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Performance of structural insulated panels with rigid skins subjected to windborne debris impacts – Experimental investigations

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HIGHLIGHTS

- Structural insulated panel with rigid skins against debris impact is studied.
- Tests were carried out by using a pneumatic cannon testing system.
- Penetration resistance capacity of SIPs against debris impacts was identified.

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ABSTRACT

Structural insulated panels (SIPs) are high-performance building materials used as building envelope for residential, industrial and light commercial construction. When the building envelope is impacted by windborne debris in cyclonic area, the debris might perforate the panel resulting in dominant openings. Dominant openings in the building envelope might cause differential internal pressurization and result in the damage to the whole building structure. In the present study, the dynamic response of SIPs with Extended Polystyrene (i.e., EPS) foam core sandwiched by two rigid skins of Oriented Strand Board (i.e., OSB) or fiber cement board were experimentally investigated by using a pneumatic cannon system for windborne debris impact. The failure and damage modes under various projectile impact scenarios were observed and compared. The performances of the SIPs were examined quantitatively in terms of the projectile penetration length, and deformation and strain time histories of the back skin. The effects of various specimen configurations, impact locations, projectile impact velocities and boundary conditions on their performance were studied. The penetration resistance capacity of the SIPs against windborne debris impact was analyzed.

1. Introduction

Modular building is becoming increasingly popular around the world due to its affordability, energy efficiency and sustainability. Structural insulated panel (SIP) is a prefabricated engineered lightweight building material which can be used in the modular building as a principal load bearing component such as exterior wall, framing, partition wall, roof, floor and structural framing. SIP is recognized as an efficient panel in the construction industry due to its advantages of being environmentally sustainable, economical, easy to install, ultra-lightweight, high strength to weight ratio, thermal insulated, moisture resistant, acoustic insulated, termite resistance, and flame retardant [1]. SIP consists of a rigid insulating polymer foam core sandwiched by two layers of facial skins. Two layers of facial skins can be metal sheet, plywood sheet, Magnesium Oxide board (MgO), Oriented Strand Board (OSB) or fiber cement board, etc. [2]. The rigid polymer foam core can be Extruded Polystyrene foam, polyurethane foam or Extended Polystyrene (EPS), etc. EPS is a closed-cell cellular plastics material with features of light weight, good thermal insulation, moisture resistance, and limited acoustic absorption [3,4]. In building industry, structural insulated panels with OSB skin and fiber cement skin have been extensively used for roof, wall and floor sheathing in various sectors of construction as shown in Fig. 1. OSB is a wood composite manufactured from narrow, long strands bonded together with resin under heat and pressure. OSB has been one of the most commonly used wood-based panels for residential construction in North America since 1980s. More than 7 out of 10 new homes in North America use OSB panels for roof and wall due to its sustainability feature [5]. Fiber cement is another popularly used

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composite building and construction material made of cellulose of wood pulp and cement. It is becoming one of the most effective manufacturing methods for composite materials due to its good performance, function and commercial value [6].

Cyclone intensity and occurrence increase every year with the climate change. The post storm investigations found that cyclone generated enormous amount of windborne debris and the windborne debris impact was highlighted as a major cause of damage to building envelope [8], as shown in Fig. 2. The windborne debris penetration through building envelope typically creates a dominant opening, which results in a differential internal pressurization that contributes to the increased loading of the building's roof and leeward walls, ultimately may lead to entire roof lifting up or even collapsing [9]. Therefore, it is important to understand the penetration resistance capacity of SIPs, especially when they are used in the regions prone to cyclones as failure is directly related to structural integrity and safety [10]. To withstand the impact of such extreme event, the penetration resistance capacity of wall or roof panels to windborne debris impact should satisfy the testing requirements specified in the respective design codes such as the Australian Wind Loading Code (AS/NZS 1170.2:2011) clause 2.5.8 [11]. Impact tests can be carried out using available facilities such as pendulum and air cannon, etc. [12–15].

The penetration and perforation resistance capacity of various plates and composites has been studied. Corbett et al. [18] conducted a comprehensive review on penetration and perforation of plates and cylinders by free-flying projectiles. Backman and Goldsmith [19] reported eight possible failure modes including fracture, spalling, scabbing, plugging, petaling in the back and front plates, and fragmentation when projectile penetrated thin or intermediate targets. Wen et al. [20] conducted penetration and perforation tests on composite laminates and sandwich panels by using flat, hemispherical and conical nosed projectiles under conditions of quasi-static, drop weight and ballistic impact. The fracture patterns and penetration resistance capacity were reported. Khalili et al. [21] found that the transverse flexibility of the sandwich panel increases and the contact force decreases with the increase of the core thickness. Hildebrand [22] reported that the stiffness and the energy absorption of the sandwich panel were affected by impact location. More energy absorbed through bending and deflection when impact occurs at the center. The composites failed in forms of shear cut-out, delamination and fiber fracture. Wen [23] also analytically predicted the penetration and perforation of composite laminates subjected to different nose shapes of projectile over a range of impact velocity, which is in good agreement with the experimental data.

Some studies on the performance of SIPs subjected to static and dynamic loadings have also been reported in the literature. Kermani [24] experimentally studied the performance of SIP with OSB skins under combined bending and axial compression action. It is found that SIP is an effective composite material which can be used as load bearing walls and column. Terentiuk and Memari [25] conducted a full-scale study on SIP wall panels under monotonic and cyclic loading to investigate the racking load behaviors and seismic response. The failure modes and load displacement data were recorded. An effective SIP design for load bearing and resistance under cyclic loading was suggested. Yang et al. [26] carried out the tests on SIPs consisting of plywood board as skins and Styrofoam as a core under bending, racking and axial loads. A composite SIPs with skin of thermoplastic orthotropic glass laminate and EPS foam core was studied by Mousa and Uddin [27]. Its global buckling behavior was investigated when it was subjected to

Fig. 1. (L) SIP house with OSB skin [7]; (R) SIP house with fiber cement skin [7].

Fig. 2. (L) Windborne missile penetrating a refrigerator in Midwest tornadoes (1999) [16]; (R) windborne missile penetrating a wall [17].