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Flexural performance of reinforced oil palm shell & palm oil clinker concrete (PSCC) beam

Md. Nazmul Huda [a], Mohd Zamin Bin Jumat [a], A.B.M. Saiful Islam [b,*]

[a] Department of Civil Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] Department of Construction Engineering, College of Engineering, University of Dammam, 31451 Dammam, Saudi Arabia

HIGHLIGHTS

- Flexural behavior of newly proposed palm shell and clinker concrete (PSCC) beam.
- Reinforced PSCC beams exhibited good ductile performance.
- Flexural mode of failure.
- Moment capacity can be taken 80% of theoretical prediction.
- Allowable cracking behavior shows worthy potential of PSCC beams.

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ABSTRACT

The recent trend of globalization has seen massive construction leading to the radical destruction of natural stone deposits. To meet the high demand of normal weight aggregate in the production of concrete is a vital issue for ecological imbalances. Solid waste management from the agricultural and manufacture industries is another environmental issue. An innovative solution to reduce the negative impact on the environment is the production of structural lightweight concrete from these solid waste. This paper presents the structural performance of singly reinforced oil palm shell and palm oil clinker concrete (PSCC) beam. The structural-grade lightweight aggregate concrete, PSCC has been produced from the combination of oil palm shell (OPS) & palm oil clinker (POC) which are an agricultural waste and a by-product of palm oil industry. The produced lightweight concrete has the compressive strength of 46 MPa. The experimental works have been conducted involving six singly reinforced beams of dimension 150 mm × 250 mm × 3300 with varying reinforcement ratios (0.70–1.26%). For each type of reinforcement ratio, two beams have been tested under four point bending until failure. The data presented in this paper include the mode of failure, moment capacity, deflection characteristics, cracking behavior and ductility indices. Although PSCC has a low modulus of elasticity, the moment capacity and the deflection of singly reinforced PSCC beams are acceptable as the span-deflection ratio satisfies the allowable limit provided by BS 8110. All PSCC beams show typical flexural performance and experiences ductile failure giving ample amount of warning before the failure. For the beams with higher reinforcement ratio, the deflections at service loads exceeded the limit, suggesting to increase the beam depths. The crack widths of PSCC beams at service loads ranged from 0.21 mm to 0.26 mm satisfying BS 8110 for durability aspects. The ultimate moments predicted using BS 8110 overestimates for the PSCC beams up to the reinforcement ratio of 1.26%. Therefore, 20% overall reduction is suggested in moment capacity calculation using BS 8110. Further investigation is recommended to understand the shear behavior of reinforced PSCC beam.

1. Introduction

Dramatically reduction of natural stone deposit has occurred to meet the high demand of normal weight coarse aggregate for the production of concrete. This is partially responsible for the ecological imbalances [1]. There is another environmental issue about solid waste management from the agricultural and manufacture industries. Nowadays, lightweight concrete is getting popular in the construction sector for many reasons. The lower size of structural elements can be taken due to a reduction in dead load, taller building height should be attained by keeping the same foundation

* Corresponding author.
E-mail address: asislam@uod.edu.sa (A.B.M. Saiful Islam).

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and greater span-depth ratio is possible for the beam in prestressed concrete construction [2]. Therefore, researchers from the area of building and construction materials are trying to find an innovative solution to reduce the negative impact on the environment as well as to produce structural lightweight concrete. The idea is to use the solid waste from the agricultural and manufacture industries as coarse aggregate in lightweight aggregate concrete which will reduce the destruction of natural resources and demonstrate the proper management of solid waste. Several researchers investigated the way for using these waste materials as lightweight aggregate in the concrete [3–9]. Malaysia is the second largest palm oil producing country in the world and it produces more than half of world's palm oil [10,11]. At the same time, Malaysia is the equal responsible country for producing the huge amount of solid waste from the palm oil industries. The residue of palm oil industries includes OPS and POC, empty fruit bunches, and palm oil mill effluent [12,13]. Instead of dumping the OPS and POC into the environment, a better waste management option is to crush the OPS and POC into desired sizes and utilize it as aggregate to produce lightweight concrete.

Flexural behavior of reinforced OPS concrete beams was reported by Alengaram et al. [14] showing more ductile behavior. Three singly and three doubly reinforced were tested with different reinforcement ratios in the study of Teo et al. [15]. The final failure occurred due to the crashing of the compression concrete with a significant amount of ultimate deflection. Yielding of the tensile reinforcement occurred before crashing of the concrete at compressive surface in the pure bending zone. The failure stage experienced significant deflection. Experimental ultimate moments (M_{ult}) and theoretical design moments (M_{des}) showed a closer relationship for doubly reinforced beams than singly reinforced ones [15]. For beams with reinforcement ratios of 3.14% or less, the ultimate moment obtained from the experiment was approximately 4–35% higher than the predicted values. They concluded that for the oil palm kernel shell concrete (OPKSC) beams, BS8110 [16] could be used to obtain a conservative estimate of ultimate moment capacity with adequate safety factor against failure for reinforcement ratios up to 3.14%. The beam with high reinforcement ratio showed slightly higher mid-span deflection curvature for OPKSC beams than the predicted value [14]. Mohammed et al. [17] reported the flexural performance of POC concrete beam that shows the similar behavior compared to the study of Teo et al. [15]. Although palm oil clinker concrete (POCC) has a low modulus of elasticity, the deflection of singly reinforced POCC beams, with reinforcement ratio less than 0.524 under the design service load satisfied BS 8110 [16] code.

However, previous studies used OPS or POC separately to produce lightweight concrete. In this research, a combination of OPS and POC has been employed for the production of consistent and improved structural lightweight aggregate concrete having the compressive strength of 46 MPa. This new structural-grade lightweight aggregate concrete will be termed as palm shell and clinker concrete (PSCC). Lightweight PSCC is still a new in construction industries and the structural performance of the concrete has not yet been investigated. Therefore, the flexural behavior of singly reinforced PSCC beams is being examined and clearly established.

2. Test program

2.1. Materials

2.1.1. Cement

For this experimental program, Ordinary Portland cement (ASTM: Type-I) was used as the binder materials in the concrete which has the specific gravity of 3.14 g/cm^3 and fineness of 3510 cm^2/g. This cement was collected from the Malaysian local market. The 7 and 28-day compressive strength of the cement was 34.2 and 45.9 MPa, respectively.

2.1.2. Fine aggregate

Local mining sand was used as a fine aggregate in the concrete mix which has the specific gravity of 2.68 and a fineness of modulus of 2.65. The maximum nominal grain size of this fine aggregate was 4.75 mm.

2.1.3. Coarse aggregate

Two types of coarse aggregates were used in the concrete mix for this study which was collected as the solid waste from the local palm oil producing factory in Malaysia (Fig. 1). One of them is OPS aggregate and another type of coarse aggregate is POC aggregates. The OPS aggregate from crashing the original larger OPS aggregate can be an appropriate method to enhance the compressive strength of lightweight OPS concrete [18]. Therefore, after collecting the OPS from the local palm oil producing factory, it was washed and crashed using a stone-crashing machine in the laboratory. The flakiness of OPS significantly decreased upon crashing, which improved the performance of the coarse aggregates and yielded higher compressive strength. Later on, crashed OPS aggregates were sieved using a 9.5 mm sieve to remove OPS aggregates with sizes lower than 9.5 mm. The size of OPS aggregate retained on the 9.5 mm sieve are 9.5 mm and larger. The mechanical properties of crashed OPS are given in Table 1. The POC had also been collected from the local palm oil manufacturer in Malaysia. The clinkers were crashed and sieved by 9.5 mm-sieve. As the larger size aggregate has the greater value under abrasion test, POC

(a) (b)

Fig. 1. Coarse aggregate (a) OPS aggregate (b) POC aggregate.