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High performance composite slabs with profiled steel deck and Engineered Cementitious Composite – Strength and shear bond characteristics

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HIGHLIGHTS

- Development of composite slab using novel Engineered Cementitious Composite (ECC).
- Conducted experimental and Code based theoretical investigations.
- Variables include concrete/profiled steel deck type, shear span and shear connectors.
- Performance evaluated based on strength, ductility and shear bond resistance.

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ABSTRACT

Composite slab/flooring system known as fast track construction with profiled steel deck and regular concrete topping is very popular. This paper presents the development and performance evaluation of a new high performance composite flooring system incorporating emerging green cost-effective Engineered Cementitious Composites (ECCs). The high strain capacity while maintaining low crack widths makes fiber reinforced an ideal durable material for the composite floor construction. The proposed ECC based composite floors can resolve the problems associated with regular concrete based composite floors. Experimental investigations as per current Standard Specifications accompanied by Code based theoretical investigations were conducted to evaluate the structural performance of such flooring system in the construction and service stages. Thirty full-scale composite slabs were fabricated and tested under simply supported four-point loading conditions. The variables in the tests included: two types of concrete (a green cost-effective ECC and a commercial self-consolidating concrete 'SCC'), two types of profiled steel sheet/deck, five different shear span and presence/absence of stud shear connectors. The structural performance of ECC based composite slabs was compared with their SCC counterparts based on load-displacement response, shear load resistance, failure modes, strain development in concrete/steel, load-slip behaviour, ductility, energy absorbing capacity and steel-concrete shear bond resistance. ECC composite slabs have shown superior performance compared with their SCC counterparts in terms of strength, ductility, energy absorbing capacity and shear bond resistance.

1. Introduction

Steel-concrete composite systems have seen widespread use in recent decades because of the benefits of combining the two construction materials. A composite slab system is one comprising of structural concrete placed permanently over cold-formed steel deck in which the steel deck performs dual roles of acting as a form for the concrete during construction and as positive reinforcement for the slab during service. Amongst the numerous advantages of composite slabs over reinforced concrete slabs are lightweight and easy handling in erection of steel decks. The deck also acts as formwork for the fresh concrete, which saves time and reduces construction costs. Once the concrete has cured and the components become a composite system, the cold-formed steel deck serves as positive slab reinforcement. Other advantages of the system that attract structural engineers are elimination or significant reduction of the positive moment reinforcement and formwork for

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concrete casting. This is in contrast to the early use (before 1950) of the steel deck-concrete floor, where the concrete was used only as a filling material [1]. The system has proven to be very attractive to structural designers because of many advantages it has over conventional systems of reinforced concrete slabs [1–3].

The behaviour of a composite profiled slab is complex and the exact nature of the bond between concrete and steel is still not well understood because of the slip at the steel-concrete interface. The partial steel-concrete interaction associated with the slip causes longitudinal shear steel-concrete bond to vary along the span. The three primary failure modes: flexure, vertical shear at support, and longitudinal shear between the steel and concrete, are important for design of composite deck. The longitudinal shear failure is the most common failure type [4]. This mode of failure is characterized by the formation of diagonal tension crack in the concrete at or near the load points, followed by a loss of bond between the steel deck and the concrete. Therefore, a proper mechanical interlocking is required to transfer the shearing forces between the concrete slab and the steel sheeting. The composite interaction can be enhanced by using mechanical shear connectors in the form of headed studs, rolled embossments/indentations onto the sheet surface, transverse wires, holes etc. [5]. Since 1960s, there have been many advances in design procedures, and a wide range of profiled sheeting with various geometry and embossments have been developed and commercially available [3].

The knowledge of the composite interaction as well as the elemental behaviour involved in the system has progressed rapidly during the past two decades [6–12]. Research on the elemental tests, full scale tests, numerical methods and mechanical models to predict the behaviour of composite slab systems has been conducted worldwide particularly in the U.S., Canada, Europe and Australia. Extensive research studies [1,13,14] have been carried out on composite slabs which leads to the formation of the basis for the ASCE standard [15] on composite slabs. Currently American, British, and European standards for the design of composite slabs are available [15–17]. There are two methods for composite slab design that are widely followed by ASCE 1992 [15], BS 5950 1994 [16] and Eurocode 4-1994 [17]. These are the shear bond method also known as the m-k method and the partial shear connection (PSC) method. These design methods need parameters those have to be obtained from bending tests. The shear bond between the profiled steel sheeting and concrete is difficult to predict theoretically since it is dependent upon several inter-related parameters including the geometry and flexibility of the profiled steel sheet itself. Given that the profiled steel sheeting is a ductile material and the conventional concrete is a brittle material, inadequate steel-concrete shear bond leading to brittle failure and poor durability are causes of concern. Therefore, more research is needed to develop new high performance composite flooring system with profiled sheets.

Although structural performance of composite slabs with traditional concrete was the subject matter of numerous research studies, limited research has been conducted to envisage the behaviour of composite slabs with different profile steel sheeting and newly emerging high performance concrete (HPCs) [18,19]. Structural behaviour of composite slab using different concretes including rubber concrete have been investigated [5,18–21].

The better shear bond interaction between steel deck and HPC can significantly improve the structural performance of composite slabs in addition to improve durability. Therefore the study of structural performance of composite slabs with different HPCs with varying profile geometry and mechanical connectors is warranted. Design of composite slabs can be achieved by using m-k method, if m (parameter that defines shear bond due to mechanical interlock between steel and concrete) and k (parameter that defines shear bond due to friction between steel and concrete) values are known from experiments. m and k values normally change with different concrete and different steel sheets [17,18]. Composite slabs with better structural performance can be obtained by using newly developed high performance concretes (HPCs) especially emerging highly ductile Engineered Cementitious Composite (ECC).

Green cost-effective ECCs (developed at Ryerson University) made of locally available materials [22,23] could yield better composite action between the profiled steel sheeting and the concrete. The high strain capacity (300–500 times greater than normal concrete) while maintaining low crack widths (less than 60 μm) could resolve the problems through shear bond optimization and improving constructability (faster construction and better concrete quality control through self-consolidation) as well as enhancing ductility and durability. Although structural performance of ECC based structural elements has been researched [24–26], no research has been conducted on the development of high performance composite slabs using ECC. There is an urgent need to conduct research on the structural performance of ECC based composite slabs compared to their traditional concrete counterparts and to develop design specifications.

Composite slab/flooring system known as fast track construction with profiled steel deck and regular concrete topping is very popular. However, problems with regular concrete based composite floors include inadequate steel-concrete shear bond leading to brittle failure and poor durability. The proposed ECC based composite floors can resolve the problems through shear bond optimization (by increasing ECC-steel deck interaction) and improving constructability (faster construction and better concrete quality control through self-consolidation) as well as enhancing ductility and durability. It is essential to evaluate the structural performance of proposed ECC based composite flooring system (to develop design specifications which are not currently available) through experimental and theoretical investigations in the construction and service stages.

This paper presents the results of experimental and theoretical investigations on the structural performance of the proposed ECC based new composite flooring system with profiled steel decks in the construction/service stages taking into account concrete types (an ECC and a commercial self-consolidating concrete 'SCC'), profiled steel deck types as well as variable shear span and shear connector characteristics. It describes the performance of profiled steel decks as formwork, ease of casting with fresh concrete (self-flowing and self-compacting characteristics of ECC and traditional self-consolidating concrete 'SCC') and other associated fresh state properties including concrete finished surface characteristics during construction. The structural performance of ECC composite slabs compared to their SCC counterparts is described based on experimental and theoretical analyses using load-displacement response, shear/moment resistance, failure modes, strain development in concrete/steel, load-slip behaviour, ductility, energy absorbing capacity and steel-concrete shear bond resistance. Recommendations are provided for the values of shear bond parameters that can be used in existing Code based design equations/specifications to predict the strength of both ECC and SCC composite slabs. The recommendations will allow construction industry to launch a new composite flooring system with enhanced ductility, durability, energy absorbing capacity and service life compared with traditional flooring systems. The results of this research will also benefit engineers, builders and local authorities when constructing structures with the proposed ECC based composite flooring system in terms of promoting efficient and durable construction.