spectrum vol. 1

Reports from science, research and materials testing

iBMB MPA TU BRAUNSCHWEIG

Institute of Building Materials, Concrete Construction and Fire Safety | Braunschweig Civil Engineering Materials Testing Institute

The Division of Concrete Construction
Innovations, recent research and development projects in concrete construction

Fire-tested fastening systems
Ensured fire resistance of anchors in the event of fire

The Centre for Fire Research (ZeBra)
Scientific building with advanced FireLab experimental unit

Dear readers,

We are delighted to present this “spectrum” edition to you for many fascinating insights into the joint work of the Institute of Building Materials, Concrete Construction and Fire Safety (iBMB) of TU Braunschweig and the Civil Engineering Materials Testing Institute in Braunschweig (MPA BS).

iBMB and MPA BS can look back on more than 50 years of successful research, science and materials testing for civil engineering. Thanks to our interdisciplinary collaboration, we can cover a broad professional range of civil engineering subjects and have by now become a globally recognised service provider for basic research issues and practical testing. The examples selected for this magazine illustrate how our engineers and technicians find solutions for a wide variety of issues.

We are especially proud of our testing facilities at iBMB and MPA. With their size, their technical innovative power and not least their uniqueness, they reflect why Germany is frequently – and rightly so – referred to as the country of engineers. Ever-increasing test forces, tests on large life-size structural members, or the simulation of dynamic loads over the structural members’ service life are customer requirements that our testing facilities have to fulfil.

Our other well-known core competence is in fire safety. You could say that Beethovenstraße 52 in Braunschweig is where today’s common methods for testing the fire behaviour of structural members originated and where the development of fire resistance test methods was essentially shaped over decades. It goes without saying that iBMB and MPA keep their technical facilities and know-how of research and materials testing always up to date and reflecting the state of the art.

At iBMB and MPA, progress never stops! We strive for continuing development and are committed to innovation and venturing forward so that we can continue to be a reliable and competent partner for all issues relating to materials testing and research.

We hope we have caught your interest and that you will have the necessary time and leisure to page through – and possibly even be impressed by – the magazine and open yourself to interesting and innovative things worth knowing. We wish you an enjoyable read!

Kind regards,

The Board of iBMB and MPA Braunschweig

The topics of this issue

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iBMB and MPA – partners for more than 50 years

For more than 50 years, the Institute of Building Materials, Concrete Construction and Fire Safety (iBMB) at TU Braunschweig and the Civil Engineering Materials Testing Institute at Braunschweig (MPA BS) have been sharing a home and address at Beethovenstraße 52, right in the heart of the university's east campus ("Campus Ost"). During this time, the premises have grown from about 12,000 m² to almost 30,000 m² and the gross internal floor area has expanded from 8,000 m² to 16,000 m², making iBMB/MPA one of the largest testing facilities of this kind in Germany.

But while the buildings are impressive from the outside, it's the inside that matters: they house the testing facilities that are responsible for iBMB/MPA's outstanding position in the market. More than 250 items of test equipment are available for the broadest range of tests imaginable, procured and operated together by iBMB and MPA. Here are some examples:

- Several wall testing furnaces measuring up to 9.7 m in width and 7 m in height
- Pressure and tensile test machines with a high testing frequency for extremely high loads (dynamic loads up to 24 MN, static loads up to 30 MN)
- Wet room test stand
- Façade test stand with smoke analysis
- Testing portal measuring 12 x 6 x 6 m for testing loads up to 4 MN
- State-of-the-art chemical/analytical testing methods (e.g. scanning electron microscopy, thermal analysis)
- Test stand for horizontal separating elements measuring approx. 10 x 4 m, with loading equipment
- Long-term performance test stands and smoke control test stand measuring 5.4 m x 5.4 m

There are, of course, already plans for new test equipment. The continuous enhancement of technical capabilities and continued investment in further test equipment are an essential part of iBMB/MPA's joint strategy, to ensure they are among the most cutting-edge testing facilities for construction, both in Germany and across Europe. Key factors are the geographical proximity at a single site, the combination of research and materials testing aspects, and the close collaboration between iBMB and MPA employees.

The iBMB/MPA cooperative partnership comprises about 200 highly qualified staff from a wide range of disciplines. They form the basis for comprehensive and interdisciplinary project handling and problem solving. Naturally this requires a high level of manual skills, as well as technical expertise and scientific knowledge.

This symbiosis and the synergies it creates are vital to ensure delivery of the broad range of services at a high professional level and with the given economic framework. While each iBMB/MPA employee is an expert in his or her field, it is the collaborative effort of all those involved that ultimately determines the success of a project.

50+ years
iBMB/MPA location
Beethovenstraße

MPA Braunschweig and iBMB – two organisations, one unit

Collaboration between MPA Braunschweig and the Institute of Building Materials, Concrete Construction and Fire Safety at TU Braunschweig is particularly close, because both organisations share the premises and facilities at Beethovenstraße. Customers benefit in several ways:

- Close ties exist between industrial practice (MPA) and applied research (iBMB).
- Sharing of knowledge and technical expertise is made easier by geographical proximity and similarity of disciplines.
- Findings gained in research and development can be applied more rapidly in materials testing.
- The need in industry for new research or new testing methods can be communicated directly by MPA to researchers.

MPA materials testing

Department/Functional unit:
- Fire Safety
- Structures and Construction Materials
- Central Services
- Certification Body
- Inspection
- DKD Calibration Laboratory
- Technical Services

Exchange

Technology:
- Knowledge
- Technical expertise
- Research experience
- Development of testing methods
- Research requirements of the manufacturing industry

Organisation:
- Buildings
- Test equipment
- Staff
- Library
- Central Services

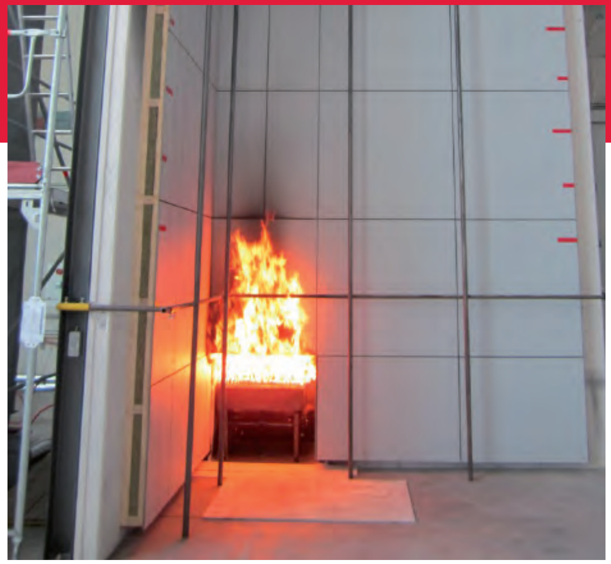
iBMB research

Divisions:
- Building Materials
- Concrete Construction
- Fire Safety
- Organic and Wood-Based Materials

Examples of the successful collaboration between iBMB and MPA

Life-cycle assessments in the transport infrastructure

The Elbmarsch flyover (K20) is one of the longest elevated bridges in Germany. It forms part of the A7 motorway south of Hamburg, near the Rugenberg section of the port of Hamburg, and connects to the tunnel beneath the Elbe River. As part of the planned widening of the motorway to eight lanes, iBMB and MPA together carried out studies on ways of connecting the transverse tendons; on existing damage to the connection points for the tendons; and on evidence of fatigue strength. This project is representative of many concerning bridges that have been shown in recalculations to have only a short useful service life left, because of increasing traffic loads and the resulting damage processes. With these studies, it was possible to exclude fatigue-based bending failure in the next twenty years. ■

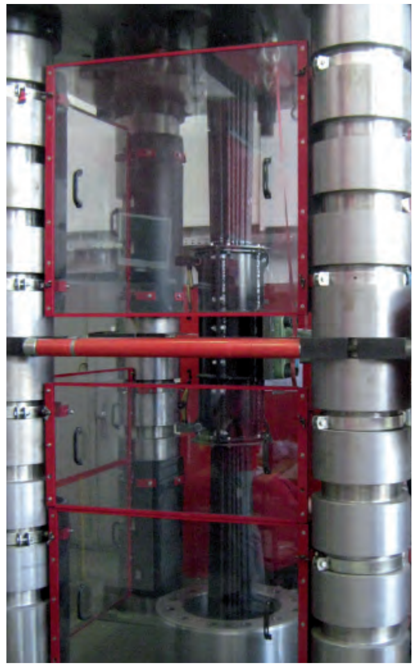


Façade fire tests

Because of several recent fires, the reaction to fire of EIFS façades using polystyrene is now under close investigation. iBMB/MPA carry out indicative tests on behalf of manufacturers, studying possible improvements to systems in the context of general approvals by the construction authorities. These also concern ventilated curtain walls. Thanks to their participation in the panel of experts of the German institute of structural engineering (DIBt) and involvement in a range of research projects, iBMB/MPA have a wealth of experience in this area. ■

(Hot) smoke tests

Before issuing building completion certificates, the authorities are increasingly asking for (hot) smoke tests to ensure that the smoke extraction provisions made and the control systems in place comply with the planning permission given. The iBMB/MPA team works across Germany, carrying out hot smoke tests to inspect the smoke extraction systems of airports, shopping centres, meeting places, arenas and atriums. With their vast experience in this field, iBMB and MPA experts can also actively contribute to preparing guidelines and research work. ■



High-performance tension members

Advancements in construction are closely linked to the emergence of new materials or new technologies. In addition to traditional materials for tension members, such as ropes, strands of metal wire, and steel bars, attention is now shifting more and more to fibre-reinforced plastics and high-performance steel with improved corrosion protection systems.
Often, these require testing with dynamic preloading and very high loads. In the 30 MN test machine operated by iBMB and MPA in collaboration, many pioneering tests have been run on high load-bearing tension members. ■

Simulation of fire tests

Fire tests are very complex and often also costly. The simulation of fire tests or real fire events, and the modelling of how structural members react to fire are more efficient and flexible. However, such simulations require validated models based on input data; in practice, these are often not available. iBMB and MPA work hand in hand to find a better solution to this problem.
The MPA team has a wealth of experience in fire testing. Fire tests serve to collect input data for models and for validation of these models by iBMB staff. This approach permits a competent collaborative assessment by iBMB and MPA of "special issues" such as the reaction to fire of LED screens, airline ticket machines and sandwich panels, or the passage of smoke through suspended ceilings.

Over the next few years, construction tasks will become more rather than less complex. Reasons are the increasingly empty public coffers and a growing need to invest in existing buildings and structures. Comprehensive solutions are required, which must embrace life cycle engineering. The meaningful recording and assessment of building structures in on-site inspections, and the classification and evaluation of innovative materials and structural elements in terms of safety and reliability are core tasks that require the full expertise of testing facilities such as iBMB/MPA. The most compelling solutions can only be found in close collaboration. ■

Foto: www.flickr.com/Dennis_Knake_Cc-by-sa

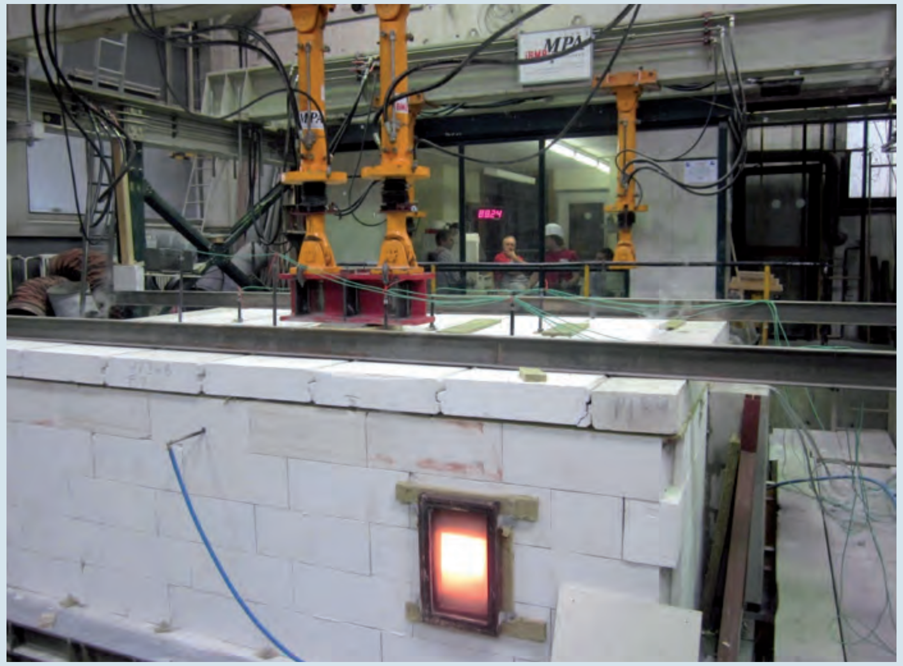
Reinforcement of existing structures

At Hall 9 of the Messe Hannover exhibition grounds, a structure with one of the most wide-span designs in Germany, the anchorage points had to be reinforced. The tendon end-anchoring points were to be secured with epoxy resin-based adhesive anchors that did not comply with the building code. Following material testing on the epoxy resin-based adhesive, supervision of the work, and a scientific evaluation of the composite's mechanisms at the anchor body by iBMB/MPA, use of the planned system for reinforcement was permitted. ■

Building improvements for energy efficiency

Building improvements for energy efficiency or thermal insulation mainly serve to reduce energy costs for heating, hot water and ventilation. Measures include, for instance, installing exterior wall insulation or renovating the windows and façade. In addition to providing energetic evaluations, the state and load-bearing capacity of the existing structure often also need to be established. In this field, too, the collaboration between iBMB and MPA is beneficial, particularly where both an inspection of structures and an assessment of non-standard construction systems are required. ■

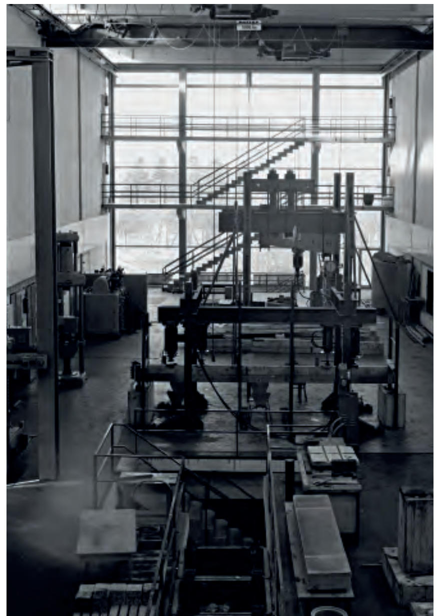
Development of innovative structural members



Innovations and the improvement of structural members and elements form part of everyday work for our partners in the manufacturing industry. Such innovations may concern a range of different areas. iBMB/MPA are frequently contacted whenever new materials are concerned, or technologies that are not approved under a building code. In these situations, tests on structural members are normally required as part of approval procedures. Because of the varying conditions of use, these are often carried out as "cold" (mechanical) or "hot" (fire) tests by iBMB and MPA together. ■

iBMB/MPA – a long history together

In 1965, what was then the Institute for Construction Material Science and Reinforced Concrete Construction started teaching and research on its new premises. 50 years later, there are not three but nine test halls at Beethovenstraße, while today's Institute of Building Materials, Concrete Construction and Fire Safety and the Civil Engineering Materials Testing Institute together have about 200 staff and are a nationally and internationally recognised teaching, research and testing organisation for civil engineering.
The history of the institute and materials testing institute goes back to the 1920s, when a first building materials laboratory for testing concrete structural members was founded. The first step in its development to the present day was the appointment in 1937 of Theodor Kristen to the Chair for Construction Material Science and Reinforced Concrete Construction in the Department of Architecture at Technische Hochschule Braunschweig. Kristen focused his research particularly on structural aspects of air raid shelters for civilians, in dedicated buildings in the Querumer Forst woods. During WWII, the institute's buildings were mostly destroyed. In the difficult period of reconstruction that followed, initial work was carried out at Kristen's initiative on structural sound insulation and fire safety, at the Institute of Construction Material Science and Materials Testing, which was founded during this time.
Also initiated by Theodor Kristen and successfully driven by Karl Kordina after 1959, was the construction of a new building at Beethovenstraße in 1963 and 1964. It comprised three test halls providing modern equipment for the key areas of work mechanical technology, sound insulation and fire safety.
Teaching and research on the new premises



50+ years
iBMB/MPA location Beethovenstraße

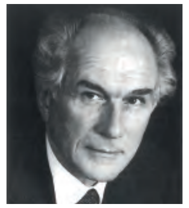
started in 1965, led by Karl Kordina. Kordina had been appointed as Kristen's successor to the Chair of Construction Material Science and Reinforced Concrete Construction in 1959 at the institute of the same name.
The institute was designated as the "Official Civil Engineering Materials Testing Institute", under the supervision of the Lower Saxony Ministry of Economics and set to work at the Beethovenstraße site. This marked the start of a successful 50-year development to date, which has been shaped by the work of several generations of creative and committed professors and staff. At the outset was Karl Kordina with his pioneering work on the load-bearing and deformation behaviour of reinforced concrete structural members. In 1968, the appointment of Gallus Rehm to the Chair of Construction

Halls 1 to 3 of the new building in the year 1965

1965

Start of operations at the new site in Beethovenstraße

1968



Appointment of Prof. Gallus Rehm

1972

Prof. Karl Kordina starts to establish the special research area „Fire behaviour of structural members"

50+ years
iBMB/MPA location Beethovenstraße

Material Science and Reinforced Concrete Construction was a major addition to the institute. Karl Kordina took over the Chair for Concrete Construction, and both professors together ran the institute, now part of the Department of Civil Engineering, and the materials testing institute.
Thanks to Kordina's vision, funding was received from the DFG German Research Association for a special research area "Fire behaviour of structural members" between 1972 and 1986 – a major milestone. It enabled the development of a broad range of expertise and excellence in structural fire safety, and the procurement of state-of-the-art test equipment, which is continuously improved to this day, making the institute and materials testing institute one of the leading facilities in this field in Europe. Along with Kordina, other local engineering celebrities such as Professor Claus Meyer-Ottens, Jürgen Wesche and many others helped promote the "Fire safety made in Braunschweig" brand.
As the institute's range of disciplines grew, a professorship for Material Structure and Polymeric Materials was created in 1977, and another for Fire Safety in 1986. In 1978, the large joint institute was renamed Institute of Building Materials, Concrete Construction and Fire Safety (iBMB), a name it still bears today. In the past 30 years, four professorships have made their mark on research and teaching:

Building Materials
Gallus Rehm (1968 to 1973)
Ferdinand S. Rostásy (1976 to 1997)
Harald Budelmann (1998 to 2017)
Dirk Lowke (since 2017)

Concrete Construction
Karl Kordina (1959 to 1987)
Horst Falkner (1987 to 2005)
Martin Empelmann (since 2006)

Fire Safety
Dietmar Hosser (1986 to 2013)
Jochen Zehfuß (since 2013)

Organic and Wood-Based Materials
(previously: Structures and Application of Building Materials)
Klaus-Peter Großkurth (1977 to 2010)
Bohumil Kasal (since 2010)

Research activities are growing, the range of research topics is expanding, and building supervision is changing to enable the free movement of goods within the European Union. As a result of these developments, the materials testing institute, which has had close links with the institute since its beginnings, is also subject to constant change. In 1999, the Official Materials Testing Institute became the Materials Testing Institute (MPA), because materials testing, supervision and certification tasks are no longer carried out on behalf of the state. That marked the beginning of a challenging time for state-controlled materials testing. iBMB and MPA signed a cooperation agreement as a basis for their collaboration. Since then, MPA has had to compete, also economically, on a demanding international market.

1976

Appointment of Prof. Ferdinand Rostásy

1977

Appointment of Prof. Klaus-Peter Großkurth

1986

Appointment of Prof. Dietmar Hosser

1987

Appointment of Prof. Horst Falkner

1993

Commissioning of the flue gas cleaning plant

1995

First accreditation on the basis of DIN EN 45001

1996

Building authority approval as a testing, monitoring and certification body in accordance with the State Building Code

1998

Appointment of Prof. Harald Budelmann

1999

The Official Materials Testing Institute becomes the Civil Engineering Materials Testing Institute (MPA)

Cooperation agreement between MPA Braunschweig and TU Braunschweig

50+ years
iBMB/MPA location Beethovenstraße


30 MN test machine

In 2002, the German state of Lower Saxony decided to cut the number of its materials testing institutes from five to three; these would no longer receive funding from the state budget. Today, MPA has to compete in a globalised market and needs to further develop its competitive strengths. In close collaboration with iBMB, synergies from science and industry have been and are used to consistently build a sustainable, strong competitive position as a neutral and independent partner for all issues relating to safety, reliability, quality and economic viability in civil engineering. To achieve this, iBMB and MPA have a joint executive board. Professors Martin Empelmann, Dirk Lowke and Jochen Zehfuß as heads of iBMB also act as Managing Directors of MPA, together with Thomas Rusack as commercial/technical head. Together, iBMB and MPA currently have about 200 staff. Its forward-looking investments are impressive proof of MPA's capacity for innovation. They include, for instance, test hall 9, built in 2013 for smoke control and extraction testing and for long-term performance tests on doors; or the 30 MN test machine for compression and tensile tests, intended, for instance, for static and dynamic tests on large bridge stay cables and tendons.

In 2015, an intensive SWOT analysis at MPA led to organisational restructuring, to bundle strengths and prepare for the major tasks of the future. MPA now has only two departments: Structures and Construction Materials (headed by Alex Gutsch and Knut Herrmann), and Fire Safety (headed by Gary Blume, Petra Aeissen and Thorsten Mittmann). Its flexible structures are aimed at handling the wide range of tasks and meeting specific customer requirements even better than before. ■


iBMB and MPA staff

2002

Reorganisation of materials testing in Lower Saxony, number of MPAs reduced from 5 to 3, allocation of state funding reduced to zero by 2006

2003

Recognition as a testing, supervisory and certification body in accordance with the German Construction Products Act (BauPG) with subsequent notification in accordance with the Construction Products Directive in Brussels

2006


Appointment of Prof. Martin Empelmann


Halls 1 to 9 in the year 2015

2010

Appointment of Prof. Bohumil Kasal

2013


Appointment of Prof. Jochen Zehfuß

Head of the Commercial/ Technical Division of MPA Thomas Rusack, Dipl.-Ing.

2017


Appointment of Prof. Dirk Lowke

A new kind of cooperation

Can notified bodies be authorised representatives in accordance with the EU Construction Products Regulation (EU CPR)?

Manufacturers, retailers, importers and distributors of construction products who have no representatives in the European Union need to have an authorised representative as contact for the national market surveillance authorities (Article 12, EU CPR). This authorised representative shall have available all necessary information and documentation to prove the conformity of a construction product (particularly the DoP – Declaration of Performance), and cooperate as appropriate with the authorities, if and when this is required to eliminate the risks posed by the construction products.

Normally, notified bodies must not act as authorised representative for interested parties, since this could endanger their impartiality and independence, and possibly even their integrity. Only if such risks can be excluded, are there no obstacles to such a collaboration in principle. This could apply, for instance, in the collaboration between the notified body and umbrella organisations of manufacturers, retailers, importers, etc.

In these individual cases, however, it has to be thoroughly checked in particular, whether any partiality can be excluded. Aspects that could restrict independence, such as consultancy services, would need to be taken into account in this.

Against this background, MPA Braunschweig has entered into collaboration with the Canadian Lumber Standards Accreditation Board (CLSAB), Canada's official organisation for the surveillance of timber quality, as their authorised EU-representative on the basis of Article 12 EU CPR. CLSAB was founded in the late 1950s as a consumer protection organisation, which subsequently evolved into a non-profit accreditation system with the following four main objectives:

- Controlling the identification and certification of timber
- Accreditation and supervision of agencies working in this field
- Review and approval of grading rules and product standards
- Facilitating acceptance in foreign markets

In Canada, the timber used in construction projects is identified and sometimes certified in accordance with CLSAB rules. In this way, information is provided about the wood species, grading criteria, mill, accreditation body, etc. National grading rules form the technical basis for identification.

Given that the export of timber products is of major importance for the Canadian timber industry, agreements have been signed for some markets accepting the CLSAB rules, e.g. for Japan, Australia and also the European Union. Canadian timber products and grading reports have therefore long been included in EN 1912 (Structural timber - Strength classes - Assignment of visual grades and species), which is referenced by the harmonised product standard EN 14081-1 (Timber structures - Strength graded structural timber with rectangular cross section - Part 1: General requirements). As a result, EN 1912 states what Canadian grading rules permit for products that are intended for import into the European market. In return, the national Canadian regulations take into account EU criteria that go beyond the Canadian requirements. They are to be applied when the product is intended for export to the European Union.

MPA Braunschweig has signed an agreement with CLSAB for products that comply with EN 14081-1, which has been in effect since 1st January 2018. This agreement deals with activities concerning collaboration with the market surveillance authorities and the certification of conformity of factory production control. This includes regular checks on site to monitor the implementation of EU criteria at various organisational levels and in the timber mills. ■

Certification Body

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Materials for construction

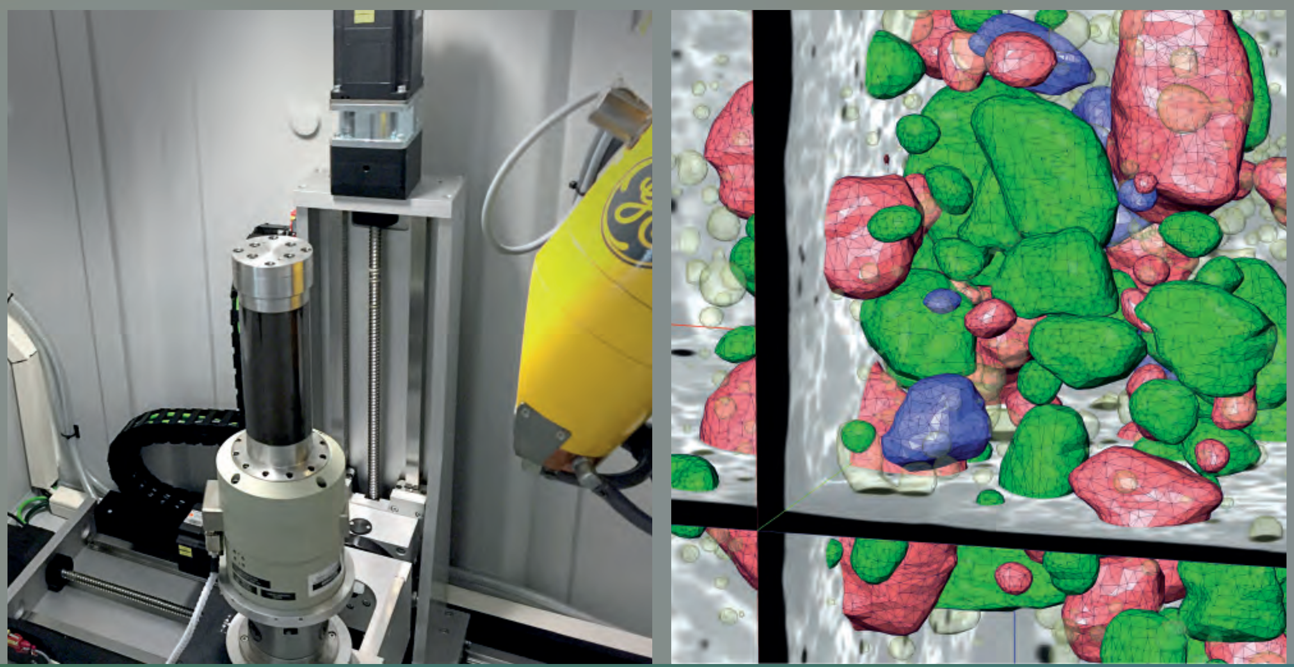
Building materials technology – Research and Teaching

Every structure needs suitable materials and application methods to fulfil its demands throughout its service life. The enormous complexity of modern building materials and the high rate of development require the constant adjustment of experimental methods and analytical models that can describe the material formation, the chemical and physical behaviour during the period of manufacture and use as well as damage processes at different size scales. As a result, the demands for research into building materials technology and also for the education of civil engineers and architects are high. This article gives an exemplary insight into research and teaching in the Division of Building Materials at the iBMB.

Teaching

Since the field of building materials technology is large and changes rapidly, facts and knowledge in teaching have to be replaced by principles and methods. In the Bachelor's programmes for civil and environmental engineers and for architects, the laws of chemistry and physics involved in the extraction, processing, binding, structure, states and properties of organic, metallic and mineral materials, and an understanding of how these are related, are essential basics.

In the Master's programme, students then specialise in work and research areas of building materials technology and building conservation, focussing on, for instance, chemical and physical damage mechanisms and their description in transport and reaction models, or on material laws and their implementation in numerical simulations.



Computed tomography system and concrete aggregates identified in a CT-scan

Research topics and examples of modern experimental methods

Research at the Division of Building Materials focuses on additive manufacturing, rheology, and the mechanical behaviour and durability of concrete. Automated **additive manufacturing** techniques such as extrusion, 3D printing or shotcrete 3D printing of concrete are finding their way into the construction industry. A central task in the development of these technologies is the optimal setting of the concrete formulation parameters, such as the type and amount of the binder, additives, grain size, water content and, optionally, the selection and dosage of further additives for controlling the rheological and setting properties. The goal is an in-situ control of the material properties. Therefore, depending on the application, the concrete formulations have to meet specific requirements regarding strength, density, density gradients, surface quality, dimensional accuracy and subsequent machinability.

The main research facility for additive manufacturing in construction at TU Braunschweig is the digital building fabrication laboratory (DBFL). The DBFL consists of two gantries, each equipped with an industrial robot. The building dimensions 17 x 9 x 3 m³ permit the production of large-scale structural concrete elements.

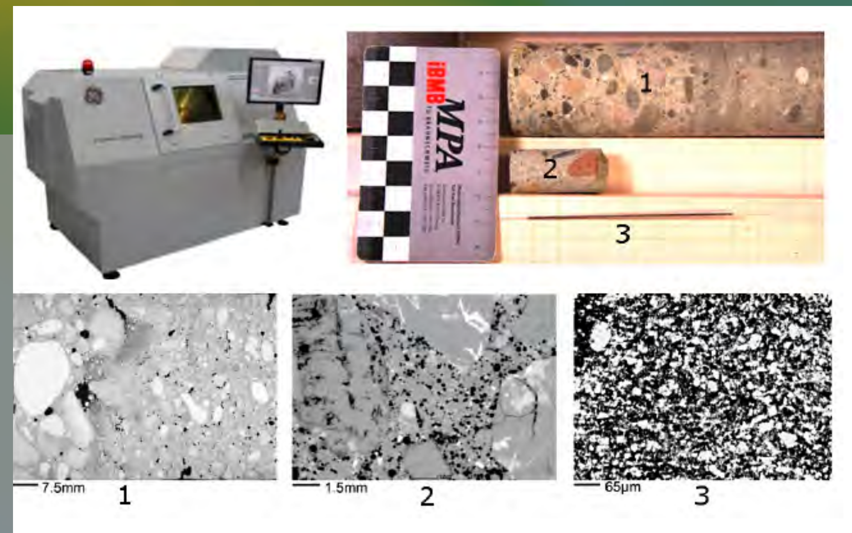
The understanding of **rheological fundamentals** is a prerequisite for the additive manufacturing of cement-based materials.

Digital building fabrication laboratory (DBFL) at TU Braunschweig

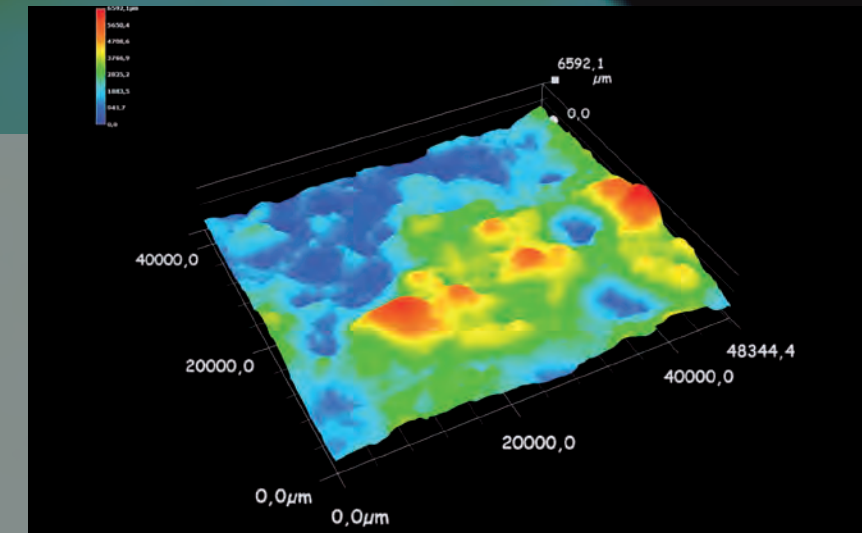
Cement-based materials in the fresh state are highly concentrated suspensions of predominantly inorganic particles in water. In addition to the wide range of particle sizes between about 100 nm and 30 mm and the high solids fraction of up to 90%, a specific feature of these suspensions is the reactivity of cement and other binders. The aim is to gain a basic understanding of the relevant processes that determine the rheological properties of fresh materials. The key to this is a detailed understanding of the energetic and mechanical interactions of reactive and non-reactive particles and the aqueous phase.

The strength and durability of cement-based materials are strongly affected by the heterogeneous structure of the material. For closer investigations, it is necessary to consider cement-based materials as heterogeneous materials and to identify and characterise the reactive and non-reactive particles of the cementitious material. One of the most innovative technologies for detecting and describing the particle structure and for characterising the particles inside cementitious materials is **computed tomography (CT)**. CT can produce high-resolution three-dimensional scans of the material and the particles.

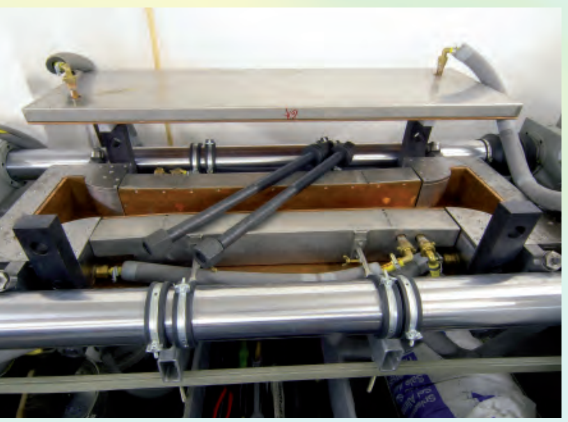
CT scans on different size scales



Digital microscope – measurement of a concrete fracture surface after a shear test



Besides computed tomography, further analytical and metrological methods are available at the Division of Building Materials.



Temperature-stress test machine (TSTM)

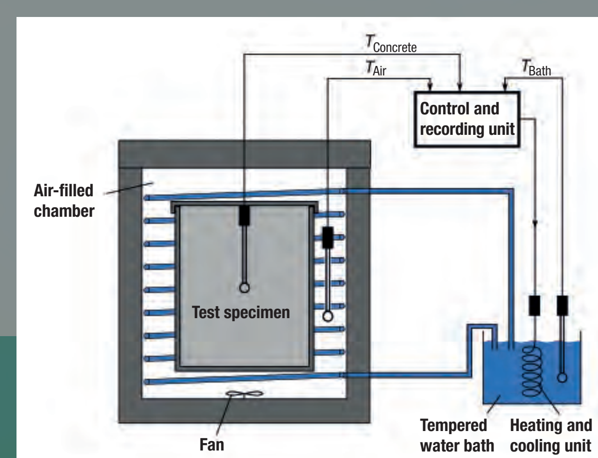
The temperature-stress testing machine (TSTM) is used to study the hardening and deformation behaviours of early age concrete. The TSTM can control temperature and stress of the concrete immediately after it is filled into the formwork. In this way, the deformation behaviour of concrete during its transition from the plastic to the solid state can be studied.

The amount of heat released and the heat release rate of concrete and mortar are determined under adiabatic conditions using isothermal, adiabatic, and semi-adiabatic calorimeters. These calorimeters can regulate the concrete temperature in such a way that completely heat-insulated boundary conditions are simulated. In particular, for solid concrete components, it is necessary to develop concrete mixtures that release less heat over long periods of time.

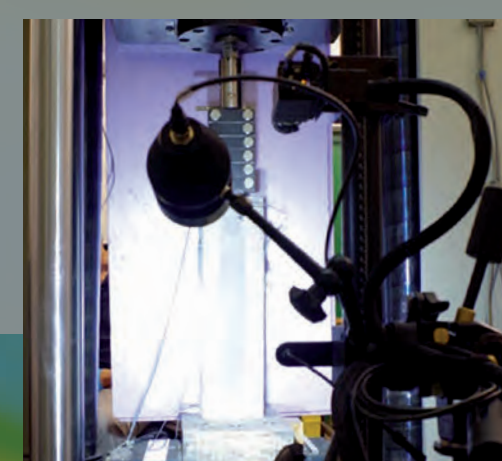
For three-dimensional visualisations of the structure of concrete, mortar, hardened cement paste as well as many other materials, a 3D micro-computed tomography system is available. Computed tomography enables the imaging of material structures and their changes under different actions in the micrometre to millimetre range. In the field of computerised tomography, e.g. for the investigation of the fibre orientation in steel fibre-reinforced concrete, for the determination of the air-pore content in hardened concrete, for the detection of corrosion processes as well as for the investigation of contact zones in concrete.

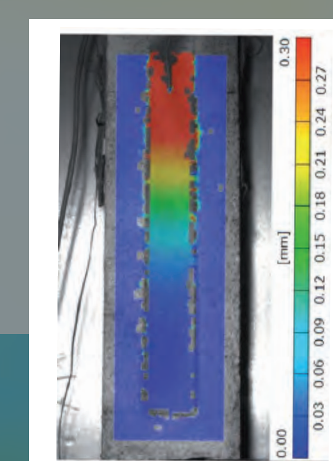
Building material surfaces can be examined using a digital microscope with a high resolution and depth of field. The system uses a moving lens to capture several sub-images, which are combined into one image with a high sharpness in all areas. A 3D image is generated from the automatically acquired images, which serves as the basis for the calculation of a height profile. Therefore, the digital microscope can provide 3D information about building material surfaces.

In addition to conventional sensors, an optical measurement system can be used for the measurement of deformations. This can capture displacements in all three dimensions on the surface of the specimens over a wide area using digital image correlation and photogrammetry. The measuring system is particularly suited to measuring the slip of externally bonded reinforcements in shear tests, or to locally observing the cracking of reinforced concrete components. ■



Adiabatic calorimeter – principle and test setup





Optical measurement system and measured displacements of a CFRP strip externally bonded to concrete

Division of Building Materials

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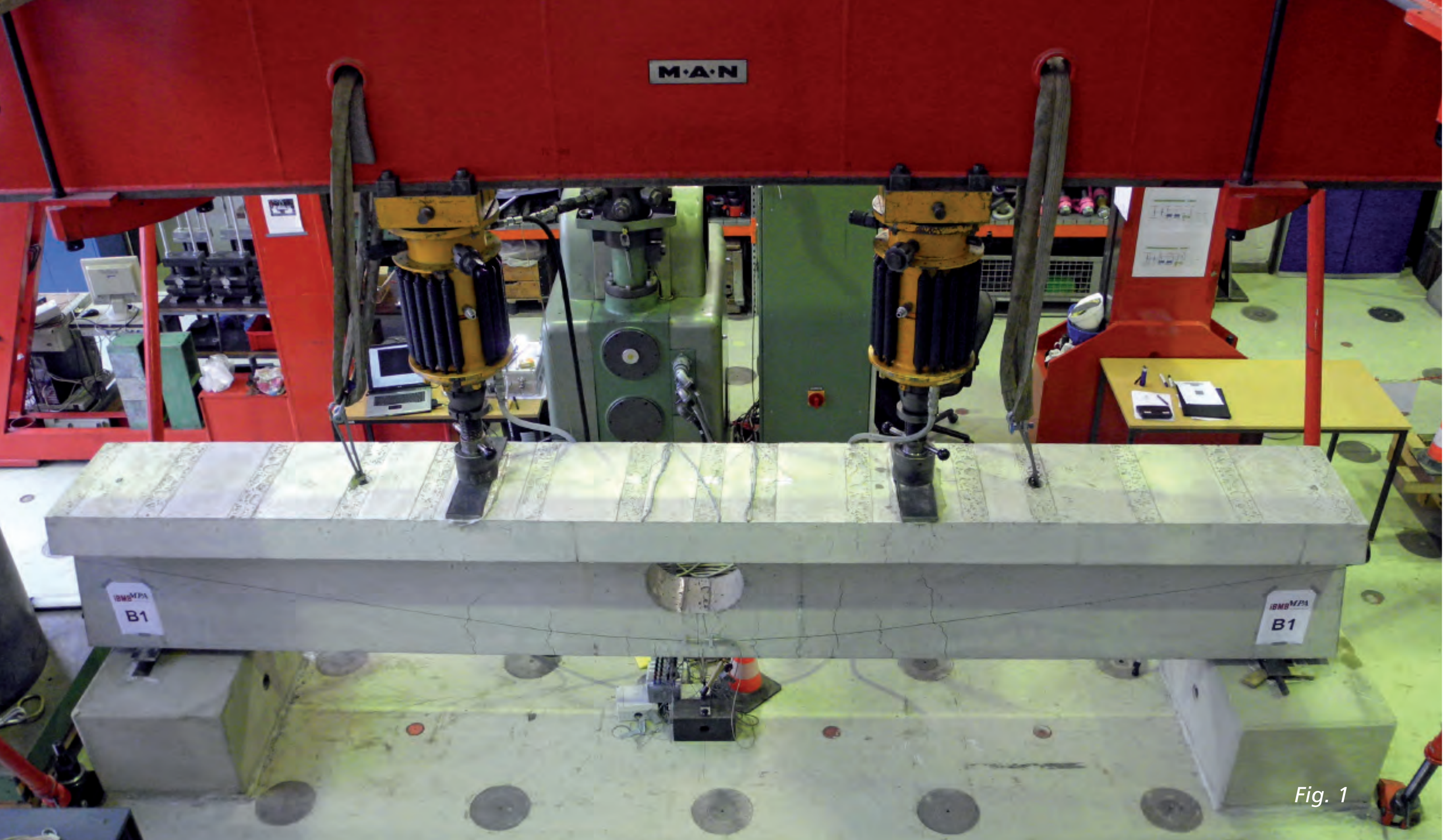


Fig. 1

Innovations in Concrete Constructions

Research at the Division of Concrete Construction

The vast majority of structures and building constructions are and are going to be built as concrete constructions. This makes safety and reliability as well as serviceability and durability of reinforced and prestressed concrete elements even more important during their intended service life. These boundary conditions form the cornerstones for the research work at iBMB's Division of Concrete Construction. Some selected recent research and development projects are presented below:

Innovative Reinforced and Prestressed Concrete Girders

The construction of industrial halls and logistic centres is dominated by the choice of girder support systems. Therefore, an optimised and economic design is of great importance. An alternative to conventional solutions are **Prestressed Concrete Girders made of Steel Fibre Reinforced Concrete.** Due to the addition of steel fibres to the concrete and the effect of prestressing, very many steel reinforcement bars are no longer needed – with the same or even better load-bearing capacity and serviceability – resulting in cost and time advantages.

Innovative Hybrid Prestressed Concrete Girders with Perforated Sheet Reinforcement (Fig. 2) represent a further development stage. In the course of increasingly demanding technical building services, it is inevitable that pipes and conduits are routed through girder web openings. Using perforated steel sheets, which are applied as "one piece" in web openings, it is possible to have even more flexible, larger and practical rectangular web openings, so that such girders are in direct competition with cellular steel and steel composite beams.
In case of wide span beams and dominating self-weight, the use of ultra-high performance concrete (UHPC) with compressive strengths of up to 200 MPa provides a high potential for innovation. The possibilities were investigated for **Monolithic Box Girders and Prestressed Segmental Components made of Ultra-High Performance Fibre-Reinforced Concrete (UHPFRC)** (Fig. 3). Even under the most diverse influences (up to combined bending, shear and torsion), the thin-walled components had an enormous load-bearing capacity. In addition, the very dense concrete composition leads to a high durability and resistance to aggressive exposures, which is also advantageous.

Thin-walled UHPFRC components are particularly susceptible to vibrations due to their high slenderness, and the effects of cyclic loads on the load-bearing mechanisms of fibres have only partially been investigated. Therefore, the **Structural Response of UHPFRC under Cyclic Tensile Loads** is currently being investigated in a further project.

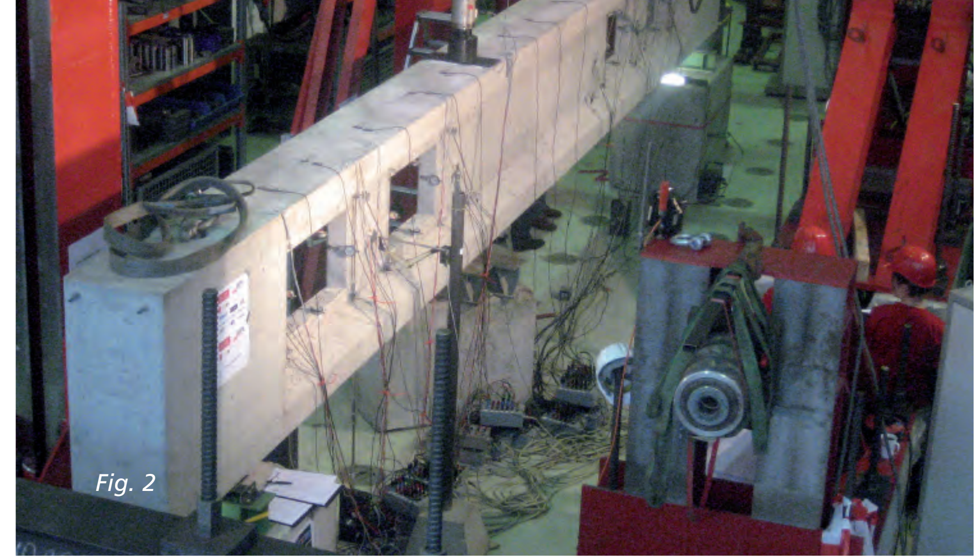


Fig. 2

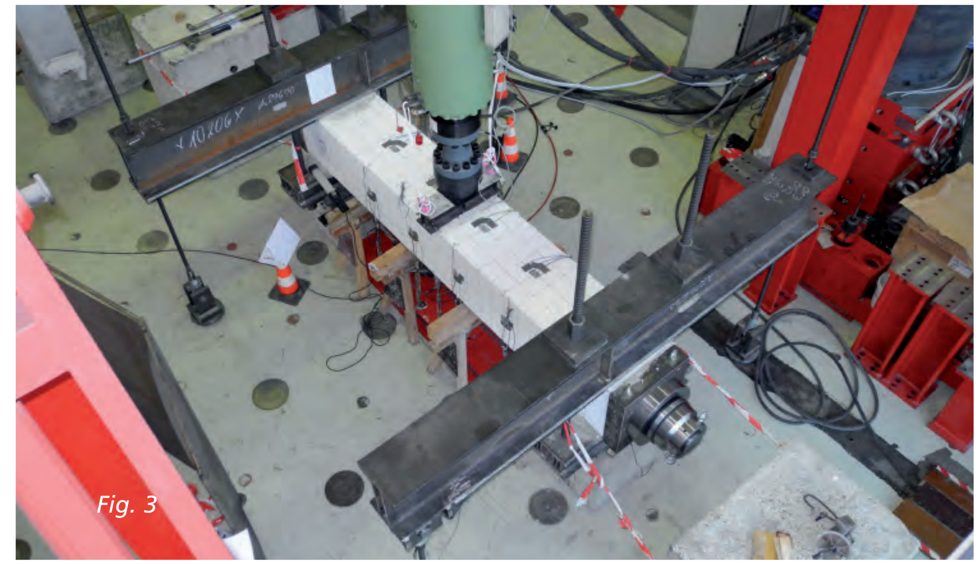


Fig. 3

Fig. 1: Investigations on the fatigue strength of tendons

Fig. 2: Innovative hybrid prestressed concrete girder with perforated sheet reinforcement

Fig. 3: Prestressed segmental component made of UHPFRC under combined loads

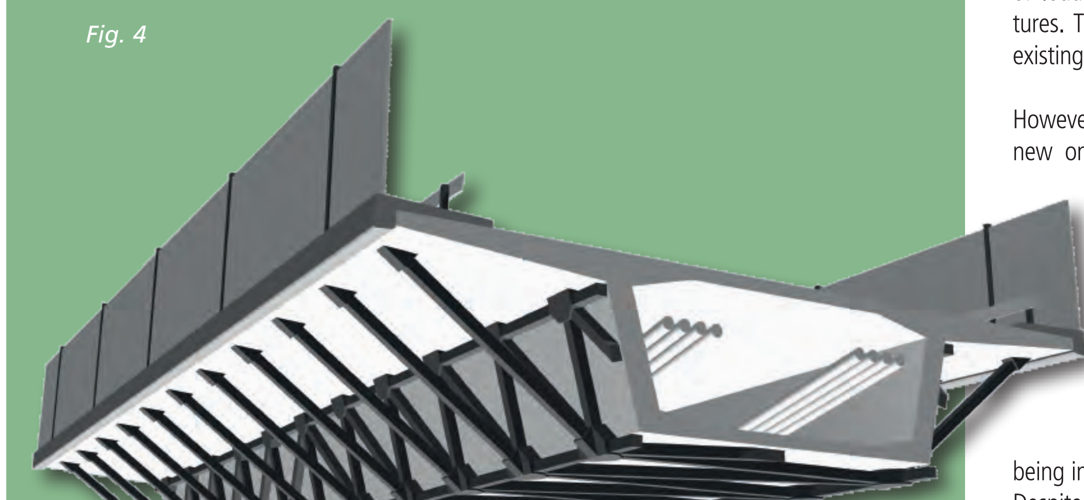
Fig. 4: Principle of the tube-in-tube adaption using an example of a box girder bridge

Life-Cycle-Engineering of Bridges

Ensuring a functional transport infrastructure becomes increasingly important for an industrial country like Germany. This is particularly due to the ever-growing traffic loads and the necessity of keeping bridges in use despite ageing processes, which is caused by public financial shortages. In this context and in view of dynamic traffic loads and, in particular the fatigue of materials, the **Fatigue Strength of Tendons** (Fig. 1) is of utmost importance. With the conducted investigations, it was possible to improve the safety of design approaches.

In addition, it is important to know the **Effects of Mechanical Aging of Concrete on the Load-Bearing Behaviour of Concrete Components** for a more accurate assessment of load-bearing capacities of existing structures. This is currently being investigated for existing bridges under shear.

Fig. 4



However, if bridges are to be replaced with new ones, the construction time and thus duration of road restrictions should be reduced as far as possible. Rapid construction progress can be achieved by using prestressed precast members. Since bridges are subjected to a high number of load cycles due to the traffic, the **Fatigue Behaviour of Prestressed Tendons** is currently being investigated.
Despite thorough planning and design with regard to future load situations, the actual loading conditions that will occur during the entire service life of structures are often not clear at the time of construction. From this

Fig. 5: Investigations on the cracking behaviour of skew reinforced concrete members

Fig. 6: Innovative, non-metallic basalt fibre reinforced polymer rebars

Fig. 7: Investigations on the load-bearing behaviour of compression members with large diameter bars

Fig. 5

Fig. 6

Fig. 7

aspect, the idea of **"Adaptive Bridges"** was developed. In this case, subsequent adaption possibilities are already considered during planning and construction, and therefore, the additional costs for strengthening turn out to be much lower. The subsequent strengthening can then be extended to the use of prestressed truss elements made of high-performance materials to achieve a so-called "tube-in-tube bridge" (Fig. 4).

Efficient and economic management of existing buildings and transport infrastructure networks necessarily leads to the implementation of suitable lifetime management systems. As a part of **"Life-Cycle Engineering Strategies and Methods"**, lifetime simulations were carried out for civil engineering structures, which allow an accurate evaluation of the structural stability and functionality in the various lifetime phases.
Another possibility for reliable service life assessment is to apply **Monitoring Concepts for Existing Buildings**, which are then included in the assessment as so-called compensation actions. Essential components comprise permanent monitoring systems and supplementary inspections of structures, which allow for obtaining a further analysis of the deficits of existing bridges and improved safety.

Serviceability and Durability

For research work dealing with the serviceability of reinforced concrete members, crack formation and the limiting of crack widths play an important role in controlling damage processes, e.g. due to corrosion. For this purpose, the **Cracking Behaviour of Skew Reinforced Concrete Members** (Fig. 5) was experimentally examined. Based on the results, an important contribution to the calculation of crack widths could be made.

A similar approach is being pursued in a current project, in which experimentally measured crack widths are collected in a database and compared with existing and new design models. The aim is to provide **Approaches for Crack Width Limitation**, which allow a safe but at the same time practical prediction of the crack widths.

In order to eliminate the problems caused by the corrosion of steel reinforcements in concrete components, as required under extreme environmental, chemical or maritime conditions, the conventional reinforcement should be replaced. This innovative idea is the subject of a project in which rebars made of **Basalt Fibre Reinforced Polymer Rebars (BFRP Rebars) in Combination with Ultra-High Performance Concrete (UHPC)** (Fig. 6) are used. This alternative type of reinforcement for extremely durable and material-saving concrete structures (e.g. offshore structures) is being investigated.

Robust and Safe Constructions

Nowadays, the post-cracking behaviour and the robustness of reinforced and prestressed concrete components in combination with the safety design levels required are getting more attention. This was the aim of experimental investigations of **Large Diameter Bars (> Ø32 mm)** (Fig. 7) in highly stressed and highly reinforced compression members. As a result, rules for design and detailing could be developed further and significantly simplified in terms of construction practice.
A similar approach was pursued in studies on the load-bearing and deformation behaviour of **Compression Members made of Ultra-High Performance Fibre-Reinforced Concrete with High-Strength Longitudinal Reinforcement**. Here, the extreme brittle behaviour of the UHPC could be compensated by an optimised interaction with the high-strength reinforcement in order to develop columns with high load capacities and good robustness.

Fig. 8: Large-scale test on a spun concrete component

Fig. 8

Filigree, Light and Ecological Constructions

Further developments in concrete construction towards sustainability, energy consumption and resource conservation will inevitably lead to designs that are optimised in terms of shape and material. **Thin-Walled Circular Hollow Components made of UHPFRC** can ensure this. The significant material savings and the use of high-strength reinforcement lead to applications similar to steel or composite constructions.
Here, **Ultra-Light, Thin-Walled Hollow Concrete Members** with wall thicknesses in the range of the usual concrete cover represent the most important development step. Inspired by bionic processes, structural forms of the bamboo plant were examined. To realise small wall thicknesses, a high-performance, self-compacting, fine aggregate concrete and a highly ductile micro-reinforcement were tested.
In order to simplify and industrialise the production of circular hollow concrete components, spun concrete is a fitting solution: Concrete is rotated at up to 600 revolutions per minute in a circular steel formwork. This results in a very smooth surface with an extremely dense structure and a very high durability. The adaption of this procedure towards the use of UHPC has led to the development of innovative **Compact Extra High Voltage Poles and Cross Arms** (Fig. 8), which enable an environmentally friendly and resource-efficient construction. In the course of the energy turnaround, the prestressed spun-concrete poles made of UHPC with their very high slenderness are supposed to replace steel lattice masts. A further step is the investigation of a **Foundation Structure for Offshore Wind Energy Power Plants**, in which ultra-high-strength spun concrete segments are joined to a **Framework Structure** that offers a safe and robust alternative for existing steel foundations. ■

Division of Concrete Construction

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We would walk through fire for you

The Division of Fire Safety

The "fire" load case is one of the "exceptional" design situations in civil engineering. Fortunately, fires are relatively rare, but they can cause significant damage to property and personal injury. Therefore, the teaching, research and further education activities at the Division of Fire Safety have for many years been dealing with the investigation of fire development, the consequences of fire and their effects on components, building materials and people.

The basis for systematic research into fire protection was laid by Professor Karl Kordina (1959-1986) within the scope of the "Sonderforschungsbereich 148",funded by the German Research Foundation (DFG), in which the fire behaviour of building materials and components was examined in depth for the first time. Professor Dietmar Hosser (1986-2013) focused research into fire safety on the experimental investigation of the spreading of fire and smoke and the modelling of fires, and he established the subject "Fire Safety" in the master programme in civil engineering. He furthermore initiated the "Braunschweiger Brandschutz-Tage" convention, which from today's perspective may be considered a milestone in the training of fire safety in German-speaking countries.

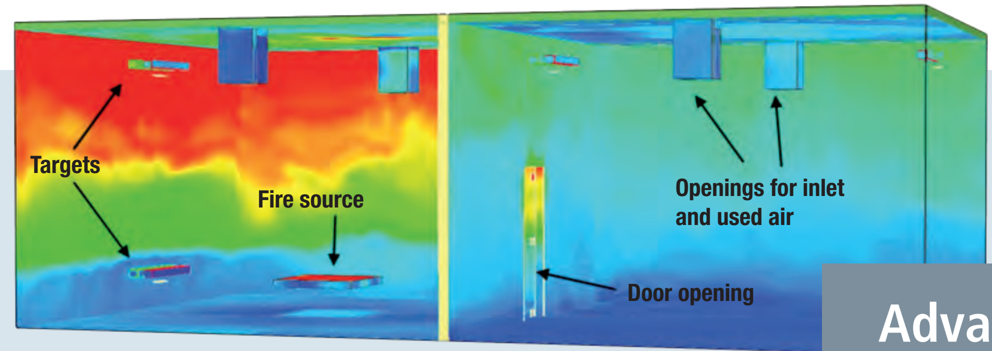
Under the direction of Professor Zehfuß (since 2013), the division's research is focused on

- fire dynamics,
- fire-proof components and constructions,
- fire safety.

The "ZeBra" Fire Research Centre, which is being established, offers unique possibilities for the experimental investigation of fire dynamics. The focus of the division's activities is still on the transfer of scientific knowledge into practice. For this purpose, the international symposium on "Structural Fire Engineering" has been launched in 2014, in addition to the "Braunschweiger Brandschutz-Tage".

Professor Zehfuß is a member of various committees: CEN TC 127 WG 8 "Fire safety engineering", CEN TC 250 / SC1 / WG4 "Concrete fire part", CEN TC 250 / SC2 / WG1 / TG5, "Actions on structures exposed to fire", Project Team SC2. T2 "New Items in EN 1992-1-2", expert committee of the DIBt (German Institute for Building Technology) for "Structural Fire Design"; Chairman of the DIN committee on "Structural Fire Engineering – Eurocode", Vice Chairman of the DIN committee on "Fire Safety Engineering", Chairman of the German Fire Protection Association (GFPA) department for "Fire Safety Engineering" and member of the GFPA board.

In the following, selected recent research projects are presented.



Advanced pyrolysis model for cables

In the field of fire safety engineering, the usage of computational simulation models to design smoke control and structural fire protection measures is getting more and more important. To simulate fire development it is necessary to know the time-dependent heat release especially for cable fires because of the high amount of cables installed within modern buildings. Within the frame of a reactor safety research project founded by the Federal Ministry for Economic Affairs and Energy, a coupled pyrolysis-heat conduction model was developed and implemented in the computational fluid dynamics code Fire Dynamics Simulator. This model couples a solid state pyrolysis model to a 3D thermal conduction model, allowing for considering thermal decomposition processes and their impact on combustion as well as on heat conduction. Validation shows that the simulated data is in good agreement with the experimental data of several small and large scale tests conducted at iBMB. In future projects the model shall be generalised for further materials as well as for application of under-ventilated fires. ■

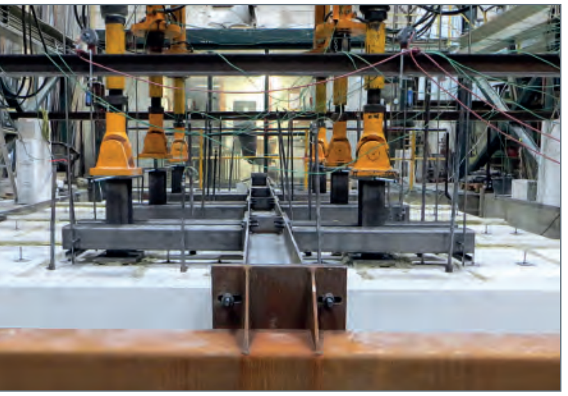
Development of a guideline for hot smoke tests

The purpose of smoke extraction is to achieve predetermined protection goals in buildings in case of fire. The term "smoke extraction" ranges from undefined smoke extraction to defined smoke and heat exhaust, with which low-smoke layers can be achieved.

The German vfdb 14/02: 2017-04 guideline describes the procedure and the suitable methods for performing hot smoke tests in rooms. The proof for the dimensioning of smoke extraction is furnished qualitatively. In the guideline, the limits are shown to be able to derive quantitative statements from hot smoke tests. For the qualitative proof of a smoke layer, it is at least necessary to carry out a similarity analysis. To clarify these questions and to compare the various systems for performing hot smoke tests, experiments were carried out at the Frankfurt Fire Department in Germany. ■

Thermal properties of fire protection materials

In case of fire, steel constructions can lose their mechanical strength with increasing component temperatures. Therefore, structural steel elements protected by fire protection materials like intumescent coating, plaster coating or fire protection boards are often applied in practice. When determining the temperature of a structural element with fire protection materials, the thermal properties of the building materials must be known to estimate the load-bearing capacity during fire. For these purposes, a joint national research project focused on experimental and numerical investigations on fire protection materials under exposure to natural fire is carried out. The temperature-dependent thermal material properties like specific heat, thermal conductivity and density of the fire protection materials are to be investigated.
Furthermore, the effects of different heating and cooling rates were investigated and boundary conditions for a standardised test method were determined. To evaluate the experimental results of the thermal material properties, a numerical model is to be implemented. For validation of the numerical model, a large-scale fire test on coated and boxed steel profiles was performed. In the fire test, the protective and insulation effects and the fire behaviour of the fire protection materials are taken explicitly into account to consider the material behaviour at high temperatures. ■

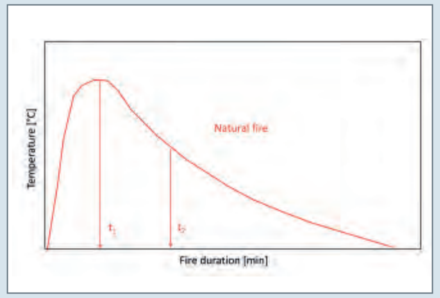


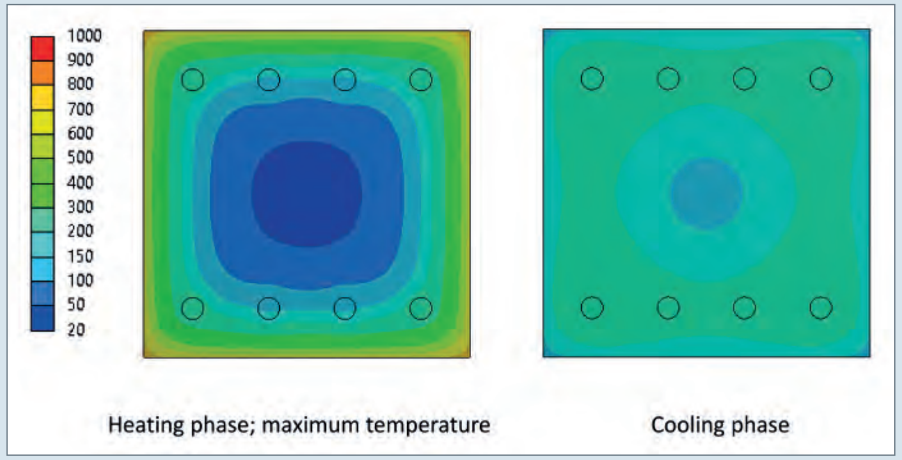
Investigation of different fire loads on façades

In the context of recent cases of fire damage to façades and the related discussion about the safety of façade systems in case of fire, experimental investigations on the fire behaviour of external thermal insulation composite systems (ETICS) are carried out. At the iBMB, fire tests are conducted to investigate heat-flux density, plume temperature and thermal radiation. At the Materialprüfanstalt Dresden based in Freiberg, five large-scale fire tests were carried out to investigate the burning behaviour of real-scale façade systems. The large-scale fire tests were conducted outside with a façade system assembled by a specialised firm. The aim of the tests was to examine the influence of different fire loads (200 kg wood crib or 200 l isopropanol pool fire) at the base of the façade. Furthermore, the influence of the construction itself was analysed, in which the number of fire barriers was changed from 1 to 3 and the façade surface was made without openings and with three window-like openings, each with 1.35 m x 1.01 m.
As a result it could be shown that there is a major influence by the type of fire load. Job site scenarios, which can be shown through melted EPS, should not be ignored just on the ground that the installation of the façade isn't finished yet. Furthermore it can be shown that a higher number of fire barriers raise the safety within a fire. With a higher number of fire barriers, the plaster layer is fixed at more points or separated into multiple smaller fields, which provides a higher resistance against dynamic stress. Window-like openings cause an earlier failure of the façade system by openings in the lintel. After the five large-scale fire tests, a sixth test would be interesting with an additional fire barrier between the second and the third opening. In conclusion, it can be seen that a separation of the façade into smaller fields has a positive influence on fire resistance in case of fire. ■

Thermal and thermo-mechanical material properties of concrete considering realistic natural fires

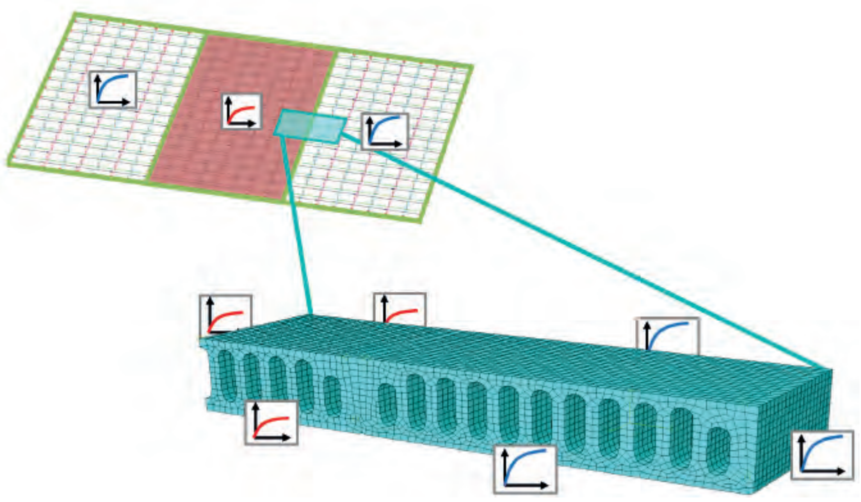
The application of natural fire models is provided in the current Eurocode generation as an alternative to the common ISO 834 standard fire for fire safety design. For determining the temperature time curves, the load-bearing capacity of the building components and structures has to be proved during the entire fire duration due to a possible failure of the components in the cooling phase because of retarded heating or high tensile forces. The application of natural fire models currently implies some uncertainties because of unidentified parameters of the material properties in the cooling phase after exposure to high temperatures.
Within a current research project funded by the German Research Foundation (DFG), the material behaviour of normal, high and ultra-high performance concrete is investigated considering realistic natural fires, including a heating-up and a cooling phase. For this purpose, temperature-dependent thermal and thermo-mechanical material properties of the concretes will be determined. ■



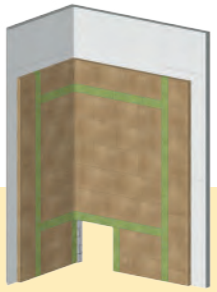


Fire behaviour of prestressed concrete hollow slabs

In cases of fire occurred in European countries, failure mechanisms were observed on ceilings made of prestressed concrete hollow slabs, which were previously unknown. A special type of failure is suspected in the formation of horizontal cracks in the plate webs, which can lead to a complete detachment of the lower plate layer. One reason for this failure is the thermal expansion of the fire-stressed bottom flange of the ceiling, where bending tensile stresses in the hollow slab cross-section and constraining forces due to expansion impairments of adjacent ceiling areas can occur. Previous experimental studies have not been able to take this fact realistically into account.
In order to clarify the effects of these thermal forces in the ceiling system on the load-bearing capacity of the hollow slabs and the failure mechanisms, theoretical, experimental and numerical investigations are carried out in this research project. Based on the thermal and mechanical material properties of the Eurocode, relevant calculation data shall be composed. In small-scale tests, the force-displacement relationship in the transverse direction of the hollow chambers is determined at normal temperature. The findings gathered are incorporated into the numerical investigations for the development of a detailed FE model - a typical ceiling system for local fire exposure. Two large-scale fire tests are planned to validate the FE model. ■



External thermal insulation systems with wood fibre insulation panels



In Germany, the application of external thermal insulation component systems (ETICS) with wood fibreboards is restricted to low buildings (e. g. single-family houses). The restrictions are mainly due to the smouldering tendency of the wood fibreboards. Thus, the development of an ETICS with wood fibreboards for higher buildings (e. g. multi-storey apartment buildings) complying with the requirements would provide a new scope of application for this sustainable insulation material. The German Federal Ministry of Economics and Technology funded this research within the Central Innovation Programme for Small- and Medium-sized Enterprises (ZIM). The operating research institutions were the Magdeburg-Stendal University of Applied Sciences, the Fraunhofer Institute for Wood Research (WKI) and the iBMB of the Technische Universität Braunschweig together with the industrial partners Endress, Weizenegger and Homanit.

As expected, first research results showed that it is not possible to stop smouldering by improving the material parameters of the wood fibreboards or using conventional fire retardants. As parallel approach, barriers were developed and examined to stop smouldering at an acceptable level. On the other hand, a "thick layer system" was developed and examined, where the plaster system mainly protects the combustible materials during fire exposure. These basic investigations of the materials and components led to system solutions, which were tested on a larger scale in a façade rig according to German standard, where the systems as unit showed a fire behaviour similar to the approved ETICS (with combustible insulation) for higher buildings or even better. In addition, a larger test according to a new and bigger façade fire scenario with a 200 kg wood crib in front of the ETICS with wood fibreboards and thick layer system (plaster) is planned. ■

Fire behaviour of composite beams

The usage of the partial connection theory for composite girders is state of the art under ambient conditions, where the minimum degree of shear connection is considered. However, the reduction of the number of shear connectors in the design of composite structures at ambient temperatures is not directly applicable to the design in case of fire. This is due to the different behaviour of the steel and concrete components at elevated temperatures, which results in high residual stresses and deformation of the composite girder. In Germany, the approach of the partial connection theory for composite girders under fire exposure is therefore only possible when considering the change in longitudinal shear forces. Therefore, the usage of the partial connection theory for composite girders with requirements concerning fire resistance is only possible with increasing effort.

In an extensive research programme, experimental and numerical investigations are conducted to analyse the usage of the approach of the partial connection theory for composite girders. A major point therefore is the description of the behaviour inside the composite joint under elevated temperatures. To gain general experimental results and to cover the relevant parameter area, different composite girder configurations are tested in large-scale fire tests. The test results are used to validate an FE-model. A parameter study has been conducted to give a statement on an extended parameter area. At the end of the project, simplified design rules should be developed to allow the usage of the partial connection theory for composite girders in case of fire. This will lead to an effective economic application of composite structures in building construction. ■

iBMB – Division of Fire Safety

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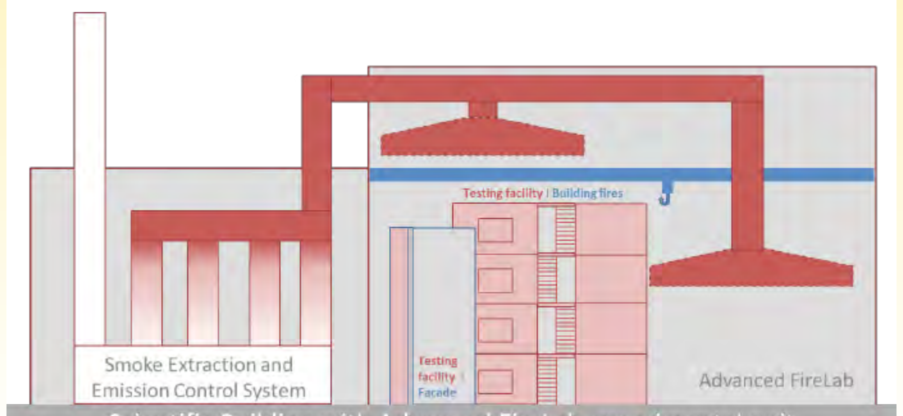
Centre for Fire Research (ZeBra)

As a part of resource conservation and the energy revolution, innovative types of construction and products are finding their way into areas of living and mobility. The development of these types of constructions, such as combustible renewable raw materials, energy storage in buildings as well as electric vehicles, can only succeed if the risk of fire is minimised and the effects of fire can be predicted precisely by efficient and resilient prediction models. In order to achieve this objective, Technische Universität Braunschweig will develop a holistic approach for the efficient modelling and simulation of fires. Therefore, under the leadership of iBMB, the Centre of Fire Research (ZeBra) is founded to enable a leap in knowledge with regard to the fire-predicting capability. Experts from different disciplines such as civil engineering, chemistry, environmental sciences, computer-aided modelling, process engineering and mechanical engineering will work together in this centre.

With regard to the fire safety of future buildings and innovative products, the following objectives are pursued in the Centre for Fire Research (ZeBra):

(1) Development and validation of experimental and theoretical methods as an essential prerequisite for the design of fire-proof and resource-efficient buildings.
(2) Systematic research on the knowledge-based design of optimised innovative products in the context of fire safety.
(3) Substantial improvement of numerical and physical models for the efficient and reliable prediction of fires.



Scientific Building with Advanced FireLab experimental unit

The Institute of Building Materials, Concrete Construction and Fire Safety (iBMB) of TU Braunschweig, in conjunction with the Civil Engineering Materials Testing Institute (MPA) Braunschweig, is already one of the leading fire safety research establishments in Germany. ZeBra connects itself excellently with research centres already based in Braunschweig, such as the Center for Light and Environmentally-Friendly Structures (ZELUBA), the Battery LabFactory Braunschweig (BLB) and the Automotive Research Center Niedersachsen (NFF) as well as the National Metrology Institute of Germany (PTB) in Niedersachsen and the Institute for Fire and Civil Protection (IBK) in Sachsen-Anhalt. ZeBra's key component is an Advanced FireLab as experimental unit with which heat release rates (up to 20 MW) and the release of smoke and particles of real fires (such as home furnishings, vehicles, and façade constructions) will be explored.
ZeBra's research issues focus on five fields of research. As shown in Fig. 1, Working Group WG 1 and WG 2 are experimentally researching fundamental issues within the Advanced FireLab and creating basics and input data. This is the basis used by WG 1 and WG 3 to develop an efficient and reliable scale-independent prediction of the fire. At ZeBra, the focus is on fundamental issues relating to fire behaviour and the potential risks posed by novel innovative construction

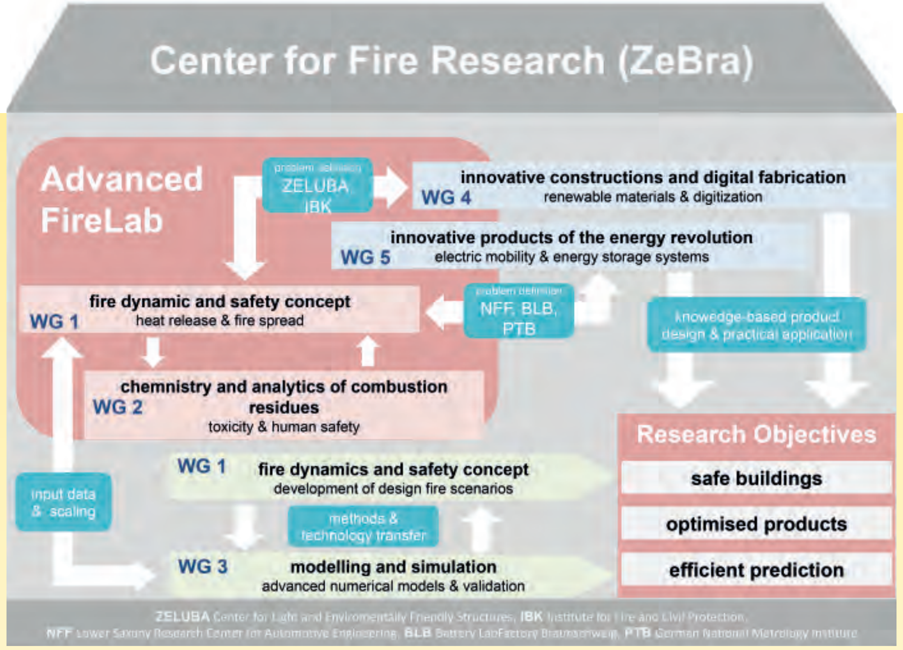


Fig.1: Structure of ZeBra with the "Advanced FireLab" large-scale device

methods and products. For developments within WG 4 and WG 5, the knowledge-based product design for practical application is thus guaranteed. The results are fire-proof and resource-efficient buildings as well as innovative products optimised in the context of fire safety.

ZeBra's research activities will initially focus on the development of fire prediction models. An essential factor of fire research is the description of the fire source, the associated fire dynamics and the heat release from small to large scale. Fig. 2 shows the history of the development of fire models. The fire hazards result from current trends like the use of renewable combustible materials and storage systems (batteries) in buildings, whose fire behaviour is largely unexplored. The long-term, multi-decade perspective and vision of the new centre is to predict the fire and fire propagation behaviour and associated pollutant exposure in buildings, based on small-scale input data from highly efficient numerical simulations. This will allow for an optimised design and the design of fire-proof buildings. In addition, the field of research can be extended to the field of mobility in the long term.

The ZeBra research building will be erected on Campus East of TU Braunschweig. The research building with a total cost of approximately € 16.7 million will have a usable area of 1,216 m², with 883 m² for the experimental unit and 333 m² for a two-storied office building. In the future, students will have the opportunity to participate in a new master's programme named "Fire Safety", which will be offered for the first time with scientific orientation in Germany. Within the programme, the work of ZeBra will be transferred to teaching and expand in-depth knowledge in fire dynamics and modelling.

Advanced FireLab

The unique multi-scale calorimeter experimental unit ("Advanced FireLab") consists of several components and devices (see Fig. 3):

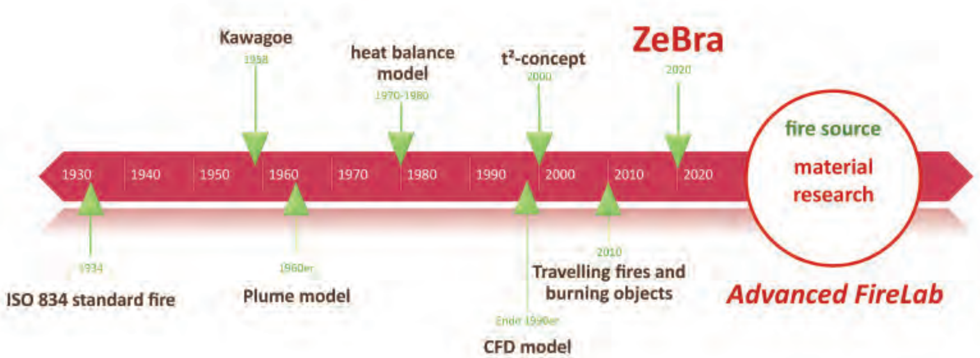


Fig.2: History of the development of fire models

Calorimeter in small and large scale

The development of the heat release rate will be determined, based on the method of oxygen calorimetry in the calorimeters of ZeBra on the laboratory scale (cone calorimeter, up to 10 kW), on the average scale (room-corner test, up to 2.5 MW) up to large scale (large calorimeter up to 20 MW). By measuring the proportion of other flue gas components (carbon monoxide and carbon dioxide), conclusions on the corresponding yields are possible. Thereby, the provided thermo-physical material properties serve as input parameters for fire simulations.
By extending the measuring devices or coupling the individual calorimeters with Fourier transform infrared spectrometers (FTIR), further organic and inorganic gas components such as nitrogen oxides, sulfur oxides and hydrocyanic, chloric or hydrofluoric acid can be qualitatively and quantitatively determined. Using an electric mobility spectrometer, particulate releases of the smoke can be measured in terms of their particle number size distribution. The determination of harmful gas concentrations and distribution of particles are of fundamental importance for the assessment of human health effects.
All combustion gases must be collected by capture hoods. For the large calorimeter, a hood with a 12 m x 12 m base area and a volume flow of up to 4150 m³ / min is essential. For this purpose, an exhaust system for generating the negative pressure must be connected to the hoods via corresponding pipe channels and linked with a flue gas cleaning system. For the average calorimeter, a hood with a surface area of 2.5 m x 2.5 m with corresponding connection to the exhaust system is planned. To derive the heat release rate of the fire loads based on the oxygen consumption method, a corresponding gas analysis instrument is installed. Another component of the exhaust system is a flue gas cleaning system to be able to filter the released noxious gases in accordance with legal regulations.

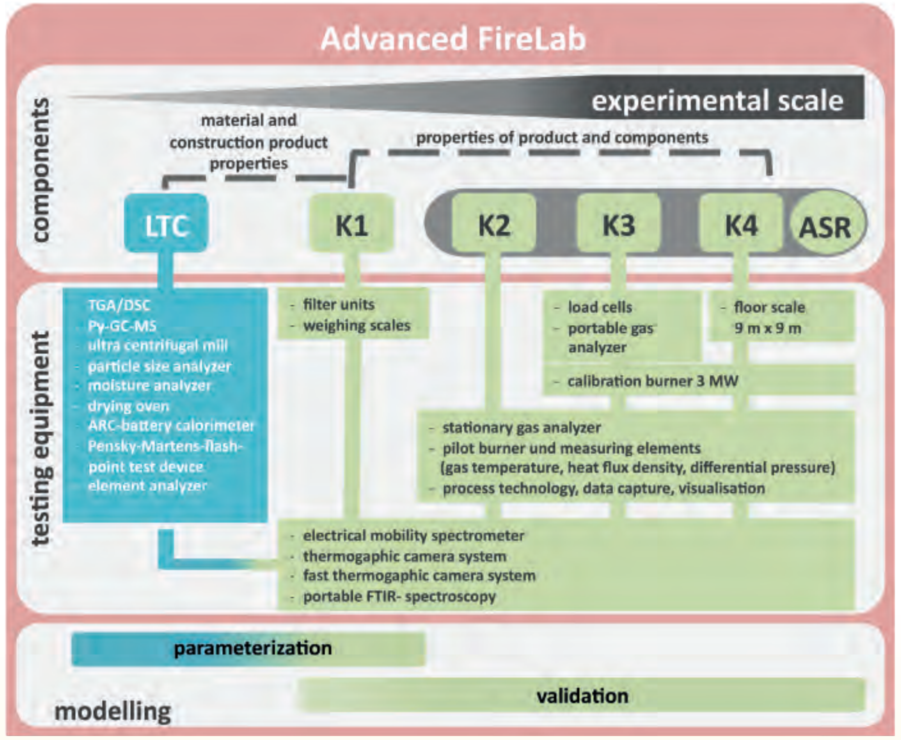


Fig. 3: Representation of the components and devices of the Advanced FireLab

Laboratory instruments and other measuring technology

For determining further thermophysical-chemical input data, systematic investigations on a laboratory scale are planned. This includes the determination of thermal material parameters such as the specific heat capacity, the thermal conductivity or phase transitions and the glass transition temperature by simultaneous „Thermogravimetric Analysis" (TGA) and „Differential Scanning Calorimetry" (DSC). A linking of TGA-DSC with a gas chromatograph and mass spectrometer (GC/MS) also allows for identifying and quantifying the relevant (further toxic, long-chain) components (molecules/molecular groups) of the sample material. A targeted, quantitative analysis of the components, which are generated by pyrolysis processes, provides an addition to the GC/MS combinable Double Shot Pyrolysator. It pyrolyses the sample under controlled conditions and delivers it to GC/MS (pyGC/MS).
To characterise the products of the energy revolution (e.g. lithium-ion battery cells), self-reinforcing exothermic reactions – the thermal runaway – can be analysed with a battery calorimeter. These processes are additionally explored with temporally high-resolution thermography, including the parameterisation of simulations of the fire behaviour of whole battery systems. ■

Division of Fire Safety

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Organic building materials

Physical, mechanical and chemical properties of organic building materials

The Division of Organic Building Materials and Wood-Based Materials (FGOB) was established in 2010 as a new division of the iBMB transformed from the "Structure and Application of Building Materials" division. The focus on inorganic and polymer materials was enhanced by including the lignocellulosic materials such as wood, flax and other plant-based fibres, FRP reinforcement, and other topics. Thanks to the appointment of Professor Kasal as Director of the Fraunhofer Wilhelm Klauditz Institute (WKI), a basis for direct collaboration between the Fraunhofer Gesellschaft and the Technical University of Braunschweig was established. The foundation of the Fraunhofer "Center for Light and Environmentally-Friendly Structures (ZELUBA)®" underlines the successful collaboration between these two institutions. Several institutes of TU Braunschweig work together with the Fraunhofer WKI to develop new materials and components combining traditional and new materials. A new research facility is being constructed on the Civil Engineering campus of TU Braunschweig and this will allow the integration of fundamentally oriented university research into industry-focused research carried out by Fraunhofer.

The division focuses on the physical and chemical properties of organic materials such as plastics, adhesives, wood, straw, seaweed, and other natural materials that can be used as building materials. Research and teaching emphasise the materials science-related aspects of organic building materials. In various projects that reflect the staff's broad range of skills and knowledge, mineral building materials and plastics are developed for specific applications. Mr Libo Yan, newly appointed to the division as junior professor, has broadened the scientific basis with the field of natural fibre-reinforced concrete.

An example of a successfully completed project in this field is the Aif/ZIM project (German Federation of Industrial Research Associations – AiF in short; and ZIM – Central Innovation Programme for Medium-size Enterprise), which received funding from the Federal Ministry of Economic Affairs and Energy (BMWi). Its subject was the design and testing of wood under dynamic loads, with the goal of developing guardrail systems made of composite materials based on renewable raw materials.

Since their introduction in the 1950s and 1960s, the guardrails have saved many lives. To date, most restraint systems have been made of steel. To design a wood-based substitute system, many aspects have to be understood in detail. The wooden system has to offer adequate levels of both stiffness and flexibility in order to keep the vehicle on the road, while also preventing the driver from being subjected to high inertia forces. The challenge was to safely divert and convert the vehicle's kinetic energy while retaining the integrity of the guardrail. Small-scale pendulum experiments were conducted first to design the best material combination.

A large pendulum with 1000 Joule capacity was designed and instrumented (see Fig. 1). The pendulum simulated the impact of a vehicle and the experiments were the basis to develop analytical models and improve the constitutive equations needed to describe the strain-rate dependent material. Figures 2 and 3 show the time history of force and strain under pendulum impact. The results of the pendulum tests were applied in the design of the 70 m long guardrail prototype that was successfully tested under the impact of the 1500 kg vehicle and 115 km/hr.

Another research project – "Development of ultra-high-performance sensor-controlled moment connection with high energy dissipation potential for timber structures in seismic regions" – studied switchable moment connections with adaptable stiffness for laminated wood frames. The project was implemented in collaboration with the Fraunhofer WKI and an industrial partner. A new generation of beam-to-column connection allows the adjustment of stiffness based on the magnitude of the transferred moments. This connection provides high stiffness under loads from wind and moderate earthquakes, and delivers high energy dissipation in extreme earthquake events.

The specific challenge was to develop a three-dimensional connection with a high load-bearing capacity and energy dissipation, and a permanently functioning switchable connection, which does not change its functionality even after several earthquakes.

Fibre-reinforced composites (FRC) play an increasingly important role in the building industry and in mechanical engineering. They are characterised by high strength combined with low weight and good chemical resistance.

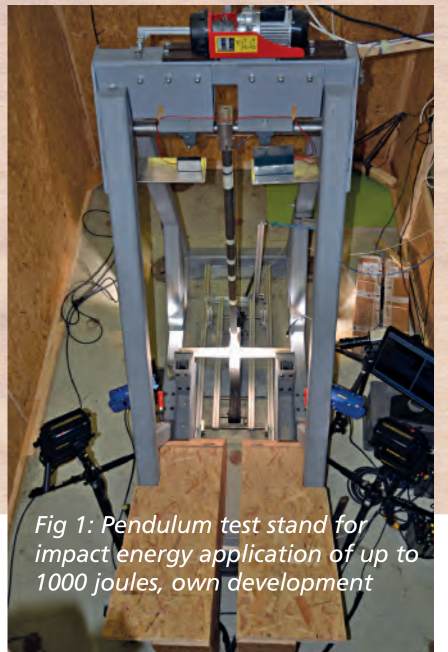

Fig 1: Pendulum test stand for impact energy application of up to 1000 joules, own development

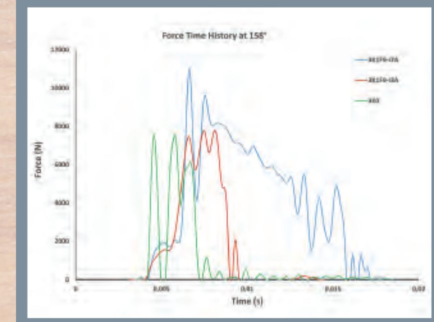

Fig. 2: Force/time diagram for pinewood (3K0), pinewood with fibreglass 900 g/m² and foam 300 g/m³ (3K1F9-I3A), pinewood with fibreglass 900 g/m² and foam 700 g/m³ (3K1F9-I7A) with a pendulum swing of 158°

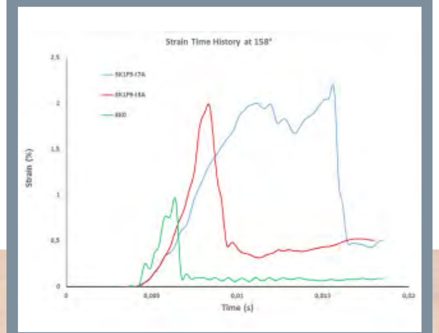

Fig. 3: Strain/time diagram for several samples, here: pinewood (3K0), pinewood with fibreglass 900 g/m² and foam 300 g/m³ (3K1F9-I3A), and pinewood with fibreglass 900 g/m² and foam 700 g/m³ (3K1F9-I7A) with a pendulum swing of 158°

The research project "Development of a remediation method for long-distance heat pipelines" implemented in collaboration with a medium-sized company, aimed to study the applicability of the so-called liner technology, commonly used today in the renovation of wastewater systems, for high-temperature applications, for example long-distance heat pipelines damaged by corrosion. The liner system is not limited to district heat pipelines, but it is intended for pipelines in general, e.g. in the chemical industry. The expectation is that high-temperature-resistant FRC liners will help avoid costly repairs of complete pipeline routes, or at least temporarily allow continued operation. The challenge of this project was to select a suitable material for the liners with different fibres and a suitable thermosetting resin system for applications at 130°C and a pressure of 13 bar, with temporary impact loads of up to 25 bar. The pure components (resins, fibres and fabrics) were tested at different temperatures and pressures after immersion tests and stress rupture tests; and a test apparatus for internal pressure and temperature loads with simultaneous application of media was developed. A LabView-based application was used for controlling and data recording (see Fig. 5).

Industrial research in the building industry and in mechanical engineering forms another major pillar. In many cases, damage events trigger more thorough, research-oriented studies; but already during the development and design of products, more in-depth and usage-based knowledge of materials science is of great importance. Additional research topics of the FGOB include the durability of adhesives under vibration stress when stressed complexly by the impact of media; early peeling-off of polymeric coatings exposed to natural weathering; stress cracking of elastomeric hydraulic hoses or floor coverings; polyethylene pressure pipes exposed to sulphuric acid for several decades; the ageing behaviour of roofing membranes or hailstorm-damaged roofing membranes; the investigation of causes for the corrosion of aluminium coolers; or simply the question why a water hose on a construction site shows cracks and causes considerable damage to buildings.

Fig. 4 (a): Example of a multi-storey wooden building with skeleton structure

Fig. 4 (b): 3-dimensional moment connector from a previous research project (model of the 3-D frame on the earthquake table)

The division is equipped with a range of analytical devices and testing equipment:

- Light microscopy (bright and dark field; fluorescence microscopy; polarisation microscopy; image analysis)
- Scanning electron microscopy (SEM) with secondary and backscattered electron imaging; energy dispersive X-ray microanalysis (EDX): elements from Bor to Uran; point and area analysis; line-scans; element mapping
- Sputter coater for gold and carbon
- Vacuum evaporation
- Atomic force microscopy (AFM)
- X-ray diffraction analysis (XRD); X-ray fluorescence analysis (XRF)
- Differential scanning calorimetry (DSC), thermo-gravimetry (TG), thermo-mechanical analysis (TMA)
- Mercury intrusion porosimetry (low pressure and high pressure)
- Universal testing machine with extensometer and temperature cabinet (-100 °C to +350 °C)
- Creep test facility
- Hardness tester (Shore A, Shore D, Vickers, Brinell)
- Impact pendulum for plastics
- Test apparatus for dynamic loading of bond seams with simultaneous time-controlled media application using different media
- Laboratory for sample preparation and wet chemical analysis
- Titrator for chloride determination in building materials ■

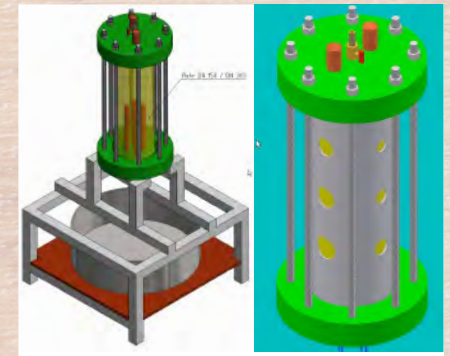

Fig. 5: Schematic diagram of a pressure pipe test stand (Left); Test pipe in a pressure pipe test stand (Right)

Division of Organic and Wood-Based Materials

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Removal of prestressing steel from structures

There are about 150,000 bridges in Germany, among them about 120,000 road bridges. The loads these bridges have to withstand are enormous.
According to a report in a well-known German daily newspaper, some heavy-goods vehicles (HGV) put as much load on a bridge as several thousand cars. These tremendous loads can be explained by the so-called 4th-power-law. As engineers calculated, the load on a road increases disproportionately with each additional axle, i.e. it is raised to the 4th power. On the road, this means: a 40-ton HGV with five axles puts as much load on a bridge as 16,666 cars weighing 1.6 tons each. Furthermore, the number of HGV and the load they carry has steadily increased in recent years.

Increasing load

With the ever-growing heavy-goods traffic on the roads, the load on bridge structures is increasing considerably. Before this could become a safety risk, the Federal Ministry of Transport and Digital Infrastructure issued a regulation for the reassessment of existing road bridges, in 2011. This regulation specifies that existing road bridges have to be reassessed based on current load assumptions, in order to ensure that they will in future be able to cope with increasing traffic loads.
This regulation requires particularly critical structures to be checked to establish whether prestressing steel with a high sensitivity to hydrogen-induced stress corrosion cracking was used.
In the period from around 1960 to 1978, prestressing steel was sometimes used that can fail suddenly, without visual signs of corrosion. Such failures may occur even after decades.
Since this phenomenon concerns only single charges of prestressing steel, samples have to be taken from the structures and tested.

Load-bearing behaviour tests

In the past, MPA Braunschweig has implemented a number of projects for the examination of bridge structures with regard to their sensitivity to stress corrosion cracking, also in collaboration with various engineering offices. When the prestressing steel has been measured according to the existing documentation or tested using non-destructive examination methods (GPR, ultrasound), the sheathing is uncovered and carefully opened to remove single prestressing steel strands with a length of approx. 60 cm. Afterwards, the sampling points are properly sealed again.

At the MPA Braunschweig laboratories, the prestressing steel strands are visually checked for corrosion pits or similar, before they are examined for fine, invisible hairline cracks in a magnetic particle test. In this test, the prestressing steel is magnetised so that small poles form at the cracks where the test powder then concentrates.
In addition, a thin section is taken from a small prestressing steel sample to examine the steel structure. In faulty manufacturing processes, the prestressing steel may become brittle and more sensitive to stress corrosion cracking during steel hardening and tempering.

If all these examinations are without negative findings, a tension test is performed on the prestressing steel strands. Since an increased sensitivity to hydrogen-induced stress corrosion cracking could also be due to an above-standard strength of the prestressing steel, the proof of a compliant strength value represents another criterion of the examinations.
If no increased sensitivity to hydrogen-induced stress corrosion cracking is established, the prestressing steel may be used without restrictions for the bridge's load-bearing behaviour, and the reassessment of the bridge structure can follow. ■

Structures and Construction Materials

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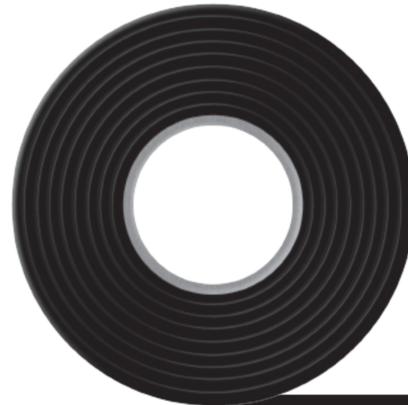
Schmidthammer test

Non-destructive localisation of reinforcement

Uncovered concrete reinforcement steel

Taking prestressing steel samples

Damp-proof courses as vapour barriers



Testing methods for examining the shear strength of horizontal bed joints in masonry with damp-proof courses inserted as a vapour barrier

Damp-proof courses have to seal against rising damp and – depending on the application – be able to transmit transverse forces in the bed joint. The use of damp-proof courses as horizontal vapour barriers in masonry is subject to a large number of different regulations, which partly contradict each other with regard to the courses actually permissible. The currently applicable standards include:

- DIN EN 1996-1-1/NA (Eurocode 6): This standard requires the installation of sanded bitumen roof sheeting of the R 500 type. Other materials may only be used if their frictional behaviour is at least equivalent.
- DIN 18533: Numerous bitumen and polymer bitumen courses (e.g. R 500, G 200 DD) as well as plastic and elastomer courses are permissible as damp-proof courses in masonry. The crucial factor in determining whether or not to use a waterproofing sheet is that the cross-sectional waterproofing sheet must not reduce the shear strength of the bed joint to such an extent that the wall slides on it. Basically, a distinction is made between damp-proof courses with transmission of transverse forces in the sealing layer (MSB-Q) and without transmission of transverse forces (MSB-nQ). Moreover, only sealing materials whose shear strength has been proved by long-term experience or in laboratory tests may be used for transmitting transverse forces in the sealing layer. Reference is made to DIN EN 1996-1-1/NA. There is no detailed description of a possible laboratory test.
- DIN SPEC 20000-202 governs the use of the waterproofing sheets referred to in DIN 18533 as cross-sectional waterproofing in or below walls. This standard also differentiates between damp-proof courses with regard to transverse forces transmission in the sealing layer. Here, too, no explanation is given as to how the transmission of forces in the sealing layer could be shown.

In Germany, it is also possible to have damp-proof courses approved that do not fall within existing regulations, i.e. on the basis of a general building authority test certificate (abP) for the type of construction concerned. In this case, too, the transmission of transverse forces in the sealing layer has to be proved by a separate certificate, of which no details are, however, given.

Regarding the transmission of transverse forces and the use of a variety of damp-proof courses that are expected to have different frictional behaviours, a suitability test under structural aspects is required, which would prove the transmission of transverse forces in the sealing layer. Only bitumen roof sheeting of the R 500 type can be excluded from this, since its suitability is confirmed by mention in the national annex to DIN EN 1996-1-1.

There is currently no national or Europe-wide harmonised testing method, and existing testing methods differ too strongly in their implementation from the tests that form the basis for the specifications in DIN EN 1996-1-1/ NA (Eurocode 6). MPA Braunschweig has developed a new and more comparable verification and evaluation procedure, which supplements MPA's service portfolio and is available to customers now.

Proof of the transmission of transverse forces of a damp-proof course in the sealing layer is conducted by means of comparative shear strength tests on pure mortar joints and on the R 500 sealing sheet, which are based on the testing method for determining the initial shear strength (adhesive shear strength) of mortar joints in accordance with DIN EN 1052-3 (Process A, test specimen type 1). The test specimen used for this is a three-brick specimen (Fig. 7), with the sealing sheet to be examined inserted in its mortar joints (Fig. 3). The test is conducted after a setting time of 28 days.

Test set-up and testing

In adhesive-shear-strength tests, the three-brick specimen is first subjected to a force that is perpendicular to the bed joints. This initial load on the bed joints simulates normal stress in the masonry that is due to the dead weight of the wall construction and additional loads. It is kept constant throughout the test. Then, the test specimen is

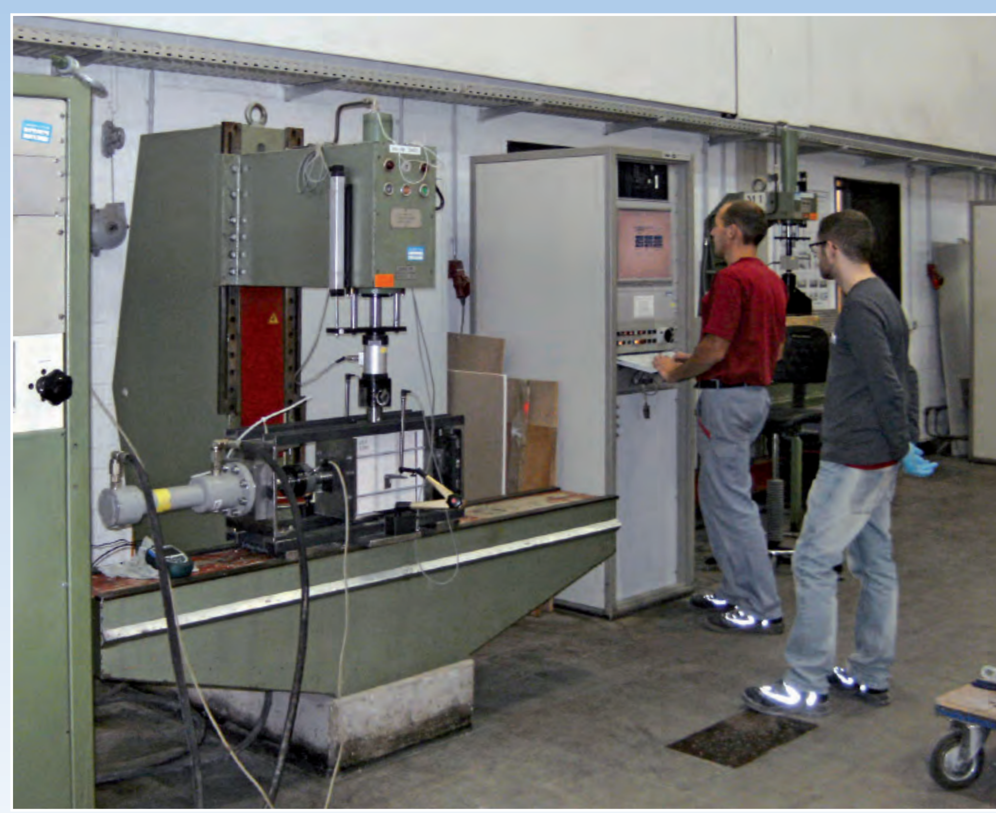


Fig. 1: Test set-up at MPA Braunschweig

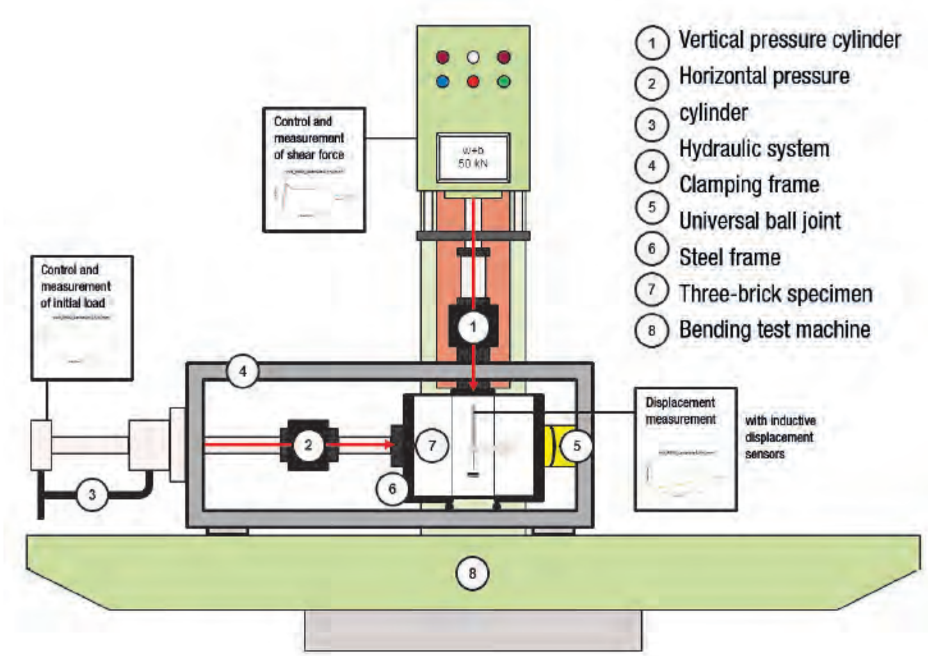
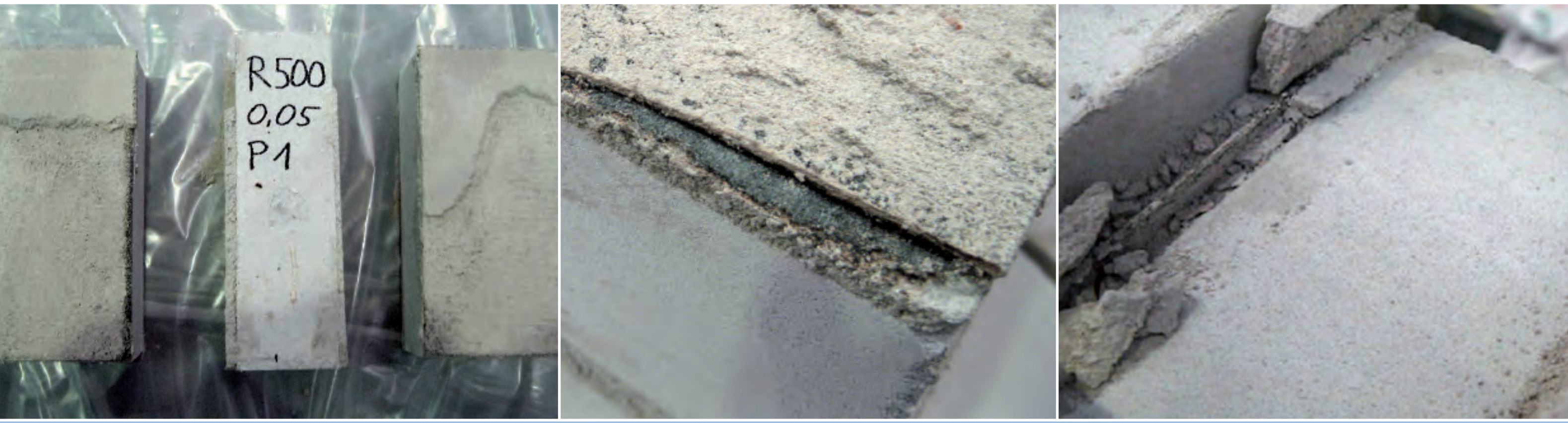


Fig. 2: Sketch of the test facility

Fig. 3: Mortar bed with inserted damp-proof course

Fig. 4-6: Test results: deformations of the bed joints and ultimate shear failure



subjected to another force, i.e. a shear force acting perpendicular to the butt-joint surface of the middle brick (Fig. 1 and 2). This force is continuously increased throughout the test, until deformations appear in the bed joints, and ultimately shear failure results (Fig. 4 – 6).
Using suitable measuring equipment, force/distance diagrams can be determined for a related initial load. From a test series with varying initial loads, a sealing course-specific friction coefficient can be determined in a regression analysis using the individual measurement curves. Proof of the sealing sheet's structural suitability is considered furnished, when, under the boundary conditions of the test, the shear carrying behaviour reached is comparable to that of the pure mortar joints and to the R 500 sealing sheet in the comparative examinations. The friction coefficient determined in the examinations serves as the benchmark. The equivalence of the frictional behaviour as stipulated in DIN EN 1996-1-1/NA or the required separate proof of transverse forces transmission in the sealing layer according to the type of construction (general building authority test certificate) is certified after the successful test. This allows use and installation of the sealing sheet for the transmission of transverse forces in accordance with the applicable regulations under building law. ■

Building Physics, Construction Materials, Building Chemistry

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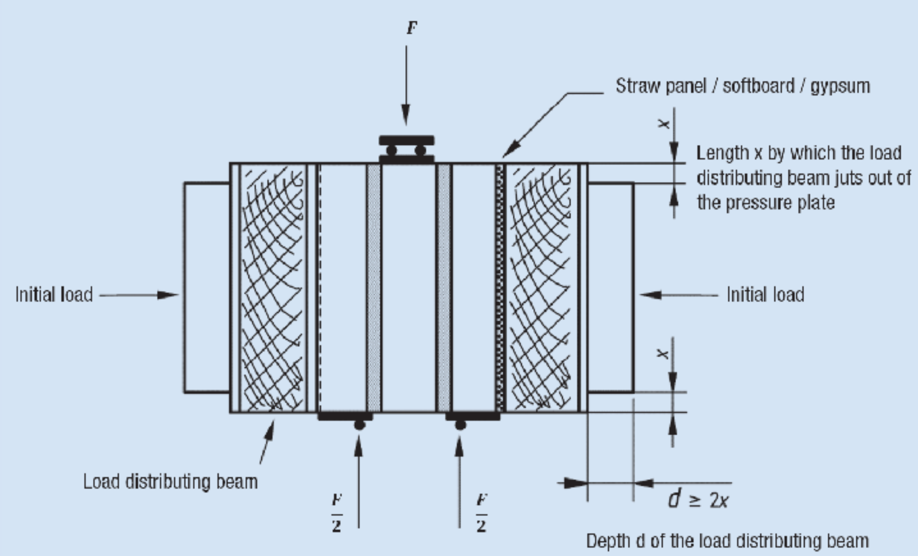
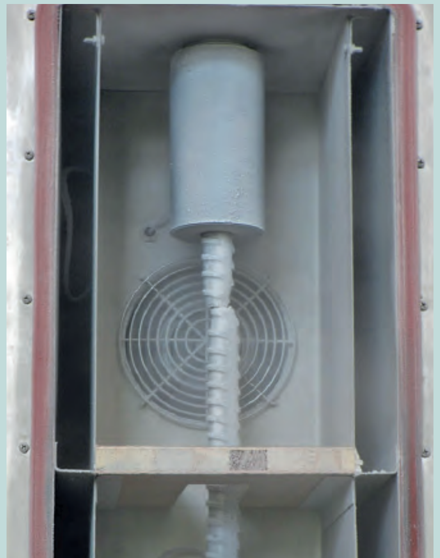


Fig. 7: Three-brick specimen

Testing tensioning systems and stay cables of bridges

For decades, MPA Braunschweig and the Institute for Building Materials, Concrete Construction and Fire Safety (iBMB) have been testing post-tensioning systems for prestressed concrete structures and the necessary prestressing steels. In the 1980s, the iBMB at TU Braunschweig ran several research projects that focussed on post-tensioning systems under low temperatures up to -170 °C. The field of application for such post-tensioning systems under these special boundary temperature conditions resulted from the construction of liquid nitrogen gas tanks (LNG tanks). This is currently regaining relevance across the globe, as is the related use of tensioning systems. Furthermore, research projects on grouting of post-tensioning systems to deduce improvements in grout-mixes, admixtures and grouting procedure have been processed at iBMB in the 1990s. Recently research projects on fatigue strength of prestressing steel are in progress at iBMB.
Over the decades, the maximum forces of

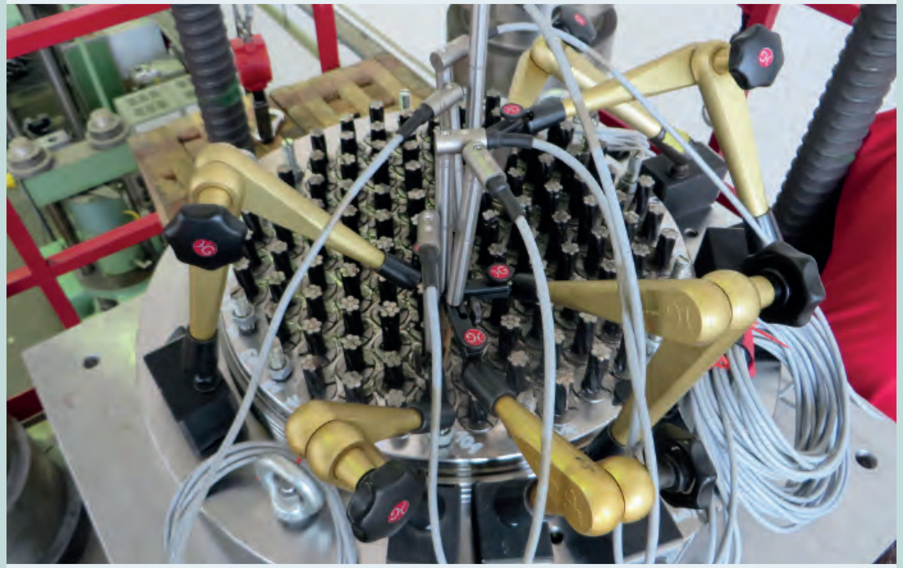
Test of coupled anchorage



Cryogenic test on reinforcement

Ultimate load test on full locked cable

30 MN machine, axial and lateral fatigue test on stay cable system



Anchorage of stay cable system with LVDT measurement

Project: Dublin-Ohio-Bridge, City of Dublin, Ohio, USA
Stay Cable: Redaelli, Italy; Photo: Crawford Hoying

Project: Yavuz-Sultan-Selim Bridge (3. Bosphorus Bridge), Turkey
Stay Cable: Freyssinet, France; Photo: Freyssinet

Project: Mandovi Bridge, India
Stay Cable: Dywidag-Systems International GmbH (DSI), Germany
Photo: DSI-Bridgecon

the post-tensioning systems have steadily increased. While the largest post-tensioning systems in the 1970s and 1990s had a maximum breaking force of about 3000 – 5000 kN, i.e. working loads of 2000 – 4000 kN, the post-tensioning systems from the late 1990s / the early 2000s became considerably larger and the maximum breaking forces increased to about 10,000 kN (which corresponds to maximum working loads of 6000 – 7000 kN) and beyond.

Since 2002, general building authority approval procedures in Germany and Europe and the tests required for post-tensioning systems are subject to the ETAG 013 regulation. This has now been replaced by the EAD 160004 regulation. As for the content, both regulations are comparable and identical in large parts. They define what tests have to be conducted on the post-tensioning systems. As a rule, the largest, the smallest and medium sizes of the post-tensioning system have to be tested. Testing here means quasi-static tension tests on the anchoring systems, dynamic tension fatigue tests with two million load cycles, and tests of the load transmission from the tensioning system to a concrete block. Post-tensioning systems with couplings have to undergo separate tests. The same applies to post-tensioning systems for special applications, like those mentioned above, which work at low temperatures for LNG tanks.

As post-tensioning systems are increasing in size, with ever-increasing maximum forces, larger testing machines are also required. In the past 15 years, MPA Braunschweig and iBMB have taken account of these developments. About 15 years ago, a 10 MN compression testing machine for quasi-static pressure tests and a 10 MN tension testing machine for static and dynamic testing of post-tensioning systems were purchased. Many tests on post-tensioining systems have been conducted with these two machines.

About 10 years ago, it became already clear that the sizes of post-tensioning systems would increase beyond 10 MN. At the same time, large bridges with clear spans of about 500 – 1000 m were very often built with stay cables. These stay cables often consist of so-called full-locked cables; these were frequently used from the 1960s, in Germany for bridges across the Rhine and the Köhlbrand Bridge in Hamburg/Germany, and in Norway for stay cable bridges. From the 1990s, stay cables consisting of strand bundles were developed and used worldwide, for example for the Oeresund Bridge connecting Copenhagen/Denmark and Malmö/Sweden, or the Rügen Bridge at Stralsund and the Wesel Rhine Bridge, both in Germany. Usually, project-related tests have to be conducted on the anchorages (dynamic tests followed by a tension test). Stay cable system tests are subject to international regulations:

- fib bulletin 30 "Stay cable systems"
- PTI/USA "Stay cable systems"
- CIP/France
- TL/TP VVS/Germany for full-locked cables; the latest version also includes strand-bundle cables

About 10 years ago, MPA Braunschweig and iBMB therefore designed a 30 MN machine, which they implemented together with European manufacturers of testing machines. This machine is one of a kind and some of its features are unique even in the world: tension tests and compression tests can be conducted in this machine under quasi-static and dynamic conditions. And transverse loads can be applied to the cables to simulate wind and rain-induced cables oscillations.

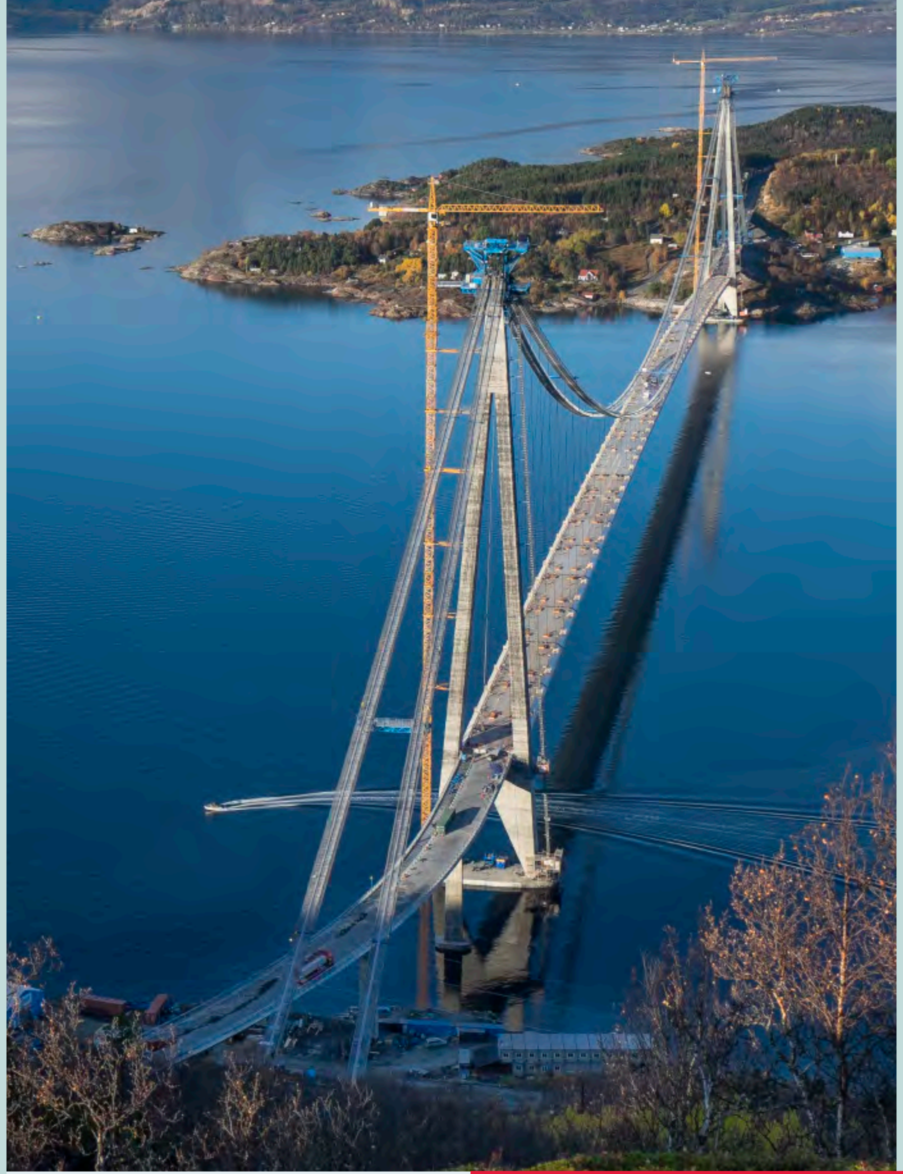
Since it was commissioned, a number of tests for various projects and research projects have been performed with this machine, such as on bridge cables and structural steelwork like highly loaded pillars from ultra-high-performance concrete with a very high percentage of reinforcement and other structural components.

Recently, there have been test orders for cables from older bridges that were found to have corrosion damage. This is often caused by weathering over decades, frequently combined with the impact of de-icing salt. The purpose of such examinations is to establish the residual load-carrying capacity of the cables. ■

BAB 30, Bad Oeynhausen, Germany,
Stay Cable: Bridon-Bekaert, Germany; Photo: Bridon-Bekaert

Project: Queensferry Crossing, Edinburgh, Scotland
Stay Cable: VSL, Switzerland; Photo: Dr. Martin Laube

Project: Ain-Dubai,VAE
Cable: Julisling, China; Photo: Beom Soo Park; Photo: Beom Soo Park



Project: Halogaland Bru, Norway
Stay Cable: Fatzer, Switzerland
Photo: Fatzer

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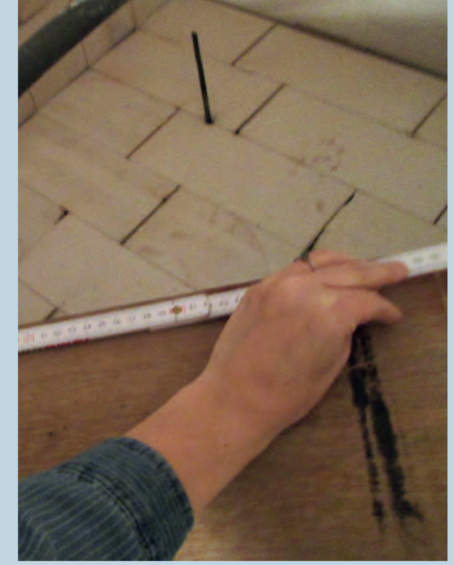


Measurement for installation of the test specimen

Installing the life-size, wooden staircase in the test furnace

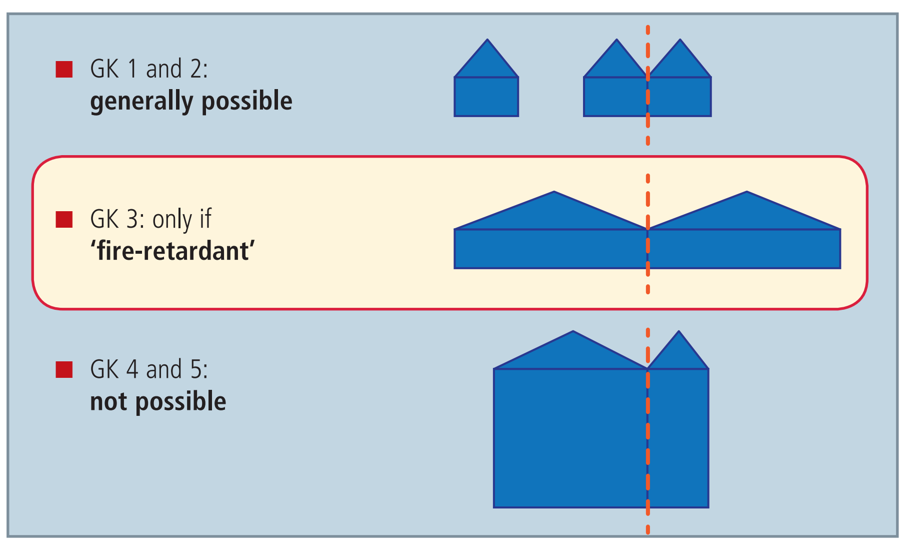
Fire resistance of wooden stairs can only be shown in a test

To classify construction products and structural members according to their fire resistance, a fire resistance test based on harmonised European standards (e.g., EN 1363-1) or, in Germany, national standards (DIN 4102-2:1977-09) is prerequisite. The standard requires load-bearing structural members to be loaded when tested. The related basic requirements can be found in the Model Building Code (Musterbauordnung – MBO) or the respective State Building Code (Landesbauordnung – LBO).

The MBO specifies that every physical structure as a whole and each of its parts must be stable on their own. Moreover, fires must be prevented and controlled, and the rescue of people and animals, and effective firefighting must be ensured. Physical structures must be safe for use. The MBO also specifies the standards that stairs (= escape routes) and connecting constructions (stairwell and landing, corridors) have to meet in terms of fire resistance and reaction to fire.

Requirements to be fulfilled for the use of wooden stairs

The MBO groups buildings into building classes (GK) according to their height, size and number of building units. The higher the building class, the higher the fire safety requirements to be fulfilled. GK 3 permits stairs made from combustible raw materials only if they are 'fire-retardant', whereas GK 1 and GK 2 impose no specific requirements with regard to fire resistance or reaction to fire.



GK 4 and GK 5 only allow stairs made from non-combustible construction materials, so they do not permit wooden stairs. This means that wooden stairs may only be installed in GK 3 buildings if they have fire-retardant properties. Building regulations therefore require proof that the stairs have such properties.

Computational proof is not sufficient

The resulting question is this: To what extent can purely computational proof work here? For example, can there be computational proof of the corner points of wooden spiral stairs? Different design types imply a complex load-bearing behaviour, which virtually rules out purely computational proof. Another factor are the different properties of the materials used, which also affect the load-bearing behaviour in the event of a fire. Are the high-temperature properties of all materials known with certainty?

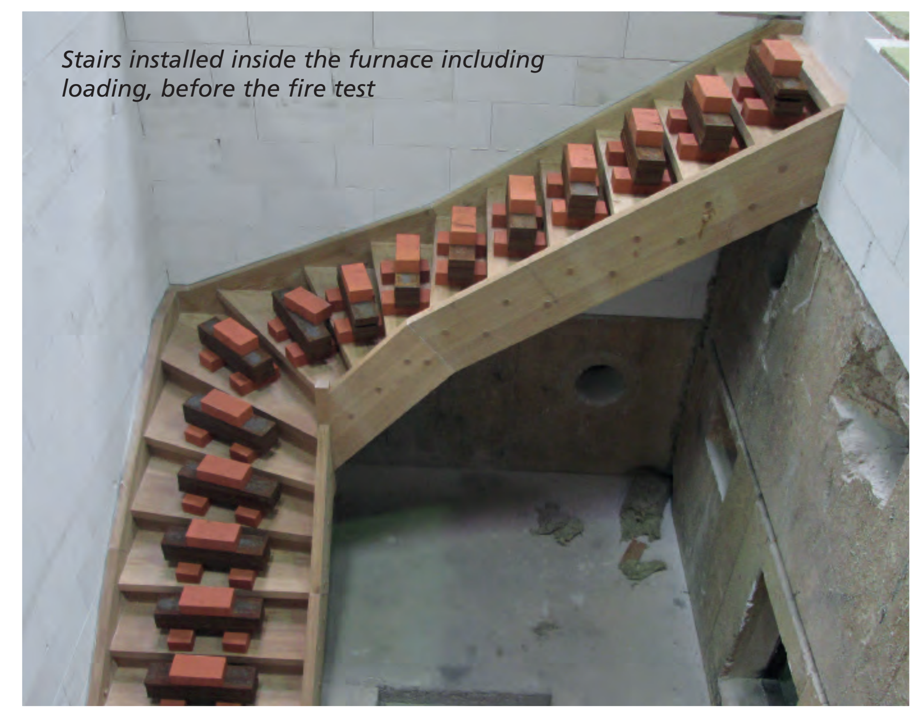
Moreover, the transition from steel to wood is always challenging for the manufacturer with regard to fire safety aspects, since steel conducts heat into the wood.

In fact, clear proof of fire resistance can only be obtained from tests. When the proof of a structural member's fire-retardant properties required by building regulations has been furnished in a test, recommendations for the use on site can be derived and a general building authority test certificate (allgemeines bauaufsichtliches Prüfzeugnis – abP) can be issued for the staircase structure.

Example from practice: test of wooden load-bearing staircase structures

Thanks to the size of the test furnaces available at MPA Braunschweig, tests to determine the fire resistance can be made with life-size specimens.

For example, two load-bearing, mortised, single-curved oak staircase structures, one with and one without riser, were tested. The customer had requested testing in accordance with DIN 4102-2: 1977-09 to determine the fire resistance when exposed to fire from several sides.



Stairs installed inside the furnace including loading, before the fire test

Description of the test specimens

Each oak-wood specimen had 16 treads, one stair string and a central square newel. The treads were mortised and the flight was onefold-curved. The structural design of the two test specimens was identical, with additional risers for specimen 1.

Test set-up and testing

At MPA Braunschweig, the life-size specimens (of storey-height) were fixed to the furnace masonry using in-wall sleeves. The structures were selected to allow for loading the staircase structure in such a way that the maximum stress resultants appear at the relevant points of the staircase structures.
Each staircase structure was installed in a test furnace with the clear dimensions length x width x height = 4000 mm x 3087 mm x 3030 mm.

The fire test with exposure to fire from four sides was conducted in accordance with DIN 4102-2: 1977-09, which means in detail:

- The furnace was exposed to fire according to the standard temperature/time curve (ETK).

Live monitoring including video recording during the test

Video screenshot after three minutes into the test

- 12 sheathed thermocouples were used to measure the temperatures inside the furnace.

- The furnace elements were arranged based on DIN EN 1365-6: 2005-02.

- The furnace pressure during the fire test was adjusted in accordance with DIN 4102-2: 1977-09, Section 6.2.5.

Test results, conclusions and recommendations

The temperatures measured inside the furnace during the fire test and the observations made during the fire test were described in detail in the test report.
Based on the test results and the performance criteria fulfilled – in this case, the maintenance of the load-bearing capacity under exposure to fire from all sides – it is recommended that the specimens tested be classified in fire resistance class ‘F 30-B’, in accordance with DIN 4102-2: 1977-09. The building inspectorate proof of usability is furnished in the form of a general building authority test certificate (abP) issued on the basis of the structure tested. ■

Fire Safety
Fire Resistance of Structures and Structural Members

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When the curtain falls

Testing non-insulating operable fabric curtains in accordance with DIN EN 1634-1

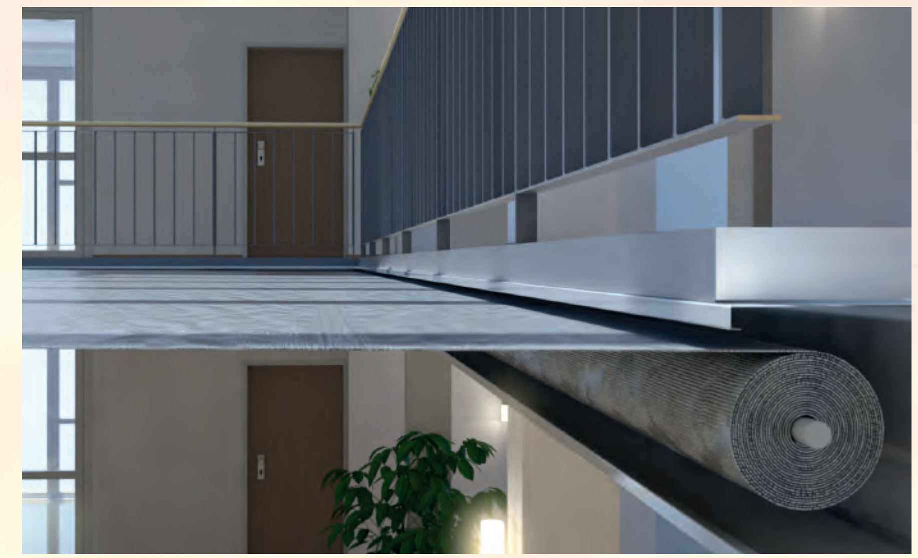
In addition to the familiar fire doors, gates and hatches, another type of fire barrier has become more and more established: operable fabric curtains.

Scope for architectural design

Especially among designers and architects, flexible systems have become increasingly popular and are considered a sophisticated alternative to conventional, massive fire barriers.
Unlike standard products for structural fire prevention, which in many cases affect the architecture of buildings considerably, operable fabric curtains can be perfectly adapted to different installation situations. The housings and guide rails of these flexible fire prevention systems blend into the structure and thus offer ample scope for sophisticated architectural designs of open-plan layouts.

Invisible protection against the spread of fire and smoke

The operable fabric curtains are installed in suspended ceilings or wall recesses, which allows for nearly complete integration into the structural environment. In normal operating situations, these flexible fire protection and smoke control curtains are hardly or not at all visible. In the event of an alarm, the self-closing systems secure wall and ceiling openings to prevent fire penetration, and fire and smoke compartments.
From a technical point of view, too, operable fabric curtains offer major advantages compared to conventional solutions: low weight, realisable system sizes and small housing dimensions.



Horizontally closing operable fabric curtain

Performance criteria and classification of operable fabric curtains

Thanks to the different structural designs (roll-off or folding technique) and use of a variety of fabrics, flexible operable fabric curtains have a wide range of applications and different safety objectives or classifications and time classes.

Depending on their criterion ‘E’ or EW’, non-insulating operable fabric curtains can be classified and used in accordance with DIN EN 13501-2, which defines the following classes for fire barriers:

According to this specification, a non-insulating operable fabric curtain with the

E	15	20	30	45	60	90	120	180	240
EW	–	20	30	–	60	90	120	–	–

Test on an 'E90' curtain measuring (w x h) = 5000 mm x 4930 mm

Test specimen measuring (w x h) = 5000 mm x 4930 mm in test minute 100

Radiation measurement on an 'E90' curtain

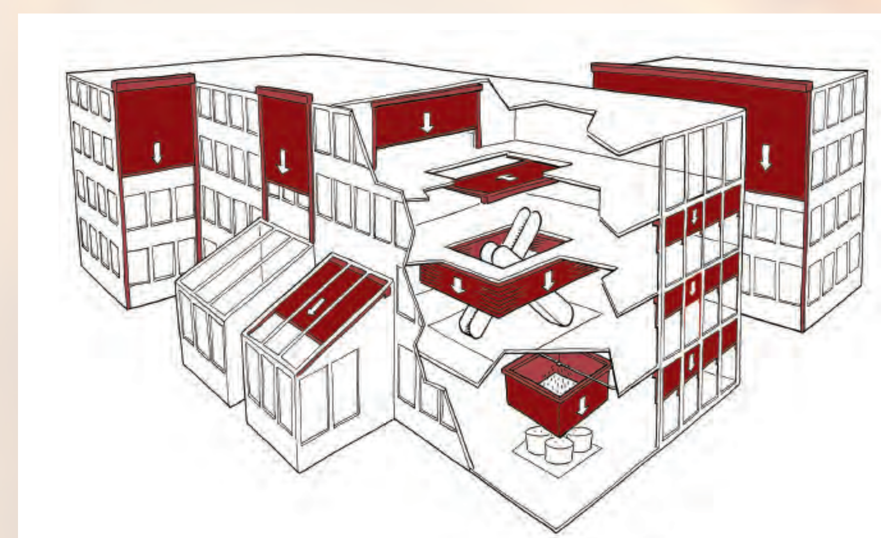
performance criterion 'E' (integrity) can be used in places, where exclusively integrity shall be ensured, i.e. where the curtain must prevent the passage of flames or hot gases.
Operable fabric curtains classified with the performance criterion 'EW' (integrity including limitation of radiation permeability) can be used, where, in addition to preventing the passage of flames and hot gases, radiation must be limited (to a maximum admissible value of 15 kW/m²) to prevent the fire spreading to adjoining materials as a result of heat radiation.
Non-insulating curtains also have to be subjected to a fire resistance test in accordance with DIN EN 1634-1. In this test, it must be considered that the failure criterion for integrity should be only gaps or openings with dimensions larger than those specified and persistent flaming on the unexposed side.

The ignition of a cotton pad does not constitute a failure criterion. The extended scope of application is defined in accordance with pr EN 15269-11.
DIN EN 1634-1 defines that the operable fabric curtain must be conditioned in accordance with DIN EN 1363-1 and subjected to mechanical pre-treatment, which is described in DIN EN 16034 (previously DIN EN 14600). Before fire resistance testing, operable fabric curtains must be tested for functionality in 25 cycles by opening them as wide as possible, i.e. at least 300 mm per cycle, starting and finishing with the curtains completely closed.
The performance criteria for classification of the self-closing properties including the durability classes C0 to C5 are also defined in DIN EN 16034 (previously DIN EN 14600).

◀ Compartment-creating operable fabric curtain that wraps around a corner (photos by Stöbich Brandschutz)

They depend on the type of intended use of the curtain and do not depend on the classifications 'E' and 'EW'.
E90-C2, E120-C1 and EW-C3 are classification examples of operable fabric curtains equipped with a closing device to fulfil the self-closing criterion.
Thanks to the modern and spacious facilities at MPA Braunschweig, non-insulating operable fabric 'E120' curtains measuring up to 5000 mm x 5000 mm and (w x h) = 9700 mm x 5000 mm can be tested. ■

▶ Hidden operable fabric curtain with insulating properties (photos by Stöbich Brandschutz)



Future-oriented construction – safety thanks to operable fabric curtains (photo by Stöbich Brandschutz)

Fire Safety

Fire Resistance and Smoke Control of Doors and Shutters

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“Really impressive“

Fire resistance test of service ducts and shafts in accordance with DIN EN 1366-5

Although DIN EN 1366-5, which regulates the boundary conditions for fire resistance tests of service ducts and shafts, was first published in Germany in June 2010, the manufacturers of construction products for service ducts and shafts showed little interest in fire resistance tests according to this European standard.

Instead, the manufacturers continued to perform fire resistance tests in accordance with DIN 4102-11 : 1985-12. These tests were mainly performed at the Materials Testing Institutes MPA Erwitte (service shafts) and MPA Braunschweig (service ducts).

Fire Safety – Fire Resistance of Building Services Installations

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MPA Braunschweig then broke new ground in 2014, when a manufacturer of fire-rated building boards placed an order for a fire resistance test in accordance with DIN EN 1366-5, which involved testing service ducts and shafts together in one test. Moreover, service ducts and shafts with different fire resistance times ranging from 30 minutes to 120 minutes would be installed in one wall and floor for this test – a considerable potential risk with regard to fire protection for both the customer and MPA Braunschweig. For the customer, because, if an ‘I 30’ duct or ‘I 30’ shaft failed, the fire test would have to be stopped and thus, there would be no test results for ‘I 60’ to ‘I 120’ components; and for MPA Braunschweig, because, if the ‘I 30’ components failed, fire could escape and cause damage to the testing facilities.

Given MPA Braunschweig’s many decades of experience in testing service ducts in accordance with DIN 4102-11 : 1985-12 and because adequate safety measures were planned for the service ducts and shafts, it was decided to ‘dare’ the fire test and the service ducts and shafts were installed as shown in the pictures.

After an incredible 133 minutes of fire testing, the customer was satisfied and requested that the test be terminated. Both the customer and MPA Braunschweig agreed that it had been “really impressive”. ■

Installed service shafts

Installed service ducts

Reaction to fire of floor coverings

Radiant panel tests for floor coverings

Fire safety for floors
The reaction to fire represents an essential and safety-critical feature of construction products. For floors, it is identified by the CE-marking for floorings. The relevant regulations are defined in the European Construction Products Regulation. The requirements for fire prevention to be met depend on where a floor covering is laid. In Germany, the building material class (colloquially called ‘fire class’) usually required for floor coverings in private residential areas is ‘Efl’. This can be shown based on the material composition and the design on the one hand, and by conducting a so-called small-burner test, which determines the ignitability of a floor covering on the other.

Placing the specimen including sub-layer and substrate on the specimen holder

Fire classification of floor coverings
In commercial areas (hotels, theatres, cinemas, retirement homes, public buildings, etc.), the fire safety standards are many times higher; normally, building material class Cfl-s1 is required here. This can be proved with a classification in accordance with EN 13501-1 ‘Fire classification of construction products and building elements’ – a classification that is based on the radiant-panel test in accordance with EN ISO 9239-1. This test measures the critical intensity of radiation and the integral of light transmission, which are measures of the risk to people and buildings in a real fire.
The test method serves to assess the reaction to fire against the airflow, and the spread of flames on floor coverings when these are exposed to a pilot flame in the standardised radiant-heat environment of a test chamber.

The test chamber

Placing the specimen in the test chamber

Pre-heating the specimen before exposure to flames using an ignition torch

Documenting the results

The results are expressed as:

- **flame-spread distance** versus time
- **critical heat flux** at extinguishment
- **smoke density** versus time

The heat from the radiant heater applied to the specimen simulates the probable degree of thermal stress acting on the floor of a corridor that is heated by flames and/or hot gases produced during the early stage of fire development in an adjacent room.
This test method is applicable to all floor coverings, such as textile and wooden floorings, cork carpets, rubber and plastic coverings, and to coatings. The results obtained in this test show the reaction to fire of the entire floor covering tested including any substrate if used.

Specimens

The specimens have to be representative of the type of floor covering in practical application. Six specimens with defined dimensions must be provided, three of them cut in the direction of production, and the other three cut across the direction of production. An official test has to comprise the test results from three specimens that are identical in every respect.

Determination of the reaction to fire when stressed with a radiant heater (ISO 9239-1:2010) – short description of the test method

The specimen is horizontally placed under a gas-heated radiant panel that is tilted by 30° to the horizontal, and exposed to a defined heat flux.

A pilot flame is brought into contact with the hotter end of the specimen. Following ignition, every flame front that develops is recorded, including its horizontal spread along the specimen length. This is done as a function of the time the flame front takes to spread over defined distances. If required, the smoke development during the test is recorded based on the light transmission in the escape shaft.
The flame-spread distances as the distance between the flame front and the specimen zero line are measured correct to 10 mm at 10-minute intervals from the beginning of the test and up to the point where the flame is extinguished. All phenomena observed, such as flaring-up, melting, blistering, duration and place of glowing after the flame is extinguished, burning through to the substrate, etc. must be recorded.
In addition, it must be recorded (measured correct to 10 mm) at what points in time the flames reach the 50-mm measuring line and the point furthest from the specimen zero line during the test period.
If the customer has not requested a longer test duration, the test is terminated after 30 minutes. Where a test lasts longer than 30 minutes, the time elapsed before the flame is extinguished must be recorded together with the maximum flame-spread distance, and converted to the CHF value.

(Sources: www.baunetzwissen.de; DIN EN ISO 9239-1) ■

Recording the observations made during the test

Fire Safety

Reaction to Fire of Construction Products and Building Elements

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Fire-tested fastening systems

Ensured fire resistance of anchors in the event of fire

Mechanical strength and structural stability are crucial prerequisites to be fulfilled by a structure. To ensure the safety of fastening systems (called anchors in the following) in construction, they have to be approved. On site, correct fastening is often an issue to be clarified, since the requirements to be fulfilled by a fastening system are normally related to a specific type of construction; and the type of construction in turn is subject to specific fire safety requirements – such as fastening systems for suspended ceilings.

Please note that, where certain criteria regarding the load-bearing behaviour have to be met in the event of fire, not all fastening systems that could be used under normal conditions would be suitable for use with direct fire exposure. And not all approvals / ETA (European Technical Approvals) for fastening systems by far include a statement with regard to the load-bearing capacity (fire resistance) under exposure to fire!

Fire safety requirements for anchors

Given the construction products regulation in force, which is implemented by the Model Building Regulation in conjunction with MVV TB, ETA for anchors will in future be issued on the basis of European technical assessment documents (EAD).

The fire safety requirements to be fulfilled, which make up the general part of the MVV TB, demand adequate structural stability for construction types and thus for their fastening systems under exposure to fire. Annex 2 of the MVV TB defines more specific requirements for the planning, dimensioning and design of anchorages in concrete.

Today, safety-relevant fastening systems are regulated as "European construction products" and may be marketed with the appropriate CE marking and declaration of performance.
But what about the declarations of performance for anchors with regard to fire safety?

Two types of declarations can be found, which depend on the type of fastening:

- Fastening systems, whose performance is declared with regard to their fire behaviour and load-bearing capacity (fire resistance)
- Fastening systems, whose performance is declared only with regard to their fire behaviour

The main reason for the different declarations of performance with regard to fire safety is very probably due to the fact that more comprehensive methods to establish the performance in the form of harmonised technical specifications (e.g., EAD) currently exist only for fastening systems in conjunction with a reinforced concrete ground.

Some examples of European harmonised specifications to determine fire-safety-related data for anchors under exposure to fire / ETAs are as follows:

- EAD No. 330232 in conjunction with TR048 for metal anchors for use in cracked concrete (previously ETAG 001 in conjunction with TR020)
- ETAG 001/6 in conjunction with TR020 (currently) for multiple fastenings in conjunction with reinforced concrete grounds
- EAD No. 330747 in conjunction with TR048 (in future) for multiple fastenings in conjunction with reinforced concrete grounds
- ETAG 020 in conjunction with TR020 for plastic anchors (façades)

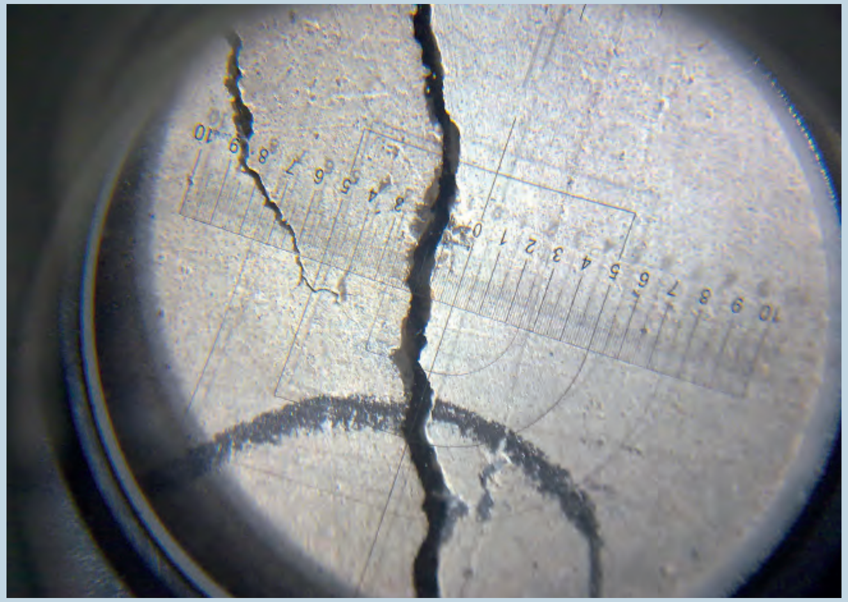
Fundamentals for anchor dimensioning

There are already many approvals for mechanical fastening systems in reinforced concrete, which contain tabular values referring to their fire behaviour and load-bearing capacity (fire resistance) under exposure to fire. Moreover, for grounds other than reinforced concrete, the existing technical documentation from anchor manufacturers can serve as reference, as they also contain tabular values that permit the dimensioning of anchors for exposure to fire.

Further basic information for dimensioning can be found in the general technical approvals applicable in Germany for construction types, product standards or technical regulations (e.g. DIN 4102-4).

Please note that, where there are significant deviations from an approval or where there is no declaration of performance with regard to fire resistance, the user on site should contact the manufacturer of the fastening system in order to find an adequate solution for the case at hand.

Panel connection (multiple fastening), steel failure



Cracked reinforced concrete

Determination of anchor performance in a fire test

Like construction types, anchors are tested according to a temperature-time curve. Today, the temperature applied is normally based on the standard temperature-time curve (in accordance with DIN EN 1363-1). The most common method is to test the individual anchors in a fire test. For this purpose, the anchors are installed in a ground, in accordance with the approval, and loaded under exposure to fire in accordance with the standard temperature-time curve. Based on the test results obtained, a proposal for dimensioning can be prepared with regard to the load-bearing capacity (fire resistance) under exposure to fire as a function of the time and load.

If there is an approved test method (e.g. TR020) or a European harmonised specification (e.g. EAD), the dimensioning values can be included in an ETA. Then, the fire resistance classes are R30, R60, R90, R120 (R for 'resistance' = load-bearing capacity).

Fastening systems, for which there is currently no approved test method, are mostly subjected to a fire test that is based on an approved test method. In this way, a proof can be furnished for a specific site.

Another option is the proof of the anchor as part of a construction type in a system test. Construction types are partly tested as a system together with the fastening or

Load adaption

Failure by pull-out of an injection anchor tested in masonry

combined with a certain suspension system or a complete assembly system. In this case, the proofs are limited to a specific fastening system, or specific parameters have to be observed with regard to the suspension system and/or fastening system (e.g. dimensions, steel grade, strength values).

An example: in accordance with DIN 4102-12i, conduits are tested together with the related suspension from the ground with regard to the steel grade and dimension. The general technical approval will then contain specifications for the suspension and the fastening system (e.g. with regard to the dimensions, steel grade and admissible steel stress).

Further examples for construction types where the fastening or suspension system is included in the test:

- Fire barriers
- Non-load-bearing lightweight partition walls
- Ventilation ducts
- Conduits for electrical installations

Testing facilities at MPA Braunschweig

Depending on the fastening systems and assembly systems to be tested for fire safety, MPA Braunschweig has a range of testing equipment / facilities, where the different systems can be tested under realistic conditions and depending on their field of application:

- Heavy-duty anchors for fastening in cracked concrete
- Brackets with multiple fastening
- Mechanical anchors (e.g. drive-in anchors, nail anchors) for applications in concrete
- Chemical anchors, frame anchors, concrete screws, e.g. for applications in masonry or reinforced concrete
- Anchor channels (e.g. for façade fastening)
- Direct assembly with nails
- Assembly systems, like installation channels, pipe clamps, pendular suspensions, etc.

For testing the fastening system, loads of up to 40 kN can be generated in the test stands. Thanks to the range of available testing equipment and loading options, the options for testing are very flexible:

- The anchors can be tested in different grounds (e.g. reinforced concrete, masonry, aerated concrete, etc.)
- Testing can be conducted in cracked and non-cracked reinforced concrete
- Additional loads can be applied to the ceiling board
- Tests can be conducted under a centric tensile or transverse load.
- In addition to the standard temperature-time curve, other temperature-time curves can be used as reference (e.g. according to ZTV-ING, the tunnel-furnace curve).

For all further questions with regard to the requirements, technical specifications, dimensioning rules, and testing options for fastening systems, please contact our specialists in this field. ■

Fire Safety

Fire Resistance of Structural Members

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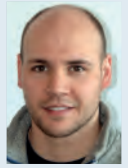

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▸ *Motion element for vertical and horizontal movements and rotations*

Joints in motion to fulfil European standard

Fire resistance behaviour of joint sealing systems in accordance with DIN EN 1366-4

The testing facility alone is impressive and demanded a great deal of concentrated and arduous work for its design and construction from Matthias Scheler and his team: To simulate the types of movement specified in DIN EN 1366-4, up to 13 aerated concrete boards can be arranged at defined distances to each other on top of a horizontal furnace measuring up to 3 x 4 metres. Each of the boards can be

- laterally displaced (lateral movement),
- displaced in its height (shear), and
- twisted (rotation).

As Dipl.-Ing. Christian Rabbe specifies: "That's what makes this joint sealing test special. In fire tests, we are able to simulate any mechanically induced movement of the opposite flanks of the joint the customer wants. In addition, our testing facility allows for a combination of lateral and shear movements. We are thus in a position to simulate all movements specified in DIN EN 1366-4 – something not many testing institutes can offer."

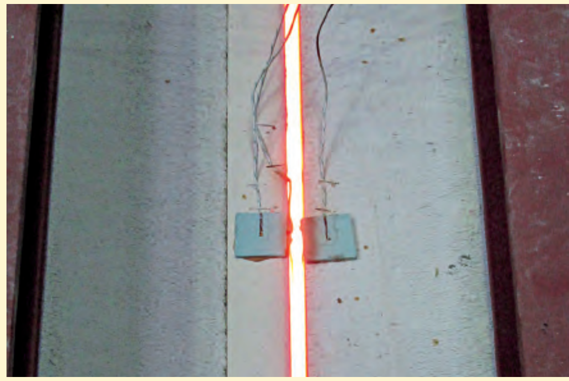
The results of this test are decisive in assessing the fire resistance behaviour of joint sealing systems. The purpose of the tests according to this European standard is to assess

- what separating effect and thermal insulation effect the joint sealing systems have;
- what effect joint sealing systems have on the integrity and the thermal insulation of a structure; and
- what effect movements of the supporting construction have on the fire resistance of the joint sealing systems.

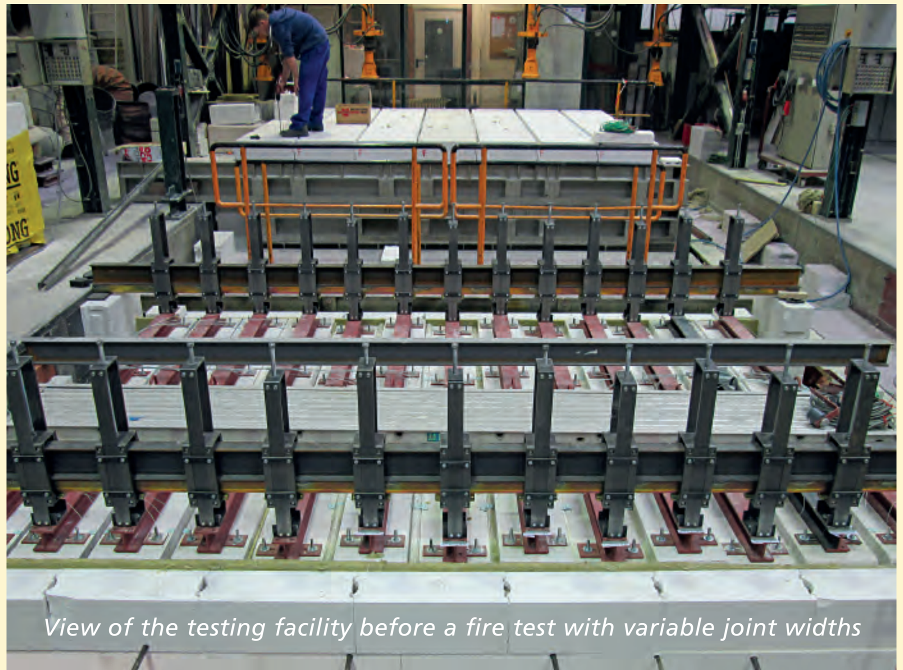
The next step will be to extend the testing facility. It will then be possible to show all types of movements specified in DIN EN 1366-4 also for joint sealing systems that are installed in a wall construction.

Should you have any questions on the fire protection of joint sealing systems, our experts will be pleased to answer them. ■

Test specimen with a shear joint during a fire test (view of the fire-exposed side)



Test specimen with horizontal joint at the end of fire testing (view of the unexposed side)



View of the testing facility before a fire test with variable joint widths

Fire Safety – Fire Resistance of Building Services Installations

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