UTILIZATION OF HIGH PERFORMANCE SILICATE COMPOSITES IN MATERIAL EFFECTIVE BUILDING STRUCTURES

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Summary

Development of sustainable material effective structure is based on the effort to reduce primary non-renewable material consumption. Utilization of high performance silicate composites creates the conditions for the dimension optimization, leading to the savings in raw materials and thus to the more favourable environmental characteristics of implemented structures.

The aim of the research was to verify the potential design of slender waffle floor structures with minimized thickness of upper slab (25 to 30 mm). Overall properties of 12 different fibre concrete mixtures were tested in order to find out optimal material for the waffle floor structure. The materials were validated both from the mechanical and environmental perspective. The final test specimens in the form of representative segment of waffle floor slab were tested by the combination of torsion and bending. The environmental evaluation of samples proved that by the shape and material optimization up to 70% of material can be saved.

Keywords: high performance concrete, sustainable development, waffle floor structures

1 Introduction

Building sector has significant impact on the global environment. It is the biggest consumer of the primary materials and energetic sources, and at the same time it is the producer of the harmful emissions. Implementation of the environmental measures in building structures is inevitable in order to reach the sustainable development.

The reduction of structural material consumption can be achieved by the shape optimization. Waffle floor structures represent such effective structure both from the perspective of static parameters and material consumption relation. The static advantages are the consequence of the ribbed cross section, bidirectional span structure and lower surface density. Waffle floor structures can reduce material consumption to 50% in comparison to full reinforced slab while keeping similar static parameters. Another 20% can be saved by utilizing high performance concrete.

2 Design of the waffle floor structure

2.1 Fibre concrete mix design

The first step of the research was to find out optimal concrete mixture from the perspective of workability, mechanical properties and environmental efficiency. The individual series differed in type of cement and fibres. The influence of polypropylene and steel fibres with and without ending was tested. The fibres content was 1% by volume. The flexural strength was tested on 28 days old thin slabs 700/250/30 by 4-point bending test.

Tab. 1 Investigated series specification and test results

Series No.	Reinforcement	Fibre tensile strength (MPa)	Flexural strength (MPa)	Compressive strength (MPa)
S-I	Reinforcing steel mesh 4/100/100	550	5.7	46.5
S-II	BeneSteel 50/35 polypropylene 35 mm	660	5.6	54.3
S-III	Fibrex A1 steel 25 mm	350	6.4	55.2
S-IV	Třinec 60 steel 60 mm	1000	7.8	54.1
S-V	Dramix ZP 305 steel 30 mm	1100	6.9	53.6
S-VI	Plain concrete	-	6.8	89.6
S-VII	Dramix RC 80/30 BP steel 30 mm	2300	7.2	83.8
S-VIII	Plain concrete	-	6.7	59.6
S-IX	Fibrex A1 steel 25 mm	350	8.6	80.0
S-X	Steel microfibres 9 mm	2400	14.8	176.5
S-XI	Dramix RC 80/30 BP steel 30 mm	2300	5.9	92.3
S-XII	Stratec 0,15 steel 13 mm	2400	10.4	136.8

The series S-I (with conventional reinforcement), S-VI and S-VIII (plain concrete) served as reference series in order to evaluate the effect of the fibres on the mixture properties. Series S-X was made by the team of prof. Schmidt from Kassel University from their UHPC mixture M2Q.

2.2 Environmental assessment of thin slabs

The environmental efficiency of slender slabs was calculated for each mix design. In this paper there are presented results of reference series S-I reinforced by reinforcing mesh, S-IV series with 60 mm long steel fibres, S-IX series from HPC concrete reinforced by Fibrex A1 fibres and S-X UHPC series reinforced by steel microfibres. Embodied energy and emissions were calculated from data for plain concrete C50/60 [1], data for individual fibres from [2] and difference in cement quality and amount were calculated from [3].

Calculated environmental impacts were embodied energy, embodied CO_2 emissions and embodied SOx emissions. The ratio of the environmental impacts to experimentally measured flexural strength (which is proportional to load capacity, i.e. to its mechanical performance) was calculated for a case of assessed slabs. The environmental efficiency of HPC and UHPC concrete is obvious from the following table (**Tab. 2**). It is due to their outstanding mechanical performance.

Tab. 2 Comparison of environmental parameters of slender slabs.

	embodied energy (MJ/MPa)	embodied CO_2 (kg CO_2/MPa)	embodied SO_x (g SO_x/MPa)
S-IV OPC, 60 mm fibres	3.55	0.38	2.71
S-IX HPC, Fibrex A1 fibres	3.18	0.30	1.32
S-X UHPC, steel microfibres	2.99	0.29	1.22

2.3 Experimental investigation of waffle floor segments

Test specimens in the form of representative segment of waffle floor structure were made from two different mixtures – S-IX with Fibres A1 fibres and from fine-grained mixture with Stratec 13mm fibres (improved S-XII mixture). All test specimens had an equal reinforcement. The steel bars R 10505 of 10 mm diameter were used. The cover layer was 15 mm. There was no shear or torsional reinforcement in the tested structure. The top thin slab (30 mm thick) was from fibre concrete without conventional steel mesh.

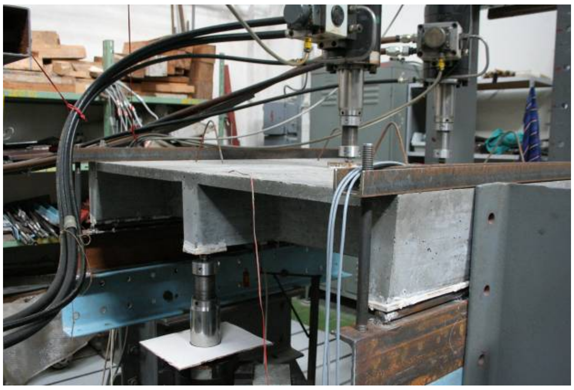

Fig. 1 Testing of the specimen

Fig. 2 Specimens destruction

The compressive strength was measured on cubes prior to tests of full scale samples. The first series had an average compressive strength of 105 MPa (hence called HPC105), while the fine-grained samples showed the average compressive strength of 140 MPa (HPC140).

Test specimens were subjected to the combinations of flexural and torsional loads. The position of load is apparent from the picture (**Fig. 1**). The loading of specimen started with introduction of torsion load. The load was applied in 1kN steps with the subsequent unloading to 1kN. At 10kN the forces were kept on that level and the middle force started to bend the sample (5kN steps and subsequent unloading to 1kN) until the destruction of the sample. All HPC105 samples withstood about the same load that was approx. 65kN induced by middle jack and torsion imposed by 10kN forces, while the maximal measured flexural strength for HPC140 samples was 85kN with the torsion held on 10kN.

2.4 Environmental evaluation

Four alternatives of floor structures have been compared: i) full RC slab from ordinary concrete C30/37, ii) waffle floor structure from ordinary concrete C30/37, iii) waffle floor structure from HPC105 and iv) waffle floor structure from HPC140. All structures were designed for the same performance – dead load 4kN/m^2, live load 1,5 kN/m^2, span 5 x 5 m, total thickness of 200 mm. The waffle floor from ordinary concrete had 60 mm thick upper deck and the thickness of the rib was 80 mm. While waffle slab from HPC105 and

HPC140 had dimensions: upper deck 30 mm, rib 50/170 mm. Embodied energy and emissions were calculated from data for plain concrete and individual fibres from [2] and difference in cement quality and amount were calculated from [3].

Tab. 3 Comparison of environmental parameters of slender slabs.

	self weight (kg/m^2)	**embodied energy (MJ/m^2)**	**CO_2 emissions ($kg\ CO_2/m^2$)**	**SO_x emissions ($g\ SO_x/m^2$)**
Full RC slab C30/37	483.2	619.5	66.9	190.4
Waffle slab C30/37	231.4	365.0	34.6	108.0
Waffle slab 105MPa, Fibrex A1	144.2	325.1	29.0	124.9
Waffle slab 140 MPa, steel microfibres	140	472.2	35.4	130.2

The table shows evident environmental advantages of all waffle structures. The reduction of concrete consumption in optimized shape of waffle FRC floor structure can reach up to 50 to 70 % in comparison with full RC slab. Moreover this results in lower load from self weight and consequently lower load on supporting structures (columns, walls, foundations).

3 Conclusions

The analysis of static and environmental parameters of subtle waffle floor slab structures showed significant potential for practical application of these structures in environmentally friendly building constructions. The tests showed higher shear and torsion capacity of subtle waffle section from fibre concrete and supported assumption that conventional shear reinforcement can be replaced by steel fibres. This approach enables design of very subtle top RC slab (30 mm thick and less) without conventional reinforcement.

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References

[1] www.bauteilkatalog.ch, 2007

[2] WALTJEN T.: Passivhaus-Bauteilkatalog 2008 – Ökologisch bewertete Konstruktionen, Springer-Verlag, Wien, 2008, ISBN 978-3-211-29763-6

[3] SCHIEßL P., STENGEL T.: Der kumulierte Energieaufwand ausgewählter Baustoffe für die ökologische Bewetung von Betonbauteilen, Wissenschatl. Kurzbericht Nr.13,2007