Zukunft Bau

Short Report

Title

Development of an ecological and economical construction method through the use of prefabricated multifunctional wall components made of graded concrete

Az.: SWD-10.08.18.7-16.48

Occasion of the study / starting position

The building industry is facing the challenge to build for more people with less material. This requires the development of new technologies which contain lightweight constructions, the minimisation of fossil based energy consumption and the full recyclability of building components.

In this context, the aim of the research project was the development of purely mineral, multifunctionally graded wall components (Figure 1). These components should be able to meet the requirements of a load-bearing wall, durability, an attractive architectural appearance and thermal insulation simultaneously, while at the same time achieving significant mass savings, a significant $C0_2$ reduction and a mono-material recyclability compared to conventional wall components.

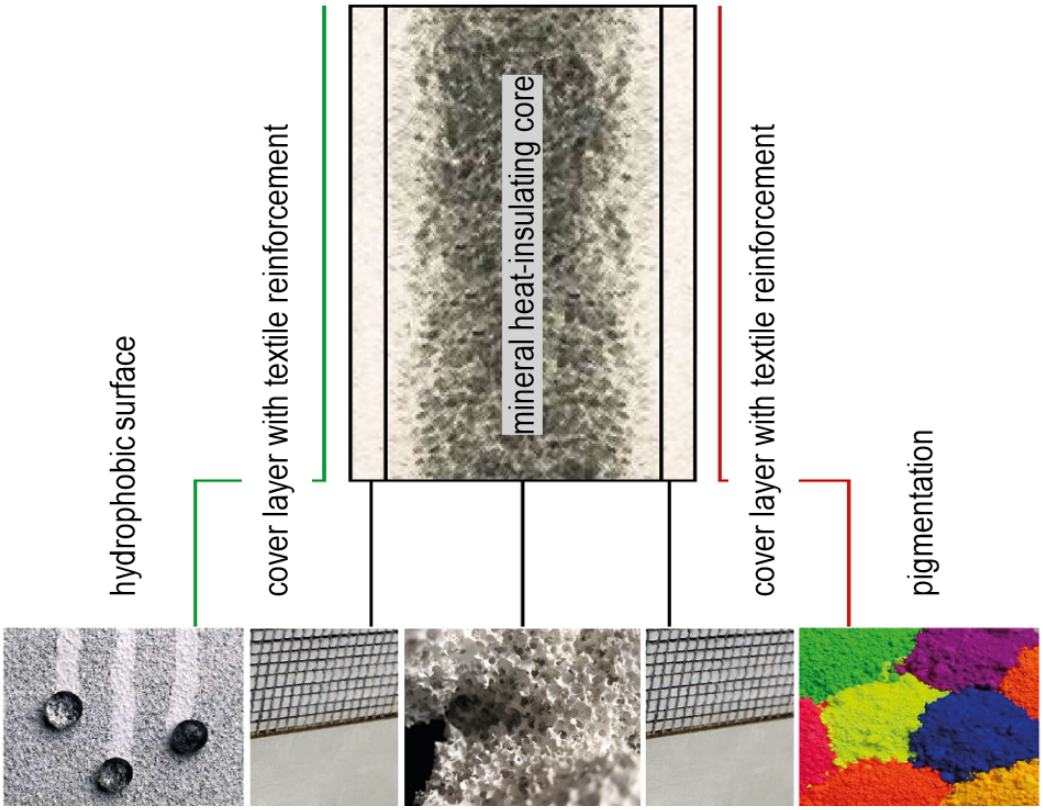

Figure 1: Conceptual setting of a multifunctionally graded wall

Object of the research project

Within the scope of this research project, the fundamentals for the off-site fabrication of multifunctional graded wall components were researched. This includes the material requirements, the manufacturing constraints and the design and calculation methods for the use of graded concrete in exterior walls of a building.

Based on the current state of research in the field of heat-insulating concrete wall systems and graded concrete, the requirements and design goals for a multifunctional graded wall could be defined. The wall should be optimized with regard to load-bearing capacity and thermal insulation without exceeding a wall thickness of 36.5 cm and an area-related mass of 500 kg/m^2. In addition, the exterior wall should also fulfil further requirements of building physics such as noise and fire protection. In order to meet these aspects, the normative regulations for the wall components were compiled at the beginning of the project to determine the boundary conditions for the design and calculation.

Further design constraints result from the material and production technology of graded concrete. In this regard the developed manufacturing techniques, such as layered casting as well as dry and wet spraying, were analyzed and evaluated for the production of multifunctional graded wall elements. It turned out that the layered casting as well as the wet spraying, under further development of the heat-insulating concrete mixtures, are potentially applicable. Due to the existing automated production platform (Figure 2) for the wet spraying, this approach was further researched, because it allows an immediate transfer of the technology to the precast factory. The investigations and tests in the project have significantly improved the overall process, including the development of new recipes for pumpable lightweight concrete and the determination of process related parameters for the automated production of graded concrete components. It turned out after extensive studies on wet spraying technology, that the layered casting has process related advantages, which allow the use of very low dense and thermal insulated concrete.

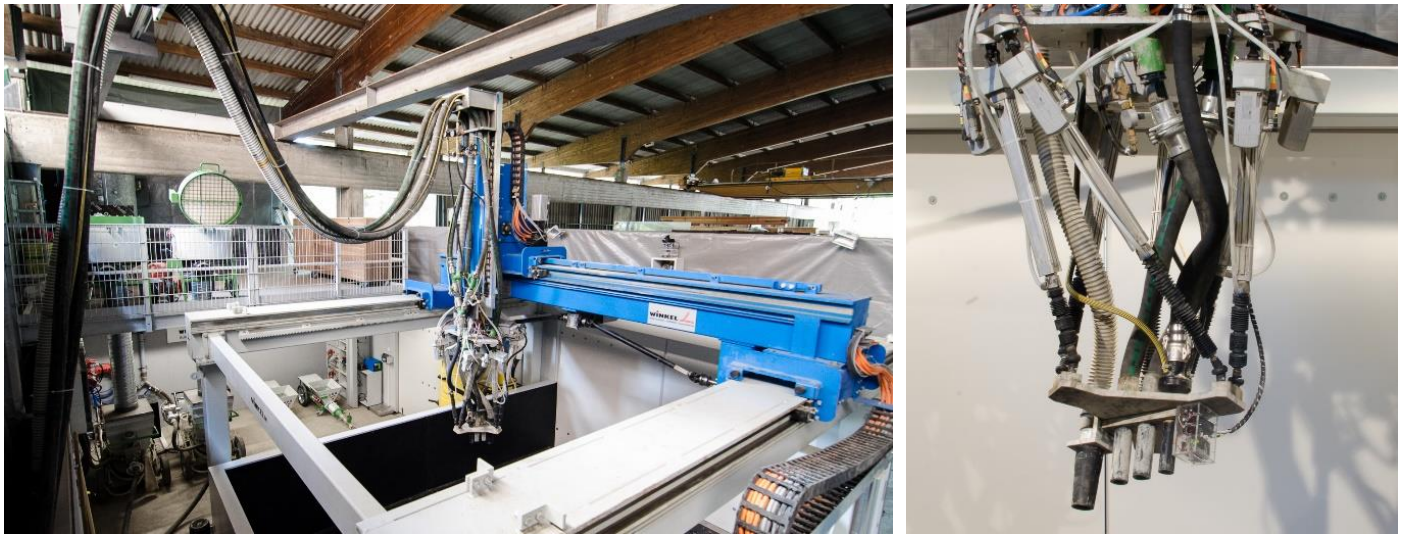

Figure 2: Gantry-system (left) with Stewart-Gough-platform (right) for the automated production of graded concrete components

Simultaneously with the investigations on the material and manufacturing level, a process-independent design approach was set up to determine the optimum density distribution inside the wall. The minimization of component weight was defined as the objective function, while maintaining the constraints of thermal insulation. In a subsequent design step, the secondary objectives such as noise or fire protection were checked. If the cross section did not fulfill these requirements, the material distribution will adjust. The optimization result of the design approach always follows a two-material composition. The optimal material distribution results in a sandwich structure consisting of two high-strength, load-bearing cover layers and a heat-insulating core. The chosen gradation influences the wall thickness but not the general distribution. With the micro gradation (aerogel concrete) applied by layer casting, a wall thickness between 22 and 26 cm is possible by a maximum mass per unit area of 280 kg/m² (Figure 3, right). By the so-called meso gradation, three layers of dense packed mineral hollow spheres provide the required thermal insulation. This achieves a surface weight of the wall of 350 kg/m² and a wall thickness of 28 cm (Figure 3, left).

Figure 3: Small scaled demonstrators of a meso graded wall design (left) and a micro graded wall design (right) exhibited at the fair Bau in Munic 2019

In scaled component tests (Figure 4) the load-bearing capacity of the wall components was tested experimentally in order to validate both the analytical design approaches and the numerical calculation methods. The results showed a sufficient match between the calculations and tests, whereby the formulated design approaches could be confirmed.

Figure 4: Experimental component test at the beginning (left) and at the end of testing (right)

Furthermore, connecting details were presented, which enable the joining of the individual prefabricated concrete elements. Conceptually details for wall-to-wall, wall-to-floor and wall-to-foundation connection were specified. They include existing solutions which are adapted to the given boundary conditions as well as new concepts based on the preliminary work done at the ILEK. In addition, a cost calculation for the two design variants (micro and meso gradation) of the graded wall was performed in the scope of the project. In comparison with the conventional wall system used on the market, the developed approaches show a competitive solution at the current research state.

By the production of a demonstrator wall in real scale the achieved project results could be validated and the potential of the technology could also be confirmed. Finally, a weight reduction of approximately 60 % was achieved compared to conventional solid walls with ETICS, while maintaining the same structural and thermal performance and, in addition, keeping a mono material recyclability.

Figure 5: Front view (left) and isometry of the micro graded sandwich wall demonstrator (right)

Conclusion

The aim of the research project could be achieved by the development of purely mineral, multifunctional graded wall components, which meet the structural and building physical requirements. For this purpose, design approaches and normative calculation methods could be formulated and experimentally validated. Also the leading manufacturing processes have been identified and were further developed. At the end of the project, the technology achieved mass savings of approximately 60 % compared to existing wall elements, by comparative construction costs. In the following projects the still open questions for the practical use of the technology must be explored.

Basic data

Short title: Prefabricated functional graded concrete wall elements

University of Stuttgart
Institute for Lightweight Structures and Conceptual Design (ILEK)
Prof. Dr.-Ing. Dr.-Ing. E.h. Dr. h.c. Werner Sobek
Dr. Ing. Walter Haase (project manager)
M.Sc. Daniel Schmeer

Institute for Building Materials (IWB)
Prof. Dr.-Ing. Harald Garrecht
M.Sc. Olga Arkhipkina

Institute for System Dynamics (ISYS)
Prof. Dr.-Ing. Dr. h.c. Oliver Sawodny
M.Sc. Benjamin Schuler

Total cost: 432.757,96 € €

Government subsidy: 278.412,92 €

Project duration: 01.11.2016 – 28.02.2019 (27 moths)

Figures

Figure 1: Konzeptioneller Aufbau einer multifunktionalen Gradientenwand.tif
Legend: Conceptual setting of a multifunctionally graded wall
Copyright: ILEK, Universität Stuttgart

Figure 2 (left): Applikationssystem.tif
Figure 2 (right): Stewart-Gough-Plattform.tif
Legend: Gantry-system (left) with Stewart-Gough-platform (right) for the automated production of graded concrete components
Copyright: ILEK, ISYS, IWB, Universität Stuttgart

Figure 3: Wände Messe Bau.tif
Legend: Small scaled demonstrators of a meso graded wall design (left) and a micro graded wall design (right) exhibit at the fair Bau in Munic 2019
Copyright: Stephan Görlich Fotografie

Figure 4 (left): Bauteilprüfung_1.tif
Figure 4 (right): Bauteilprüfung_2.tif
Legend: Experimental component test at the beginning (left) and at the end of testing (right)
Copyright: ILEK, Universität Stuttgart

Figure 5 (left): Ansicht Sandwichwand.tif
Figure 5 (right): Querschnitt Sandwichwand.tiff
Legend: Front view (left) and isometry of the micro graded sandwich wall demonstrator (right)
Copyright: ILEK, Universität Stuttgart