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Effect of oil palm shell treatment on the physical and mechanical properties of lightweight concrete

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HIGHLIGHTS

- Different surface treatments are applied on oil palm shell (OPS).
- Effects of treated OPS on physico-mechanical properties of concrete are studied.
- Lime treatment increases the mechanical properties of OPS concrete.
- Sodium silicate treatment has not enhanced the bond between cement paste and OPS.
- Prewetting OPS and PVA treatment reduces the shrinkage and thermal conductivity.

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ABSTRACT

The overuse of natural aggregates for construction causes many environmental problems. In light of their environmental impact, the discussion has increasingly focused on using alternative plant-based materials and processes such as oil palm shells (OPS). However, previous studies show that OPS have a weak adhesion with cement paste, which results in a decrease in the physical and mechanical properties of OPS concretes. One of the solutions for this problem is to carry out a surface treatment on OPS before using them in concrete. This study has examined the influence of five treatments on the physical and mechanical properties of concrete: treatment with lime (CH), sodium silicate (SS), polyvinyl alcohol (PVA), heat treatment (TH) and OPS saturation (SAT). Lime treatment (CH) on OPS showed good improvement in the mechanical properties of concrete, compared to untreated OPS.

1. Introduction

Concrete is currently one of the most widely used construction materials. Its wide popularity can be explained by its interesting mechanical properties, its low cost and its extensive range of applications. However, concrete has a negative impact on the environment as it requires a great quantity of natural resources [1]. To eliminate or reduce the negative impact of concrete, several research have been undertaken on the use of by-products and recycled materials for construction. Oil palm shell (OPS) is a by-product of oil palm production. It consists of small hard particles of different shapes and sizes that can be used as aggregate in concrete.

For years, authors have demonstrated the potential use of OPS for producing structural lightweight concrete. This biomass can be used to obtain concrete with a density ranging from 1725 to 2050 kg/m^3 [1], which corresponds to a 15–25% reduction in density compared to ordinary concrete. Therefore, using OPS as aggregate leads to a decrease in the loads of concrete structures and consequently a reduction in the cost of construction. Olanipekun et al. [2] found that the cost of construction can be reduced by 42% when using OPS in concrete.

However, it has been noted that the mechanical properties of the concrete decrease as the concentration of OPS aggregate in concrete increases [2]. Adebayo [3] has reported that the total

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substitution of ordinary aggregates by OPS results in an approximately 50% decrease in strength. Other studies have proven that OPS-based lightweight concrete has lower mechanical properties than concretes made from other artificial and natural lightweight aggregates [4].

The experimental results in the scientific literature on this subject have shown that the decrease in the OPS concrete strength is linked to the intrinsic properties of OPS and the weakness of the adhesion between OPS and the cement paste. OPS is a porous material with a high water absorption capacity. Its water absorption capacity, which can reach 33% [5], can be harmful to concrete properties. OPS may absorb a part of the mixing water intended for the cement hydration. Studies [6] have shown that the porosity of the interface between aggregate and cement paste increases with the absorption capacity of aggregate. Treating OPS before using them in concrete has been suggested to prevent this behaviour. By analogy to wood treatments, the literature cites different methods that can be applied on OPS: partial oxidation of the aggregate, waterproofing, treatment with hot water, heat treatment, etc. [7–9] Mannan et al. [8] have observed, for example, that treating OPS in a solution of PVA (polyvinyl alcohol) improved the mechanical performance of the concrete. Yew et al. [9] improved the compressive strength of OPS concrete after heat treatment at 60 °C for 30 min. It is often difficult to compare the results of published works as the number of variables taken into account by the authors is high. The treatments, the formulation methods (water-to-cement ratio, cement concentration, aggregate quantity), the particle size and curing of the concrete vary from one author to another. It is therefore impossible to draw a conclusion as regards which treatment is the best.

The general objective of this study was to examine different OPS treatments, to analyse and compare their influence on the properties of concrete. In our research, parameters such as the formulation method, the processing conditions and the curing conditions of concrete were kept constant. Five different treatments were applied to the OPS, then their effects on the following properties of concrete were studied: apparent density, porosity accessible to water, ultrasound waves speed, compressive and flexural strength and drying shrinkage.

2. Materials and treatment methods

2.1. Materials used

The cement used was a CEM I 42.5 from the company CIMTOGO produced according to EN 197-1. This cement had a relative density of 3150 kg/m^3, a bulk density of 1060 kg/m^3 and a BET specific area of 2.96 m^2/g.

The OPS used came from "Société Immobilière et Financière de la Côte Africaine" (SIFCA), a palm oil company. Before any treatment and/or utilisation, OPS were washed in water to remove soil and fat residues and air dried. They were then sieved, and only the particles with a diameter less than 8 mm were retained. OPS particle-size distribution is shown in Fig. 1. Their relative density was 1340 kg/m^3, their bulk density was 560 kg/m^3 and their 24-h water absorption capacity was 23.3%. These OPS properties were similar to those published in scientific literature. In general, OPS density varies from 1170 to 1370 kg/m^3 and their 24-h absorption capacity ranges from 21% to 33% [10–13].

Sand from a local river was also used. Its particle-size distribution is also shown in Fig. 1. It was a poorly graded sand with a uniformity coefficient C_u of 3 and a curvature coefficient C_c of 0.9. The sand equivalent test gave a value of 98. This indicates that the sand used was very clean and suitable for making concrete of high quality. It had a density of 2680 kg/m^3, a bulk density of 1530 kg/m^3 and a Fineness modulus of 2.90.

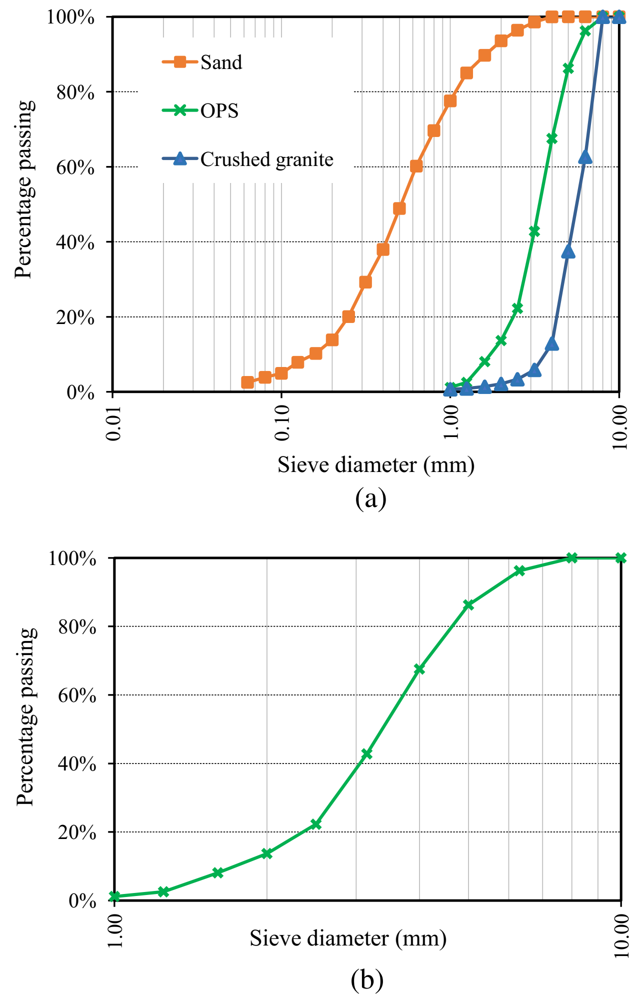

Fig. 1. Gradation of sand, OPS and crushed granite.

In order to compare the properties of treated OPS concrete to those of ordinary concrete, a granite-based aggregate concrete was prepared. The gravel used had a density of 2660 kg/m^3, a bulk density of 1510 kg/m^3, and a 24-h water absorption capacity of 0.4%. Its particle-size distribution is shown in the Fig. 1.

2.2. Nature and methods of treatment

Five different treatments were studied. Their purpose was to reduce the hydrophilic behaviour of OPS or to modify the OPS surface.

A first treatment (CH) consisted of mixing the OPS in a solution of lime ($Ca(OH)_2$) for 2 h. The saturated solution was dosed at 40 g of lime per litre of water. The mix was stirred repeatedly during the entire treatment duration to avoid decantation of lime particles. Authors [14] have observed that lime treatment modifies the surface of the lignocellulosic aggregates used and improves the mechanical strength of their composites. The lime treatment was therefore chosen for these reasons.

A second treatment (SS) comprised the soaking of the OPS for 2 h in a solution containing 100 g/l of sodium silicate. A previous study on lightweight concretes containing wood chips [15] showed that the presence of amorphous silica on wood chips improves bonding with cement paste.

The third treatment (PVA) consisted the covering of the OPS with a solution of 5% polyvinyl alcohol. This type of solution was used to make each of the particles waterproof [8]. The OPS was