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Ductility performance of lightweight concrete element containing massive palm shell clinker

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HIGHLIGHTS

- Aggregate replacement up to 70.5% by agricultural waste materials.
- Ecofriendly and economic concrete for heavily loaded structure.
- Significantly higher modulus of resilience and toughness of PSC concrete than NWC.
- Higher Displacement and torsional ductility of PSC concrete element compared to NWC element.
- Torsional ductility always higher than displacement ductility of PSC concrete element.

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ABSTRACT

Lightweight and high strength concrete are commonly needed for a variety of structural applications. Structure with lightweight concrete should assure adequate performance of member under heavy loading. In this study, experimental investigations have been conducted to study the displacement ductility and torsional ductility of lightweight concrete element containing high volume of waste materials. Crushed oil palm shell (OPS) is used as coarse aggregate in different mixes and palm oil clinker (POC) as fine aggregate for sand replacement. In this experiment using those waste materials palm shell clinker (PSC) concrete has been produced. Furthermore modulus of elasticity, modulus of resilience, modulus of toughness, stress–strain and torsional behavior of PSC concrete are obtained and compared with normal weight concrete (NWC) and POC lightweight concrete. The study reveals that PSC concrete, in contrast to various types of structural lightweight concrete (LWC) and NWC, is a ductile material in structural element. Though the modulus of elasticity of PSC concrete is 30% and 37% of NWC and POC lightweight concrete respectively, its modulus of resilience and modulus of toughness are significantly higher. The displacement ductility index of PSC concrete element is 2.8 times higher than NWC and POC lightweight concrete. In contrast the torsional ductility index of PSC lightweight concrete element is obtained 3.3 times higher than corresponding concretes. This study found that the torsional ductility of PSC concrete is higher than displacement ductility because of good interlocking properties yet for NWC, displacement ductility is higher than torsional ductility. Furthermore the modulus of toughness of PSC concrete is higher, more energy required to completely break this concrete containing high volume of waste materials. Thus PSC lightweight concrete may be more suitable than NWC and POC lightweight concrete in the earthquake-resistance of concrete structures subjected to compressive and torsional loading structure.

1. Introduction

In various structural application lightweight and high strength concrete are expected to reduce the weight and size of structural elements. Those concrete are commonly used in slabs and joists in high rise buildings and bridge decks in highway bridge structures as well as offshore and marine structures. Knowledge on lightweight aggregate (LWA) concrete is inevitable [1] for advantageous construction of such structural elements. In design, a structural engineer should not afford only strength acceptability but should also assure that the member shows acceptable ductility under heavy loading [2]. Though satisfactory ductility is vital for constructions in high seismic areas, numerous and serious

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difficulties relating to the behavior of reinforced concrete structures under severe seismic action can be traced to the poor characteristics of reinforced concrete when subjected to compression and torsion. It is well recognized that the failure of concrete is sudden and brittle in nature in case of diagonal tension [2]. For example, the pattern of diagonal tension failure of torsion critical concrete element is brittle and the element fails with little or no warning which is similar to the diagonal tension failure of shear critical member [2]. However, ductility of concrete ensures safe escape from a structure in the event of serious overstress, such as from blast or earthquake. Khayat et al. [3] shows the RC columns subjected to concentric compression to be more ductile in the case of self-compacting concrete (SCC), than in similar normal concrete (NC) columns. These observations can be usefully applied in designing reinforced concrete (RC) compressed columns and torsional beam in seismic regions [4]. In fact, according to Eurocode 8 [5], the lack of attaining required ductility causes a compensation for the loss of resistance due to crushing.

Ductility of LWC is important because it gives desired warning before ruin of the structure. Recently several investigators [6–15] have carried out experiment on LWC using available local waste materials. The country like Malaysia produces a lot of waste materials in palm oil industries such as oil palm shell, and palm oil clinker. Malaysia is the second largest palm oil producing country in the world and it produces more than half of world's palm oil. Every years Malaysia produce 4.0 million ton oil palm shell and a huge amount of palm oil clinker as waste materials. Oil palm shell (OPS) and palm oil clinker (POC) both are reusable source of lightweight aggregate (LWA) from the agricultural waste in palm oil industries. Contemporary studies have shown that OPS and POC can be used as LWA for producing structural LWC with compressive strength in the range of 17–53.6 MPa which is a range of normal strength to high strength ranges of LWC. Although previous researches have shown separately that OPS or POC can be successfully used as structural LWC [6,12,14–18], the LWC is still not a common construction material in the construction industry and there has been some reticence concerning its use in concrete structures.

Teo et al. [17] have shown that the LWC beams containing 0.52% and 0.75% reinforcement ratios fulfilled the maximum tolerable deflection as per BS 8110 [19] code requirement at service loads. Incorporation of a 1.13% reinforcement ratio noted deflection exceeding the maximum limit. They suggested that larger beam cross-sections should be well-thought-out to satisfy the deflection criteria. Mohammed et al. [15] found that palm oil clinker concrete (POCC) beam satisfies the deflection criteria of BS8110 code up to 0.54% of reinforcement. The Grade 30 OPS concrete shows 24% higher shear strength than normal weight concrete [20]. However, the ductility of those structures is very important to sustain in condition of earthquake and impact loading [21,22]. Even the torsional ductility of lightweight concrete was rarely studied in the previous literatures. In this study, the displacement ductility and torsional ductility of PSC lightweight concrete have been studied for high volume of waste materials replacement and compared to POC lightweight concrete as well as normal weight concrete.

Hence the objective of the study is to investigate the ductility behavior of light weight concrete element containing high volume of waste materials. Complete and stable stress–strain curves and torque vs. angle of twist curves were obtained. The deformation characteristics can be measured by the displacement ductility index and torsional ductility index, which is defined later in the paper. For the range of variables tested, the results indicate that increasing POC as sand replacing materials decreases the displacement and torsional ductility index of compression critical and torsion critical members as well as decreases compressive strength. The PSC concrete shows better ductility than NWC and POC lightweight concrete. On the other hand the torsional ductility is constantly higher than displacement ductility for PSC lightweight concrete, though for NWC torsional ductility is less than the displacement ductility.

2. Methodology

In this study the displacement ductility and torsional ductility of structural element were investigated. To carry out the investigation, high volume of waste materials as aggregate replacement was considered. Details of materials used and experimental works are given in the following section.

2.1. Materials used

2.1.1. Cement

The Ordinary Portland Cement (OPC) was used with a specific gravity of 3.14 g/cm^3 for all the specimens. The class of OPC was 45.9 MPa is type I OPC cement. The Blaine's specific surface area of the cement was 3510 cm^2/g.

2.1.2. Superplasticizer (SP) and water

Sika viscocrete®-2199 as a high range water reducing admixture was used in the study, supplied by Sika Kimia. This admixture is chloride free according to BS 5075 and is compatible with all types of Portland Cement including Sulfate Resistant Cement (SRC). The super plasticizer was used as 1% of cement weight.

2.1.3. Aggregates

Local mining sand with a specific gravity, fineness modulus, water absorption and maximum grain size of 2.66, 2.89, 1.17% and 4.75 mm, respectively, was used as fine aggregate. OPS and POC aggregates are considered as a renewable source of aggregate from waste materials which were collected from a local palm oil factory. The POC was obtained in large chunks during the oil palm shell and fiber incineration process [23]. POC was washed and dry after collecting from the palm oil factory. Then it was crushed with the stone crushing machine in the laboratory. The crushed POC was sieved with 9.5 mm and 4.75 mm sieve, then particles below 4.75 mm is considered as fine aggregate, as well as above 4.75 mm particles is considered as coarse aggregate. Palm oil clinker was used as 25%, 37.5% and 50% by volume of sand replacement. Moreover, the POC fine aggregates have specific gravity, fineness modulus and water absorption of 2.08, 3.12 and 3.61% respectively. Also the chemical composition of POC and OPS waste materials is shown in Table 1.

Another two types of coarse aggregate used in the study are OPS and granite. All the aggregate ranges were considered in same size. As in previous researches [6–8,10,13,24] OPS in different shapes were used as the coarse aggregate. The OPS were collected from a local crude palm oil producing mill. Then it is stored in an open train about six months to wash the oil and remove the ash from the shell. The advantages of using old OPS in concrete were reported by Shafigh et al. [13]. The measured ranges of shell thickness were 0.45–4.05 mm which is in the ranges shown by Shafigh et al. [11]. Its flakiness index is high, about 65% of that obtained by Mannan and Ganapathy [9]. Flakiness of OPS is significantly decreased due to crushing its larger sizes, which results in a better performance of coarse aggregate and consequently improved the compressive strength of concrete. After collecting OPS from the industry is keep in open train at least to remove the oil and fiber from the surface of OPS. Then it was washed and dried, after drying it was crushed with the stone crushing machine in the laboratory. The crushed OPS was sieved with 4.75 mm and 9.5 mm sieve. The particles in between the range of 4.75 mm and 9.5 mm were considered as coarse aggregate as the same size of POC coarse aggregate. All the coarse aggregates were submerged under water for 30 min before mixing because of those lightweight aggregates are high water absorbing materials. After that they were moved from the water and kept in open-air to remove free

Table 1
Chemical composition of POC and OPS waste materials.

Oxides	SiO_2	K_2O	CaO	P_2O_5	MgO	Fe_2O_3	Al_2O_3	SO_3	Na_2O	TiO_2	Cr_2O_3	Others
POC	59.63	11.66	8.16	5.37	5.01	4.62	3.7	0.73	0.32	0.22	–	0.58
OPS	46.61	9.88	14.76	1.95	2.91	10.19	3.33	7.84	1.15	–	1.38	–