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Effects of heat treatment on oil palm shell coarse aggregates for high strength lightweight concrete

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ABSTRACT

In this study, the effects of heat treatment on oil palm shell (OPS) coarse aggregates are evaluated for high strength lightweight concrete (HSLWC). OPS coarse aggregates are subjected to heat treatment at two temperature settings (60 and 150 °C) and duration of heat treatment (0.5 and 1 h). The reduction in density is found to be within the range of HSLWC when heat-treated OPS aggregates are added into the oil palm shell concrete (OPSC). The results reveal that workability of the OPSC increases with an increase in temperature and duration of heat treatment of the OPS aggregates. It is found that the maximum achievable 28-days and 90-days compressive strength is 49 and 52 MPa, respectively. Furthermore, the ultrasonic pulse velocity (UPV) is examined and the results showed that a good condition is achieved for the OPS HSLWC at the age of 3 days. The average modulus of elasticity (i.e. (*E*) value), is found to be 15.9 GPa for all mixes, which is higher than that reported in previous studies and is within the range of normal weight concrete. Hence, the findings of this study are of primary importance as they reveal that the selection of a suitable temperature and duration of heat treatment for OPS aggregates can be used as a new eco-friendly alternative method to enhance HSLWC.

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1. Introduction

Oil palm shell (OPS) is an agricultural solid waste originating from the palm oil industry. The palm oil industry is a significant industry in the Malaysian economy. It has been shown that high strength lightweight aggregate concrete (HSLWAC) has a compressive strength of typically between 34 and 69 MPa through the incorporation of various pozzolans and water reducers. HSLWAC has a water to cement ratio of less than 0.45 and an air-dry density of less than 2000 kg/m^3 [1]. The utilization of OPS as lightweight aggregate (LWA) in the production of lightweight aggregate concrete (LWAC) has been a topic of research as early as 1984 by Abdullah [2] in Malaysia. Malaysia currently accounts for 51% of world palm oil production and 62% of world exports [3]. Approximately 80% of the volume from fresh fruit bunch processing is removed as waste [4]. OPS is one of the wastes produced during palm oil processing. Recently, a large amount of OPS waste is generated as a lignocellulosic material due to the increasing number of plantations of oil palm trees [5]. It is estimated that over 4.56 million tonnes of OPS waste is produced annually [6]. Pressed fibres and shells are traditionally used as solid fuels for steam boilers to run turbines in order to generate electricity for palm oil mills. However, a couple of problems arise with the burning of solid fuels, namely, the emission of dark smoke and carryover of partially carbonized fibrous particulates due to incomplete combustion of the fuels [7]. OPS is porous aggregate with a porosity of roughly 37% [8]. Porosity is one of the factors affecting the thermal conductivity of concrete, whereby the thermal conductivity is reduced by the enclosed pores due to the low thermal conductivity of air [9]. Consequently, the cellular structure of OPS provides thermal insulation for OPSC. The density of the shells is within the range of a majority of commonplace lightweight aggregates [10] and the specific gravity of the shells range between 1.14 and 1.37. A number of studies over the last two decades show that OPS can be employed as LWA in order to produce structural LWAC, with a reduction in density of 20–25% compared to normal weight concrete [11]. A cost analysis in Nigeria [12] reveals that a cost reduction of 42% is possible for concrete made from OPS. Several studies have shown that although the engineering properties of OPSC are generally satisfactory [13–16], there is still reluctance with respect to the implementation of OPSC compared with other types of LWAC. The reason for this is given by Okafor [10], who concluded that OPS is incapable of producing concrete with a compressive strength above 30 MPa. However, recent studies show high strength LWAC can be produced [17,18].

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Table 1
Chemical composition and physical properties of OPC.

Chemical composition (%)							Physical properties	
SiO_2	Fe_2O_3	CaO	MgO	Al_2O_3	SO_3	LOI	Specific gravity	Blain surface specific area (cm^2/g)
21.28	3.36	64.64	2.06	5.60	2.14	0.64	3.14	3510

Most current studies on OPSLWC focused on the investigation of their engineering properties and no information is available regarding the influence of heat treatment on OPS physical properties. Mitchell [19] reported that the extent of change in timber properties during heat treatment depends on the method of thermal modification, wood species and their characteristic properties, initial moisture content of the wood, surrounding atmosphere, treatment time and temperature. However, it is shown that temperature has the most significant impact on numerous timber properties. Hence, this study is motivated on the foundation that heat-treated OPS aggregate exhibit improved characteristics and therefore offer interesting opportunities for OPS LWAC. The methods proposed based on the results of these studies are commonly termed "OPS modification methods". Considerable research has been devoted on the application of heat treatment to modify the properties of OPS aggregates in LWAC. Heat-treated OPS is considered to be an eco-friendly alternative compared to chemically impregnated OPS materials [20,21]. The chemical modifications that occur in wood at high temperatures are accompanied by several favourable changes in their physical properties such as reduced shrinkage and swelling, improved biological durability, low equilibrium moisture content, enhanced weather resistance, decorative and aesthetic dark colour, improved thermal insulation properties, low pH, flow of several extractives from the wood, and greater resistance to decay [22].

2. Materials and methods

2.1. Materials

2.1.1. Cement

The cement used in this study was ASTM type I ordinary Portland cement (OPC) [23] with a specific gravity of 3.14 g/cm^3. The Blaine's specific surface area for this cement was 3510 cm^2/g. The chemical composition and physical properties of OPC are presented in Table 1.

2.1.2. Water and superplasticizer (SP)

Potable water was used for all mixes. The SP used in this study was polycarboxylic ether (PCE) supplied by BASF, which complies with ASTM: C494/C494M-13. The SP was mixed with a constant amount of 1.1% of the cement weight in order to facilitate workability.

2.1.3. Aggregates

Local mining sand was used as the fine aggregate, having a specific gravity, fineness modulus, water absorption and maximum grain size of 2.68, 2.72, 0.97% and 4.75 mm, respectively, whereas OPS was used as the coarse aggregate in this study. The OPS were collected from a local crude palm oil producing mill area. The shells are considered old as they have been discarded for more than six months. It is generally known that more than 50% of fresh OPS grains contain fibres. However, the percentage of fresh grains is less than 2% for old OPS, which improves contact between the mortar and OPS grains and consequently increases the compressive strength. The benefits of using such aggregates in OPSC were reported by Shafigh et al. [17]. The OPS were washed and sieved using a 12.5 mm-sieve. The OPS aggregates that were retained in the sieve were crushed using a stone-crushing machine in the laboratory. The flakiness significantly decreases upon crushing, which improves the performance of the coarse aggregates and yields higher compressive strength [18]. The crushed OPS aggregates were sieved using a 9.5 mm-sieve to remove OPS aggregates with sizes more than 9.5 mm. The OPS aggregates were heat-treated at 60 and 150 °C over a period of 0.5 and 1 h using a temperature-controlled laboratory oven. Once the OPS aggregates have cooled to room temperature, they were weighed under dry room conditions and immersed in water for 24 h. The OPS aggregates were subsequently air dried in the laboratory to attain an approximately saturated surface dry condition. The difference in quality of the OPS surface between heat treatment and without heat treatment (WHT) conditions is shown in Fig. 1.

2.2. Mix proportions

The mix proportions used in this study are presented in Table 2. The dosage of water and superplastisizer were kept constant for all mixes.

2.3. Testing methods and curing regimes

The procedure for mixing the OPSC comprises of the following steps. Firstly, the sand and OPS were poured into a concrete mixer and dry mixed for 1 min. Secondly, the cement was spread and dry mixed for 1 min. Water and superplasticizer were then added and mixed for 5 min. Slump test was performed on the mixture prior to sample casting. The concrete specimens were cast in 100-mm cube

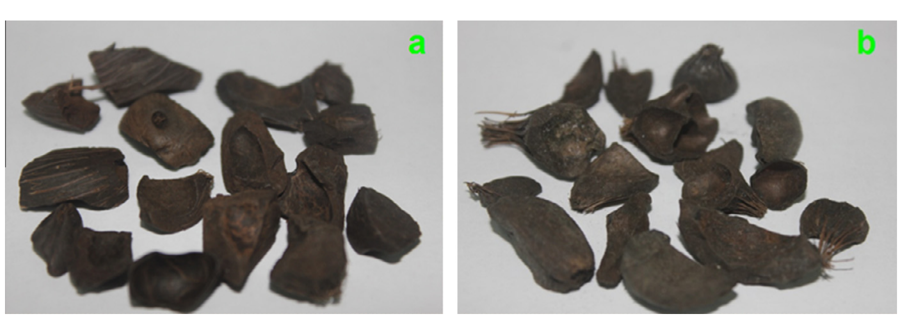

Fig. 1. Surface quality of OPS aggregates (a) with heat treatment and (b) without heat treatment.

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