TECHNISCHE UNIVERSITÄT KAISERSLAUTERN

BAUINGENIEURWESEN
Fachgebiet Massivbau und Baukonstruktion

Paul-Ehrlich-Straße
Gebäude 14, Zimmer 572
67663 Kaiserslautern

Telephone: +49 (0)631 205-3083
Telefax: +49 (0)631 205-3555

matthias.pahn@bauing.uni-kl.de
catherina.thiele@bauing.uni-kl.de
www.massivbau-kl.de

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FEHR Technologies

Outline report of the research project

Project:	Sandwich load-bearing behaviour of core-insulated prefabricated wall panels under fire load
	(Reference number: SWD-10.08.18.7-17.25)
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Project team:	Prof. Dr.-Ing. Matthias Pahn
	apl. Prof. Dr.-Ing. Catherina Thiele
	Marcin M. Haffke, M.Sc.Eng.
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Pahn C. Thiele Haffke

Prof. Dr.-Ing. Matthias Pahn — apl. Prof. Dr.-Ing. Catherina Thiele — Marcin M. Haffke, M.Sc.Eng.

Table of Contents

1 Motivation

External walls are more and more often manufactured as precast concrete elements with internal thermal insulation. As a result of increasingly denser building development, situations in which a sandwich wall is supposed to serve as a firewall arise frequently. A lack of scientific information about the behaviour of sandwich walls in the fire situation, taking into account the connectors and the facing layer, as well as existing building law requirements, prevent their use for passive fire protection of buildings.

2 Implementation of the research project

Although a high fire resistance of sandwich walls has already been reported in the literature, no criteria for the design of the wall component have been specified, which would allow the integration of this multi-layered concrete elements as a fire wall. The number of possible products and the fire behaviour of the materials used can cause difficulties in this process. The compliance with the criteria of fire walls remains of great interest due to the increasingly dense building development and possible extension of the existing buildings. Thus, the influence of an increased temperature on the load-bearing behaviour of the multi-layer wall element should be investigated for the wall element, so that this can be taken into account in the fire protection design. Due to their three-layered structure, the sandwich walls offer the possibility of reducing the concrete wythe thickness compared to a single concrete wall of the same fire resistance. The consideration of the realistic load-bearing behaviour – the sandwich composite load-bearing behaviour – can make that possible. The scientific explanation and the mechanical background of the load-bearing behaviour of the sandwich wall in case of fire and its fire resistance were investigated within the framework of this research project. Theoretical and practical investigations were carried out.

The sandwich walls were tested as fire walls in large-scale classification tests under fire load, an eccentric load and a subsequent impact load. The investigated parameters were the side of the exposure to fire as well as the core layer thickness. The fire resistance REI120-M was confirmed in all tests. The test results have shown that the load-bearing behaviour of a sandwich wall under fire load is strongly influenced by the temperature-dependent contribution of the core layer. The sandwich composite load-bearing action in case of fire with relatively soft insulation and GFRP-connectors was also present. During the analysis of the thermal behaviour it was recognized that the penetration of the wall cross-section with hot water steam has the most significant influence on the heat transfer in case of fire. Neither the insulation nor the connectors have led to any fire propagation or excessive heat transfer. The thermal bridges observed as a result of the GFRP-connectors' presence in the large-scale tests led to a slight increase in temperature on the unexposed side compared with the rest of the wall. In addition, no dropping or dripping of materials outside the core layer was observed. The suspended facing wythe was never detached from the supporting layer in an uncontrolled manner.

In order to determine the shear carrying properties of the core layer as a function of the temperature rising in the event of fire, a series of fire tests was carried out on sandwich wall cross-sections. Two conventional insulating materials, alone and in combination with two types of connectors, were tested at specified elevated test temperatures.

The experimentally determined properties of the core layer components have provided information on their realistic fire behaviour in a sandwich wall structure. In general, the core layers showed good mechanical properties until a specific decomposition temperature was reached at which these properties were lost. The results show that the tested non-combustible (mineral wool) and flame retardant (EPS) insulation materials are well-suited for the production of fire-resistant sandwich walls, although they exhibit different shear behaviour with rising temperatures. Mineral wool can retain its thermal insulation function also in a fire situation, even if only a small contribution is provided to the bending stiffness of the wall. The EPS insulation makes a high contribution to the shear stiffness of the core layer, which, however, is reduced at relatively low temperatures and subsequently completely lost. The fire behaviour of the core layer components did not impair the functionality of the concrete wythes in any test. It was observed that the rigid insulating materials (such as the tested EPS) could improve their bond to the concrete at low elevated temperatures and had a significant stabilising effect on the connectors. Neither smoke development nor a contribution to fire propagation were observed, although the supply of oxygen was not prevented in this test setup.

The tested GFRP-connectors showed a low sensitivity of their shear-bearing behaviour up to temperatures close to the melting point of the resin. However, a change in their failure mechanism was observed. Even at slightly elevated temperatures, the bars formed several cracks in the flamed area instead of, as in the reference experiments, preferably one large crack over the entire length. The tested steel flat connectors showed no sensitivity to elevated temperatures. It was not possible to achieve their softening temperature in the test setup used, as the 7 cm thick concrete wythe failed first in tests at 500°C and higher. It was found that the long fire duration in combination with thin concrete wythes and rigid connectors can result in stress concentration and failure of the fire-exposed concrete wythe. However, this failure mechanism was induced by the experimental setup, as large-scale tests on sandwich walls have shown that the actual relative displacement of the concrete wythes are of a much smaller order of magnitude.

In order to combine the determined shear properties of the core layer with the load-bearing behaviour of the sandwich walls in large-scale fire tests, a numerical analysis of the temperatures occurring in the core layer was carried out depending on the concrete wythe thickness and fire duration. In the case of sandwich cross-sections, especially with fire-resistant insulating materials, significantly higher temperatures are achieved in the wythe exposed to fire than for single concrete walls of the same thickness. The combination of the results of the two fire test series has shown a good agreement. The calculated and experimentally determined temperatures of the water steam release as well as the thermal softening of the GFRP-connectors also showed good compliance.

The findings were then summarised in a proposal for a classification concept. The special features of the sandwich structures to be taken into account in the evaluation of the fire tests were discussed.

3 Summary and practical recommendations

The usability of the sandwich walls with GFRP-connectors as fire walls was experimentally confirmed. A clear dependence of the bending load-carrying behaviour on the thermal loading of the core layer could be observed. The boiling of water in concrete and insulation has proven to be the most important heat transfer medium. The investigated core layer components showed stable shear properties resulting in a stiffening of the wall. The influences of these core layer properties could be linked to the fire resistance of the structural element by thermal simulations. The fire-resistant, shear-carrying and yet flexible connection of the concrete layers proved to be the optimal solution.

4 Key data

Short title: Fire behaviour of steel-reinforced sandwich walls

Researcher / Project management: SWD-10.08.18.7-17.25

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Project duration: 06.2017 to 07.2019, 26 months

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6 Figures

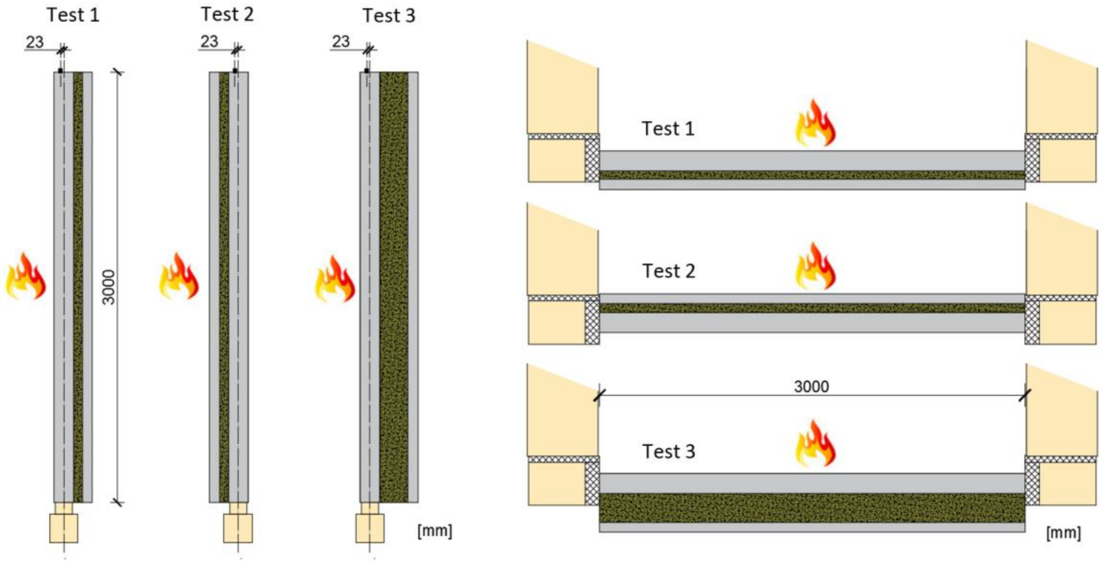

Figure 1: Fire tests on sandwich panels.jpg

Capture: Orientation of the test wall: vertical setup and position of the eccentric vertical load (left); horizontal test setup (right)

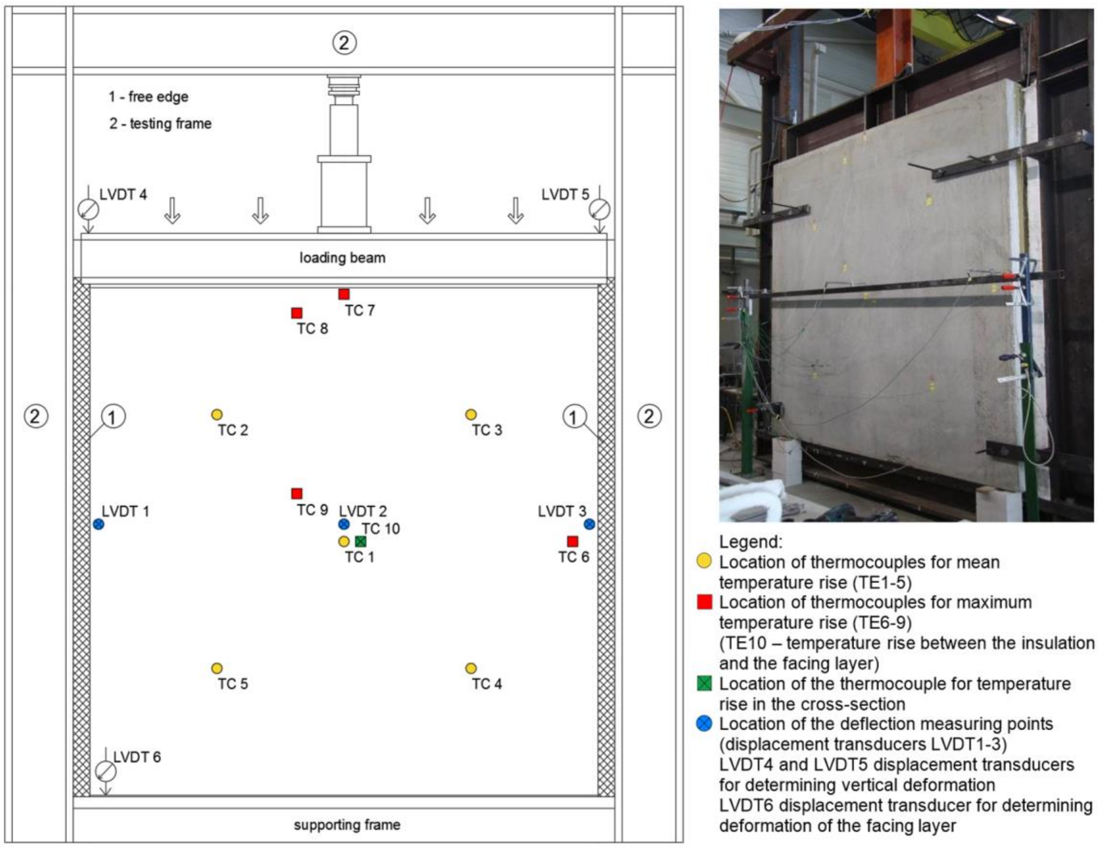

Figure 2: Experimental setup of the classification tests.jpg

Capture: Test setup of the classification tests; positioning of the test specimen in the test frame of the furnace (right), built-in test wall (left)

Figure 3: Dismantling of the sandwich wall.jpg

Capture: Dismantling of the sandwich wall to examine the core layer of the fire test specimen

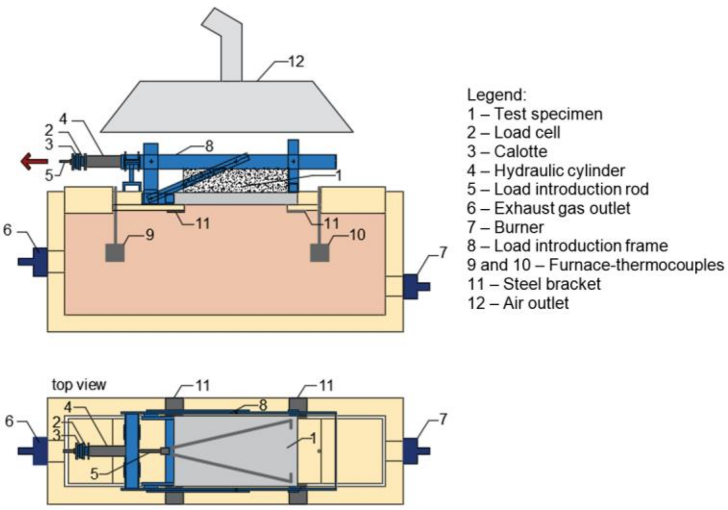

Figure 4: Setup of a small-scale fire test specimen.jpg

Capture: Schematic drawing of the small-scale fire test setup specimen in the furnace

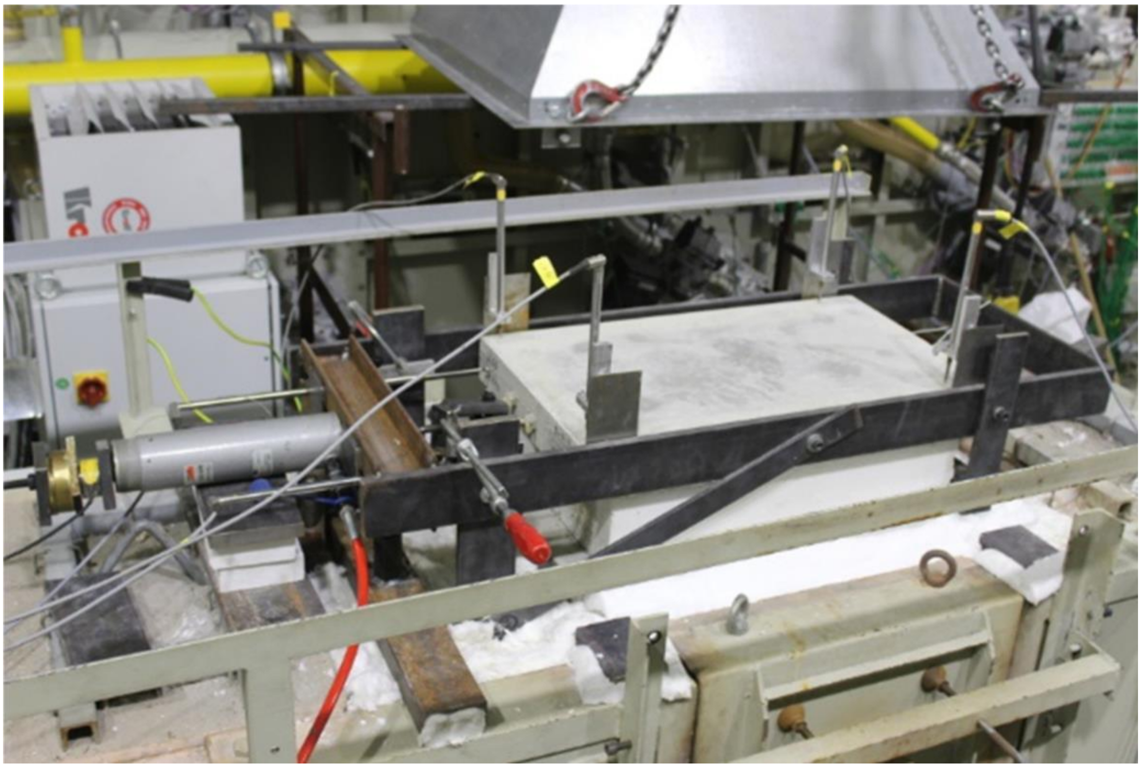

Figure 5: Experimental setup of fire tests on sandwich core layers.jpg

Capture: Experimental setup of fire tests on sandwich core layers

Figure 6: Thermal damage to the mineral wool.jpg

Capture: Thermal damage to the mineral wool after cooling of the test specimen