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Feasibility study on the use of high volume palm oil clinker waste in environmental friendly lightweight concrete

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HIGHLIGHTS

- Waste palm oil clinker powder to partially replace cement in eco-friendly concrete.
- 15% POC powder produced optimum result in terms of strength and water absorption.
- 37% of waste materials from palm industry in the development of green concrete.
- The highest compressive strength of 65 MPa obtained using low cement content.

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ABSTRACT

Huge amount of virgin materials is being used in the production of concrete and the negative impact caused by exploitation of natural resources to our eco-system is beyond recovery. In order to produce a cleaner and greener concrete, waste palm oil clinker (POC) powder, a by-product from palm oil industry was used as filler and amorphous material in the development of sustainable and environmental friendly lightweight concrete. The utilization of POC powder as cement replacement in concrete will certainly have positive impact on the environment due to potential reduction in greenhouse gas emission. Further, whole replacement of virgin crushed granite coarse aggregate with coarser POC as coarse aggregate would enable conservation of natural resources. The properties including workability, density, compressive strength in different moisture contents, splitting tensile and flexural strengths, stress-strain curve, modulus of elasticity, ultrasonic pulse velocity (UPV) water absorption and sorptivity of the sustainable lightweight concrete were obtained and analysed. It has been found that the addition of 15% waste POC powder produced the optimum mixture as the strength enhancement of compressive and flexural strengths of 30% and 15%, respectively, was found. In addition, the filler effect of waste POC powder could be seen as it decreased the water absorption and sorptivity. Moreover, the use of two palm oil industrial waste materials up to a volume of 56% in concrete as replacement to cement and coarse aggregate will not only reduce cost but it will spur research and commercial interests as environmental friendly high strength lightweight concrete could be produced using these wastes.

1. Introduction

The construction industry consumes a huge amount of concrete and as concrete is composed of natural resources such as water, sand, gravel and crushed granites or other rocks, the overuse of such natural resources has implacable consequences on global environment. Research shows the annual consumption of natural aggregates amounts to 8–12 billion tons [1,2] and 2.8 billion tons cement [3]. Due to high volume of quarrying activities of natural resources for both rocks and cement production, it is not an eco-friendly activity and has significant environmental, social and economic impacts [4]. Thus in order to achieve sustainable development, one of the paramount alternatives is to use the waste and industrial by-product materials instead of virgin materials in concrete [5].

Further, the use of the renewable resources by concrete industry could lead to greener and sustainable construction materials for better quality of human life and to reserve natural resources for future generation. The lightweight aggregate concrete (LWAC)

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made of artificial LWAs such as expanded clay, slate, shale, or blast furnace slag, is a type of eco-friendly construction material. The benefits of LWAC include reduction in dead load, minimize micro cracks in concrete compared to normal concrete (NWC) due to significantly lower stiffness of lightweight aggregate in LWAC, and uniform stress distribution at the micro level in lightweight concrete that enhances the durability in severe environments compared to normal weight concretes [6,7]. However, the main concern in the production of lightweight aggregate is the need of energy and its associated cost. In addition, LWAC needs more quantity of cement and cementitious materials and this leads to more cost. This is an energy-intensive industry with energy cost normally accounting for about 40% of operational cost and its comes from solid coal or other liquid or gaseous fossil fuel from biomass waste are used [8].

On the other hand, there are alternative resources for lightweight aggregate through natural lightweight aggregates which do not consume a significant energy compared to artificial lightweight aggregates. Some of these aggregates can be obtained from natural lightweight rocks. However, due to the limitation of natural recourses, the use of solid wastes from palm oil industry, such as palm oil clinker (POC) and oil palm shell (OPS) could be considered as lightweight aggregates and concretes developed using these wastes will be more sustainable [9–11]. Also OPS has better structural performance compared to crushed granite aggregate in case of blast loading [12] and ductility [13,14]. The oil palm industry operates in tropical region countries, like Malaysia, Indonesia, Thailand, Nigeria. Palm oil industry produces a wide variety of waste such as OPS, POC, palm kernel fibre etc. in large quantities [15–17]. POC is one kind of solid waste generated during power production due to burning of OPS and palm kernel fibre in certain proportions [13]. POC is abundantly available and is normally treated as a waste with no economic value. It is like a porous stone, grey in colour, flaky and irregular in shape [18]. Original POC (POC directly collected from oil palm mill) is in bolder size and crushed in stone crusher to utilize it as lightweight aggregate in concrete.

A lightweight concrete made using POC as coarse aggregate has compressive strength in the range of 27–35 MPa and could be considered as moderate strength concrete [19]. But as POC aggregates have rough surface with lot of pores and hence it requires more paste to have appropriate bond with matrix. Thus, use of palm oil clinker powder could lead to sustainable concrete in the development of high strength lightweight concrete. Also in the case of production of POC powder no carbon di-oxide generated. Ahmmad [13] et al. showed POC contains 60% of pozzolanic silica SiO_2, and 8% of CaO. Huntzinger and Eatmon [20] showed that the production of a ton cement generates a ton of CO_2, causing an increase of temperature on the earth's crust. However, the use of POC powder reduces cement content and hence reduces CO_2 emission. So, the aim of this study is to develop a new type of high performance lightweight concrete by incorporating POC as the coarse aggregate and as waste POC powder as additional cementing and filler material to minimize CO_2 emission by reducing cement content in concrete. Currently, there is no published research article on the use of POC powder as cementitious material in concrete.

2. Materials and method

2.1. Raw materials

2.1.1. Cement

Ordinary Portland cement (OPC) cement with 3, 7 and 28-day compressive strengths of 26, 34 and 46 MPa, respectively, was used in all the mixtures. The specific gravity and Blaine specific surface area of the cement used were 3.14 and 351 m^2/kg, respectively.

2.1.2. Lightweight coarse aggregate

The POC was collected from the local palm oil factory. The POC was crushed in the laboratory stone grinding machine and then sieved to different sizes between 5 and 12.5 mm then used as lightweight coarse aggregates.

2.1.3. Local mining sand as fine aggregate

Local mining sand with a specific gravity, fineness modulus and water absorption of 2.66, 2.89 and 1.17%, respectively, was used as fine aggregate. Its grain size was in the range of 75 μm–4.75 mm.

2.1.4. Additional environmental friendly cementing and filler materials

Palm oil clinker (POC) of size below 5 mm was further ground in Los Angeles (LA) grinding machine to increase its surface area. The POC powder has crystalline phases dominated with quartz (within 2-theta angle of 0–10°) as shown by the X-ray diffraction (XRD) result (Fig. 1). The phase of POC is majorly crystalline with few traces of amorphosity indicated by diffusive halo between 25 and 30 °C (2-theta). This could be possibly due to short range order of $CaO\text{-}MgO\text{-}Al_2O_3\text{-}Fe_2O_3\text{-}SiO_2$ structure within the POC as reflected in the XRF results (Table 1). The peaks in the POC diffractogram include the quartz (Q-SiO_2), iron (F-Fe_2O_3), akermanite (A-$CaOMgOSiO_2$), calcite (C-$CaCO_3$) and wollastonite (w-$CaOSiO_2$).

The particle size and volume of OPC and POC powder is shown in Fig. 2. It is seen that the POC particle slightly coarser than OPC while the more particle volume was observed in POC compared to OPC as more volume of particle higher than 0.1 mm was found in the former than the latter. Also, the utilization of waste POC powder would be a boost to environmentalists as it could reduce CO_2 emission and also could bring wealth from waste.

2.1.5. Superplasticizer

A high range water-reducing admixture was used as the superplasticizer (SP) with a quantity of 1.5% of the mass of binder in all the mixtures.

2.1.6. Water

Portable tap water was used for mixing with the water to cement (w/c) ratio of 0.45 to maintain the water content of 189 kg/m^3 for all mixtures.

2.2. Mixing proportion

POC concrete containing 420 kg/m^3 OPC (mixture MPOC00) with addition of POC powder of 5%, 10%, 15% and 20% by the weight of cement is considered as variables in the mixtures. Normal mining sand was used as fine aggregates. Table 2 shows the details of the constituent materials for all mixtures. All mixtures have the same quantity of materials except for POC powder and SP, which was proportioned such that the latter increased with the former.

2.3. Specimen preparation

The cement and aggregates were blended in a mixer for 5 min. Then 70% mixing water was added to the mixture and mixing continued for another 5 min. The rest of the water together with SP was added to the mixture and mixing proceeded for another 5 min before the slump test was performed. The concrete specimens were cast in steel moulds of 100 mm cubes for compressive strength, cylinders of 100 mm diameter and 200 mm height for splitting tensile strength and modulus of elasticity as well as stress-strain curve. The prismatic specimens of 100 × 100 × 500 mm^3 were used for flexural strength tests. All the specimens