Zukunft Bau

SHORT REPORT **ILEK** **1|2011**

Functionally Graded building components

Long Title:

Production procedures and fields of application for functionally graded building components in construction

Az.: Z6-10.08.18.7-08.37

Occasion of the study/starting position

(Figure 1: Reticulated polyurethane foam, source: ILEK)

The objective of this research project has been to transfer the idea of functional graded materials, which has already been used successfully in other engineering disciplines like aviation and space travel [1], to the construction industry. Functionally graded building components show a continuous variation of properties in their cross-section (Figure 1). This gradation of material properties is achieved either by varying the porosity of the material, or by varying the ratio of components in a mixture of materials.

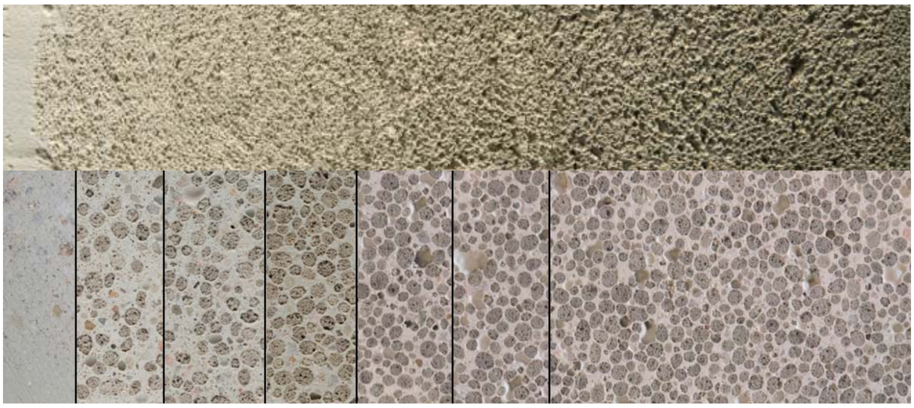
Graded materials make it possible to achieve a higher degree of material efficiency by matching the material properties precisely to the actual applied load. This is a useful alternative to the common design of a building component due to its most heavily stressed point. The continuous or graded change of properties removes the weak point, as for example various thermal extensions on the limiting surface of functional layers. It provides the possibility to combine different functional zones in one building component made of a single material. Porous areas improve heat insulation, a closed texture keeps out water and damp, and local fiber reinforcement can be positioned in areas of high stress.

Object of the research project

Within this research project, various classes of construction materials (concrete, textiles, wood, metals and polymers) and possible production methods and areas of application (bearing structure, building shell, joining technology) for functionally graded building components were investigated and evaluated. A First Evaluation of potential production methods and their practical use in the construction industry was followed by initial trials regarding to the possible manufacturing methods of prototypes and sample components. These were tested on their relevant specific material properties. Structural and thermal tests were carried out.

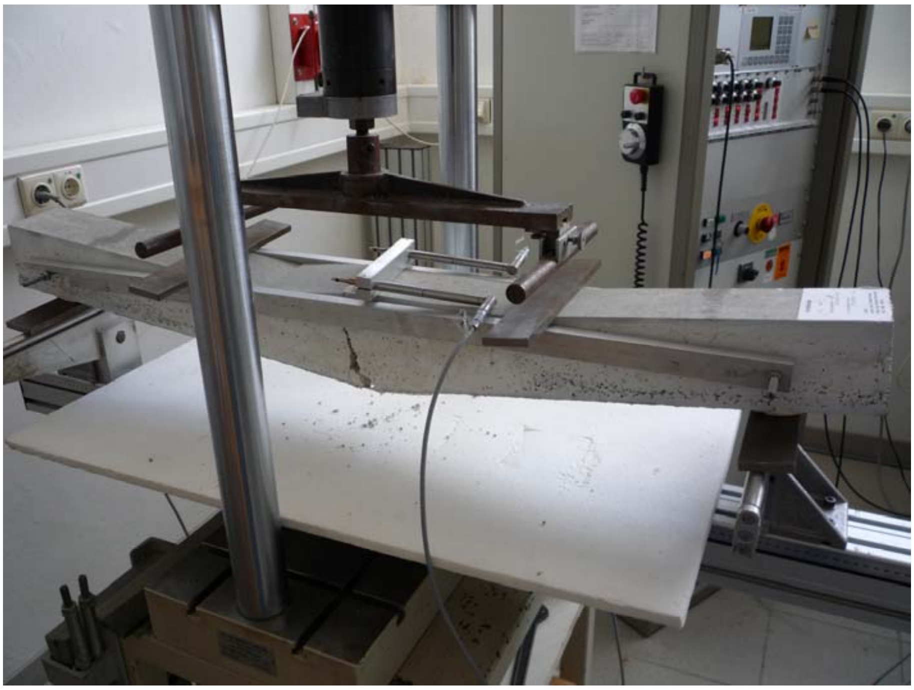
Another objective of the project was to evaluate the new design possibilities offered by graded materials. Investigating these from the architectural point of view and give application proposals for their possible use in various areas.

Concrete



(Figure 2 top: density graded aerated concrete, source: ILEK;
Figure 2 bottom: homogenous concrete mix with graded density for material testing [2], source: ILEK)

Concrete predominates as a construction material and offers the most considerable potential for material and energy savings. Therefore it was the most important material investigated in the research project (see Figure 2). The relevance and urgency for material and CO_2 savings in construction was confirmed by direct feedback from several worldwide leading industry partners, who were involved in the project.



(Figure 3: Functionally graded slab specimen, source: ILEK)

In a first step the fundamental structural properties of concretes of varying porosity (and therefore varying bulk density, thermal conductivity and stiffness) were investigated (see Figure 2). Concrete mix design, reflecting a range of properties from ultra-high performance to ultra-light (bulk density < 400 kg/m^2), was done.

Through the use of highly porous mineral aggregates a concrete mix with a thermal conductivity lower than EPS was developed. This exceptionally light concrete makes it possible, based on the idea of material gradation, to achieve purely mineral concrete external walls that are less thick than comparably effective thermal insulation composite systems. At the same time the recyclability can be improved and mass and resources can be saved in a significant amount.

In a second major area of application the possible mass savings of functionally graded concrete floor slabs were investigated. Structural tests (see figure 3) have shown that employing this approach in concrete slabs can result in material savings of over 60%. Because this reduces the cement content by the same proportion, equally significant savings in the embodied energy and CO2 emissions associated with cement production can be achieved, in addition to the dramatic material and weight savings.

The greatest challenge in the pursuit of functionally graded materials lay in the development of an economical manufacturing process to achieve the desired material property gradients. Porosification was achieved in concrete through the use of porous lightweight aggregate and the additional introduction of entrained air voids in the cement matrix. Three-dimensional gradation was achieved using a simultaneous spray process, in which the consistency of the spray is continuously varied, and depending on the position of the spray nozzle, the appropriate concrete mix is applied.

Other materials

Graded coatings of textiles make it possible to create gradations in permeability (Figure 4) and in stiffness. For example, moisture transfer processes could be locally defined within a continuous building shell, as it is already state of the art in functional clothing. The variation in stiffness makes it possible to overcome the change between stiff and flexible components. This could provide the basis for completely novel architectural solutions in future.

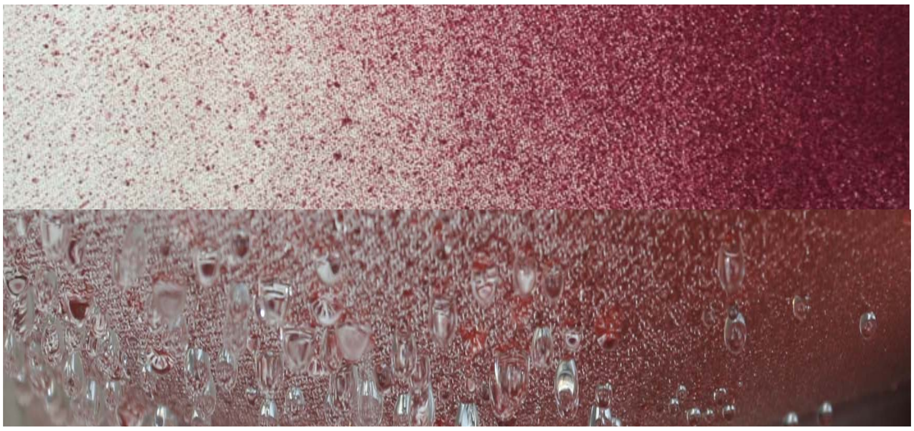


Figure 4 top: sprayed colored silicon gradient, source: ILEK
Figure 4 bottom: testing permeation with a defined water column, source: ILEK)

It can be shown that open-celled foam elements with variable porosity patterns can be produced by a grading process. By infiltration with a second material, these foams can be processed to components with a varying distribution of stiffness properties to meet the requirements of the given case. (Figure 5).

(Figure 5: Graded infiltration of reticulated polyurethane foam with cement slurry for the varying of stiffness, source: ILEK)

In addition to porosity gradation, material gradation also has great potential. Seamless transitions from one material (see figure 6) to another would make possible high-performance and aesthetically fascinating alternatives to traditional connection techniques such as screwed and glued joints, which often represent weak points in structural systems due to load concentrations and thermal expansion issues. Manufacturing processes for seamless transitions between wood, aluminum, plastic, and fiber reinforced composite materials are still in the experimental phase.

(Figure 6: Vision: flowing material transitions (wood to aluminium), Photomontage, source: ILEK)

Conclusion

The development of functionally graded building technology is first and foremost a significant contribution towards the realization of truly resource-efficient architecture. In addition, the improved properties of the materials in terms of building physics and bearing structure can make a further contribution to the saving of energy and materials [3]. In the field of joining technology, flowing material transitions make it possible to avoid the weak points that have existed in the past.

But it also gives rise to new aesthetic possibilities, and in fact redefines the traditional relationship between form and function: It allows the material properties of a building component to be designed irrespective of its outer shape – whether through changes in porosity, stiffness, or transitions between materials. While in the past the predominant optimization technique was to design form as a function of material, functionally graded building components offer an entirely new approach: the design of material as a function of form [4]. This represents an important stimulus for German building culture to meet the major ecological challenges of our time.

Basic data

Short title: Functionally Graded building components

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Total cost: 164.000,00 €

Government subsidy: 109.500,00 €

Project duration: März 2009 bis Februar 2011

References

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[2] Heinz, P. Herrmann, M.; Sobek, W.: Herstellungsverfahren und Anwendungsbereiche für funktional gradierte Bauteile im Bauwesen, Abschlussbericht Forschungsinitiative Zukunft Bau (1/2011), Stuttgart: ILEK, Februar 2011.

[3] Sobek, W.: Zum Entwerfen im Leichtbau, Bauingenieur, (1995), 70, 7-8.

[4] Heinz, P.: Gradientenwerkstoffe und Architektur, Universität Stuttgart, Diplomarbeit, April 2007.

Figures:

Figure 1:

Figure 1 Gradierter PUR-Schaum.tif

Legend:

(Figure 1: Reticulated polyurethane foam, source: ILEK)

Figure 2:

Figure 2 top Dichtegradierte Porenbetonprobe.tif

Figure 2 bottom Homogene Betonmischung.tif

Legend:

(Figure 2 top: density graded aerated concrete, source: ILEK;
Figure 2 bottom: homogenous concrete mix with graded density for material testing [2], source: ILEK)

Figure 3:

Figure 3 Vierpunkt Biegeversuch.tif

Legend:

(Figure 3: Functionally graded slab specimen, source: ILEK)

Figure 4:

Figure 4 top Glasfasergewebe mit Silikonverlauf.tif

Figure 4 bottom Permeationsgradient.tif

Legend:

Figure 4 top: sprayed colored silicon gradient, source: ILEK
Figure 4 bottom: testing permeation with a defined water column, source: ILEK)

Figure 5:

Figure 5 Mit Zement graduell infiltriert.tif

Legend:

(Figure 5: Graded infiltration of reticulated polyurethane foam with cement slurry for the varying of stiffness, source: ILEK)

Figure 6:

Figure 6 Vision Fließende Materialübergänge.tif

Legend:

(Figure 6: Vision: flowing material transitions (wood to aluminium), Photomontage, source: ILEK)