FRPRCS-14, Belfast - June 2019

The Triple-layer Sandwich Panel Made from Lightweight Self-Compacting Concrete and Reinforced with Hybrid GFRP/Steel bars and meshes

Kakusha, V. A.[1], Kornev, O.A.[1], Lapshinov, A.E.[1], Solovyov, V.G.[1], Zastrelov, A.N.[1], Litvinov E.A.[2]

[1] Moscow State University of Civil Engineering, Russian Federation

[2]Galen Limited Liability Company

Abstract

This paper presents the development and testing of triple layer sandwich panel made from concrete with lightweight aggregate (expanded-clay) and GFRP bars and mesh. Lightweight triple-layer sandwich panels can be used as outside wall structures for multi-storey residential buildings up to 33 storey. With the usage of lightweight self-compacting concrete with density 1600 kg / m3 it could be possible to reduce total weight of 7.5 m long panels from 7 to 4.5 tons. The internal reinforcement of outside layer was completely from GFRP - mesh, straight and bent bars. The internal reinforcement of inner layer was with steel rebars and GFRP mesh. The inner and outside layers connected with wall ties made from stainless steel. Usage of FRP materials in outside layers improves durability of outside wall structures. The results of testing for flexure, fire resistance and anchorage of lifting loops are discussed.

Keywords: GFRP, GFRP mesh, lightweight concrete, expanded clay, sandwich panel, fire resistance, flexure, LWSCC

Corresponding author's email: La686@ya.ru

Introduction

The technology of panel house construction in the territory of Russia has been used from the 60-s years of the 20th century. Over these years significant experience of designing, production and operation of external, single and triple layer wall panels from heavy and lightweight concrete has been gained. Analysis of the results of investigation of residential multi-storey buildings allowed determining one of the main reasons for crack formation in wall panels made from expanded clay aggregate concrete, which is a significant difference in concrete density across the section. The difference in expanded clay concrete density across the panel's section was 90-210 kg/m^3 and was the reason for critical stresses in products, which lead to through vertical and horizontal cracks in the outer layer.
Analysis of the technology of production of wall panels with light aggregate allowed determining that in most cases delamination of concrete in the panel external layer was induced by vibration of low slump concrete with concrete cone slump of from 2 to 15 cm. During vibration the aggregate comes up due to its lower density (400-800 kg/m^3) in comparison with the mortar (1900-2100 kg/m^3) which results in the difference in density across the section of a finished product and following crack formation. Besides, the investigation often showed corrosion of reinforcing bars and meshes in the outer layer, which caused crack formation, concrete cover delamination and resulted in the necessity of early repair of such panels. With the use of non-corrosive materials (such as GFRP reinforcing bars and meshes) in the outer layer of triple layer panels, the problems regarding to corrosion can be solved and the lifecycle of a structure can be extended.

Materials

During fabrication of a triple layer cladding wall panel, materials the panel consists of and the panel itself were tested.

Lightweight concrete

In order to eliminate a possibility of delamination of lightweight concrete mix during formation it was decided to use lightweight self-compacting concrete (LWSCC). Based on the preliminary design results , the minimum requirements for 1 day steam treated concrete were as following: B15 (C12/15) compressive strength grade, 1600 kg/m^3 mix density, 49-55 cm cone flow diameter. Meeting with these requirements shall ensure high quality forming and required panel properties.
During design of concrete mix composition the following raw materials were chosen: cement CEM I 52,5N; microcalcite (ground marble) Karbolux 100; masonry river sand with fineness modulus of 2,1; 500 grade claydite gravel of 5-10 fraction, superplastifier MasterPolyheed 3045.
In the result of laboratory test, the nominal composition of LWSCC was developed, where the mix density is 1560 kg/m^3, cone slump 52 cm, compressive strength one day after stream treatment at 6 hour isothermal curing at 60°C is 20,4 MPa.
The composition developed was tried out during manufacture of batch of experimental panels in amount of 10 pieces. During the panel fabrication, the concrete mix fully filled a mould without vibration. According to the results of tests of the samples selected from the experimental batch, it was established that the concrete density is almost the same across the section and does not differ by than 20 kg/m^3. As a result, the use of LWSCC let ensure the uniform distribution of concrete density across the outer layer of a panel and eliminate one of the main reasons for crack formation during operation.

Reinforcement

GFRP bars provided by GALEN LLC were tested as per Russian Standards (GOST 32492, GOST 32486, GOST 32487, TU 22.29.29-014-13101102 and TU 22.29.29-012-13101102). Results of the tests met requirements of GOST 31938 and exceeded the values requires by regulatory documents (see table 1). GFRP was chosen due to it's high durability properties and relatively low cost in comparison with different types of FRP.

Table 1: Galen GFRP rebar test results

Characteristics	Imperial units		Metric units	
	GFRP 0,55 in	GFRP 0,78 in	GFRP 14mm	GFRP 20mm
External Diameter, d	0,55 in	0,78 in	14,0 mm	20,0 mm
Nominal Diameter, d_{nom}	0,5783 in	0,8031 in	14,69 mm	20,40 mm
Tensile Strength, σ_B	166,519 ksi	174,013 ksi	1148,11 MPa	1199,78 MPa
Tensile Modulus, E_f	7631,75 ksi	8472,77 ksi	52619,05 MPa	58417,66 MPa
Compression strength, σ_{BC}	99,770 ksi	93,982 ksi	687,89 MPa	647,98 MPa
Transverse Shear Strength, τ_{sh}	28,500 ksi	28,026 ksi	196,50 MPa	193,23 MPa
Bond Strength, τ_r	2,435 ksi	2,080 ksi	16,79 MPa	14,34 MPa
Weight Loss of Bars Conditioned in Alkaline Solution, Δm	0,62%	0,72%	0,62%	0,72%
Tensile Strength of Bars Conditioned in Alkaline Solution, σ_{B1}	145,859 ksi	151,126 ksi	1005,66 MPa	1041,98 MPa
Tensile Strength Reduction of Bars Conditioned in Alkaline Solution, $\Delta\sigma_B$	12,41%	13,15%	12,41%	13,15%
Tensile Modulus of Elasticity of Bars Conditioned in Alkaline Solution, E_{f1}	6941,847 ksi	7544,197 ksi	47862,35 MPa	52015,41 MPa
Bond Strength of Bars Conditioned in Alkaline Solution, τ_{r1}	2,234 ksi	1,826 ksi	15,40 MPa	12,59 MPa
Bond Strength Reduction of Bars Conditioned in Alkaline Solution, $\Delta\tau_r$	8,28%	12,23%	8,28%	12,23%
Ultimate Service Temperature, $T_э$	297,59°F	295,34°F	147,55°C	146,30°C

Design&Modelling

A panel of 7,5 m in nominal length and 3,0 m in nominal height was used as a test specimen. The actual structural dimensions of the panel were 7,488×2,888(2,65) m. The width of the outer layer was 70 mm, the internal – 100 mm. A 150 mm thick insulation layer is inserted between the two layers. The layers are connected by means of truss-type ties from stainless steel. The panels of this type are supported by means of steel embedded members installed in pairs (the top and the bottom) at the edge and in the center of a panel. Structural scheme of buildings in which these panels are used frameless, with load-bearing interior walls. Therefore, the exterior panels are cladding and non-loadbearing. The layers are reinforced with reinforcing meshes and separate bars. The internal layer is reinforced with A500 grade steel rebars and GFRP meshes. The outer layer is reinforced with separate GFRP bars and meshes from GFRP bars. The additional straight bars are installed in corners of window openings. Bent reinforcing members are designed in corners of the outer and internal layers for anchoring the longitudinal reinforcement. GFRP members are designed in the outer layer, while steel ones – in the internal layer. The internal and external reinforcement layouts are presented at Figure 2. As the panel observed is not loadbearing, structure design was performed for loads due to transportation and installation and for

operation loads due to wind action. The panel was designed for wind pressure for buildings of up to 100 m high.
Due to absence of design methods for structures with ties in design rules and in order to compare the design and test data, structure modeling and design in SCAD ver.21. were performed.

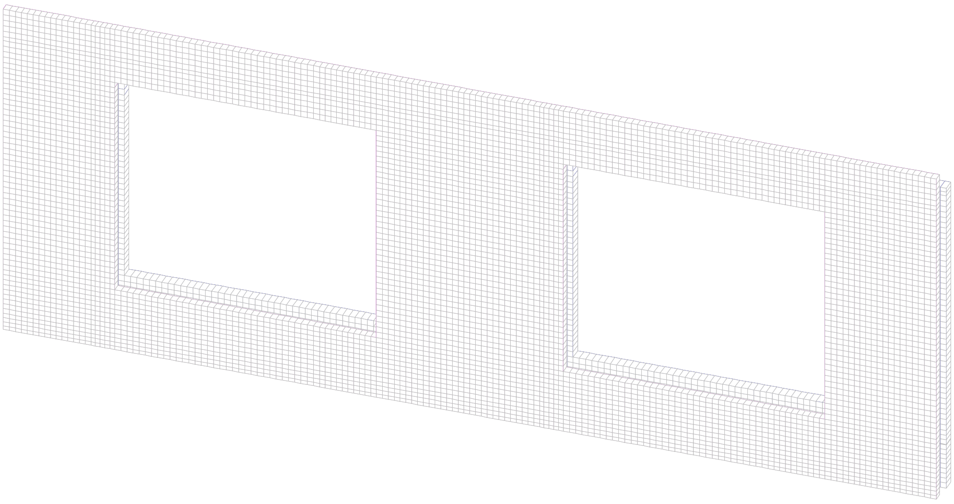


Figure 1. General view of design scheme of a panel in SCAD ver. 21

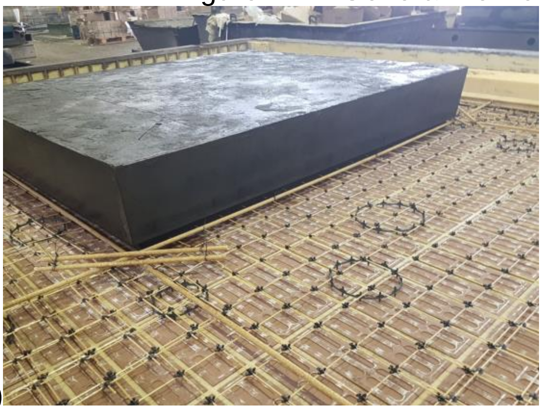
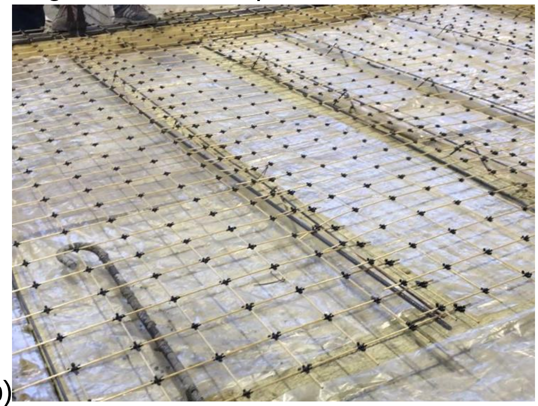
a)  b) 

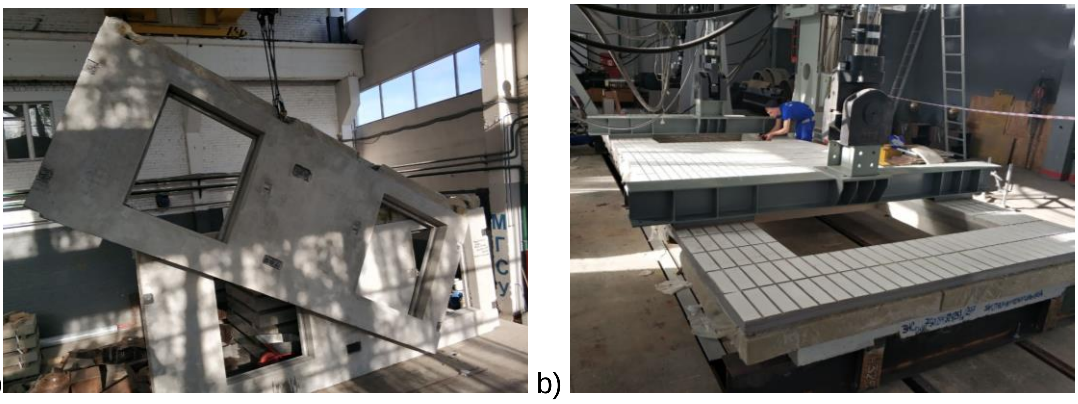
Figure 2. General view of exterior (a) and interior (b) layer's reinforcement layout

The maximum operation factor of 0,21 was applied during design for operation and wind action. The operation factor of 0,61-0,99 was applied during design for construction loads in places of embedded members for lifting.

Testing

General

Tests of the finished products were carried out on the base of proprietary methodologies (GOST 8829-94) and included the following:
1. Test of a panel for interaxial shear.
2. Test of a panel for strength and deformability under wind action (See Figure 3b).
3. Determination of strength of the lifting loop unit (see Figure 3a).
4. Fire test.



a) b)

Figure 3. Determination of strength of the lifting loop unit (a) and Test of a panel for strength and deformability under wind action (b)

Results of testing

According to the results of testing the structure of a triple layer panel exceeds the requirements of regulatory documents.

Conclusions

A new sandwich wall panel was developed with hybrid steel/GFRP reinforcement made from LightWeight Self-Compacting Concrete. Implementing of GFRP bars in outside layer of the panel improves durability, extends service life and reduces life cycle cost of such structures. With the use of expanded-clay lightweight self-compacting concrete it could be possible to reduce total dead weight of 7.5 m long panels from 7 to 4.5 tons.

Acknowledgements

This research was supported by The Head Regional Shared Research Facilities of the Moscow State University of Civil Engineering.

References

[1] Mohammed Bida, S.; Nora Aznieta Abdul Aziz, F.; Saleh Jaafar, M.; Hejazi, F.; Nabilah, A.B. Advances in Precast Concrete Sandwich Panels toward Energy Efficient Structural Buildings. Preprints 2018, 2018100147 (doi: 10.20944/preprints201810.0147.v1).

[2] Manalo, A., Aravinthan, T., Fam, A., and Benmokrane, B., (2017). "State-of-the-Art Review on FRP Sandwich Systems for Lightweight Civil Infrastructure." ASCE Journal of Composites for Construction, Vol. 21, No. 1, p. 04016068-1.

[3] Haffke, Marcin & Schmitt, Andreas & Pahn, Matthias. (2016). EXPERIMENTAL INVESTIGATION OF FLEXURAL BEHAVIOUR OF THIN SANDWICH WALL PANELS REINFORCED WITH GFRP REBARS. Eighth International Conference on Fibre-Reinforced Polymer (FRP) Composites in Civil Engineering (CICE 2016)

[4] Chris P. Pantelides, M.ASCE; Rajeev Surapaneni; and Lawrence D. Reaveley. Structural Performance of Hybrid GFRP/Steel Concrete Sandwich Panels. Journal of Composites for Construction Vol. 12, Issue 5 (October 2008) https://doi.org/10.1061/(ASCE)1090-0268(2008)12:5(570)