Engineering Structures 41 (2012) 320–334

Contents lists available at SciVerse ScienceDirect

Engineering Structures

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

Structural behavior and modeling of full-scale composite structural insulated wall panels

Mohammed A. Mousa [a,b], Nasim Uddin [a,*]

[a] Department of Civil, Construction and Environmental Engineering, University of Alabama at Birmingham, Birmingham, AL 35294-4440, United States
[b] Department of Civil Engineering, Faculty of Engineering at Shoubra, Benha University, Cairo, Egypt

ARTICLE INFO

Article history:
Received 27 April 2010
Revised 12 March 2012
Accepted 12 March 2012
Available online 4 May 2012

Keywords:
Sandwich structures
Thermoplastic composites
Wall testing

ABSTRACT

This paper investigates the structural behavior of a new type of Composite Structural Insulated Panels (CSIPs) for load-bearing wall applications. The proposed composite panel is made of low cost orthotropic thermoplastic glass/polypropylene (glass-PP) laminate as a facesheet and Expanded Polystyrene Foam (EPS) as a core. The proposed CSIP wall is intended to overcome problems of the traditional Structural Insulated Panels (SIPs). These problems include termite attack, disintegration due to flood water, mold buildups and poor penetration resistance against wind borne debris. Full scale experimental testing for three CSIP panels was conducted to study the behavior of CSIP walls under eccentric load. Further, pull off strength tests were conducted to determine the bonding strength between the glass-PP facesheet and EPS foam core. Facesheet/core debonding was observed to be the general mode of failure. This study provides also analytical models to predict the interfacial tensile stress at the core/facesheet interface, critical wrinkling stress and deflections for a structural CSIP wall member. In addition, finite element modeling was also conducted using ANSYS software in order to model the response of CSIPs walls under in-plane loading. Experimental results were validated using the proposed analytical models and FE modeling, and were observed to be in good agreement. Furthermore, a parametric FE study was conducted to investigate the influence of key design parameters on the behavior of CSIPs. The study showed that span-to-depth ratio and core density have a significant effect on the structural performance of CSIP wall panels.

1. Introduction

Traditional Structural Insulated Panels (SIPs) are made of wood-based facing and foam core. These SIPs are often subjected to termite attack, mold buildups, rotting and have poor penetration resistance against wind borne debris. So the need for an effective alternative became an urgency. Composites are a great candidate to replace the traditional panels for housing applications. This paper presents a new composite panel system: Composite Structural Insulated Panels (CSIPs) which were developed by the authors. CSIPs are made of low cost orthotropic thermoplastic glass/polypropylene (glass-PP) laminate as facesheets and Expanded Polystyrene Foam (EPS) as a core. CSIPs take the concept of the sandwich construction that consists of two strong, thin facings and a soft lightweight thicker core. The facesheets carry the bending stresses while the thick core resists the shear loads and stabilizes the faces against bulking or wrinkling [1]. The core also increases the stiffness of the structure by holding the facesheets apart. Core materials normally have lower mechanical properties compared to those of facesheets. Despite the high strength resulting from this combination, deflection and debonding are other significant aspects that are considered in the design of CSIPs [2]. Several investigations have been conducted at the University of Alabama at Birmingham (UAB) by the authors and others on developing composite panels for building applications using rigid and soft cores with thermoset and thermoplastic facesheets [2–8]. It was demonstrated by these studies that the developed panels can provide much higher strength, stiffness, and creep resistance than traditional ones that are made with wood-based facing. The developed CSIPs have a very high facesheet/core moduli ratio ($E_f/E_c = 12{,}500$) compared with the ordinary sandwich construction where the ratio is normally limited to 1000 [1]. Further, CSIPs are characterized by low cost, high strength to weight ratio, and lower skill required for field construction, etc. These panels can be used for different elements in the structure, including structural elements (e.g., load bearing walls, floors, and roofs) and non-structural elements (e.g., non-load bearing walls, lintels, and partitions).

Many theoretical and experimental studies have been conducted on sandwich construction to investigate their behavior under different types of loadings including in-plane and out-of-plane loadings. A general review of failure modes of composite sandwich beams

* Corresponding author.
E-mail addresses: mmousa@uab.edu (M.A. Mousa), nuddin@uab.edu (N. Uddin).

0141-0296/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.engstruct.2012.03.028

construction was given by Daniel et al. [9] while those of sandwich wall were given by Gdoutos et al. [10]. Failures modes for sandwich beams include yielding of facesheet in tension, core shear failure, and local buckling of facesheet in compression which is known as wrinkling of facesheets. Failure modes of sandwich wall include global buckling, local buckling "wrinkling", and core failure. In case of global buckling, the core may exhibit a substantial shearing deformation whereas in case of local buckling the core acts as an elastic foundation for the facesheets in compression [11,12]. The local buckling can be outward or downward. Outward buckling is known as debonding whereas downward buckling is known as core crushing. The former occurs in case of a sandwich panel with closed cell cores (e.g., EPS foam) while the latter is more characteristic of sandwich panels with open cell cores (e.g., honeycomb core) [13]. Among the first to study the behavior of sandwich panels were Gough et al. [14] and Hoff and Mautner [15]. They tested sandwich specimens under compressive loading and observed that the general mode of failure was facesheet wrinkling. They also developed formulas to predict the stress in the facesheet at wrinkling. These formulas were then modified to fit the experimental results. The results showed that the wrinkling stress is independent of loading and boundary condition and mainly depends on the facesheets and core moduli. The objectives of the current work are: to investigate the structural behavior of full scale CSIP walls under eccentric loading; to develop models to determine stresses associated with debonding, and to develop a model for equivalent CSIP wall stiffness considering the core deformation effects to determine the deflection of a CSIP wall member.

2. Materials and specimens

CSIP walls that are developed and evaluated in this study are made of low cost thermoplastic glass/polypropylene (glass-PP) laminate as a facesheet and Expanded Polystyrene Foam (EPS) as a core (Fig. 1). Thermoplastics (TP) polymers offer advantages in terms of short processing time, extended shelf life, and low-cost raw material. TP also possess the advantages of high toughness, superior impact property, and ease of reshaping and recycling over thermoset polymer composites.

Thermoplastic laminates used in this study consist of 70% bi-directional E-glass fibers impregnated with poly-propylene (PP) resin. Thermoplastic composites are produced using a hot-melt impregnation process, also called a DRIFT process [16]. In this research, the 3.04 mm (0.12 in.) thick glass-PP composite sheets were directly obtained from the manufacturer [17]. The mechanical properties of glass-PP composites used in this research are listed in Table 1.

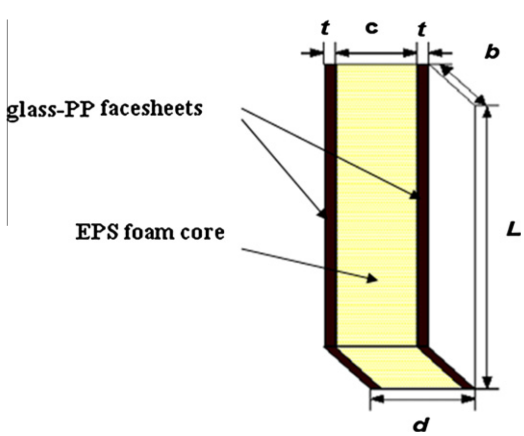

Fig. 1. Schematic diagram for the proposed CSIPs wall.

Table 1
Properties of the glass-PP facesheets.

Nominal thickness, t	0.12 in. (3.04 mm)
Weight% of glass fiber	70%
Density (ρ_f)	61 PCF (980 kg/m^3)
Longitudinal modulus (E_x)	2,200,000 psi (15, 169 MPa)
Transverse modulus (E_y)	2,200,000 psi (15, 169 MPa)
Through thickness modulus (E_z)	149, 350 psi (1030 MPa)
υ_{xy}	0.11
υ_{yz}	0.22
υ_{xz}	0.22
G_{xy}	261,000 psi (1800 MPa)
G_{yz}	108, 750 psi (750 MPa)
G_{xz}	108, 750 psi (750 MPa)
Tensile strength	46,000 psi (317 MPa)
Flexural strength	60,000 psi (414 MPa)

Table 2
Properties of the EPS core.

Nominal thickness, c	5.5 in. (140 mm)
Density (ρ_c)	1 PCF (16 kg/m^3)
Elastic modulus (E_c)	180–220 psi (1.2–1.5 MPa)
Flexural strength	25–30 psi (0.1–0.2 MPa)
Shear modulus (Gc)	280–320 psi (1.9–2.2 MPa)
Shear strength	18–22 psi (0.1–0.15 MPa)
Tensile strength	16–20 psi (0.11–0.14 MPa)
Compressive strength	10–14 psi (0.07–0.1 MPa)
Poisson's ratio	0.25

Table 3
Dimensions CSIP wall panels.

Facesheet thickness (t)	0.12 in. (3.04 mm)
Core thickness (c)	5.5 in. (140 mm)
Total thickness (d)	5.74 in. (146.08 mm)
Width (b)	48 in. (1219.2 mm)
Length (L)	96 in. (2438.4 mm)

Foam is a material characterized by low cost and low weight. It also has good fire and thermal resistance as well as excellent impact properties. Because of these properties, it works very well as an insulation material. There are many types of foams, such as Polystyrene, Polyethylene, and Polyurethane foam. These types vary in both properties and cost. Because of the lower cost, Expanded Polystyrene Foam (EPS) was selected for use as a core for CSIPs. Table 2 describes the properties of the EPS foam used in this study as provided by the manufacturer [18]. All these properties lead finally to the high performance of the panels. The glass-PP facesheets were bonded to the EPS core using a hot-melt thermoplastic spray adhesive. This method of manufacturing is fast and less labor intensive than manufacturing of traditional SIPs. To ensure quality of processing, CSIPs wall panels tested in this study were manufactured at a casting and molding facility (Fig. 2). Facesheets and core thicknesses were optimized and designed according to a number of iterations using sandwich construction formulas. The overall dimensions (length and width) of the CSIP wall panels were maintained the same as that for traditional SIPs [19] which are given in Table 3.

2.1. Pull off strength testing

The adhesive used for bonding the facesheets to the core is the most important component in a sandwich structure. The use of proper adhesive ensures effective load transfer between facesheets and the core. It is well known that debonding between the core and