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Pre-fabricated sandwich panels using cold-formed steel and textile reinforced concrete

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HIGHLIGHTS

- A novel prefabricated sandwich panel using profiled steel sheet and textile reinforced concrete.
- Response behavior of sandwich panel was investigated for floor applications.
- The panel showed ductile behavior even after 25% reduction in ultimate load.
- Numerical simulation for sandwich panels using nonlinear finite element analysis.

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ABSTRACT

A novel prefabricated sandwich panel consisting of profiled steel sheet as a core material and textile reinforced concrete (TRC) as outer skins was developed. TRC consists of cementitious binder and an alkali resistant glass textile as reinforcement. The dimension of the TRC panel chosen for study was 1170 mm × 650 mm × 70 mm. Experimental investigations were carried out to determine the response behavior of sandwich panel under flexural load. It is observed that the ultimate flexural stress of the panel is 28.12 kN/m^2 and is suitable for floor applications. Further, the panel showed ductile behavior even after the 25% reduction in ultimate load. Further, numerical modeling of two types of TRC sandwich panels was done using finite element software ABAQUS. TYPE-I sandwich panel considers perfect bond between profiled steel sheet and TRC. In TYPE II sandwich panel, self tapping screws were provided to connect profiled steel sheet and TRC skin. This panel is modeled with screws for attaching sheet and face skins. For material modeling, TRC, profiled steel sheet and self tapping screws were modeled as elastic–plastic. A displacement controlled analysis was performed for the TRC sandwich panels under two point loading condition. It was observed that the ultimate loads predicted by numerical models are in good agreement with experimental results.

1. Introduction

The development and construction of lightweight prefabricated structural panels in building construction is a growing trend in construction industry all over the world due to its high strength-to-weight ratio, reduced weight, and good thermal insulation characteristics. By exploiting the potential of different structural materials leads to light weight and sandwich construction form and has distinct advantages over conventional structural sections. Sandwich composite structure possesses excellent flexural and shear properties and their inherent lightweight characteristics make them ideal structural components where weight reduction is desirable.

Sandwich elements consists of thin face sheets or encasement of high performance material and a thick, lightweight and low strength material as core. Skins in sandwich structures are generally made of steel, aluminum or Fiber reinforced polymers. Core material generally takes forms of honeycomb cores, corrugated cores, truss cores, Z-cores, C-cores, I-cores or solid form cores [1,2]. Due to light-weight and high impact absorption capacity, sandwich panels are suitable as floor panels. It is observed that lightly profiled sandwich panels are subject to local buckling and flexural wrinkling effects [3]. The skins of sandwich panels are usually attached to the core either by screws or by some adhesives. The provision of truss shaped shear connectors ensures sufficient degree of composite action and specimen can undergo large deflections prior to failure. In this case, the stiffness of shear connector is

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a deciding factor for achieving the desired ultimate strength and the degree of composite action [4]. The application of GFRP composite shell connectors to join the two concrete wythes with rigid foam core was proved to be efficient in resisting out of plane loads and also in providing resistance to horizontal shear between the two wythes [5]. Investigations were reported in literature stating that the type of failure of a sandwich structure varies with the span length. The final failure of a sandwich structure under bending load may be different from bending failure for short span [6]. From the above discussion, it can be concluded that there is lot of scope for the development of alternate materials and connections for sandwich panel construction.

With the availability of many construction materials with different characteristics for sandwich construction, it is important to have a numerical tool to predict the response behavior and failure pattern. From the limited studies towards the numerical simulation of sandwich structure, it is observed that finite element analysis can be used for accurately simulate the sandwich panel behavior. By performing proper optimization analysis, it is also possible to predict optimized value of weight of the structure [7].

A relatively new material development known as textile reinforced concrete (TRC) has open up many possibilities of structural application. TRC is regarded as highly versatile thin material possessing superior non-corrosive properties [8,9]. TRC can help to avoid abrupt failures without compromising much on the load carrying capacity for structural components [10,11]. Research has already been reported on the performance of sandwich construction consisting of TRC faces [12]. By using proper infill material as core between two glass textile reinforced concrete encasements better structural behavior can be arrived at. The stiffness of sandwich panel depends mainly on the core density and the shear stiffness, while an increase of TRC reinforcement enhances deflection capacity. Cuypers and Wastiels [13] investigated the performance of sandwich panels with TRC faces with Inorganic Phosphate Cement (IPC) as matrix material. It was observed that the stiffness and load deflection curve of the sandwich panel depends upon the layers of reinforced IPC. Janetzko and Gries [14] developed a method for the construction of thin-walled sandwich for a small building using TRC. It was found that in the case of façade panels, a decrease in weight by a factor of four could be achieved by utilizing TRC instead of traditional steel-reinforced concrete. It can be observed that the application of textile reinforced concrete opens up new possibilities in the pre-fabrication of thin-walled sandwich elements.

In the present paper, a pre-fabricated TRC panel is developed, which is novel and first of its kind to authors' knowledge in which TRC is used as skin material, profiled cold-formed steel sheet as core material and self tapping screws as connection between skin and core. The details of experimental and numerical investigations are reported in this paper.

2. Material characterization

2.1. Profiled steel sheet – material for core

Profiled steel sheet used as core material is cold-formed sheet of grade Fe250. Dumbeled shape steel specimen is used to carry out the uniaxial tension test. The stress–strain behavior of cold-formed steel obtained from experiment is shown in Fig. 1. It is observed that, up to the stress of 202.59 N/mm^2 a linear behavior is seen and after that behavior changes to plastic.

2.2. TRC – skin material

TRC is an innovative building material with versatile properties. It is composed of thin layer of fine grained cementitious matrix as binder and an alkali resistant glass textile as reinforcement. The binding matrix consists of cement, fly ash, silica fume, water, super plasticizer, quartz powder and quartz sand. The maximum aggregate size used is limited to 0.6 mm to allow for more penetration of binder to glass textile. Super-plasticizer was also added to obtain an improved flowing capability for the binder. Silica fume and fly ash were used to reduce the amount of alkali as compared to pure Portland cements. In TRC used structures, the textiles are alkali resistant and thus will not be affected due to corrosion. As a result which the excess protective cover is not required, ultimately being able to produce thin structures. The most advantageous property of this material is the control over the orientation of the textiles which can be arranged easily in the direction of stresses.

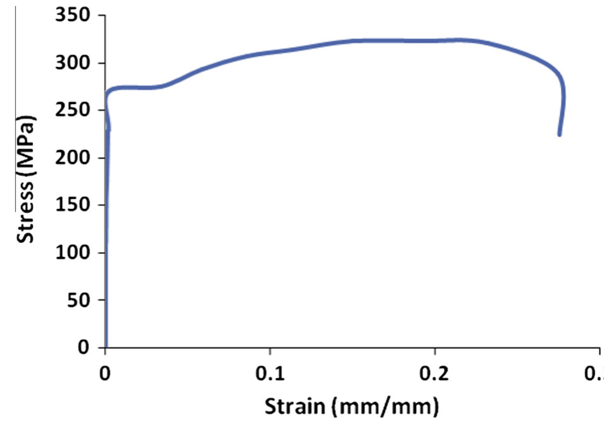

Fig. 1. Stress–strain for steel used in profiled steel.

2.2.1. Textile as reinforcement

In TRC, the reinforcement can be made of carbon, aramid or alkali resistant glass fibers and in various forms like wrap knitted or woven textiles or bonded textiles or mesh type. This reinforcement is provided to increase the loading capacity or avoid catastrophic failure of the structure. In the present study, two types of alkali resistant glass textiles with brand names SRG-45 and AR1 are used as reinforcement and are having mesh type geometry. The details of Glass textile mesh SRG-45 are: Mesh size: 25 × 25 mm, weight: 225 g/m^2, number of filaments in each yarn: 1600, filament diameter: 14 μm, tensile strength 45 kN/m. The details of glass textile mesh AR1 are: Mesh size: 10 × 10 mm, weight: 110 g/m^2, no of filaments in each yarn: 800, filament diameter: 14 μm, tensile strength 29 kN/m.

2.2.2. Cementitious binder

FABmix is cementitious binder developed by authors for TRC. Cement: OPC 53 grade cement was used having specific gravity of 3.15 and particle sizes ranging from 31 to 75 μm. Silica fume: The particles were found to have specific gravity of 2.2 and particle size ranging from 0.2 to 25 μm, Processed fly ash: The particles were found to have a specific gravity of 2.2 and particle size ranging from 0.2 to 25 μm, Quartz powder (0–0.2 mm), Quartz sand (0.2–0.6 μm), Super plasticizer (polycarboxylate): SP used was gleniumB233. Super plasticizer having pH of 6.5, Water: Distilled water was used. The details of mix proportions of FABmix can be seen in Gopinath et al. [10]. Four cylinders of FABmix were tested in compression to determine the stress strain behavior of TRC. Fig. 2 shows the stress–strain behavior of the FABmix. It was observed that ultimate compressive stress of FABmix is 34 MPa.

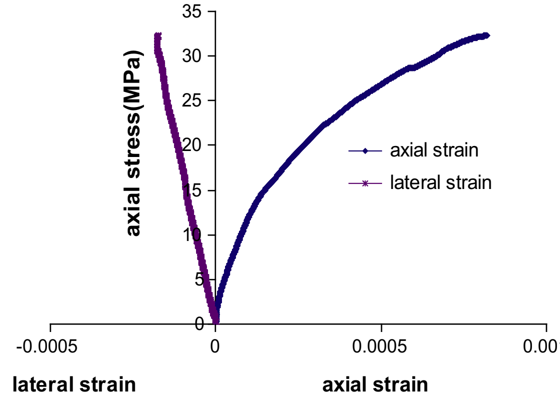

Fig. 2. Stress–strain of FABmix under compression.