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INVESTIGATION OF HYBRIDIZED POLYURETHANE, GLASS FIBRE REINFORCED CEMENT AND STEEL LAMINATE IN STRUCTURAL FLOOR PLATE SYSTEMS

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Abstract: Sandwich components have emerged as light weight, efficient, economical, recyclable and reusable building systems which provide an alternative to both stiffened steel and reinforced concrete. These components are made of composite materials in which two metal face plates or Glassfibre Reinforced Cement (GRC) layers are bonded and form a sandwich with light weight compact polyurethane (PU) elastomer core. Existing examples of product applications are light weight sandwich panels for walls and roofs, Sandwich Plate System (SPS) for stadia, arena terraces, naval construction and bridges and Domeshell structures for dome type structures. Limited research has been conducted to investigate performance characteristics and applicability of sandwich or hybrid materials as structural flooring systems. Performance characteristics of Hybrid Floor Plate Systems comprising GRC, PU and Steel have not been adequately investigated and quantified. Therefore there is very little knowledge and design guidance for their application in commercial and residential buildings. This research investigates performance characteristics steel, PU and GRC in Hybrid Floor Plate Systems (HFPS) and develops a new floor system with appropriate design guide lines.

Key words: Sandwich panel, Experimental testing, FEM

1 INTRODUCTION

Reinforced concrete and composite concrete and steel are widely used construction materials in the construction industry. They are material with high embedded energy and consume more energy to recycle or reuse after their intended design life. Due to rapid economic developments, buildings are demolished at the end of their commercially useful life which could be sometimes 20 years although they have a design life of 50 years or more. Therefore, there is a need determined by environmental and conservation principles to use recyclable or reusable materials in new infrastructure construction and high rise buildings. This will reduce the construction waste disposal and decrease the use of raw materials in construction industry. However, the conventional reinforced concrete and composite deck slabs have been extensively used for structural flooring in almost all of the structures including steel framed buildings. Currently, there is no significant alternative material which can be easily recycled or reused, for the construction of structural flooring.

In this context, hybrid or sandwich structural components have recently emerged as light weight, efficient, economical, recyclable and reusable building systems which provide an alternative to both stiffened steel and reinforced concrete. Sandwich panel consist of two thin sheet of dense material ―face” bonded by low density material ―core”. Faces are made of thin steel sheets or fibre reinforced cement layers such as Glassfiber Reinforced Cement (GRC). Core materials are Polyurethane (PU), polystyrene or mineral wool. Such sandwich panels possess many attributes such as high strength-to-weight ratio, long spanning capability, transportability, fast erectability, prefabricatability, durability, reusability and recyclability (Narayan, 2003). Further, they possess good thermal and sound insulation properties and sandwich panels have been used for building components such as wall cladding and roof systems.

A limited number of studies have been conducted to investigate their performance characteristics, especially regarding the applicability of sandwich or hybrid materials as structural flooring systems. Hybrid Floor Plate Systems (HFPS) using GRC, PU and Steel seem to have the potential for use as floor structures with many desirable features. They can be prefabricated as structurally efficient, light weight, cost effective, durable, demountable, and reusable and recyclable floor plates. This paper discusses the importance and potential use of HFPS. Further, it discusses applicability of GRC-PU-GRC panel as a short span floor plate as a part of HFPS. For that FE modelling was used with the support of experimental testing.

2 APPLICATION OF SANDWICH CONSTRUCTION

There are a number of applications in sandwich construction which have been developed combining deferent facing and core materials. Three major sandwich construction applications can be identified in the field of Civil Engineering. Those are Light weight Sandwich panels, Sandwich Plate System (SPS) and DomeShells Structures.

2.1 Light weight sandwich panels

Light weight Sandwich panels are manufactured using steel or aluminium facing with low density polyurethane core. This has been developed and used for wall claddings and roof panels of buildings over three decades. Thin steel sheets are the most common material used as facing for light weight wall and roof sandwich panels. They are generally used in three forms: flat, light profiled, and profiled as shown in Fig. 01.

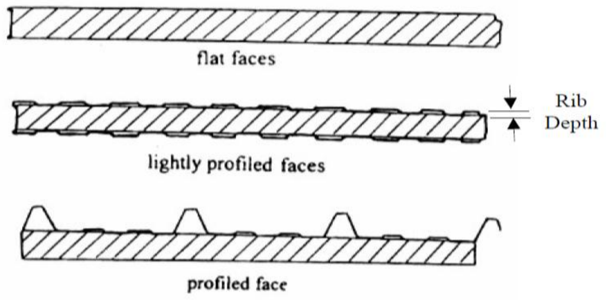

FIGURE 01: Light weight sandwich panels (Narayan, 2003)

Profiles provide flexural stiffness and protection for the core. Tensile and compressive stresses are supported by faces in these panels (Davies, 2008).

The core keeps the faces apart and stabilizes faces against local failure and provides the connection between the faces. Further, it increases the moment of inertia of the section. Core materials are basically categorised in to two types those are bonded cores and foamed cores. Bonded cores usually consist of either polystyrene or mineral fibres, which are bonded to the face plate by using a suitable adhesive (Chong & Hartsock, 1993; Davies, 2008). Formed cores are manufactured by mixing two fluids. During this process as a result of chemical reaction mixture hardens and strongly adheres to external surfaces without the support of adhesive (Davies, 2008). Therefore, most common foam core material is Polyurethane (PU).

However, light weight sandwich panels are susceptible buckling failures under the action axial compression and bending. Although profiled faces are used still these panels are vulnerable for local buckling or flexural wrinkling buckling. Therefore this kind of panels has not been used as floor panels.

2.2 **Sandwich Plate System (SPS)**

The Sandwich Plate System is a new composite material technology, comprising thick metal plates and high density Polyurethane elastomer core (Refer to Fig. 02). The SPS was initially developed as a deck repair and replacement system for deteriorating ship decks. Current and potential SPS applications include ship repair, new-build ship components, maritime overlays, new bridge construction, bridge deck repair/rehabilitation, grandstand floors, stadium risers, and building floors.

FIGURE 02: SPS panel (Intelligent Engineering (UK) Ltd., 2009)

SPS provides a wide variety of structural benefits because of the combined inherent properties of two materials. Middle elastomer core transfers the shear between each palate during the use of SPS component. Further, the use of high density polyurethane elastomer core eliminates the need for stiffeners and associated joints because it provides continuous support to the plates and thus is structurally equivalent to the stiffened steel plate. Therefore, local plate buckling is also prevented at the same time. Flexural stiffness and strength of the SPS can be changed by varying the thickness of the sandwich elements (Braun, Kennedy, Kennedy, & Allen, 2002).

SPS system uses high density polyurethane and thicker steel plates than steel sheet which is used in light weight sandwich materials. Studies have been conducted in relation to naval construction, bridge structures and some grandstands floors. Proper study has not been carried out to evaluate the performance characteristics of SPS in floor structures. SPS may not be economical due to the use of two steel face plates in structural flooring.

2.3 **Domeshells structures**

DomeShells is a new concept of residential building design coupled with innovative building technology. These structures combine the structural qualities of the compound curved shell and the sandwich panel. The typical Domeshells structure includes a diameter of 6-10m, with 2.1m vertical walls rounding to maximum height of 3.2-4.0m at its centre (Gaston, Thambiratnam, Button, & Nasir, 2004). Sandwich material consists of external and inner layers of Glass Fibre Reinforced Cement (GRC) and lightweight polyurethane core in between (refer Fig. 03) in the DomeShell structures. Currently, Domeshells Australia Pty. Ltd use this material for their DomeShell structure projects.

FIGURE 03: Sandwich panel used in Domeshells structures

Some research has been devoted to providing verification through finite element modelling and testing, for the application of this technology. According to the outcomes, high structural qualities of the sandwich section and compound curved shell provided very good performance under static and cyclonic wind loading (Gaston, Thambiratnam, & Button, 2005). Generally, entire sandwich section subject to compression stresses in dome type of structures. However, Suitability of a GRC-PU-GRC sandwich section as a floor panel has not been evaluated in any study.

3 MAJOR MATERIALS USED IN SANDWICH CONSTRUCTION

3.1 **Polyurethane (PU)**

Polyurethane is the common core material, which is used in most of sandwich construction applications. It achieves the bonding with the faces during the foaming process. PU can be formulated and processed into foams of varying densities. The foams are identified either as flexible or rigid with the density ranging from 16 kg/m^3 to 1240 kg/m^3 (Sharma & Raghupathy, 2008). Mechanical properties vary over this density range. Sharma and Raghupathy (2008) have investigated the elastic modulus, shear modulus, and shear strength properties of polyurethane foams with different densities.

PU can be used as sound and vibration damping material. Braun et al. (2002) conducted a experimental investigation on a 12 m long SPS grandstand double riser unit with of 32mm PU core and 3.8 mm face plates. Damping ratio was obtained as 2.1% for that structure. Generally the damping ratio is about 1% for steel or pre stressed concrete structures of similar span. This improvement was obtained using a very thin PU layer. Therefore, PU can be effectively used as core material while improving the vibration damping if it use in a floor structure.

PU has low environmental impact. PU itself is inert and non toxic and can be recycled at the end of useful life. (Ashby & Johnson, 2002, pp. 201-202). It can be successfully recycled from a variety of forms to more usable formats. There are various methods that are currently used, such as mechanical recycling, chemical processing, thermo chemical processing, and energy recovery (Zia, Bhatti, & Bhatti, 2007).

3.2 **Glass fibre Reinforced Cement/Concrete (GRC)**

GRC is a composite material consisting of ordinary Portland cement, Silica sand and water mixed with alkali-resistant glass fibres (National Precast Concrete Association Australia [NPCAA], 2002). The percentage, arrangement and method of application of Glass fibre can be engineered to suit a wide range of applications. The advantage of Glass fibre is for carrying the tensile force, thus overcoming the main disadvantage of cement, which has low tensile strength.

To understand the qualities of GRC, the knowledge of its properties are important. Generally, the density of GRC is about 1800-2000 kg/m3 (NPCAA, 2002). The mechanical properties of the GRC vary according to the percentage of fibre present in the mix and usually glass content is about 5% by total wet weight of materials (NPCAA, 2002; Brookes & Maarten, 2008, pp 71-89).

It has been shown that the addition of a polymer to GRC improves the performance and mechanical properties of GRC (Bijen, 1990). Improvement in bending strength and ultimate tensile strength is marginal for polymer modified GRC compared to the normal GRC In the methods explained above, chopped glass fibres are added to the mix and therefore fibre arrangement in the matrix is random. GRC provides better performance in compression. Ferreira and Branco (2004) showed that GRC provides greater ductility under compression when compared with normal concrete

The environmental impact effect of GRC is less than that of reinforced concrete according to a study conducted by the International Glass fibre Reinforced Concrete Association (2003). The main constituents of GRC are based on the naturally occurring earth oxides that are used in the manufacture of cement and glass fibres.

4 HYBRID FLOOR SYSTEM

GRC, PU and steel hybrid can be combined as a hybrid with potential for use as floor structures with many desirable features. They can be prefabricated as structurally efficient, light weight, cost effective, durable floor system. They are light weight structures compared to conventional systems hence they can be demountable and reusable at the end of commercial useful life. As identified previously component material has lower environmental impact and can be recycled. The properties of GRC, PU and steel can be combined to deliver optimum performance. That can be obtained by mobilising the strength characteristics of the individual component materials to offset weakness in composite action. However, their behaviour is complex and hence their performance characteristics require extensive investigation for development of qualitative design techniques.

Performance characteristics of floor plate systems comprising GRC, PU and steel hybrid has not been studied previously studied. Static performances under dead and live loads and dynamic performance under human induced loads have to be evaluated for the development of applications using HFPS.

Proposed HFPS will be assembled using component materials as shown in the Fig 04. Width of the HFPS is limited 2 m as this is proposed as prefabricated system. Length of the HFPS can be varied by changing the material properties, component material thickness and beam depth. GRC-PU-GRC panel spans one way 1000 mm between beams with cantilever span of 500 mm in HFPS. This behaviour and configuration for GRC-PU-GRC panel has not been investigated previously.

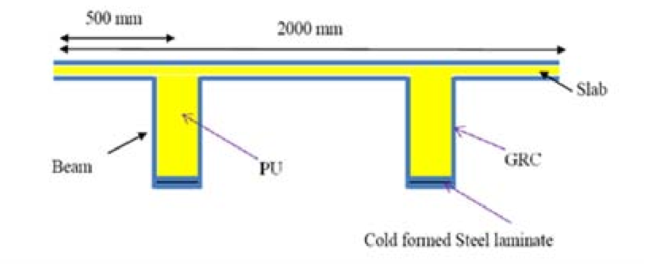

FIGURE 04: Cross section of proposed HFPS

5 PERFORMANCE OF GRC-PU-GRC AS FLOOR PANEL

The first objective of this study was to determine the performance characteristics of GRC-PU-GRC panel as a floor slab. This has been carried out using computer modelling with the support of experimental testing. A finite element model was developed and validated using experimental testing using one way span GRC-PU-GRC panel. The calibrated finite element model was used to determine performance characteristics of sandwich panel for one-way and cantilever span. These performance characteristics were serviceability criteria such as stress limit, deflection and cracking limits and natural frequency.

5.1 **Experimental testing**

Four sandwich panels with different sandwich layer thickness were fabricated. Type A panels included a 56 mm thick PU core and 10mm thick GRC faces. Whereas type B consist of a 45 mm core along with 8mm faces. Glass fibre content of GRC was 1.9% of the dry weight of the mix and density of the PU was 44 kg/m^3.

Impact hammer tests were carried out on every panel to obtain the first natural frequency. Three tests were carried out on each of the panel. Two supports, which allow translation along the span and rotation about the span, were fabricated. One end was clamped using –G” clamps to avoid the unnecessary vibrations of the panel as shown in Fig 05. The first natural frequency of the test panels was found from the frequency response curve.

Static tests were carried out on all panels to obtain the load deflection curve. Two supports, allowing translations along the span and rotations about the span, were used. The loading arrangement of the test consisted of a spreader circular steel roller to achieve an evenly distributed line load across the whole panel as shown in Fig 06.

5.2 **FE modelling and validation**

An uniform finite element models using shell elements and layered three-dimensional FE models using 3D brick elements were developed to simulate plate bending behaviour and free vibration of the sandwich panels. FE models were validated with experimental results. Validation with static load test is shown in Fig 07 & 08 and validation with impact hammer test is given in Tab. 01.

TABLE 01: Validation of FE model using impact hammer test

Panel Name	**Finite Element Model Type**	**Fundamental frequency ,Hz**	
		Finite Element model	***Test avg***
Panel A	Uniform model	66.25	66.5
	Layer model	65.30	
Panel B	Uniform model	64.20	62.25
	Layer model	63.10	

FIGURE 05: Impact hammer test

FIGURE 06: Static load test

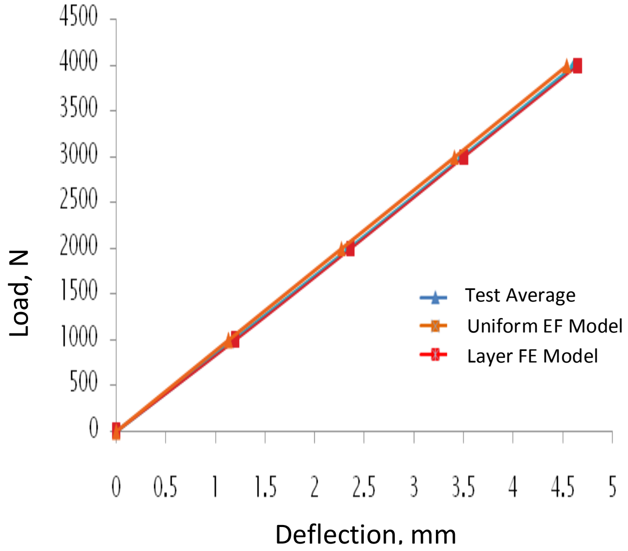

FIGURE 07: Validation for FE model for static test (Type A panel)

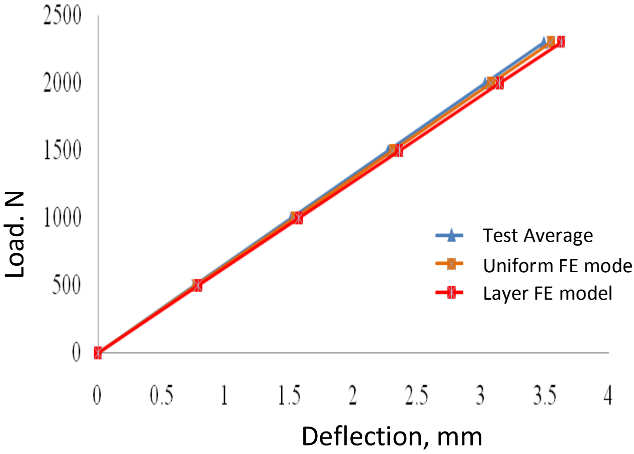

FIGURE 08: Validation for FE model for static test (Type B panel)

6 RESULTS AND DISCUSSION

The validated FE model was used to find the optimum one-way and cantilever spans obtained under two load cases which were residential use and commercial use. According to the analysis results 80 mm thick panel can be used for one way span of 2 m in residential floor and 1.5 m in office floor. Cantilever span that could be achieved with the same thickness was 1 m and 0.75 m in residential floor and office floor respectively. These results confirmed that the 60mm to 80mm thick GRC-PU-GRC panel can be used for one way span of 1000 mm and cantilever span of 500 mm. Therefore, these spans were adopted for the HFPS configuration.

7 CONCLUSION

GRC-PU-GRC panels can be used in HFPS for shorter spans. That can be effectively used in HFPS. The fundamental frequencies of these spans were relatively high, (all were over 20 Hz) due to small spans. The proposed HFPS will have larger spans and their acceleration response under human induced loads will be investigated in future studies.

Proposed HFPS will be sustainable structural floor system in different aspects. That will be prefabricated floor system which can be manufactured in an offsite factory under controlled conditions to achieve a product of superior quality with low embedded energy. This floor system will be about 50% lighter in weight compared to the conventional concrete floors. Therefore, product can be easy to transport, handle and erect. HFPS has the potential to revolutionize the construction of structural floor systems by replacing slow, labour intensive and low quality construction materials with factory based manufacturing process. Manufactured floor pates can be assembled with simple connections on site eliminating the heavy, cumbersome and time consuming material handling, transporting and erecting processes while minimising the safety hazard. HFPS can be demounted and reused in another application or can be recycled as whole component at the end of commercial useful life.

8 FUTURE STUDIES

HFPS using GRC, PU and steel will be developed with different geometrical configurations where both the slab and beams are joined together to achieve high strength and serviceability performance. Performance characteristics of those materials in Hybrid Floor Plate Systems (HFPS) will be investigated. Preliminary FE studies shows that 300mm depth of the section can be used for 6 m span considering commercial use. 3m span scale model HFPS will be used for static and dynamic experimental investigations. Then FE model will be validated with that results and will be used for further studies Parametric studies on material properties and section geometry will be carried out to improve and refine the performance characteristics of HFPS. Finally, design guidelines will be developed based on the fundamental parameters for design of HFPS floor structures. An analytical method will be developed using span, sectional configuration, properties of hybrid materials thickness, damping and loading as the variables.

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