LARGE SCALE TESTS AND ENVIRONMENTAL EVALUATION OF THE WAFFLE FLOOR SLABS FROM FIBRE CONCRETE

P. Hájek[1], M. Kynčlová[2], C. Fiala[3]

Abstract:

Development of sustainable material effective structure is based on effort to reduce primary non-renewable material consumption. Utilization of fibre concrete creates the conditions for the optimization of dimensions, leading to savings in raw materials and thus to the more favourable environmental characteristics of realized structures.

The aim of the research is to verify the potential design of slender waffle or rib floor structures with minimized thickness of upper slab (25 to 30 mm). The slab of this size can not be effectively reinforced by conventional reinforcement thus the possible usage of fibre concrete is being verified while keeping safety on high level.

Totally 11 various series were tested. The individual series differed in types of fibre and concrete mixture usage. The influence of fibre types on mechanical properties was monitored. Based on the test results the optimal mixture was chosen for full scale test specimen in form of representative segment of waffle floor slab with dimensions 1200 x 1270 mm. Ribs were reinforced by steel rods, upper deck only by steel fibres. The specimens were tested by the combination of torsion and bending.

The tests showed that utilization of high performance fibre concrete can lead to the design of slender structures with reduced environmental impact while keeping safety and durability of the structure on the required high level.

Keywords: (fibre concrete, sustainable structures, waffle floor structures)

1 Background

Buildings in EU and other developed countries are responsible for more than 40% of the total energy consumption, and the construction sector generates approx. 40% of all man-made wastes [1]. There is obvious need for the reduction of raw material consumption.

The reduction of structural material consumption can be achieved by the shape optimization. Waffle floor structures represent such effective structure both from the

[1] Czech Technical University, Faculty of Civil Engineering, Thakurova 7, Prague 6, 166 29, petr.hajek@fsv.cvut.cz
[2] Czech Technical University, Faculty of Civil Engineering, Thakurova 7, Prague 6, 166 29, magdalena.kynclova@fsv.cvut.cz
[3] Czech Technical University, Faculty of Civil Engineering, Thakurova 7, Prague 6, 166 29, ctislav.fiala@fsv.cvut.cz

perspective of static parameters and material consumption relation. The static advantages are the consequence of the ribbed cross section, bidirectional span structure and lower self weight. 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. Load reduction is reflected in lower reinforcement consumption and in lower load on supporting structures. Additional savings are in transportation cost. The motivation is not based only on economical but also on environmental advantages followed from sustainable development criteria.

Partial task of the research was to verify the option of slender waffle and rib floor structures design with minimized upper deck thickness (up to 30 mm). The slab of this thickness cannot be effectively reinforced by conventional reinforcement and thus the possibility of fibre concrete utilization is being verified while maintaining structure reliability on high level.

2 Small scale tests – thin slabs specimens

The first step of the research was to find out optimal concrete mixture from the perspective of workability and mechanical properties. 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. Test specimens were in the form of slender slabs with dimensions 700/250/30 mm.

Verification of mechanical properties of slender slabs was performed according to standard 4-point bending test method. Test samples were tested after 28 days. Load was applied in 0,25kN steps for period of 60s. Test results are shown in following table (Tab. 1).

Tab. 1 Test results of thin slabs

Series No.	**Type of reinforcement**	**Fibre length (mm)**	**Flexural strength (MPa)**
S-I	Reinforcing mesh 4/100/100	-	5,7
S-II	BeneSteel 50/35	35	5,6
S-III	Fibrex A1	25	6,4
S-IV	Třinec 60 mm	60	7,8
S-V	Dramix ZP 305	30	6,9
S-VI	Plain concrete	-	6,8
S-VII	Dramix RC 80/30 BP	30	7,2
S-VIII	Plain concrete	-	6,7
S-IX	Fibrex A1	25	8,6
S-X	Steel microfibres 9 mm	9	14,8
S-XI	Dramix RC 80/30 BP	30	5,9

2.1 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-IX series from HPC concrete reinforced by Fibrex A1 fibres and S-X UHPC series reinforced by steel microfibres. Series of S-X specimens was produced in Kassel University from their UHPC (thanks to prof. M. Schmidt and his team). Embodied energy and emissions were calculated from data for plain concrete C50/60 [2], data for individual fibres from [3] and difference in cement quality and amount were calculated from [4].

Calculated environmental impacts were embodied energy, embodied CO_2 emissions and embodied SO_x 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 graph (Fig. 1). It is due to their outstanding mechanical performance.

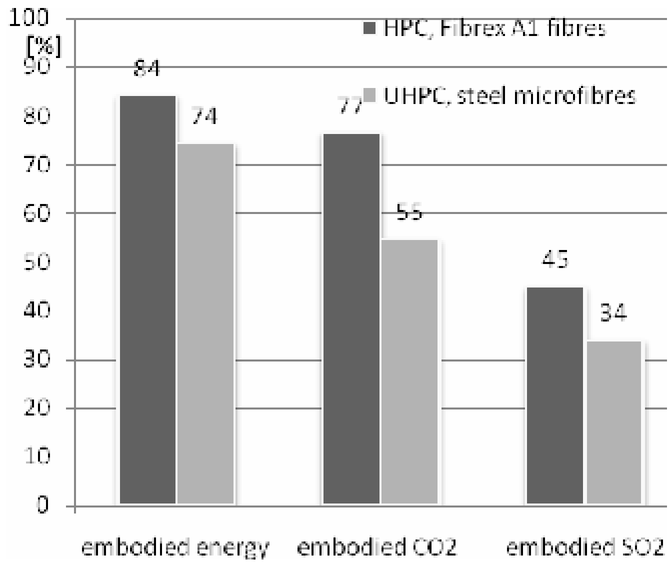

Fig. 1 Comparison of environmental parametres of thin slabs. Reference level 100% is represented by a slab reinforced by reinforcing mesh.

3 Full scale tests – segments of waffle floor slab

To investigate the structural behaviour of lightened subtle waffle slabs exposed to flexural and torsional loads, three specimens (representative parts of waffle slabs) were tested. Based on the test results of small slab specimens, it was decided to use the mixture with Fibrex A1 fibres. All test specimens had an equal reinforcement. The steel bars R 10505 of 10 mm diameter were used. The same class of concrete with compressive strength of approx. 100 MPa was applied. 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.

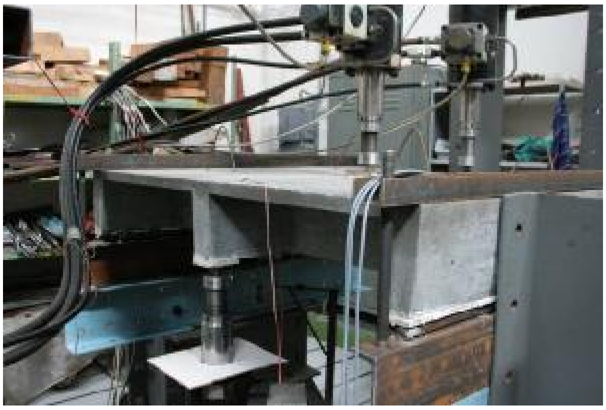

Fig. 2 Position of jags.

Test specimens were subjected to different combinations of flexural and torsional loads. The position of load is apparent from the picture (Fig. 2). The first was applied the torsion. At 10 kN the forces were kept on that level and the middle force started to bend the sample until the destruction of the sample. All samples withstand roughly the same load that was approx. 70kN induced by middle jack and torsion imposed by 10kN forces.

Fig. 3 Destruction of the specimen.

3.1 Environmental assessment

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 fibre reinforced high performance concrete and iv) waffle floor structure from UHPC. All structures were designed for the same performance – dead load 4kN/m2, live load 1,5 kN/m2, span 5 x 5 m, same 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 HPC and UHPC had dimensions: upper deck 30 mm, rib 50/170 mm. The data source used in the analysis is Passivehaus-Bauteilkatalog (2008).

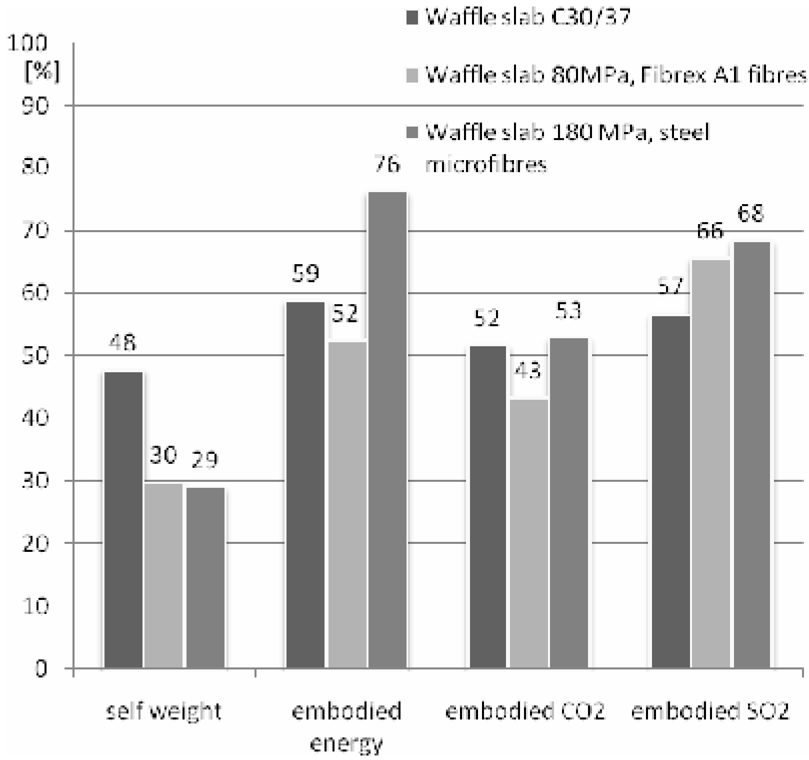

Fig. 4 Comparison of environmental parameters of RC floor slabs. Reference level 100% is represented by a full RC slab.

The graph shows evident environmental advantages of 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).

The environmental efficiency of waffle floor structure from UHPC is worse than from HPC concrete and even from ordinary concrete. When compared to environmental assessment of thin slabs it is obvious that structures from UHPC concrete are environmentally effective structures only if their mechanical performance is fully utilized.

4 Conclusions

Analysis of static and environmental parameters of various kinds of fibre concrete showed significant potential for practical application of subtle waffle floor slab structures (made from fibre reinforced HPC) to be used 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 (25 – 30 mm thick) with evident material savings.

Aknowledgements

These results have been achieved with the financial support of the Grant Agency of the Czech Republic Grant Project No. 103/07/0400 and doctoral grant Grant Project No. 103/09/H085. All support is gratefully acknowledged.

References

[1] CIB 1999: *„Agenda 21 on Sustainable Construction“*, CIB Report Publication 237, Rotterdam

[2] www.bauteilkatalog.ch, 2007

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

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