Engineering Structures 175 (2018) 457–466

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Testing and modeling the behavior of sandwich lightweight panels against wind and seismic loads

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ARTICLE INFO

Keywords:
Sandwich panel
Expanded polystyrene
Lightweight concrete
Calcium-silicate board
Wind velocity
Seismic loading

ABSTRACT

The behavior of non-structural sandwich lightweight panels against wind and seismic loadings is not well understood. Such panels are typically composed of two calcium-silicate board (CSB) wythes separated by a core infill made of expanded polystyrene lightweight concrete (LWC). This paper provides understanding regarding the mechanisms of panel connectivity by tongue-and-groove, including transfer of forces through steel dowels to the existing structure. Series of LWC mixtures having 470 to 975 kg/m^3 density were tested using suitably established testing procedures to determine the flexural strength, core shear strength, interfacial bond between LWC and CSB, and pullout forces transmitted through the steel dowels. Special emphasis is placed on modeling the effect of wind and seismic loads on a 3.6 × 3 m^2 partition wall constructed using LWC sandwich panels. The highest stresses and deformations generated from the model are compared to those determined experimentally, which allowed establishing different charts that can predict the safety factors as a function of LWC density and type/magnitude of the lateral loading applied.

1. Introduction

Expanded polystyrene (EPS) beads are commonly used for producing lightweight concrete (LWC) with enhanced thermal and sound insulations. These thermoplastic polymeric materials are expanded by the use of steam or expansive agents, resulting in a density ranging from 10 to 25 kg/m^3. Generally, it is agreed that workability of fresh concrete increases with such additions, given their spherical shape and hydrophobic nature that reduce internal friction and water absorption in the plastic mixture [1,2]. Fathi et al. [1] estimated that the water-to-cement ratio (w/c) decreased by about 5% when 20% coarse scoria aggregates are replaced by EPS beads having 2–4 mm particle sizes. On the hardened state, it is well established that EPS additions reduce concrete density and mechanical properties such as compressive strength, splitting tensile strength, and modulus of elasticity [3–5]. Babu et al. [6] reported that concrete durability including water permeability and chloride penetration are affected by the size and volume of EPS. The incorporation of silica fume and/or reduction in w/c are beneficial to increase the interfacial bonding between EPS beads and cement paste, which would compensate the drop in strength. Sayadi et al. [7] found significant improvements in thermal conductivity and fire resistance with EPS additions, provided the cement paste is increased in concrete. For given density, Cui et al. [8] concluded that EPS concrete has better ductility and energy dissipation compared to ordinary limestone-aggregate concrete.

It is to be noted that LWC fracture behavior and mechanical properties are substantially different than those resulting from normal-weight concrete [3,9–11]. For example, it is well established that the interfacial transition zone between mortar-aggregate is the limiting strength factor in normal-weight concrete; failure typically occurs in dynamic (explosive) mode with fractured debris. In contrast, the failure becomes more ductile in LWC containing EPS or lightweight aggregates, as specimens are capable of resisting the load for longer periods of time without full disintegration. The reduction in w/c is common to alleviate the detrimental effect of lightweight inclusions, thereby controlling the drop in LWC strength and bond to reinforcing bars [2,11].

The use of EPS-based concrete as core infill in non-structural sandwich lightweight panels found wide acceptance in the construction industry [12–14]. Compared to other partition systems [15], the lightweight sandwich panels present major advantages including enhanced thermal and sound insulations, good resistance to fire, and high durability. As shown in Fig. 1, the panels typically consist of two calcium-silicate board (CSB) wythes separated by the LWC, without any reinforcing steel connectors. These are commercialized in 2400-mm height, 600-mm width, and various thicknesses of 100, 150, 200, and

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https://doi.org/10.1016/j.engstruct.2018.08.041
Received 17 April 2018; Received in revised form 2 July 2018; Accepted 13 August 2018

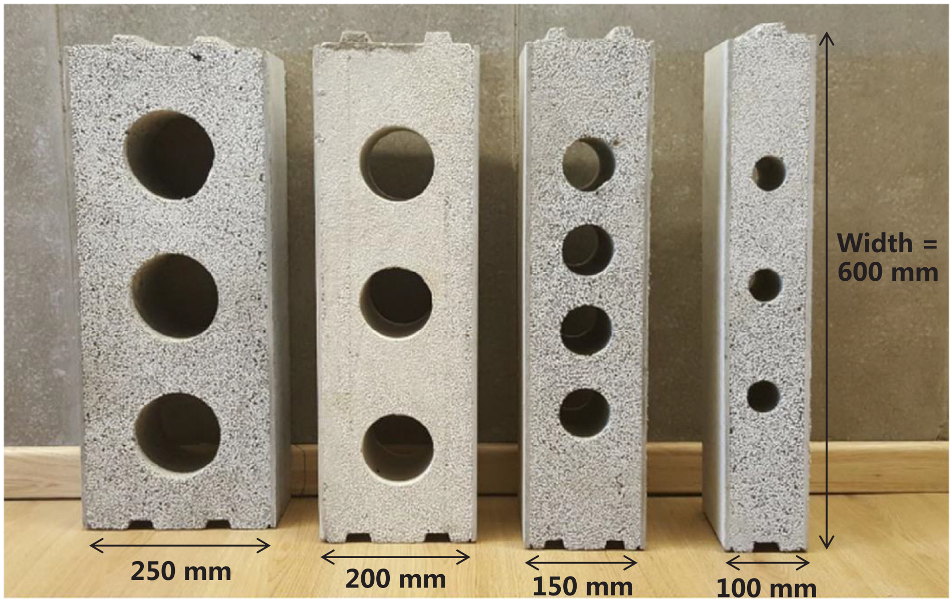

Fig. 1. Typical sections for EPS-based commercialized sandwich panels.

250 mm; which can be placed side-by-side and connected through their tongue-and-groove joints during erection [16]. Generally, one tongue-and-groove joint is created in the 100-mm thick panels, while two joints can be made in thicker panels (Fig. 1). A certain number of holes can be created during manufacturing to lighten the weight of panels and/or facilitate passage of electrical wires and service tubes.

From the design point of view, several investigations have shown that the incorporation of steel connectors (whether inclined, straight, or truss-shaped) during the manufacturing process of sandwich panels can greatly improve the stiffness and flexural behavior of the composite system [17–20]. The purpose of these connectors is to attach the inner and outer CSB wythes together, thus inducing a joint structural behavior between the composite layers and allowing adequate transfer of shear forces resulting from the bending between them. Chen et al. [21] developed an innovative fiber reinforced polymer (FRP) shear plate connector with specially designed anchoring schemes, and studied its effect on flexural behavior of insulated concrete sandwich panels. The authors concluded that the FRP plate can be adequately used to transfer shear between the two concrete wythes, allowing the composite panel to meet the American Code Institute requirements for roof and floor applications.

Limited studies are carried out to understand the behavior mechanisms of un-reinforced sandwich panels during service conditions, including their connectivity through the tongue-and-groove joints as well as their attachment to the existing structure. Recently, Fernando et al. [22] tested the performance of 2400-mm height panels under compressive and flexural loads. The LWC had an average density of 700 kg/m^3; it contained 380 kg/m^3 of cement and 22 kg/m^3 of EPS. The authors reported that the presence of 5-mm thick CSB on either side of the panel allows greater load-carrying capacity due to confinement effects; at failure, the average compressive strength increased from 2.13 to 4.06 MPa for panels made without or with CSB, respectively. The corresponding flexural strength increased from 0.31 to 1.64 MPa, respectively. Fernando et al. [22] concluded that EPS-based un-reinforced sandwich panels can be used as non-load bearing partitions in multi-story buildings, and as load bearing walls in single story constructions.

This paper is part of a comprehensive research project undertaken to assess the performance of non-structural lightweight panels against wind and seismic loads. It is divided in two main parts; the first seeks to evaluate the effect of EPS additions on density and key strength properties of LWC used as core infill in lightweight sandwich panels. Special emphasis was placed on developping suitable testing methods that reflect the behavior of such panels and connectivity to the existing structure during service conditions. Series of regression models are proposed to predict the coupled effect of w/c and EPS content on LWC hardened properties and transfer of forces to embedded steel dowels. The second part of this paper aims at modeling the effect of different amplitudes of wind and seismic loads on the behavior of a 3.6 × 3 m^2 wall constructed using LWC panels. Series of practical charts are proposed to predict the variations of safety factors as function of LWC density. Such data can be of particular interest to construction engineers and consultants dealing with the behavior and safety of lightweight panels during service conditions.

2. Part 1: Experimental program and discussion of results

2.1. Materials

Portland cement conforming to ASTM C150 Type I was used; its Blaine surface area, median particle size, and specific gravity were 3750 cm^2/g, 21.2 µm, and 3.03, respectively. Well-graded siliceous sand complying to ASTM C33 specification was employed as fine aggregate; its bulk specific gravity, absorption rate, and fineness modulus were 2.65, 1.01%, and 2.54, respectively. Naphthalene-based high-range water reducer (HRWR) complying with ASTM C494 Type F was used; its specific gravity, solid content, and maximum dose are 1.19, 39%, and 3.5% of cement mass, respectively.

Commercially available spherical-shaped EPS was used. This white-colored material is obtained by subjecting small expandable thermoplastic polystyrene beads to steam, which causes them to soften and expand in volume to about 3-mm in diameter. The EPS is extremely light (i.e., density of 17 kg/m^3), which makes it suitable for LWC panel production. Its compressive strength at 10% deformation and water absorption after 24-h immersion are 62.5 kPa and 2.1%, respectively. These are determined as per ASTM C165 and C272 Test Methods, respectively.

Commercially available asbestos-free CSBs are used for testing; their thickness, modulus of rupture, and modulus of elasticity are 6.6 mm, 11.4 MPa, and 8.86 GPa, respectively. The CSBs possess relatively low density of 750 kg/m^3, making them good thermal and sound insulators. These exhibit no or minimal shrinkage up to a maximum exposure temperature of 850 °C. The thermal conductivity of the composite