 hour KOH 	<ul style="list-style-type: none"> Activated carbon impregnated with KOH showed the highest surface area (3160 m²/g) and pore volume (2.38 cm³/g). XRD: Data supported activated carbon impregnated with KOH has disorder carbon structure and crystallite layer if compared to carbonized sample [48]. The obtained activated carbon can remove Cu²⁺, Cr⁶⁺ and Cd²⁺ ions.
Jackfruit peel waste		<ul style="list-style-type: none"> Phosphoric acid 	<ul style="list-style-type: none"> Adsorption capacity of methylene blue was increased with contact time (6, 24 hours), adsorbent dosage (0.5 to 1.5 g) and initial concentration (1 to 2 mg/L) [49].
<i>Elaeagnus</i> stone	<ul style="list-style-type: none"> 600 °C for 6 hours 	<ul style="list-style-type: none"> ZnCl₂ 	<ul style="list-style-type: none"> BET surface area and micropore volume strongly depended on the concentration of zinc chloride such as 20% (1121 m²/g, 0.22 cm³/g), 30% (1588 m²/g, 0.08 cm³/g) and 40% (1404 m²/g, 0.01 cm³/g) [50]. Removal of rhodamine B, methylene blue, malachite green fitted with Langmuir isotherm and pseudo second order kinetic model.

Continued

Green coconut shell	<ul style="list-style-type: none"> 650°C for 1 hour ZnCl₂ 	<ul style="list-style-type: none"> Volatile matter (17.2%), fixed carbon (78.9%), ash content (0.9%), surface area (995 m²/g), micropore volume (0.37 cm³/g) in the obtained activated carbon were reported [51]. Removal of methylene blue greater than 90% when the contact time about 9 - 10 hours.
Apple pulp and apple peel	<ul style="list-style-type: none"> Modified microwave oven was used Furnace was used during the activation process. Activation agent: phosphoric acid 	<ul style="list-style-type: none"> The highest removal of methylene blue was 94.6% and 87.2% for pulp-based, and peel-based activated carbon [52]. BET surface area showed the highest value (1552 m²/g) in apple peel based activated carbon if compared to pulp based (1103 m²/g).
Orange peel	<ul style="list-style-type: none"> Tubular furnace was used, 1073 K for 1 hour -- 	<ul style="list-style-type: none"> Removal of phenol onto activated carbon was 88 mg/g when the contact time is 3 hours [53] The adsorption data support pseudo second order model. The best pH values are in the range of 4 to 8.
Banana peel waste	<ul style="list-style-type: none"> 350°C for 1 hour Sulphuric acid 	<ul style="list-style-type: none"> The highest iodine number could be observed when H₂SO₄ was used during the activation process [54]. Percentage of yield increased from 33.56% to 61.4% as concentration of H₂SO₄ decreased from 6 N to 1 N. BET surface area increased from 367 to 426 m²/g with increasing the concentration of sulfuric acid.

The adsorption of carboxylic acid formed during fermentation has been investigated by Hector and co-workers [59]. The adsorption data revealed that higher adsorption capacities could be observed in basic medium (potassium hydroxide) if compared to acid medium (phosphoric acid). Because of more favorable superficial chemistry and higher development of porosity.

Lua and Guo [60] reported the use of activated carbon for gas (SO₂ gas) phase adsorption. The experimental data supported linear relationship between surface area, porosity and adsorptive capacity. Purification of hydrogen from hydrogen-methane gas mixture was carried out by Sheila and co-workers [61] using activated carbon. The maximum adsorption capacity of pure methane could be observed at 20°C, following by mixture gas of CH₄/H₂ and pure hydrogen. The adsorption data support the Langmuir model. Arash and co-workers [62] prepared activated carbon under various concentrations of zinc chloride. They found that large volume of micropores in carbon. They conclude that 100% net increase in the methane capacity under carbon dioxide if compared to a flow of nitrogen.

Izan and co-workers [63] highlighted that activated carbon was used in supercapacitor electrode application. During the experiment, there are several aqueous electrolytes were provided. Results showed that achievable operating potential values were 1 V, 1.2 V and 2 V for sulfuric acid, potassium hydroxide and Na₂SO₄ electrolyte, respectively. The highest energy densities about 7.4 Wh/kg for the sample

Table 2. Advantages and disadvantages of activated carbon adsorption.

Advantage	Disadvantage
Low cost-raw material	Cannot remove dust and pollen
Simple technology	Possible impurities can leach into a liquid
High removal capacity for organic component	Nonselective removal for certain molecules
Reuse	
Purify large volume of gas or liquid	

prepared in Na_2SO_4 electrolyte. Hendriansyah and co-workers [64] highlighted that the obtained carbon has capacitance of 1.75 F/g. General physical properties such as surface area (8 - 451 m^2/g), pore volume (0.05 - 1.06 cm^3/g) and pore size (2.9 to 20.7 nm) were reported. During the experiment, working electrode and second electrode are activated carbon and nickel oxide, respectively.

Basic dye adsorption such as methylene blue was investigated by using oil palm shell based activated carbon. The adsorption data supported the pseudo-second order model in untreated and HCL-treated activated carbon [65]. The equilibrium data revealed that higher adsorption capacity (303 mg/g) was observed in HCL-treated carbon. Thermodynamic data showed endothermic in nature. Mook and co-worker [66] reported that activated carbon produced from palm shell. The obtained carbon showed surface area of 759 m^2/g , average pore diameter of 4.96 nm, micro pore volume of 0.299 cm^3/g . The dye removal efficiency increased with increasing adsorbent dose from 2 to 10 g/L, temperature from 18°C to 38°C, decreasing pH from pH 11 to 2. Experimental results revealed that reactive black 5 adsorptions were endothermic, supported Langmuir model, and fitted pseudo-first order model.

Experimental results showed that activated carbon was made from oil palm shell under physical and chemical activation process. The obtained activated carbon was used in hydrogen storage, super capacitor electrode application, gas and liquid phase adsorption. Table 2 indicated the advantage and disadvantage of activated carbon adsorption.

3. Conclusion

Currently, Malaysia ranked as second largest palm oil producer in the world. Generally, producer in the country is grouped into private, smallholder and joint venture. The primary importing countries: such as China, Pakistan, United States and European Union. Oil palm shell has many applications as highlighted in paper. Oil palm shell based activated carbon could be used as adsorbent to remove pollutant in waste water and gas phase adsorption. Activated carbon produced by using these raw materials has high surface area, high adsorptive capacities. Other findings showed that oil palm shell has potential to be employed in concrete. Oil palm shell is the hard stony endocarp but is lightweight and naturally sized. It could be used as a good replacement of coarse aggregate.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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