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Structural behaviour of composite sandwich panels with plain and fibre-reinforced foamed concrete cores and corrugated steel faces

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ABSTRACT

This paper studies the four-point bending response and failure mechanisms of sandwich panels with corrugated steel faces and either plain or fibre-reinforced foamed concrete core. Mechanical properties of both plain and polyvinyl alcohol fibre-reinforced foamed concrete were obtained, which are needed for the design of sandwich panel and numerical modelling. It is found that the fibre-reinforcement largely enhances the mechanical behaviour of foamed concrete and composite sandwich panels. Finite element code Abaqus/Standard was employed to investigate the influence of face/core bonding and fastening on the four-point bending response of the sandwich panels. It was found that face/core bonding plays a crucial role in the structural performance while the influence of fastening is negligible.

1. Introduction

Foamed concrete is a type of cellular solid comprised of cement mortar matrix and air-void of minimum 20% in volume. It is made by incorporating air-voids into the cement matrix using preformed foam. Foamed concrete is a lightweight, low cost and easy-to-manufacture material with good workability and excellent performance on thermal insulation, acoustic insulation, fire resistance, corrosion resistance and shock absorption [1–4]. However, foamed concrete is not used as structural material due to its low compressive strength.

Inclusion of fine aggregates in the mortar matrix to improve the mechanical properties of foamed concrete has been investigated by several researchers [2,3]; however, studies of the use of fibre-reinforcement in foamed concrete are very limited. Zollo [5,6] reported that polypropylene fibre-reinforced cellular concrete with density of 640 kg/m^3 presented a significant improvement of mechanical and impact properties. It was shown that the fibre reinforcement can change the typical brittle behaviour of cellular concrete into ductile elastic–plastic behaviour [6], which has been also observed for lightweight concrete reinforced by steel fibres [7]. Jones and McCarthy [2] reported that the compressive strength of polypropylene fibre-reinforced foamed concrete exhibited an increase of 52% when compared to the unreinforced foamed concrete. High-performance fibres have also been used to reinforce lightweight concrete. Arisoy and Wu [8,9] used polyvinyl alcohol fibres as reinforcement for aerated concrete with density of 800–1600 kg/m^3. They found that the fibre-reinforced aerated concrete showed increases of flexural strength, flexural ductility and toughness when compared to plain aerated concrete.

The capacity of foamed concrete in structural applications has not been fully investigated. Due to its low density and low strength characteristics, it is an ideal core material for composite sandwich structures. Othuman Mydin and Wang [10] studied sandwich panels made with profiled thin steel face sheets (0.4 mm thickness) and foamed concrete core under uniaxial compression. Uddin et al. [11] investigated the flexural behaviour of composite panels made with carbon fibre reinforced polymer face sheets and autoclaved aerated concrete core. It was found that the flexural strength of the panels is increased considerably when compared to the strength of the autoclaved aerated concrete.

This research is motivated by the lack of knowledge in the study of fibre-reinforced foamed concrete and composite sandwich panels with foamed concrete core for structural applications. In this work, tensile and compressive properties of plain foamed concrete and polyvinyl alcohol fibre-reinforced foamed concrete are presented. Two different methods are used to obtain compressive properties of foamed concrete and their results are discussed. Sandwich panels with corrugated steel faces and either plain or fibre-reinforced foamed concrete core are studied. The behaviour of the sandwich panels in four-point bending test is described and the various failure mechanisms observed in the test are reported. Finite element method was employed to understand the influence of face/core bonding and fastening on the four-point bending response of the sandwich panels. Materials and experimental details are described in Section

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Table 1
Mix constituent proportions of foamed concrete for 1 m^3.

Constituent material	Content
Cement (kg)	539.58
Dry sand (kg)	269.79
Water (*l*)	269.79
Foaming agent (*l*)	0.74
Water for foaming agent (*l*)	25
Foam required in the mix (*l*)	469.96

Table 2
Polyvinyl alcohol fibre properties from the manufacturer [12].

Diameter (mm)	Length (mm)	Density (kg/m^3)	Tensile strength (GPa)	Young's Modulus (GPa)
0.04	8	1260	1.6	40

2. The experimental results and discussion are presented in Section 3. Numerical simulations are described in Section 4, which is followed by conclusions in Section 5.

2. Materials and methods

2.1. Foamed concrete

The foamed concrete mix design used in this study is shown in Table 1. The mixture was prepared using ordinary Portland cement, sand, water and foam. The mixture in Table 1 is referred as plain foamed concrete (PFC). Fibre-reinforced foamed concrete (FRFC) was prepared using the same mix design in Table 1 with Table 3. 3% volume fraction of polyvinyl alcohol (PVA) fibre. Dry density of 1000 kg/m^3 was targeted in this study for both PFC and FRFC. The actual density of the samples was measured.

2.2. Foamed concrete preparation

Foamed concrete is prepared in a procedure consisting of three stages, i.e., (i) slurry preparation, (ii) foam preparation, and (iii) mixing of slurry and foam. The slurry was prepared from ordinary Portland cement, sand and water mixed in a 300-l cement mixer. Water:cement ratio of 0.5 and sand:cement ratio of 0.5 were used (Table 1). The wet density of the slurry was 2036 kg/m^3. The foam was prepared separately using EABASSOC foaming agent and a foam generator Portafoam PM2 system. To prepare the foam, the foaming agent is added to the water in the quantities indicated in Table 1. This mixture is then poured in the foam generator container. The container is pressurised to 0.414 MPa (60 psi) which produces a foam density of 70–80 kg/m^3. Finally, the foam is poured into the mixer until a targeted wet density of 1150 kg/m^3 is achieved. For FRFC, 8-mm PVA fibres type RECS15 with diameter of 0.04 mm supplied by Kuraray Co. were used. PVA fibre properties from the manufacturer are shown in Table 2 [12]. The FRFC was prepared using the same aforementioned procedure for PFC with 3.3% volume fraction of PVA fibre added to the slurry.

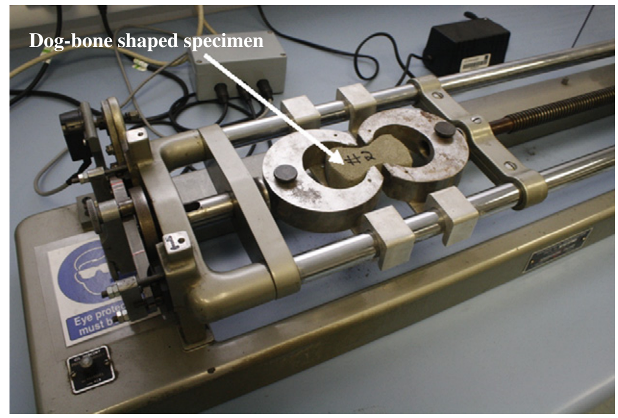

Fig. 1. Tensile test set-up.

2.3. Mechanical characterisation of foam concrete

Due to the brittle nature of foamed concrete, two different tests were performed to obtain compressive properties, i.e., (i) uniaxial compression test, and (ii) indentation test for both PFC and FRFC. In addition, tensile properties were obtained using dog-bone shaped specimens tested in uniaxial tension. All specimens were left to cure for at least 28 days before testing.

2.3.1. Uniaxial compression test

Uniaxial compression tests were performed according to BS-EN-12390 using an Instron servo-hydraulic machine at fixed displacement rate of 5 mm/min. Three cubes with dimensions of 100 × 100 × 100 mm were tested.

2.3.2. Indentation test

For indentation tests, three cylinders of 100-mm thickness and diameter of 150 mm were manufactured. A 20-mm diameter flat nosed indenter was mounted in an Instron servo-hydraulic machine and the load was applied at a nominal displacement rate of 5 mm/min. The indentation test allows for the tested material to be confined by the surrounding material whilst the compression load is being applied.

Table 3
Mechanical properties of PFC and FRFC.

Properties	PFC	FRFC
Uniaxial compression elastic modulus (MPa) E	1002.19 ± 60.47	1228.93 ± 59.45
Uniaxial compression strength (MPa) σ_c	4.78 ± 0.57	8.83 ± 0.35
Uniaxial compression yield strain (%) ε_{yc}	0.84 ± 0.06	0.95 ± 0.008
Indentation compressive elastic modulus (MPa) E_i	1358.67 ± 106.79	2148.8 ± 131.85
Indentation compressive strength (MPa) σ_{ci}	9.34 ± 0.3	11.17 ± 1.58
Indentation compressive yield strain (%) ε_{yi}	1.44 ± 0.1	0.67 ± 0.05
Tensile elastic modulus (MPa) E_t	3.48 ± 0.09	9.34 ± 1.1[a]
Tensile strength (MPa) σ_t	0.272 ± 0.018	1.79 ± 0.22[a]
Tensile yield strain (%) ε_{yt}	8.15 ± 0.21	20.75 ± 1.06[a]

[a] *Note*: specimen #3 was not used in the measurements due to a premature failure.