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Technical note

Shear behaviour and mechanical properties of steel fibre-reinforced cement-based and geopolymer oil palm shell lightweight aggregate concrete

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HIGHLIGHTS

- Shear behaviour of steel fibre cement-based and geopolymer OPS LWAC investigated.
- Mechanical properties comparison of steel fibre cement-based and geopolymer LWAC.
- Tensile strength and toughness increase more evident for cement than geopolymer LWAC.
- Shear capacity improved with fibres and existing prediction equations are conservative.

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ABSTRACT

The shear behaviour and mechanical properties (compressive, splitting tensile and flexural strengths) as well as the flexural toughness of steel fibre-reinforced cement-based and geopolymer oil palm shell lightweight aggregate concrete (OPS LWAC) were experimentally investigated in this paper. Steel fibres were added at various volume fractions for the cement-based OPS LWAC (0%, 0.5% and 1.0%) and geopolymer OPS LWAC (0%, 0.5%). Test results showed that steel fibre improved the mechanical properties of concrete, particularly for the splitting tensile strength whereas flexural toughness enhancement with the use of steel fibres was more evident for the cement-based OPS LWAC than the geopolymer concrete. The shear resistance of OPS LWAC beams was also found to improve with the addition of steel fibres and existing prediction equations for shear capacity of steel fibre-reinforced lightweight concrete was determined to be conservative for the steel fibre-reinforced cement-based and geopolymer OPS LWAC.

1. Introduction

Utilization of lightweight aggregate concrete (LWAC) exerts certain advantage over normal concrete (NC) in structural members, such as reduction in self-weight, favourable effects towards seismic forces and foundation of buildings supported by soil with low bearing capacity [1]. Commonly used lightweight aggregate includes expanded clay and expanded shale while recent researches in South East Asia also suggested the alternative of incorporating oil palm shell (OPS) – a solid waste material from agriculture industry – as lightweight aggregate to produce structural LWAC [2]. The potential saving in transportation costs for pre-fabricated LWAC members has since encouraged the development of geopolymer OPS LWAC [3]. This is because apart from the elimination of cement usage, one of the greatest benefits of geopolymer concrete is the short curing time and early strength gain, which is suitable for pre-fabricated concrete products.

However, LWAC often failed in a more brittle manner than NC. Shear failure of LWAC members is known to be one of the major problems that cause collapse of structures [4]. Besides that, the use of weaker lightweight aggregate is likely to cause reduction in aggregate interlocking effect in LWAC which could further reduce the shear capacity of reinforced concrete member [5]. Smooth shear failure paths were observed in LWAC [4] due to reduced aggregate interlocking effect as a result of cleavage of lightweight aggregate [6]. Kim and Jang [7] also found that the shear strength of LWAC beam reinforced with FRP bars were lower compared to the corresponding NC beam. Therefore, it is desired to increase the ductility of LWAC through the incorporation of steel fibres. Combination of steel fibres with reinforcement is ideal due to the enhanced toughness of material which reduces crack width and increases tension stiffening [1].

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In the past, it was found that the inclusion of steel fibres had beneficial effects in enhancing the flexural toughness of LWAC, such as those from expanded clay [8] and sintered pulverized fuel ash aggregates [9]. Moreover, steel fibre-reinforced LWAC was found to exhibit superior mechanical properties than plain LWAC, particularly the splitting and flexural tensile strengths. It was reported that the enhancement in the splitting and flexural tensile strengths to range between 61–140% and 117–200%, respectively when steel fibre of between volume fractions of 0.5–2.0% were added into concrete prepared with lightweight coarse aggregate such as pumice [10], shale [11], expanded clay [12] and cold-bonded fly ash [13]. When reinforced concrete structural beam was considered, Kang et al. [14] observed a 30% increment in the shear strength capacity of LWAC beams when 0.75% steel fibres were added. Swamy et al. [15] found out that the increase in shear capacity of lightweight concrete I-beams could be increased between 60 and 210% in the presence of 1.0% steel fibres. Shoiab et al. [6] also reported that the shear failure was more ductile and experienced greater crack widening in the case of steel fibre-reinforced LWAC beam compared to the beam without fibres. This was attributed to the pulling out of the steel fibres from the cement matrix and such ductile failure could provide important warning about the imminent shear failure.

Past researches have shown similar encouraging performances of steel fibre-reinforced OPS cement-concrete as well as the resultant reinforced concrete structures [16]. On the other hand, there are only limited literature available regarding the performance of steel fibre-reinforced geopolymer concrete, with Ganesan et al. [17] and Ng et al. [18] carried out research work on enhancing the mechanical properties and shear capacity of geopolymer NC, respectively through the use of steel fibres.

There is no previous research done on improving the shear behaviour of OPS LWAC as well as the corresponding geopolymer concrete through the use of steel fibres. Hence, this paper describes a comparative study on the shear behaviour of cement-based and geopolymer OPS LWAC with and without added steel fibres. In addition, the relevant mechanical properties and flexural toughness of the concretes are discussed.

2. Research significance

LWAC is known to have lower shear capacity compared to NC and hence this study aims to explore the effectiveness of steel fibre in enhancing the shear capacity of concrete made with local OPS waste as lightweight aggregate. While there are some studies of steel fibre-reinforced NC and other types of LWAC, it is important to ascertain the efficiency and thus the feasibility of incorporating steel fibres in OPS LWAC. In addition, with the growing trend of research in sustainable cement-less geopolymer concrete, the investigation of the effect on the shear and mechanical performances due to the addition of steel fibres could provide a platform for the development of geopolymer concrete as a future construction material.

3. Experimental programme

3.1. Materials and mix proportion

Coarse and fine aggregate used for this study were crushed OPS aggregate (2.36–9 mm) and local mining sand (0.3–5 mm), respectively. The sieve analysis of OPS aggregate and local mining sand is shown in Fig. 1. The specific gravity of the coarse and fine aggregates was 1.35 and 2.60, respectively. Crushed OPS were pre-soaked in water and used in saturated surface dry condition for casting of concrete.

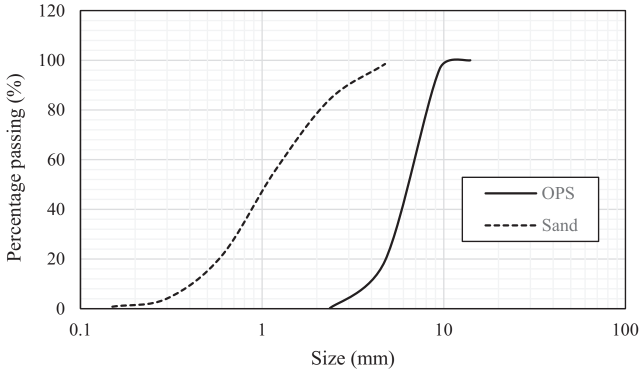

Fig. 1. Sieve analysis of OPS and mining sand.

For the cement-based OPS LWAC, the binding material was ordinary Portland cement (OPC) while the binding material for the geopolymer OPS LWAC was Class-F fly ash, activated with the combination of 14 M NaOH and liquid Na_2SiO_3 at a ratio of 2.5.

Laboratory pipe water was used as mixing water for both mixes and a polycarboxylate ether-based superplasticizer (SP) was added in the case of cement-based OPS LWAC to facilitate workability.

Hooked-end shape steel fibres of 35 mm length and aspect ratio of 65 were used as fibre reinforcement. High-yield steel bar of grade 500 MPa with diameter of 12 mm was used as main reinforcement in reinforced concrete beam.

Table 1 shows the mix proportions of the cement-based and geopolymer OPS LWAC, respectively. The mix proportions were chosen based on trial mixing to obtain targeted cube compressive strength of 30 MPa for the concretes without fibres. For the cement-based OPS LWAC, there are three different steel fibre contents, namely 0%, 0.5% and 1.0% addition by volume whereas for the geopolymer OPS LWAC, there is the control specimen without fibre and specimen with 0.5% steel fibre volume. Based on trial mixing, due to the viscosity of the geopolymer OPS LWAC, it is impractical to incorporate 1.0% steel fibre volume and hence such mix was omitted from the investigation. Fig. 2 shows the preparation of geopolymer concrete.

3.2. Specimen testing

After de-moulding, the cement-based OPS LWAC specimens were subjected to water-curing for 28 days before testing while the geopolymer OPS LWAC specimens were heat-cured for 24 h at temperature of 65 °C followed by air-curing in laboratory conditions until day 28 for testing.

Mechanical properties tests such as cube compressive strength, splitting tensile and flexural strength tests were carried out in accordance with BS EN 12390-3: 2002, BS EN 12390-6: 2000 and BS EN 12390-5: 2000, respectively. Prism specimens measuring $100 \times 100 \times 500$ mm^3 were tested for flexural toughness based on ASTM C1018-97.

For the testing of the shear behaviour, reinforced concrete beam with cross-section area of 150 mm × 150 mm and length of 1300 mm was cast. The longitudinal reinforcement consisted of 2 steel rebar of 12 mm diameter and the concrete cover was 25 mm. No shear link was provided for the beam. The loading arrangement for the shear-critical reinforced concrete beam is shown in Fig. 3. Loading from actuator was transferred to the beam via a spreader beam of 700 mm length. The loading rate was fixed at 2 mm/min and the mid-span deflection of the beam was measured using a LVDT.