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SHORT REPORT

F 958

Development of an Innovative Wall Construction with High Heat Insulation made of Foam SCC and Textile Reinforced Concrete

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The authors are responsible for the content of the research report.

1 AIM OF THE RESEARCH PROJECT

Usually external wall constructions of residential buildings are made of single leaf or cavity masonry walls. The aim of this research project was to develop an innovative system as alternative to the common wall constructions. On the one hand the new wall system should meet the requirements of the heat insulation and on the other hand it should have a very high surface quality. In addition, no further thermal insulating materials should be used to keep all materials completely recyclable. This new wall construction consists of an integrated formwork made of textile reinforced concrete (TRC) as well as of self-compacting lightweight foam concrete (SCLFC) as concrete infill. The SCLFC is composed of a lightweight aggregate and a porous matrix. By the use of this innovative system, the technical properties of the individual components can be combined positively whereby ecological and economical advantages could be achieved.

2 REALIZATION OF THE RESEARCH PROJECT

The research project is divided into four main subjects: the design of the integrated formwork, the development of the SCLFC, the wall production and finally the wall testing. Each wall consists of two integrated formwork elements and the developed SCLFC.

Within the framework of the research project, four centric compression tests on storey-high (2.75 m) and one meter wide wall elements were planned. The wall thickness was determined to 0.35 m by the use of building physical calculations (Glaser-method /DIN01/). Initially, the four walls should be produced in a precast plant. However, since the SCLFC segregated during two concretings, the further walls were manufactured at the Institute of Building Materials Research.

During the first two concretings at the institute difficulties arose. The concrete did not segregate but additional was not sufficiently stable. As a consequence, the SCLFC subsided. In spite of the initial problems, two walls were finally produced and tested under compressive load at an age of 28 days.

Due to the aforementioned difficulties the mixture was modified (replacement of the cement type). As a result, a stable SCLFC could be obtained and two more walls could be produced and tested.

3 SUMMARY OF THE RESULTS

The aim of the project was the development of a prefabricated wall using an integrated formwork made of TRC as well as a self-compacting lightweight foam concrete (SCLFC) as concrete infill.

Just like a conventional formwork sheet, the integrated formwork made of TRC must absorb the flexural tensile and compressive stresses resulting from the fresh concrete pressure during concreting. Figure 1 shows the static system for the design of the formwork element. The fresh concrete pressure in the amount of 16.5 kPa acts as load during concreting. The formwork element is supported at the back by transverse braces which are arranged at a spacing of 0.5 m. First, a suitable fine grained concrete mix was developed. In addition the fine grained concrete mix was modified using two different types of short fibres. Resulting from the findings of previous research projects, the shape of the integrated formwork elements was designed as web slab. During preliminary tests, the shear force capacity of the web slabs was investigated. As a result, the shear force capacity could be increased by using one of the two short fibre mixes, but the workability was insufficient. Hence, the fine grained concrete mix without short fibres was used to produce all further web slabs.

To determine the dimensions and the spacing of the webs, a parameter study was carried out using two different calculation methods. The results of the slab beam theory and the FE-simulation were compared. There were partly significant discrepancies between both calculation types. This is probably because the slab action of the web slabs was not considered by using the slab beam theory. However, two cross-sections of the web slabs could be chosen to examine the load bearing behaviour in a three-point bending test. From this, the absorbable positive as well as the absorbable negative moments were determined because moments of span as well as support moments arise when filling the formwork elements. By comparing the experimental tests with the results of calculation, the shear force could be found as the decisive parameter for the design of the integrated formwork elements. Figure 2 shows the final cross section of an integrated formwork element.

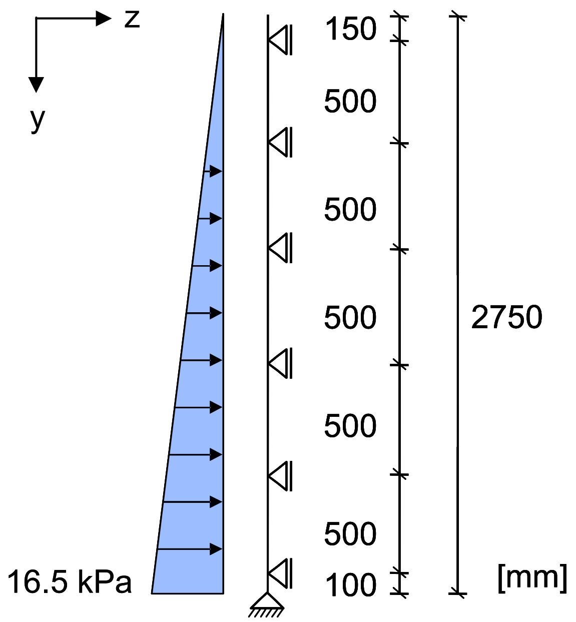

Figure 1: Static system of the integrated formwork element under fresh concrete pressure

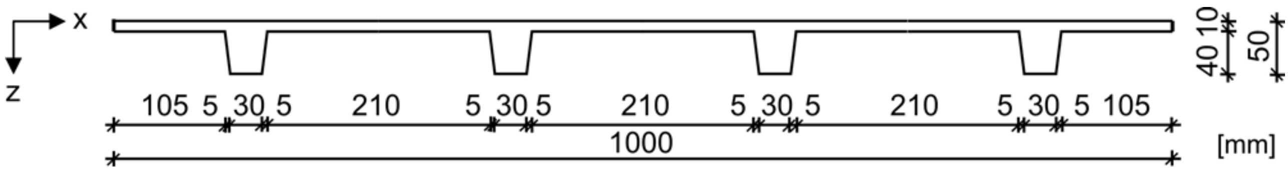

Figure 2: Cross section of the formwork element

The integrated formwork elements were concreted in a precast plant. It turned out that the spraying technique is the best production technique to insert the fine grained concrete into the formwork. Besides it is possible to produce building members with a high surface quality.

When the mix of SCLFC was developed, the main focus was on yielding a low bulk dry density. At the same time a sufficient strength to provide for the load bearing capacity as well as a low thermal conductivity should be ensured. This was important to meet the requirements of the heat insulation at a practicable wall thickness. The developed SCLFC consisted of lightweight aggregate and prefabricated foam made of foaming agent. The optimized mixture featured a fresh concrete bulk density of 500 kg/m³ and a slump flow of 680 mm. The concrete was developed as a self compacting to save time, compaction energy and the required manpower to compact the concrete. After 28 d, the compressive strength was 2.21 N/mm² and the static modulus of elasticity amounted to 1,300 N/mm². The bulk dry density was 380 kg/m³ and the corresponding thermal conductivity according to DIN 52612 /DIN79/ amounted to $\lambda = 0.101$ W/(m·K).

Figure 3 shows the cross section of a wall. Considering the thermal conductivities of SCLFC and of fine grained concrete, a building physical calculation was performed. As the production and testing of the four walls were carried out both before and after the introduction of the German Energy Conservation Regulations 2009 (EnEV 09), the calculations are based on a heat transfer coefficient amounting to 0.315 W/(m²•K). This value resulted from the assumption that the heat transfer coefficient of the German Energy Conservation Regulations 2007 (EnEV 07) (0,45 W/(m²•K)) would be 30 % higher in the currently valid version. In fact, there was a 53 % increase so that the wall thickness would amount to 0.435 m. To retain comparability of the four wall tests, the 53 % increase was not realised but a wall thickness of 0.35 m was maintained.

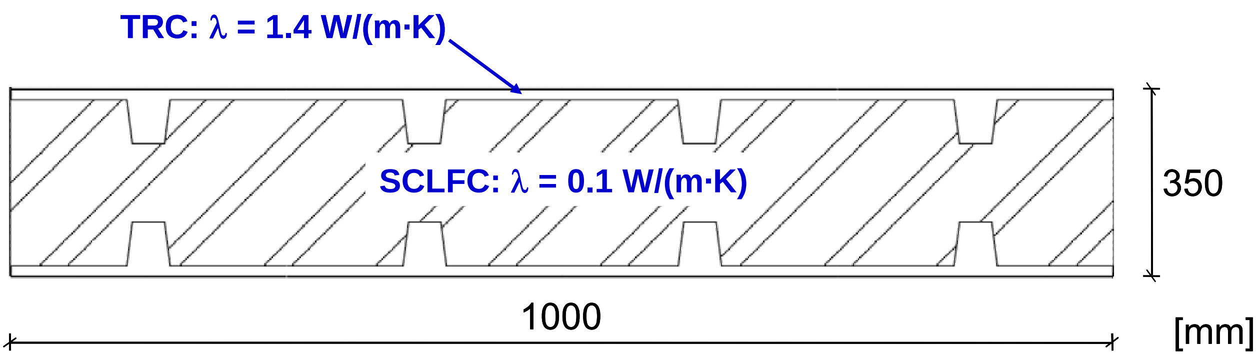

Figure 3: Cross section of the wall

Initially, the prefabricated walls were concreted in a precast plant, but during the filling of the walls difficulties arose because that the lightweight aggregate could not be wetted in advance and it floated. Hence, the further concretings took place at the Institute of Building Materials Research. During the production of the first two walls the SCLFC was not sufficiently stable. As the dead load was too high the SCLFC de-aerated. Further two walls were produced by using quick-setting cement. Thus, each concrete layer which was inserted into the formwork was already hardened before the next layer was filled in and the SCLFC could not subside anymore. As the SCLFC was inserted via the longer side, additionally the filling height was reduced (Figure 4a)). The production of the walls showed that the filigree integrated formwork elements could absorb the loads arising from the fresh concrete pressure during concreting.

The hardened concrete properties compressive strength, static modulus of elasticity and bulk dry density of the mix using quick-setting cement were in a similar range to those of the mix using the normal hardening cement. Thus, the same heat insulating properties were expected.

The centric compressive strengths of all four walls were tested using a 5-MPa-testing machine (Figure 4b)). The displacements of wall 1 and 2 were almost corresponding but as a result of an insufficient bonding behaviour of the integrated formwork and the SCLFC, the maximum load of wall 2 was only 846 kN. In comparison, the maximum load of wall 1 amounted to 1180 kN.

a) 

b) 

Figure 4: a) Concreting of a wall, b) Test set-up of centric compression test

Concerning the reproducibility, the walls 3 and 4 could only partly be evaluated. The arrangement of the displacement transducers at the front end of the wall was modified to examine the detachment of the integrated formwork from the SCLFC more exactly. Thus, the transverse displacements could not be compared. The longitudinal displacements coincided very well. As with wall 2, the maximum load of wall 3 was only 733 kN due to an insufficient bonding behaviour of the integrated formwork and the SCLFC. In comparison, the maximum load of wall 4 amounted to 1108 kN.

The transverse displacements of wall 4 revealed that the integrated formwork and the SCLFC detached from each other at an early stage of the test. Assuming that this detachment already corresponds to the failure of the wall then only small loads can be set. As a result, the integrated formwork elements have to be connected inside the system to achieve higher loads.

Finally, a distribution of the maximum load over the integrated formwork and the SCLFC was determined. The load supporting component amounted to 69.3 % for the integrated formwork and 30.7 % for the SCLFC. A comparison with the actually measured loads and displacements showed that the load supporting component of the integrated formwork is probably still higher. It must be the objective to decrease the load supporting component of the integrated formwork for example by using lightweight aggregate to produce the formwork elements.

In conclusion, it can be said that the aim of the project was partly achieved. A new wall construction was developed which consists of an integrated formwork made of TRC as well as of self-compacting lightweight foam concrete as concrete infill. With a wall thickness of 0.435 m the requirements of the German Energy Conservation Regulations 2009 (EnEV 09) can be fulfilled concerning the heat transfer coefficient in the amount of 0.24 W/(m² • K). To realise an industrial production of the wall system considerable efforts are still needed. The practicability of very light lightweight concrete with a foamed matrix is not given yet and has to be developed by choosing the basic materials and the production process. In addition, a further reduction of the density is necessary.

4 LITERATURE

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/DIN01/ DIN 4108-3:2001-07 Wärmeschutz und Energie-Einsparung in Gebäuden; Teil 3: Klimabedingter Feuchteschutz, Anforderungen, Berechnungsverfahren und Hinweise für Planung und Ausführung