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Oil palm shell lightweight concrete containing high volume ground granulated blast furnace slag

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1. Introduction

Concrete is the most widely used construction material in all types of civil engineering works, including infrastructure, low and high-rise buildings, defence installations, environmental protection and local/domestic developments [1]. Today the concrete industry annually consumes 1.5 billion tonnes of cement, 9 billion tonnes of sand and rock together and 1 billion tonnes of mixing water [2]. This means that huge amounts of natural resources and raw materials are being used for concrete production around the world. Because of the vast amount of concrete produced today, even a small reduction in the environmental impact per ton of concrete will result in considerable benefits to the environment [3].

Portland cement, which is an essential constituent of concrete, is manufactured by heating a mixture of limestone and clay (two
largely available, natural, non-renewable materials) in a kiln at about 1500 °C to produce cement clinker [4]. The production leads to the release of a significant amount of CO₂, which amounts to about 5% of the global anthropogenic CO₂ emissions [4], of which 50% is from the chemical process and 40% is from burning fuel for the manufacturing process [5]. Because of a world-wide increase in the demand for ordinary Portland cement, it was estimated that cement production could represent nearly 10% of the global anthropogenic CO₂ emissions in the near future [6] and the current level of CO₂ in the atmosphere may increase from 380 ppm to 800 ppm by the end of the century [7]. It was reported that, in 2000, between 2.3 and 15 million tonnes of NOₓ were produced to make Portland cement [8]. In addition to these emissions, the cement manufacturing process produces millions of tons of waste product cement of kiln dust each year, contributing to respiratory and pollution health risks [9].

Green concrete consists of a blended concrete mix containing recycled materials that include recycled aggregates and supplementary cementing materials. Sun et al. [10] demonstrated that one of the main characteristics of green high performance concrete includes the use of different types of mineral admixtures to partially replace Portland cement. The use of pozzolanic materials such as silica fume, ground granulated blast furnace slag (GGBFS), rice-husk ash, coal ash, wood ash, natural pozzolans and other similar pozzolanic materials, not only can reduce the use of manufactured Portland cement clinker, but also at the same time, produce concrete that is more durable [11]. Nowadays, the use of slag and fly ash in concrete, both as a constituent of cement or as an addition are widespread, and, in some countries, blast furnace slag cement has the main share of the market [12]. Songa and Sarawathy [13] reported that GGBFS is an important partial substitute of cement in concrete, the notable characteristics of which include energy saving, clinker saving, low cost, environmental protection and social as well as economic benefits.

It has been reported [14] that after Portland cement, coarse aggregate is the next major source of CO₂ emission generated by typically commercialized produced concrete mixtures, being responsible for 20% of CO₂ emissions. In addition, since the majority of natural resources are limited, any effort to use waste and recycled materials in concrete production can reduce resource depletion and promote energy conservation in the construction sector. For many years, recycled concrete aggregate (RCA) as coarse aggregate in concrete was investigated and used practically in construction industry. Also, agricultural solid wastes such as oil palm shell, coconut shell, rice husk, pistachio shell and tobacco waste as aggregate were successfully used in concrete making. In countries in the tropical regions such as Malaysia, Indonesia and Nigeria, where the palm oil industry is important, there are large quantities of solid waste produced by the oil mills, namely oil palm shell (OPS). Malaysia currently produces more than half of the world’s total output of palm oil and over 4 million tonnes of oil palm shell solid waste are produced annually [15]. The density of the shells is within the range of most typical lightweight aggregates [16,17]. It has been reported [18,19] that by using OPS as coarse aggregate the 28-day air dry density and compressive strength of OPS concrete are within the range for structural lightweight concrete. Recent studies [20] revealed that OPS can be used as lightweight aggregate for producing high strength lightweight concrete. Therefore, it is possible to produce environmentally friendly and economical concrete (greener concrete) by reusing post-consumer waste and industrial by-products as aggregate and supplementary cementing materials.

2. Research significance

Oil palm shell (OPS) is an agricultural solid waste and is available in huge amount in tropical countries. It has been successfully used as lightweight aggregate (LWA) to produce structural lightweight concrete. On the other hand, using slag, which is a by-product of the steel industry, as cement replacement in concrete, can help to achieve significant advantages. The advantages of using lower cement content is clear as many types of emissions in the cement industry such as CO₂, SOₓ, NOₓ dust and heavy metals and also huge amount of natural resources, energy, fossil fuels, and water are used [21]. In addition, it is well known that the cement industry ties a substantial share of its production costs to meeting its energy needs [22] and the manufacture of Portland cement is the third most energy-intensive process, after aluminum and steel manufacture [8].

The main aims of this paper are to achieve a greener lightweight concrete by incorporating OPS as solid waste instead of natural or artificial lightweight coarse aggregate and GGBFS as partial cement substitution. OPS lightweight concrete containing high volume GGBFS and low cement content will be a new type of environmentally-friendly lightweight concrete, which results not only for better environmental performance but also for better economical consequences.

3. Experimental details

3.1. Material

3.1.1. Binder

Ordinary Portland cement (OPC) with a specific gravity of about 3.14 and specific surface area of 3,52 m²/g and GGBFS with a specific gravity of about 2.87, bulk density in the range of 1,180–1,250 kg/m³ and the specific surface area of 4,12 m²/g were used as a binder. The chemical composition of OPC and GGBFS are shown in Table 1.

3.1.2. Aggregate

OPS collected from a local crude palm oil producing mill were used as coarse aggregate. 0.5% OPS (OPS without fibres) were used to achieve better workability of the fresh OPS concrete and a better bond between the OPC and the OPS paste [23]. Before the OPS were used, they were washed and then air-dried in the laboratory until surface dry condition. The physical properties and grading of OPS are shown in Tables 2 and 3, respectively.

local mining sand with a fineness modulus of 2.65, specific gravity of 2.68 and maximum grain size of 4.75 mm was used as fine aggregate.

3.1.3. Superplasticizer

Previous studies [18,24] have shown that selection of type of superplasticizer (SP) and its dosage have a significant effect on OPC concrete in both the fresh and hardened states. Several types of SP have been tested. The SP used in this study was Sika ViscoCrete-15RM, supplied by Sika, which is in conformity with EN 934-2. The recommended dosage for concrete is 0.4–1.5% by mass of cement. In this study, the amount of SP was fixed at 1% by mass of binder for all mixes.

3.1.4. Water

Potable water, free from impurities and chemical contaminants was used for all mixes.

3.2. Mix proportions and procedure

Four mixes of concrete were produced to evaluate the influence of incorporation of GGBFS on the compressive strength of OPS concrete. In all the mixes, the W/B ratio = 0.35 and the amount of binder (cement + GGBFS) was fixed as 500 kg/m³. Details of the mixes are given in Table 4.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Chemical composition of OPC and GGBFS (by mass).</th>
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<tbody>
<tr>
<td></td>
<td>OPC</td>
</tr>
<tr>
<td>SiO₂</td>
<td>18.47</td>
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<tr>
<td>Fe₂O₃</td>
<td>2.96</td>
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<tr>
<td>CaO</td>
<td>64.09</td>
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<tr>
<td>MgO</td>
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<tr>
<td>K₂O</td>
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<tr>
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<tr>
<td>Cl⁻</td>
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<td>LOI</td>
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</table>

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