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Experimental and numerical investigations of steel-polymer hybrid floor panels subjected to three-point bending

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ABSTRACT

A new floor system for steel buildings was developed that can replace conventional concrete deck slab systems. The floor system is designed with a new type of composite panel with a polymeric material filling between the top and bottom steel plates. Its salient features are its light weight and simple installation that reduce structural materials and shorten the construction period. Experiments with various independent variables were performed to evaluate the flexural capacity of the proposed composite panel, and a finite element analysis was also conducted to examine the state of the stresses generated between the steel plate and the polymeric core. The test results showed that the proposed panel exhibited very ductile behavior and maintained its structural integrity even after a maximum load. No other failure mode than the face yielding of the top and bottom steel plates was observed. The bond strength between the polymeric material and the steel plates was confirmed to be sufficient, even without any special surface treatment or any additional shear connectors, to maintain the stability of the proposed panel and to resist the forces generated at the interface between the two materials. Design equations for predicting the flexural strength and stiffness of the proposed panel were proposed, and its suitability was verified. Additionally, the experimentally tested efficient methods for field applications of the proposed panel regarding cutting and joining were presented in this paper.

1. Introduction

A concrete slab system has been the most common floor system for buildings because of its convenience in controlling the volume formation in a large surface area. However, installation of the formwork and curing of poured concrete are factors that prolong the construction period and increase field work. The precast concrete (PC) floor system was introduced to overcome such disadvantages and to save time as prefabricated members are installed at the construction site. However, to maintain the structural integrity of the entire system, skilled workmanship is required for precise work on the joints, and a concrete topping is necessary. Moreover, additional costs for PC production, transport to the construction site, and lifting the PC members into place are directly associated with higher construction costs. Owing to such disadvantages, the PC floor system has not yet been widely used.

There is another floor system for buildings in which planar members such as panels are placed on the structural beam and then connected to each other to form a floor. In particular, sandwich panels consisting of two thin skin layers and a low density core have excellent structural efficiency and are suitable for flooring. A high-strength and high-stiffness material is mainly used for the skin layers, and the skins provide bending resistance and flexural stiffness to the panel. The core is bonded to the skin layers and supports the skin layers to behave as a continuum.

Various types of sandwich panels have been developed thus far and are widely used in construction, shipbuilding, aircraft construction, and other branches of industry. Sandwich panels are also characterized by their diversity of materials and shapes according to their purposes and functions [1,2]. In the aircraft construction and shipbuilding industries, various types of sandwich panels have been mainly developed as the exterior panels for aircrafts or ships. Lightweight metals such as aluminum are widely used as skin layers, and honeycomb and truss core

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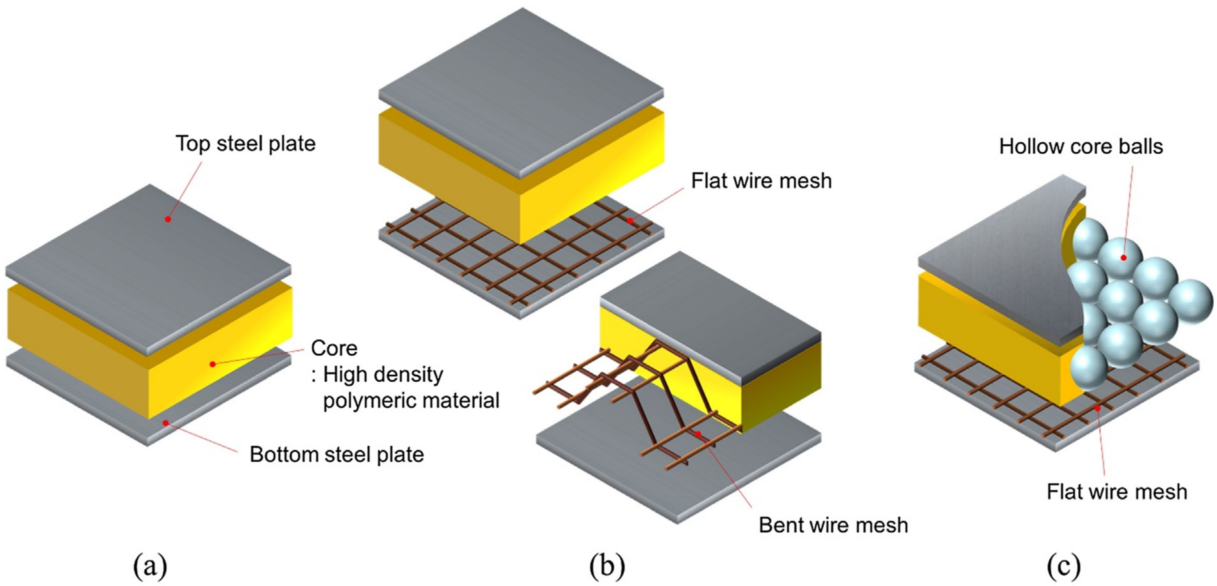

Fig. 1. Components of the *iFLASH* floor panel: (a) Basic core; (b) Core with a wire mesh; (c) Core with a wire mesh and hollow core balls.

structures are employed for efficient impact load absorption [3–7]. A recent trend observed in all branches of industry is the replacement of conventional core materials with metal foams, and metal-foam sandwich panels are being studied in various application fields [8–10].

In the construction sector, research on steel-concrete-steel sandwich panels has been performed extensively since the late 1980s. The steel plates fulfill both functions of serving as a formwork and resisting the bending moment, thus demonstrating excellent production and structural efficiency. However, because of the weak bond strength between the concrete and steel plates, shear connectors also need to be used to ensure integrated behavior between the two materials as composite structural elements. Oduyemi et al. [11] and Robert et al. [12] attempted to increase the bond strength between the steel and concrete by using welded stud connectors, and Richard Liew et al. [13] proposed using a J-hook as shear connectors in the sandwich panel. Tata Steel Europe Ltd. [14] developed the Bi-Steel panel in which steel round bars used as shear connectors are directly connected to the two steel layers to obtain the effective shear transfer. Leekitwattana [15] integrated bi-directional corrugated strips with a core material to enhance the interaction between the steel plates and the concrete.

An increasing number of studies in which the metal skins were replaced with glass fiber reinforced polymers (GFRPs) have been conducted recently by several researchers [16–20,30]. Reis and Rizkalla [16] introduced and studied a sandwich panel in which GFRP laminates and a polyurethane foam were used as the skin layers and core respectively, and top and bottom skin layers are connected together with through-thickness fibers to overcome delamination problems. Fam and Sharaf [17] investigated the effect of various configurations of internal and exterior GFRP ribs on flexural performance of a GFRP sandwich panel with low density polyurethane core. Awad et al. [18] developed a new type of GFRP sandwich panel using a phenolic foam as a core material. In this study, experimental and numerical analyses were conducted to find an analytical model for the phenolic core material. These sandwich panels with GFRP skins have been largely used for flooring system of timber structures because the panels can be easily connected to timber beams [18,20]. Therefore, to extend application of the GFRP sandwich panels to floor system of a building constructed with steel and concrete, it is necessary to investigate the connection methods for structural integrity between steel or concrete beams and GFRP floor panels.

Along with increasing interest in modular construction technologies, sandwich panels using plywood as skin layers and expanded polystyrene foam (EPS), extruded polystyrene foam (XPS), or polyurethane foam as the core have been developed and used for low-rise housing buildings in some countries, especially in the USA [21]. They are superior to metal-skin sandwich panels in terms of the unit product cost and insulation performance and can also be used as wall members. However, these panels are primarily targeted at modular housing with two or three floors and are thus not suitable for high-rise buildings.

In this research, a new composite floor system was proposed that can replace the concrete deck slab systems of steel structures and has excellent workability. For field application of the developed floor system, a series of studies have been conducted. As a first step in the development of the floor system, this paper will focus on the static response of the developed composite floor panel subjected to three-point bending. The flexural capacity of the proposed panel was tested in experiments with various independent variables that should be considered at construction sites. A finite element analysis (FEA) was also carried out to verify the stress level at the interface between the skin layers and the core material. Additionally, design equations for calculating the flexural strength and stiffness of the newly developed panel were established.

2. *iFLASH* System

2.1. Concept

The composite floor system developed in this study is an assembly system of composite panels consisting of top and bottom steel plates with infilled polymeric material (Fig. 1(a)). A wire mesh for strengthening flexural strength under fire conditions and hollow core balls for reducing the polymer weight can be added to the core (Figs. 1(b) and (c)). The proposed system was named the *iFLASH* System, an acronym for innovative, fireproof, lightweight, absorbed, shallow, and hybrid system. Owing to the high length-to-thickness and strength-to-weight ratios, the floor height and material requirements can be reduced, and the construction time can be reduced owing to the simple in-situ installation and high workability. Moreover, the core material has an elastomeric function; thus, it exhibits high vibration and noise absorption capacities, and its high thermal storage performance endows it with excellent insulation and fire resistance capacities. Another salient feature of the proposed composite panel is the recycling capacities of both the steel plate and core so that no waste treatment is necessary.

The *iFLASH* System allows for modular manufacturing that is