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EMI

FRAUNHOFER INSTITUTE FOR HIGH-SPEED DYNAMICS, ERNST-MACH-INSTITUT, EMI

ANNUAL REPORT 2014/15

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»HANDOVER AND NEW OPPORTUNITIES«

Prof. Dr.-Ing. habil. Stefan Hiermaier
Director Fraunhofer EMI

Dear reader,

Handover and new opportunities in a university environment – those are the two topics which have shaped the turn of the year 2014/2015 at EMI. The first marks an era that can only be named after the director who has run the institute since 1996 – the Thoma era. It was distinguished by the development from an institute exclusively conducting military technology research into a Fraunhofer institute with the four business units Defense, Space, Transport, and Security. In all four, it has since gained an outstanding reputation nationally and internationally. It was a period in which the mixed financing, the strategic focus, the scientific excellence, and the infrastructure were pushed to Fraunhofer level. Klaus Thoma has rendered this possible with vision, commitment, perseverance, and a good intuition. As his companion and longtime deputy director, I could witness this development and I have the greatest respect for Klaus Thoma. At the EMI Christmas party 2014 and at the scientific colloquium in honor of Prof. Thoma in March 2015, we could see that the entire institute does so, too. Merely a day after the colloquium, a sign of symbolic character was set for the new era: the Sustainability Center Freiburg kick-off in the presence of Fraunhofer President Reimund Neugebauer, the rector of the University of Freiburg Hans-Jochen Schiewer, Freiburg Mayor Dieter Salomon, and many other characters from politics and society. The entirely new quality of the collaboration of the Albert-Ludwigs-Universität Freiburg and the Fraunhofer-Gesellschaft was appropriately pictured this way. One major part of this picture is the planned third institute of the technical faculty.

The Department of Sustainable Systems Engineering with its planned 14 professorships is supported in equal parts by the University of Freiburg and Fraunhofer. Through the professorship for Sustainable Engineering Systems, the Ernst-Mach-Institut is finally directly connected to university, which is in close vicinity, is embedded in an excellent faculty, and offers the unique opportunity to explore new topics without having to abandon continuity. The new research areas can be realized as advancement of existing ones. This is valid both for the sustainability of materials and the resulting engineering systems as well as for resilience research.

The scientific focus of my professorship is on the application of integrated experimental-numerical methods for the development and optimization of materials and structures under consideration of the sustainability of the resulting product. The resource saving choice of materials comes first and is continued in the identification of efficient material processing methods. The utilization phase of the products defines both the choice as well as the process chain with the recycling process at its end. This process sets additional requirements regarding choice and processing and marks the beginning of the next usage cycle with the recycled materials.

In the context of resilience, facilities and networks which have a high relevance for a functioning society will be at the center of research. Public utility infrastructure, building infrastructure or technical facilities which are important in order to maintain our everyday life as well as their respective resilience are examined regarding catastrophic natural and man-made influences. The aim of resilience research is to regain the original performance of systems through intelligent preparation, by providing efficient crisis management, and by enabling a fast reconstruction in a short period of time.

On January 1, 2015, I have taken over a well-organized institute. The success of EMI is an achievement of all its employees, and all supporters and customers from economy and politics. I want to thank all of you for your commit-

ment, your motivation, and your dedication. I am looking forward to all the challenges we will face in the future. Together, we will maintain and develop our strengths, and together, we will seize the new opportunities and grow new strengths.

Enjoy reading! Let yourself be inspired by the enthusiasm for our unique research results, for exciting networks, and a time full of new opportunities!

Sincerely,

Stefan Hiermaier

»MIT SICHERHEIT DYNAMISCH«

The Thoma era

On May 5, 2015, a colloquium took place at the Konzerthaus Freiburg honoring Professor Klaus Thoma's work as director of Fraunhofer EMI. Fraunhofer President Reimund Neugebauer also thanked Prof. Thoma for his work by handing him over the Fraunhofer coin, the second highest award at Fraunhofer.

Presenters from the research community, politics, and industry held speeches on Prof. Thoma's remarkable success – in the eighteen years as director of the Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI, he has truly shaped an era. The key measures and developments that distinguish EMI today were implemented during his time as executive director, in which he was being responsible for the personnel and scientific development as well as the balanced financing of the institute after the Fraunhofer model.

The precondition for this was a fundamental restructuring of an institute that, at the beginning of the Thoma era, still organized its research activities depending exclusively on the current needs of the German Federal Ministry of Defence. Thus, Prof. Thoma's speeches and presentations were repeatedly titled "EMI – an institute in transition" over a period of more than ten years.

Concerning the "further development of the institute", the preface of the EMI's annual activity report of 1995 read: *"The plans regarding the development of the Ernst-Macht-Institut had in the last years been characterized by the German Federal Ministry of Defence's plans to integrate the institute into the German-French Research Institute ISL in the mid run. Due to the current political situation and organizational difficulties, those plans have been revoked."*

The discussion about the incorporation of EMI into ISL had ended when Prof. Thoma became director on May 1, 1996. A time of uncertainty, which had been depressive for the institute and, especially, for its staff, had finally been overcome.

In a determined and spirited manner, Prof. Thoma started to extend the institute's range of research topics by also focusing on civil research, especially research which was of interest for the automotive industry. New research fields continuously evolved at EMI due to the imagination of the new director and the already present potential in personnel and infrastructure. The examples most worth mentioning are:

- The characterization of materials under impact loads and crash-relevant loads
- The development of meshfree methods and their coupling to finite elements
- The development of sensors for acceleration measurement under extreme dynamic loads as they occur at high velocity impact on solid targets
- The development of an X-ray tomo-cinematography for temporally resolved 3D screening of extreme dynamic processes

***1** Mrs. Barbara Thoma (right) with the former Fraunhofer President Prof. Dr. Hans-Jörg Bullinger and his wife; **2** Prof. Dr. Klaus Thoma and Barbara Thoma welcome Dr. Karsten Michael; **3** Prof. Dr. Klaus Thoma with Prof. Dr. Ulrich Buller; **5** Prof. Dr. Reimund Neugebauer, President of the Fraunhofer-Gesellschaft, Prof. Dr. Hans-Jörg Bullinger, former Fraunhofer President with his wife, Harald Stein, President of the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support, Guido Rebstock, ministerial director of the Ministry for Finance and Economics Baden-Württemberg, and Dr. Dieter Salomon, Mayor of the city of Freiburg i. Br. (from left to right); **6** Prof. Dr. Hans-Jochen Schiewer, rector of the University of Freiburg, Albert-Ludwigs-Universität Freiburg, is holding his laudatory speech.*

SCIENTIFIC COLLOQUIUM IN HONOR OF
PROF. DR. RER. NAT. KLAUS THOMA, MARCH 5, 2015


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SCIENTIFIC COLLOQUIUM IN HONOR OF
PROF. DR. RER. NAT. KLAUS THOMA, MARCH 5, 2015


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- The extension of the investigation of spacecraft damage resulting from hypervelocity impact to the resulting dynamics of the overall structure
- The investigation of new concepts for active protection systems and electrical armor
- The development of materials for protective structures against blast loads using bio-based materials
- The development of quantitative risk and hazard analysis
- The research field of safety technology

Prof. Thoma not only made the topic "safety technology" a new business unit of the Ernst-Mach-Institut – furthermore, the contemporary national and international resilience and safety technology research landscape is closely connected with his name. Klaus Thoma has developed this topic, especially in its engineering sciences oriented approach, through his relentless dedication in committees as well as in carrying out a multitude of research projects and cooperations. Prof. Thoma has at all times thought and acted in the interest of all those involved, which is something that distinguishes him in all his functions as spokesman. He has thus contributed tremendously to establishing the position of safety research, so that the topic became an individual group in the Fraunhofer-Gesellschaft and has gained its current position in the national and international research landscape.

At his home institute EMI, the realization of Klaus Thoma's goals on the organizational level was accompanied by continuous reorganization of the department structure. The former departments "Drive Processes" and "Detonics" merged into the new department "Experimental Ballistics". The development of new high acceleration resistant sensors and new X-ray flash instrumentation was thus brought closer to application. Furthermore, the new departments "Material Characterization and Numerical Simulation" and "Dynamics in Microstructures" were established. Both departments focus on the experimental characterization of all kinds of materials under dynamic loads, the formulation of corresponding constitutive models, and the development and application of numerical methods.

The new research fields in the Thoma era also demanded for an ongoing adaptation of the infrastructure and, consequently, for appropriate construction measures at EMI. Since 1996, comprehensive constructional extension measures were carried out at all three branches of the institute. Spacious laboratories for material testing were built. The computer capacity has continuously been increased to more than 1000 processors in a central, Linux-based high-speed server.

The accelerator facilities at EMI by now range from the two stage light gas gun for spacecraft technological applications to the full vehicle crash facility. In newly built halls, two new, large light gas guns with acceleration performances - which have before only been achieved in the USA - were installed. The range of the accelerator facilities available at EMI as well as their instrumentation is truly unique worldwide!

***7** The participants of EMI's Science Slam; **8** Enthusiastic applause from the audience; **9** Fraunhofer President Prof. Dr. Reimund Neugebauer presents Prof. Dr. Klaus Thoma with the Fraunhofer coin; **10** Pictures form the Thoma era are reminiscent of small and large events; **11** Prof. Dr. Wolf-Uwe Reimold from the Museum für Naturkunde, Leibniz Institute for Evolution and Biodiversity Science during his dinner speech; **12** The present made by the precision mechanics at EMI Freiburg was a big surprise: a miniature set of the doctoral hats, the originals of which are displayed in the EMI foyer.*

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ERNST-MACH-INSTITUT

PROFILE

The Ernst-Mach-Institut recognizes its task in understanding the physics of high-speed, transient processes in order to derive solutions for applications in the industry. EMI adopts interdisciplinary and comprehensive material strategies to investigate crash, impact, and shock-wave phenomena by experiment and simulation. The spectrum of applications includes:

- Examination and modeling of material behavior under dynamic loading.
- Development and application of new sensors and measuring techniques in high-speed physics.
- Development of numerical computing methods in structural dynamics, fluid mechanics and the coupling of fluid-structure interaction.
- Development and use of acceleration facilities for objects with masses between a few grams and some hundred kilograms to velocities of up to 40,000 kilometers per hour.

The solutions acquired at EMI by experimental, computer-based and analytical methods aim at improving the security and reliability of components and structures under dynamic loads. With the aid of the most recent research results for technical applications, their efficiency is increased. Thereby, society profits from optimized systems in the areas of Defense, Security, Space, Transport, Aviation and Sustainability.

Integration into the academic research landscape on the one hand, and networking and competent presence in the development departments of the relevant industries on the other hand, are prerequisites for pursuing the kind of applied research which is common standard for the institutes of the Fraunhofer-Gesellschaft in an economical way.

Positioned at the interface between basic research and systems development, EMI puts special emphasis on integrated experimental-numerical research. Nationally as well as internationally, EMI ranks among the best addresses concerning this claim.

The wide range of dynamic processes examined at EMI demands a high degree of flexibility as far as experimental facilities and the used software are concerned. This flexibility can only be achieved if the in-house development of test facilities, instrumentations, sensors and computer programs are rendered possible. Experienced senior scientists, PhD students, house-internal workshops as well as a high percentage of technical staff are committed to these in-house developments.

CONTACT PERSONS

Director
Prof. Dr.-Ing. habil. Stefan Hiermaier
Phone +49 761 2714-101
stefan.hiermaier@emi.fraunhofer.de

Advisor of the institute management
Sarah Gnädinger
Phone +49 761 2714-100
sarah.gnaedinger@emi.fraunhofer.de

Deputy Director
Business Unit Security
Strategy and Communication
Dr. Tobias Leismann
Phone +49 761 2714-102
tobias.leismann@emi.fraunhofer.de

Deputy Director
Business Unit Space
System Solutions Department
Prof. Dr. Frank Schäfer
Phone +49 761 2714-421
frank.schaefer@emi.fraunhofer.de

Business Unit Transport
Material Dynamics Department
Dr. Jens Fritsch
Phone +49 761 2714-472
jens.fritsch@emi.fraunhofer.de

Business Unit Defense
Dr. Manfred Salk
Phone +49 761 2714-120
manfred.salk@emi.fraunhofer.de

Impact Physics Department
Dr. Matthias Wickert
Phone +49 761 2714-384
matthias.wickert@emi.fraunhofer.de

Experimental Ballistics Department
Dr. Marek Dolak
Phone +49 7628 9050-730
marek.dolak@emi.fraunhofer.de

Safety Technology and Protective Structures Department
Dr. Alexander Stolz
Phone +49 7628 9050-646
alexander.stolz@emi.fraunhofer.de

Dynamics in Microstructures Department
Dr. Michael May
Phone +49 761 2714-337
michael.may@emi.fraunhofer.de

Strategic Management
Daniel Hiller
Phone +49 761 2714-488
daniel.hiller@emi.fraunhofer.de

Press and Public Relations
Birgit Bindnagel
Phone +49 761 2714-366
birgit.bindnagel@emi.fraunhofer.de

Scientific Communication
Brigitta Soergel
Phone +49 761 2714-362
brigitta.soergel@emi.fraunhofer.de

Administration
Marcus Iwaszkiewicz
Phone +49 761 2714-353
marcus.iwaszkiewicz@emi.fraunhofer.de

EMI BRANCHES

Branch Freiburg

Eckerstrasse 4
79104 Freiburg, Germany
Phone +49 761 2714-0

Branch Efringen-Kirchen

Am Klingelberg 1
79588 Efringen-Kirchen, Germany
Phone +49 7628 9050-0

Branch Kandern

Am Christianswuhr 2
79400 Kandern, Germany
Phone +49 07626 9157-0

Three branches
More than 300 employees of the Ernst-Mach-Institut work at the three branches Freiburg, Efringen-Kirchen and Kandern.

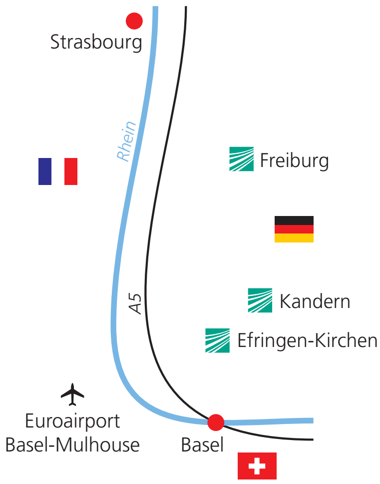
Freiburg
Close to the city center of Freiburg, our employees work in the administration, in the precision engineering workshop, in the electronic laboratory, in the test laboratories and scientific departments. In Freiburg, you can find the Space Gun, the fastest accelerator of Fraunhofer EMI, which is currently used for experiments in the context of preventing the collision of meteo-rites with the earth.

Efringen-Kirchen
At the Efringen-Kirchen branch, civil engineers and scientists investigate issues regarding the protection of structures and safety technologies, among other things. The new EMI shock tube, the biggest test facility of the institute, is located on the large premises of the institute.

The EMI crash center with the full vehicle crash-facility and the component crash-test facility can be found here.

Kandern
EMI's largest light gas accelerator is located at the Kandern branch, including numerous labora-tories and test facilities for defence-related tasks. Here, charged batteries for electric vehicles can be examined at a special test bench.

The distance between the institute branches:
Freiburg – Efringen-Kirchen 62 kilometers
Freiburg – Kandern 59 kilometers
Efringen-Kirchen – Kandern 15 kilometers



Fraunhofer EMI

For more information, visit www.en.emi.fraunhofer.de

THE ADVISORY BOARD

The EMI Advisory Board at their meeting in June 2014.
From left to right: Univ.-Prof. Dr.-Ing. habil. Norbert Gebbeken, Dr. Rolf Wirtz, Brigadegeneral Erich Könen, Dr. rer. pol. Hans-Ulrich Wiese, Prof. Dr. Wolf Uwe Reimold, Patrick Hoyer, Dr. Gerhard Schwehm, Dr. Herbert Scholles, MinR´in Dr. rer. pol. Ehrentraud Graw, Prof. Dr. Rodolfo Schöneburg, Dr.-Ing. Michael Holzner, Thomas Homberg, Prof. Dr. Klaus Thoma, Dr. Rainer Kroth, MinR Wolfgang Förster, Armin Papperger und MinR Dipl.-Ing. Norbert Michael Weber.

The Advisory Boards of the various Fraunhofer Institutes advise the directors of the institute and the Executive Board of the Fraunhofer-Gesellschaft. The Advisory Board also enhances the institute's contacts to organizations and to the industry.

Univ.-Prof. Dr.-Ing. habil. Norbert Gebekken
Professorship of the Institute of Engineering Mechanics and Structural Mechanics, Universität der Bundeswehr, Munich.

MinR´in Dr. rer. pol. Ehrentraud Graw
Head of Division 73: Automotive and Manufacturing Industries, Logistics, Ministry of Economics, Baden-Württemberg, Stuttgart

Dr.-Ing. Michael Holzner
Chief Executive Officer iCONDU GmbH, Ingolstadt

Thomas Homberg
Chief Executive Officer MBDA Deutschland GmbH, Schrobenhausen

Dr. Wolf-Hendrik Junker
Head of Division 522: Security Research, German Federal Ministry of Education and Research (BMBF), Bonn

Brigadegeneral Erich Könen
Head of Division "Combat", Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support, Koblenz

Dr. Rainer Kroth
Chief Executive Officer Diehl BGT Defence GmbH & Co.KG, Überlingen

Prof. Dr. Gunther Neuhaus
Vice Rector/Vice President for Research, Albert-Ludwigs-Universität, Freiburg

Armin Papperger (Chairman)
Chairman of the Executive Board Rheinmetall AG, Düsseldorf

Prof. Dr. Wolf Uwe Reimold
Professor of Mineralogy and Petrography, Deputy Head of the Research Department, Museum for Natural History, Leibniz Institute for Evolution and Biodiversity Science, Berlin

Dr. Herbert Scholles
Chief Executive Officer ADS – Gesellschaft für aktive Schutzsysteme mbH, Lohmar

Prof. Dr. Rodolfo Schöneburg
Director Passive Safety/Durability/Vehicle. Daimler AG, Functions Mercedes-Benz Cars, Development, Sindelfingen

Dr. Gerhard Schwehm
Director of the Scientific Member Planetary Protection, ESTEC, SRE-OOR, Rosetta Mission Manager, Noordwijk ZH, The Netherlands

MinR Dipl.-Ing. Norbert Michael Weber
Head of Division AIN II2, Federal Ministry of Defence, Bonn

Dr. rer. pol. Hans-Ulrich Wiese
Former President of the Fraunhofer-Gesellschaft (retired), Gräfeling

Dr. Rolf Wirtz
Senior Vice President, Head of Sensors & Electronic Warfare. Avionics, Airbus Defence and Space GmbH, Ulm

THE INSTITUTE IN NUMBERS

Staff structure

In 2014, more than 315 people were employed at EMI in total, which is an increase compared to the previous year. The average number of regular staff members was 240 persons. The share of university graduates (scientists and engineers) directly involved in research amounted to an average of 60 percent of those regularly employed.

In 2014, 29 apprentices were employed at EMI. This corresponds to a share of 12 percent of those regularly employed. It is intended to maintain the high number of apprenticeships. Due to the difficult situation in the work force, not all vacant positions at EMI could be filled. As an annual average, up to ten positions were vacant. The shortage of engineers in Germany renders the personnel recruitment a difficult and time-consuming task. For this reason, the Fraunhofer-Gesellschaft intensifies its activities in personnel marketing in order to attract qualified staff for the future.

Operating and investment budget

The financial development of Fraunhofer EMI is shown in the chart on the next page. The institute's operating budget has amounted to 22.18 million euros in 2014. The investment budget for procurement of devices added up to 2.97 million euros. In total, the overall budget amounted to 25.15 million euros in 2014. Most importantly, it can be noticed that the development of earnings continues to be successful. Altogether, the financial development at EMI has remained positive despite the tight public budget.

Financial development at EMI

In million euros	**2010**	**2011**	**2012**	**2013**	**2014**
Staff costs	12.29	12.45	13.65	14.86	15.87
Material costs	7.05	4.75	4.89	5.64	6.31
Investment costs	2.92	3.01	4.09	2.95	2.97
Total	**22.26**	**20.21**	**22.63**	**23.45**	**25.15**

Construction at Fraunhofer EMI

At the Efringen-Kirchen branch, the construction work for an additional floor on top of an existing laboratory building has been concluded. In the context of the renovation of EMI's Efringen-Kirchen branch, the creation of an open space surrounding an existing laboratory has also been concluded. Renovations of the laboratory have begun at the same time. Furthermore, the plans for a storage space (infrastructure) have been finalized and a building permit has been applied for.
In Kandern, the planning process for a free-flight testing range has been completed and a construction permit has been obtained.

At the Freiburg branch, the planning process for expanding the existing institute building has been almost completed. Plans include an office/laboratory building with 4/5 floors and underground parking at Albertstr. 26-30, covering a usable surface area of approximately 1300 m². After the new development plan had been approved, a corresponding building application was filed to the Freiburg construction authority.

Head of Administration
Marcus Iwaszkiewicz
Phone +49 761 2714-353
marcus.iwaszkiewicz@emi.fraunhofer.de

THE INSTITUTE'S EPONYM
ERNST MACH 1838–1916

Professor Ernst Mach, born in 1838, can rightly be titled an "all-rounder". This significant Austrian researcher was active in many branches of science: Philosophy, psychology, theory of science and especially physics are counted among his fields of work. Due to his criticism of Newton and his purely mechanistic view on physics, Mach is deemed to be one of the intellectual pioneers paving the way for Einstein's theory of relativity.

Ernst Mach's physical research activities concentrated on the fields of optics, acoustics, gas dynamics and ballistics. After calling attention to himself by proving the Doppler effect, he devoted himself to the phenomenon of shock waves. Mach was the first to recognize the nature of shock waves and their behavior in air. He investigated how shock waves are reflected by barriers or other shock waves and thus detected their irregular pattern of reflection.

Mach was especially concerned with supersonic phenomena, for example, why you can hear a bang twice when firing a supersonic projectile. He found that the reason for this and other phenomena lies in the behavior of shock waves at supersonic speed. In order to acknowledge his merits within this field of research, the Mach number was named after him.

Starting from his basic research, Ernst Mach addressed himself to ballistic experiments and explored the different kinds of shock waves produced by projectiles. Mach was the first to photograph a projectile at high speed. This marked the beginning of studies concerning supersonic aerodynamics. Professor Mach considerably refined these recording techniques even though only simple resources were at his disposal. By means of ingenious experimental assemblies, he developed modern measuring techniques for the field of high-speed dynamics.

This inventive spirit is still alive at Fraunhofer EMI. In Freiburg, Efringen-Kirchen and Kandern, scientists apply the research methods developed by Ernst Mach to new areas. The facilities available for their work have immensely improved. Instead of schlieren photography, our scientists today can resort to state-of-the-art high-speed cameras, light-gas guns, high-performance computers and also to the new full vehicle crash test facility.

On the basis of Mach's investigations on shock waves, a wide field of research has evolved. During the early years, EMI scientists mainly concentrated on the continuation of Mach's studies on shock waves. Apart from gas dynamics, the propagation of shock waves and the characterization of their acceleration behavior were investigated. Today, the principles discovered by Mach are enhanced with the aim to practically apply them in the EMI business segments Transport, Defense, Space and Safety.

The characterization of the pressure shock propagation is important in impact research, for example, in order to explore how a wall reacts to detonation.

Such experiments form the basis for designing numerical methods, particularly for the application in fluid dynamics, structural dynamics and electrodynamics. Experimental tests at EMI are nowadays often supplemented by simulation calculations based on numerical methods. Ballistronics, a combination of ballistics and microelectronics, constitutes a new discipline developed at EMI. This field of research also draws on Mach's insights regarding the propagation of shock waves in many respects.

Ernst Mach – the eponym of our institute.

THE FRAUNHOFER-GESELLSCHAFT

Research of practical utility lies at the heart of all activities pursued by the Fraunhofer-Gesellschaft. Founded in 1949, the research organization undertakes applied research that drives economic development and serves the wider benefit of society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration.

At present, the Fraunhofer-Gesellschaft maintains 66 institutes and research units. The majority of the nearly 24,000 staff are qualified scientists and engineers, who work with an annual research budget of more than 2 billion euros. Of this sum, around 1.7 billion euros is generated through contract research. More than 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Almost 30 percent is contributed by the German federal and Länder governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

International collaborations with excellent research partners and innovative companies around the world ensure direct access to regions of the greatest importance to present and future scientific progress and economic development.

With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent role in the German and European innovation process.

Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe. They do so by promoting innovation, strengthening the technological base, improving the acceptance of new technologies, and helping to train the urgently needed future generation of scientists and engineers.

As an employer, the Fraunhofer-Gesellschaft offers its staff the opportunity to develop the professional and personal skills that will allow them to take up positions of responsibility within their institute, at universities, in industry and in society. Students who choose to work on projects at the Fraunhofer Institutes have excellent prospects of starting and developing a career in industry by virtue of the practical training and experience they have acquired.

The Fraunhofer-Gesellschaft is a recognized non-profit organization that takes its name from Joseph von Fraunhofer (1787–1826), the illustrious Munich researcher, inventor and entrepreneur.

Fraunhofer

For more information, visit www.fraunhofer.de

Left: The headquarters of the Fraunhofer-Gesellschaft in Munich.

ERNST-MACH-INSTITUT

RESEARCH 2014/15

IMPACT PHYSICS

IMPACT PHYSICS

The Impact Physics Department examines phenomena related to the transfer of high values of energy and momentum into materials, structures, and components. This comprises classical impact and shock wave based processes, but also the effects related to high electric current pulses or laser radiation.

We operate high performance light-gas gun accelerators in our laboratories capable of reaching velocities of up to 8 kilometers per second. Thus, within the laboratory we can study diverse hypervelocity impact processes such as the impact of meteorites or space debris. However, because the orbital velocity of both debris and satellites in low Earth orbit is about 8 kilometers per second, debris particles are likely to impact space assets with a relative velocity of up to 16 kilometers per second for encountering orbits. Therefore, it is of great interest to examine the vulnerability of space assets with test series in which the velocity of 8 kilometers per second can be exceeded. For this reason, Fraunhofer EMI has developed a new concept. The TwinGun, a light-gas gun with two parallel pump tubes, shall be introduced on the following pages. EMI has built a demonstrator for this innovative accelerator technology, which is currently being evaluated and prepared for potential applications.

Standard accelerator technology within the department is currently used in projects addressing impact phenomena on planetary surfaces or space objects like asteroids. The great diversity in asteroid texture involves a wide range of macroscopic porosity. This porosity can reach values of more than 50 percent. For this reason, impact cratering phenomena have been studied with respect to target object porosity. For representing an impact on earth, the geological material sand stone has been examined with respect to the structure and the temporal pressure profile of impact induced shock waves. These types of processes have effectively formed stone materials in regions of the earth strongly influenced by their geological impact history like the Nördlinger Ries. For pressure measurements inside such material structures, it was necessary to develop a suitable sensor concept and build the sensor device.

The response of metallic structures to high electrical current pulses was addressed in a new scientific approach aiming to capture the resulting structural mechanical response. A model for the effect of a high electrical current pulse was developed and implemented in simula-

Dr. Matthias Wickert
Head of Impact Physics
Phone +49 761 2714-384 | matthias.wickert@emi.fraunhofer.de

tions. This work provides a theoretical base for the understanding of the response of construction materials to lightning stroke or the application of electromagnetic effects in advanced armor applications.

Finally, this report discusses the material effects of directed energy in form of laser radiation. In the framework of the European security research project Encounter, the effects of high energy laser radiation onto energetic materials was examined. In the experiments, temperature and pressure were measured simultaneously to allow modeling of the reaction kinetics for exemplary energetic materials. We are aiming to model the reaction of energetic materials in order to allow for a controlled neutralization of IEDs at large distances based on understanding of the laser-material interaction.

Besides the analyses of laser impact onto target materials, the laser technology group prepares for addressing laser sinter technology as an additive manufacturing technology. A large sample size 3D-printer will be installed in 2015, which will allow the manufacture of large metal objects. It is intended to invent and analyze innovative design concepts for material structures and components.

TwinGun – Concept for a new light-gas gun type accelerator

The ever-growing man-made space debris population in near-Earth orbit as well as natural micrometeoroids pose a constant threat to spacecraft. In low Earth orbits, relative velocities can be as high as 16 kilometers per second. Impacts of small but frequent particles in the millimeter size regime can damage spacecraft components upon impact and cause termination of a mission.

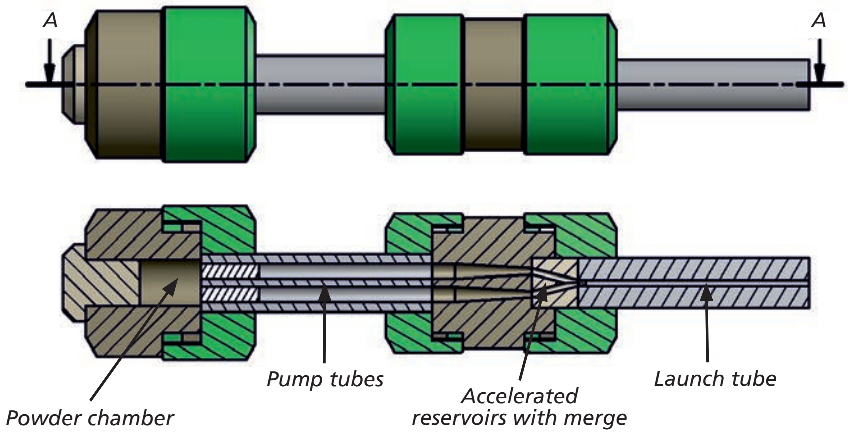
To study the effects of such collisions, accelerators are required that are capable of reproducing the impact conditions in a laboratory. Two-stage light-gas guns are the main workhorse for scientific research in this area. The main reasons for this are the versatility and reproducibility inherent to this type of accelerator.

State-of-the-art accelerators currently being used at Fraunhofer EMI and comparable institutions worldwide routinely achieve velocities in the range of seven to eight kilometers per second. At Fraunhofer EMI, a novel concept for a light-gas accelerator is currently investigated. Such an accelerator shall be capable of routinely achieving more than eight kilometers per second in the laboratory.

The concept is based on the well-established two-stage light-gas gun principle. The accelerator consists of a compression stage and an accelerator stage. In the compression stage, molecular light gas is compressed to very high pressure (in the range of several thousand bars). This compressed gas is then used to accelerate a projectile.

In conventional two-stage light-gas accelerators, the driver gas is compressed by a piston in a tube (called the pump tube). The piston is stopped in a conical part (called the accelerated reservoir or high pressure section) at the end of the pump tube. The cone forces the arriving piston to deform. While the piston as a whole is decelerated, the front face is accelerated significantly. This deformation process causes a fast pressure increase towards the end of the compression phase, which is required for a high accelerator performance. In conventional two-stage light-gas accelerators, the high pressures can be maintained for a short duration only. Typically, the compression stage is driven by a propellant charge. It creates a pressure pulse at the breech of the accelerator stage, which accelerates the projectile.

Compared to such conventional light-gas accelerators, the TwinGun is equipped with a novel compression stage. In a second pump tube, a second piston is accelerated almost synchronously to the first. Figure 1 shows a schematic sketch of the TwinGun. Carefully adjusted, slightly differing parameters of this second piston compressor cause the two pistons to reach their respective accelerated reservoir with a slight delay. This leads to a prolonged pressure pulse with a similar amplitude. This prolonged pressure pulse also leads to an increased amount of energy being transmitted to the projectile, causing a higher exit velocity. Figure 2 shows a schematic pressure vs. time curve of a TwinGun accelerator compared to a conventional two-stage light-gas accelerator.



1 Schematic sketch of the TwinGun accelerator developed at Fraunhofer EMI. Compared to conventional two-stage light-gas accelerators, the compression stage of the TwinGun features a second pump tube.

Successful operation of a TwinGun accelerator requires effective and reproducible piston delay generation to ensure an optimum pressure history at the beginning of the acceleration stage.

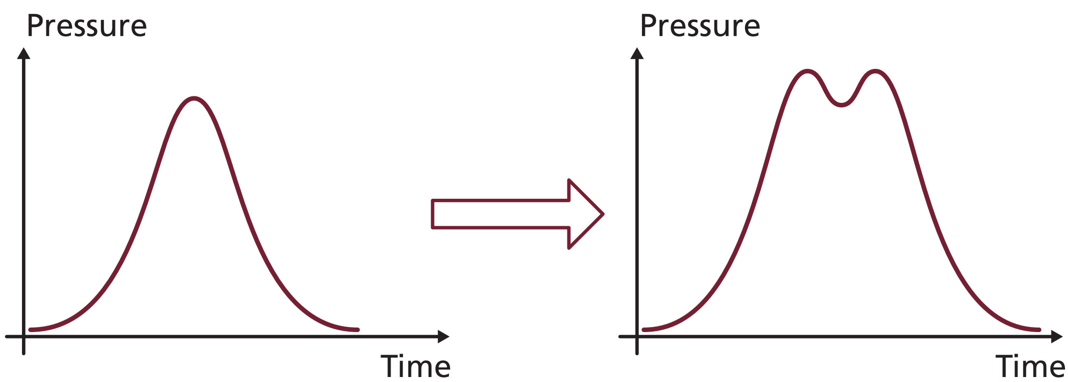
The first step to a successful synchronization of the two pistons is the use of a joint powder chamber for both pump tubes. The propellant charge burning process is usually subject to considerable time jitter (the measured variation at the TwinGun accelerator is several milliseconds). The joint powder chamber ensures a rough synchronization of the movement of the two pistons.

Feasibility of the concept was studied numerically. In the simulations, a TwinGun accelerator was capable of achieving the same exit velocity as a conventional light-gas accelerator of the same size, but at reduced peak pressure. Further investigations focused at techniques to effectively manipulate the piston delay. From those investigations, variation of the piston mass proved to be the most effective approach.

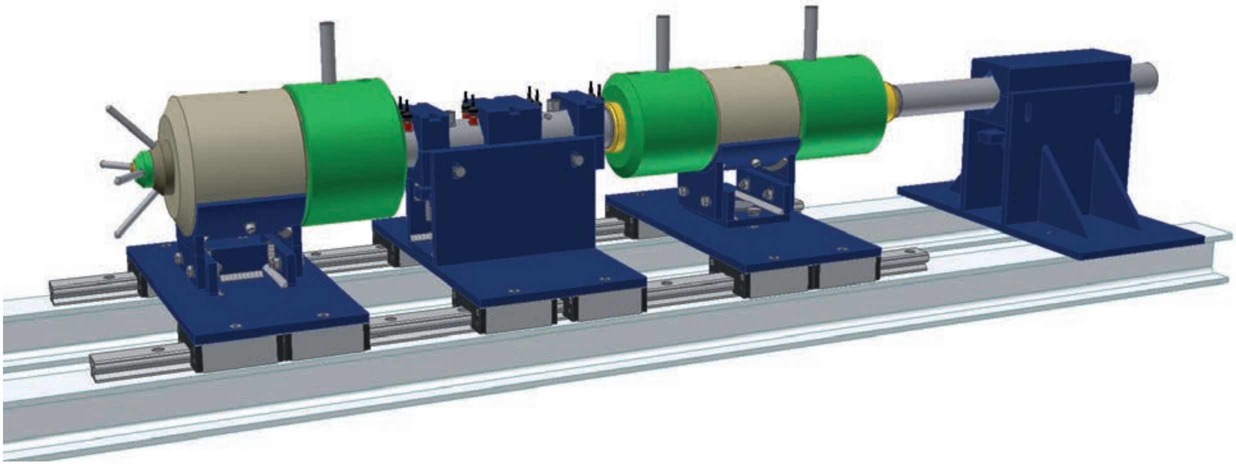
Following the successful feasibility assessment, a TwinGun accelerator was designed, constructed, built and initially operated. Figure 3 shows a 3D CAD representation of the TwinGun accelerator. Figure 4 shows the accelerator prototype prior to initial operation.

During initial operation, a few experiments were sufficient to show feasibility of the concept. The acquired data show a prolonged pressure pulse at the entrance of the accelerator stage. Figure 5 shows an example pressure measurement at the entrance of the accelerator stage.

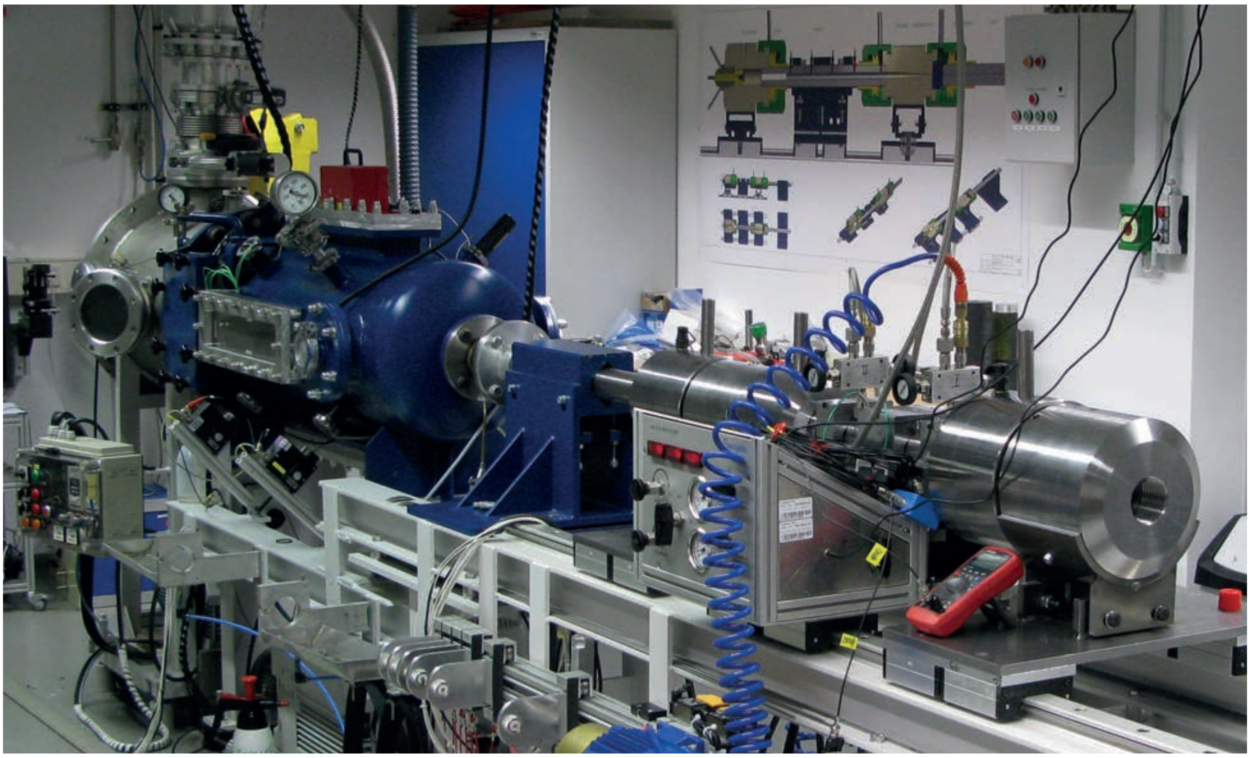
In this experiment, the delay between the two pistons was approximately 90 microseconds as they entered their respective accelerated reservoir. The time delay between the two pressure maxima is also about 90 microseconds.



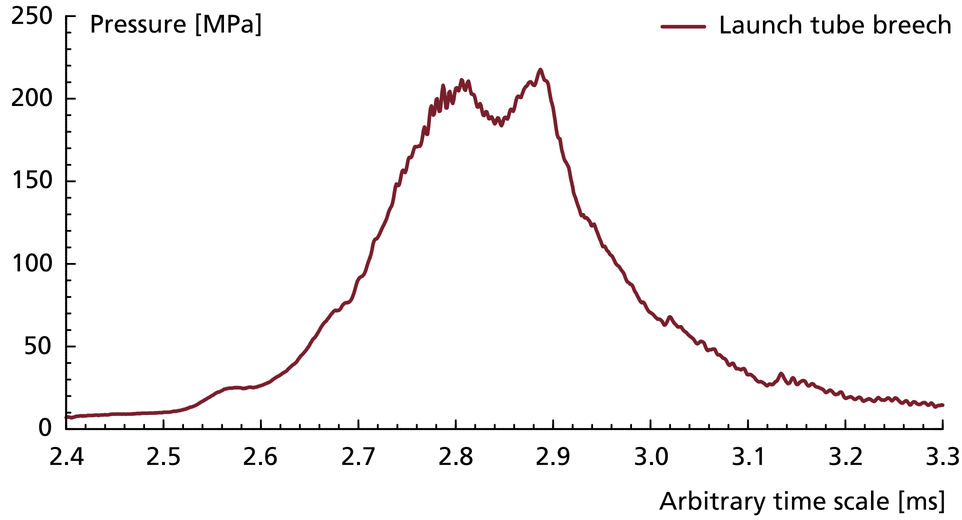
2 Schematic comparison of the pressure vs. time curve generated at the entrance of the accelerator stage. The conventional two-stage light-gas accelerator is left, the TwinGun accelerator is right. The second pump tube causes a prolonged pressure pulse to be created in the compression stage, leading to a higher exit velocity of the projectile.



3 3D CAD representation of the TwinGun.



4 Photograph of the TwinGun accelerator prior to initial operation.



5 Measured pressure vs. time at the entrance of the accelerator stage from the TwinGun accelerator at Fraunhofer EMI. The recorded pressure-time curve meets the expectations from theoretical considerations and demonstrates feasibility of the concept.

Qualitatively, the pressure measurement as seen in Figure 5 resembles the conceptually expected pressure history from Figure 2. The contribution of the two pump tubes can be distinguished clearly from the two distinct maxima. This is only true when the piston delay exceeds a certain duration. For shorter piston delays, pressure from the two pumps integrate into a single, elongated pulse which maintains the amplitude. This is in fact the desired mode of operation, since the maximum pressure loading of the components is maintained.

The presented concept incorporates the robustness of the components of the accelerator into the acceleration cycle. This allows maximization of the exit velocity while maintaining load to the components of the accelerator at an acceptable level.

The initially performed feasibility analysis indicated numerically that the concept presented facilitates an increase in performance. This enhanced performance is achieved by an elongated pressure pulse acting on the projectile. An accelerator implementing this concept is currently in operation. The experimental data gained so far show that the modified compression stage of the accelerator is capable of generating the desired prolonged pressure pulse.

Currently, the concept is being further investigated experimentally. Subsequent work will focus on reproducible piston motion as well as effective piston delay manipulation. Ultimately, peak velocities obtainable with the concept for impact experiments will be investigated.

Planetary science: Studies on the impact of celestial bodies

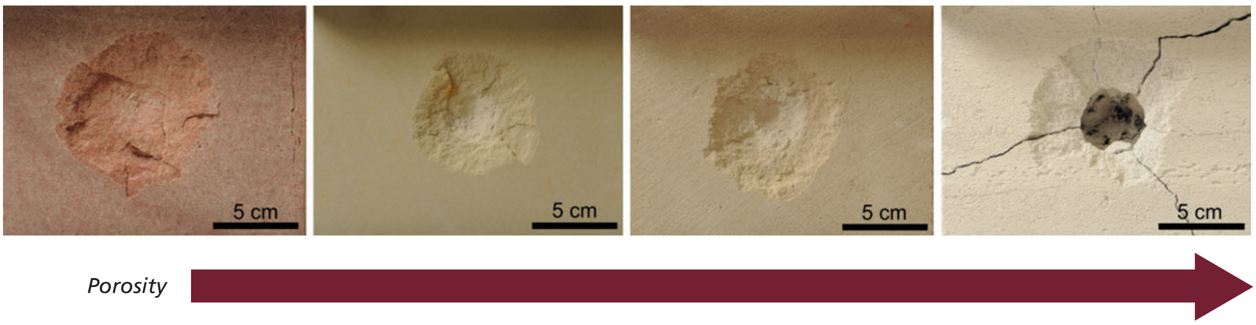
Impact cratering is a fundamental geological process. At EMI, the transient physical processes that occur during impact of celestial bodies are analyzed with experimental methods. In the experimental studies, projectiles are accelerated up to 8 kilometers per second via two-stage light-gas guns to generate impact craters in rock targets. The impact process, the crater formation and the ejection of target material are investigated in the laboratory at small geometric scales compared to planetary processes. Impact tests in the laboratory occur at extremely short time scales – within microseconds or milliseconds. They can be analyzed experimentally only with specific high-speed diagnostics. Therefore – amongst other things – high-speed cameras and specific sensors are used to characterize the ejection process and the pressure amplitudes in the target material caused by the impact.

The results show that the porosity of a material has a significant influence on the impact crater formation and the ejection process. Figure 6 shows four impact craters in quartzite, sandstone, limestone and cellular concrete, which were formed by 5 millimeter aluminium projectiles at an impact speed of approximately 6 kilometers per second. The materials feature very different porosities between 3 percent (quartzite) and 87 percent (cellular concrete).

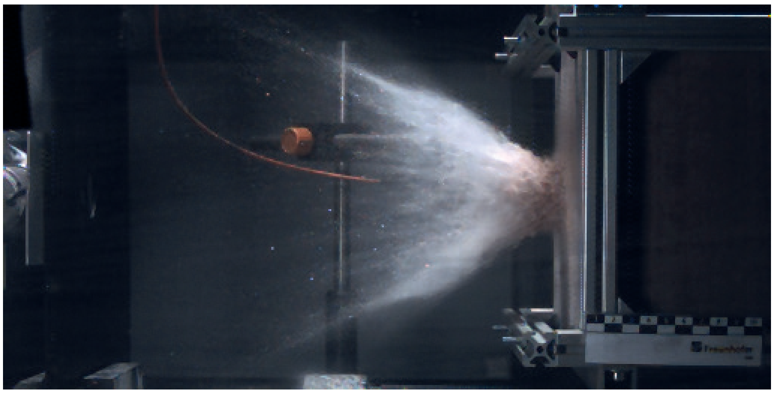
Figure 7 shows two high-speed images of the impact processes in quartzite and sandstone. The pictures were taken with an acquisition speed of 40,000 frames per second.

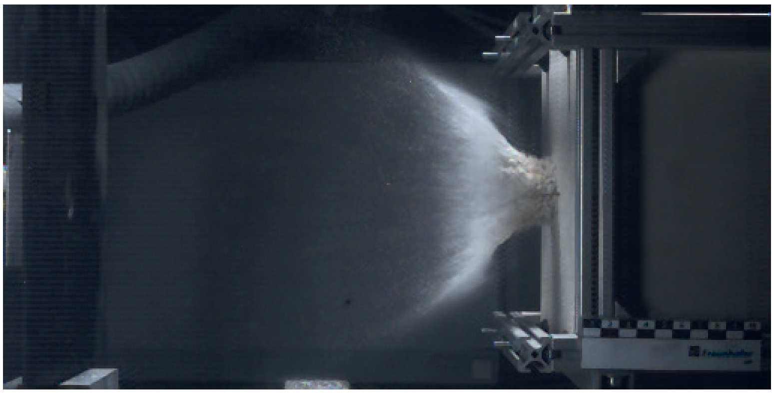
Both materials show a conical ejecta cloud, however, the cloud from quartzite is steeper than from sandstone. By comparing several successive pictures, the speed of the tip of the ejecta cloud can be measured, showing that material from the quartzite is ejected at higher speeds than material from sandstone.

The events on February 15, 2013, when almost simultaneously, a meteor strike in Chelyabinsk, Russia, and a close encounter of an asteroid occurred on the same day have raised public awareness of the potential threats caused by the impact of a near-Earth object ("NEO"). At EMI, a specific method for deflecting near-Earth objects is investigated within the European Union funded NEOShield project. Purpose of this project is to investigate the possibility of deflecting a celestial body by making a mass at high-speed collide with it. Besides the momentum transferred directly by the projectile, the material ejected opposite to the impact direction (Figure 7 on the following page) delivers additional momentum to the target. This so-called momentum multiplication factor β is the ratio of the momentum imparted on the target and the projectile momentum. Hence, β is a quantity that can be measured directly in impact experiments. The ejection of material opposite to the impact direction leads to $\beta > 1$.

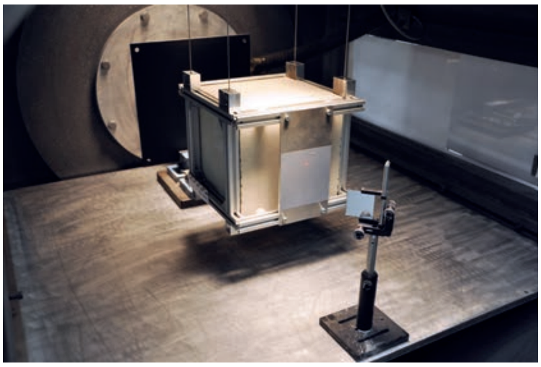


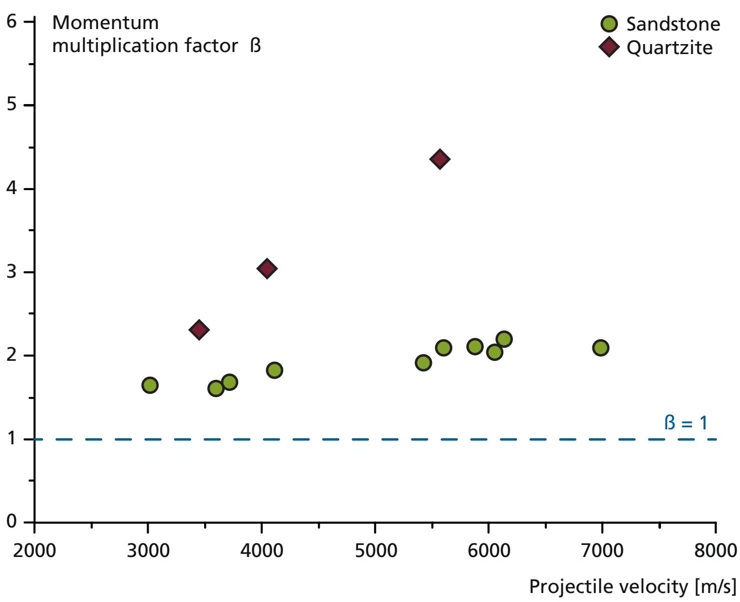
6 Comparison of the four impact craters, which were generated in materials with different porosity: quartzite, sandstone, limestone and cellular concrete.





7 Comparison of the ejecta between quartzite (at the top) and sandstone (at the bottom).





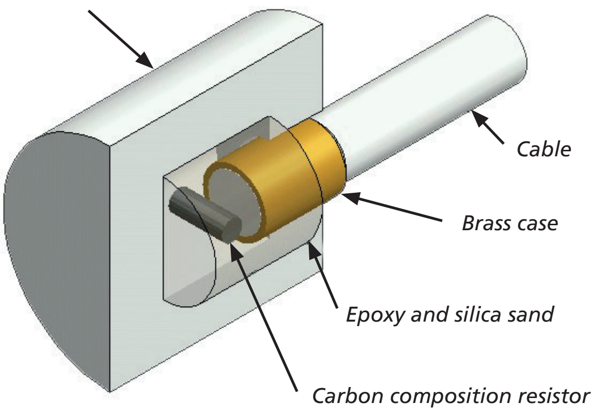
8 Momentum multiplication factor β depending on the projectile velocity.

Figure 8 shows the experimental setup, in which the target is fixed in a ballistic pendulum. During the experiment, the extension of the pendulum is measured contactless with a laser interferometer. Figure 8 shows experimentally measured values of the momentum multiplication factor β. The results indicate that β depends on the impact velocity as well as on the properties of the target material: Porous materials such as sandstone have smaller β-values than non-porous materials like quartzite. For quartzite, the increase of β with increasing projectile velocity is steeper than for materials with higher porosity. This difference is a direct result of the different ejecta dynamics of porous versus non-porous materials (Figure 7).

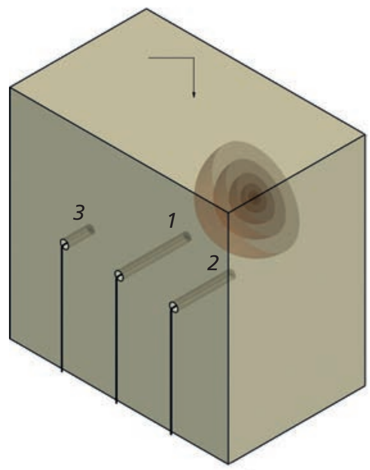
Following an impact, a shock wave is generated, which spreads out hemispherically in the target material and which merges gradually into an elastic wave. The pressure amplitude that is generated from the impact is difficult to measure, since a suitable pressure sensor has to be embedded in the target that does not disturb the wave. Furthermore, geological materials such as sandstone feature inhomogeneous and anisotropic characteristics, which impede the measurement. On this account, a specific pressure sensor was developed at EMI, which can be embedded in brittle and porous materials such as concrete or rocks and which provides reliable results even in high pressure ranges. The sensor basically consists of a carbon composition resistor, which changes its resistance as a function of mechanical pressure. Figure 9 shows the resistor element, which is embedded in resin to ensure a uniform transmission of stress. It also prevents local pressure peaks from individual grains of the surrounding material. The density of the resin is adapted to the density of the surrounding target material through additives such as quartz flour.

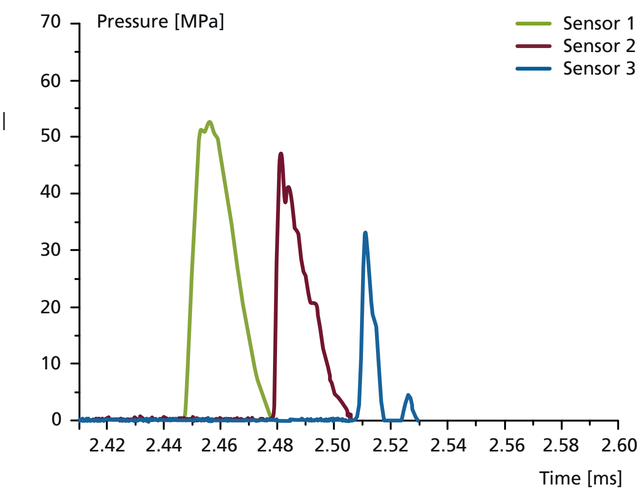
The sensor was used for measuring the pressure amplitudes and the decay behavior of the impact-generated wave in the sandstone target. Furthermore, experiments concerning the calibration of the sensor were conducted.

Figure 10 shows the experimental setup of the sensors in the test specimen as well as the recorded pressure signals at variable distances from the impact location. The first onset of the wave is clearly visible. The signal rises steeply and reaches its maximum within a few microseconds.



9 Schematic setup of the sensor.





10 Recorded signal of an impact-generated pressure pulse at three different locations.

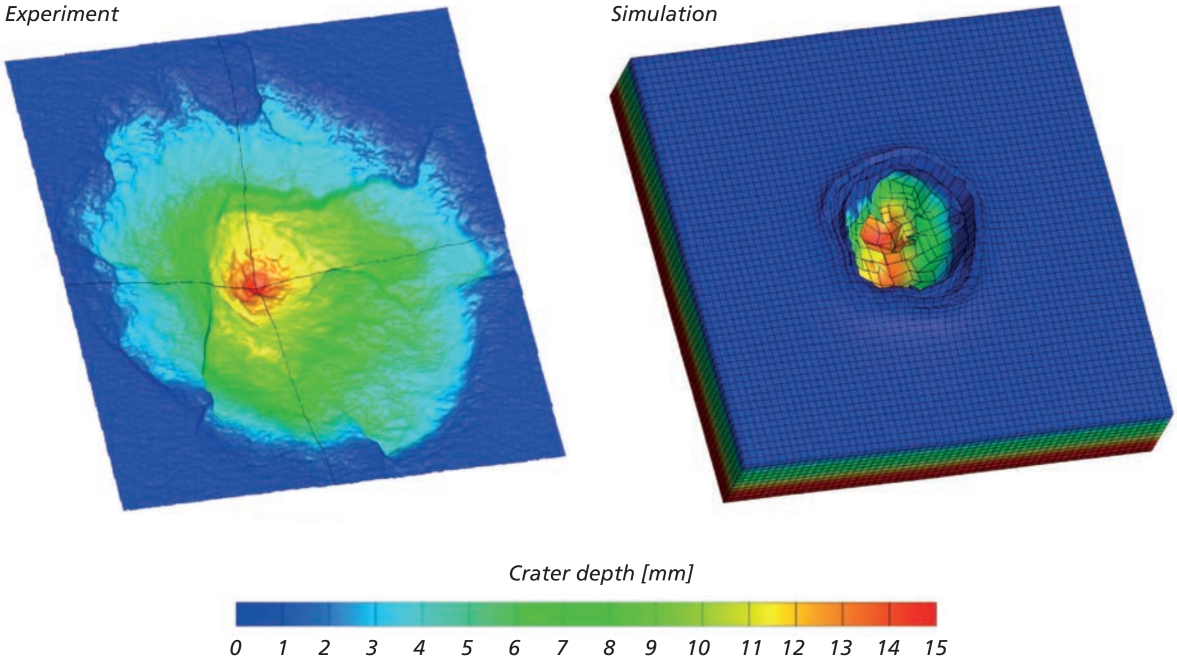
The decay of the amplitude during the propagation of the wave in the target is obvious. In subsequent experiments involving constant impact parameters, signal rise times and maximum amplitudes can easily be reproduced.

In addition to the impact experiments, numerical simulations of the impact and the crater formation process were conducted. Figure 11 shows the comparison of the crater depth of an experimental and a numerically simulated impact crater in quartzite. The 3D model of the experimental crater shown in this figure was generated by a lightscan procedure. The simulation reproduces the depth of the crater well.

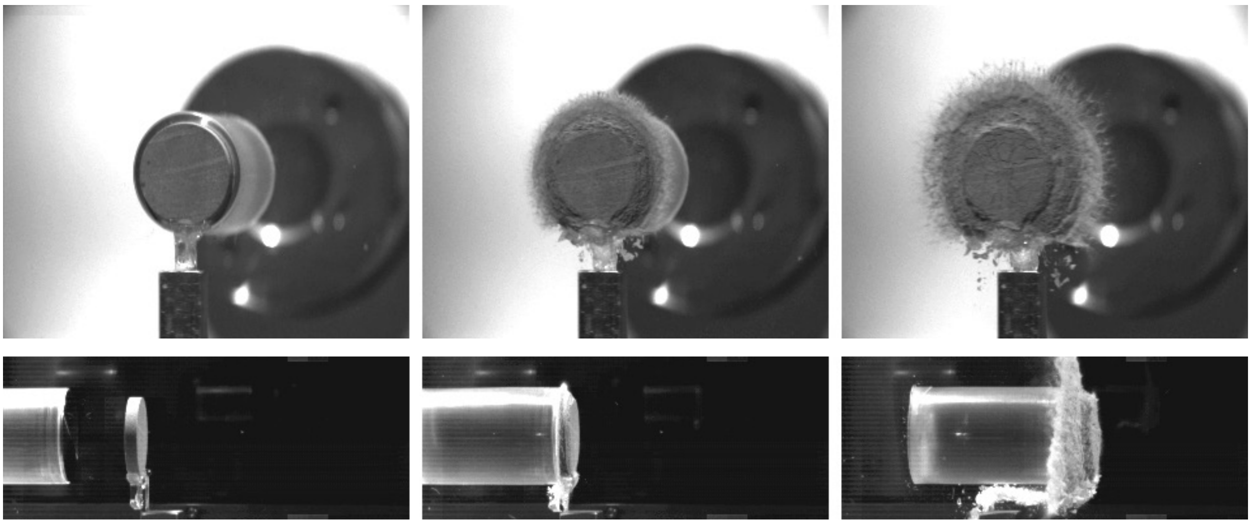
In the impact experiment, a significant amount of the crater volume is caused by spallation, i. e. the failure of target material under dynamic tensile loading. To simulate crater volume and crater morphology well, material models of the target materials involved are required. Such material models can be generated at EMI in a variety of static and dynamic material tests.

The characterization of the material is carried out over a wide strain rate. To achieve very high strain rates, so called planar plate impact tests are conducted with disc-shaped projectiles and targets. Figure 12 shows high-speed images of a planar plate impact from two perspectives. Via a laser interferometer, the speed of the target's rear surface can be measured contact-free und with a very high temporal resolution.

The accelerators at EMI in connection with special high-speed diagnostics, numerical simulations and material characterizations over a wide strain rate lead to new scientific insights into the highly dynamic and complex impact cratering process. Thereby, the experimental and numerical methods are constantly enhanced and can be applied in basic research and industrial applications.



11 Comparison of the crater depth between an experimentally created and a simulated impact crater in quartzite.



12 Planar plate impact for the highly dynamic characterization of sandstone. At the top: backside sandstone sample, at the bottom: side view.

Structural mechanics response to high electrical current pulses

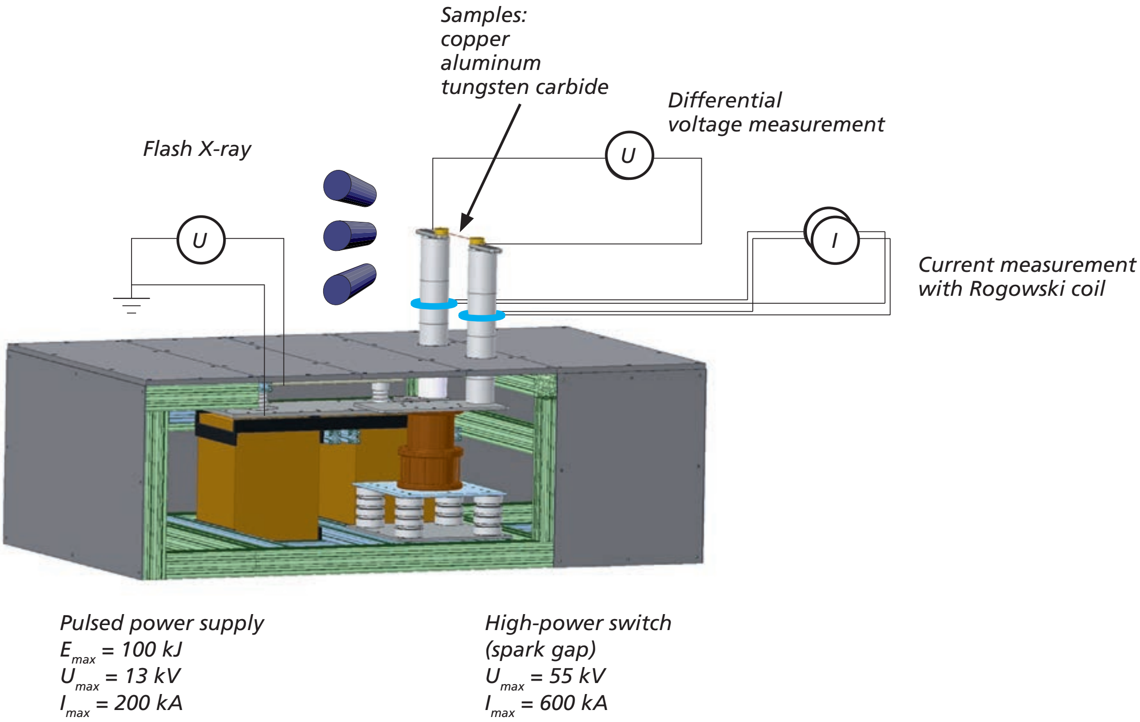
Fraunhofer EMI examines the response of materials and structures under extreme dynamic loads. Such a dynamic load can be represented by an impact or a shock. However, an extremely high electric current, as it may occur in lightning, also represents such an extreme load, although in a more indirect manner, which can cause target materials or structures to be exposed to high thermo-mechanical loads.

In a fundamental approach, the response of metallic structures to high electric current pulse loads has been examined experimentally, and the material response was captured in a model to allow numerical simulation.

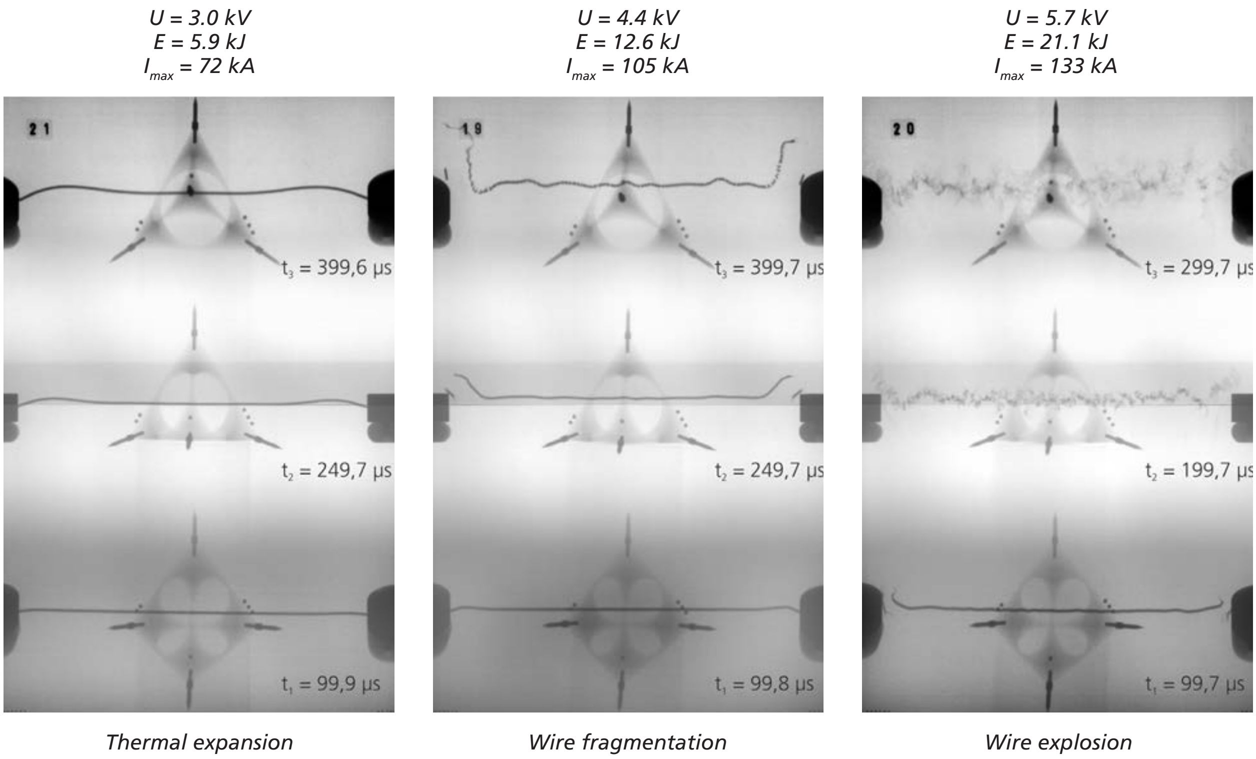
First, an experimental test rig was designed and constructed. It is used for the examination of thin cylinders made of copper, aluminum, and tungsten carbide. The test rig is constructed in a way that allows flash X-ray diagnostics to capture the state of samples at defined points in time. Samples with a length of about 300 millimeters and a diameter of a few millimeters will be loaded in such a way that the mechanical response can be examined well before wire explosion effects develop at increased current levels.

The scheme of the test rig is displayed in Figure 16. The capacitors can be loaded up to a voltage of 13 kilovolts making an electrical energy of up to 100 kilojoules available for experiments. A spark gap is used to initiate the current pulse which may achieve very high values of up to 200 kiloamperes.

The flash X-ray images in Figure 17 show the structural mechanical response of a copper wire sample to various intense electrical current pulse loads. For the given sample diameter of 2 millimeters, the images first show a thermal expansion at an amplitude of 72 kiloamperes followed by sample fragmentation and wave shape modulation of the displacement of the individual sample fragments for cur-



16 Schematic drawing of the experimental test rig for investigation of pulsed power loading up to wire explosion processes.



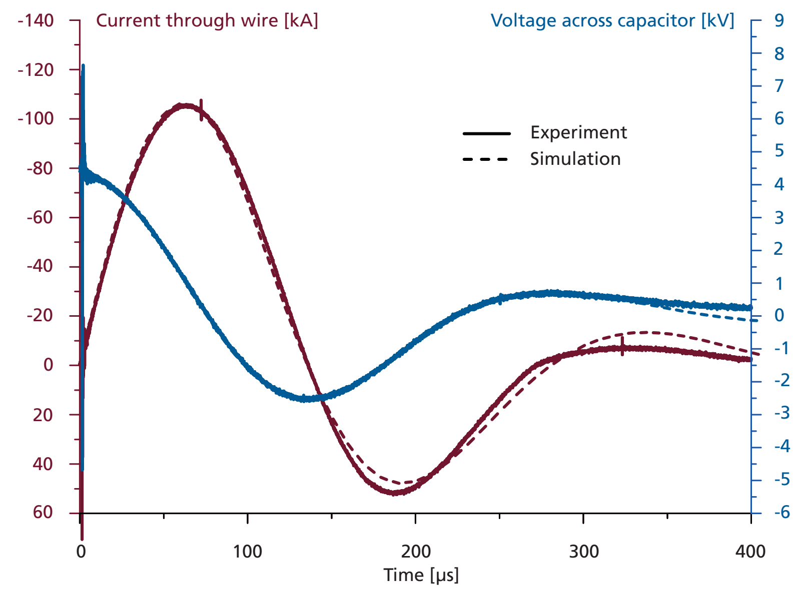
17 Triply exposed radiographs (t_1 = 100 microseconds, t_2 = 250 100 microseconds, t_3 = 400 100 microseconds). Material behavior of a copper sample with a diameter of 2 millimeters, which has been exposed to various levels of intense electric currents. The copper wire sample expands thermally (left), fragments at the clamps (center), and explodes (right).

rents up to 105 kiloamperes. Wire explosion has set in at 133 kiloamperes, which results in complete disintegration of the sample.

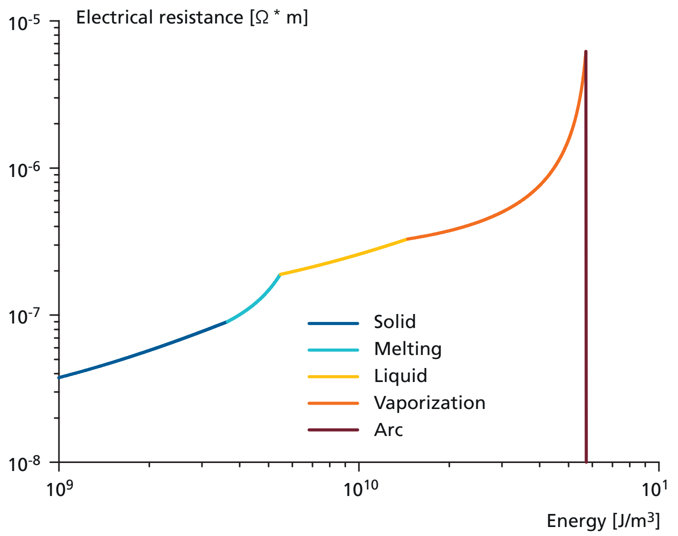
Based on a multi-physics approach, a model to simulate the structural mechanical response of the bending and fragmentation before wire explosion was developed. Starting with the electrical circuit scheme of a strongly damped oscillator, which gives the electrical current response with respect to time as displayed in Figure 18, the model links the thermodynamic aspects caused by the heating of the materials due to high electric currents, the resulting electromechanical forces acting on the sample, and the structural mechanical response of the sample.

Due to the dynamic nature of the process, the various physical aspects have to be coupled in a suitable manner to allow recursion of the material response onto the whole process.

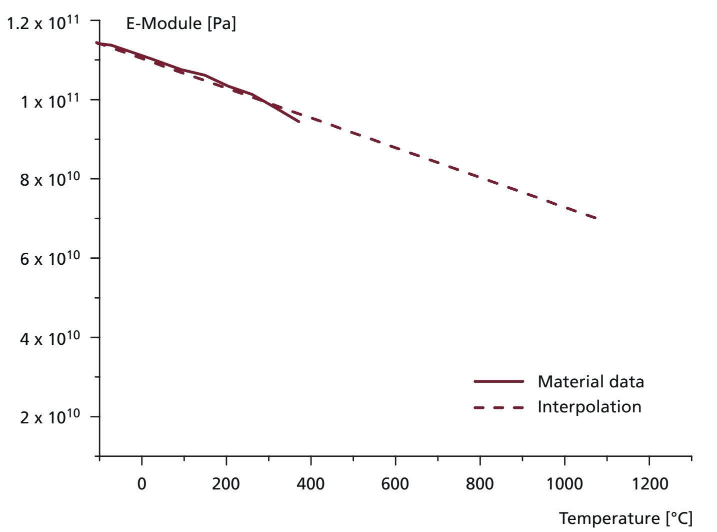
For a representation of the process, it is necessary to employ models for the characteristic material parameters over an extremely wide range of values. For example, the specific electrical resistivity with respect to the internal energy shown in Figure 19 (next page) and the dependence of mechanical properties like the elastic modulus on temperature as displayed in Figure 20 (next page) have to be employed.



18 The comparison of the electric current (red) and voltage (blue) between experiment (solid) and simulation (dotted) shows good agreement.



19 Electrical resistivity of copper as a function of energy. The colored areas emphasize the physical states of the material.

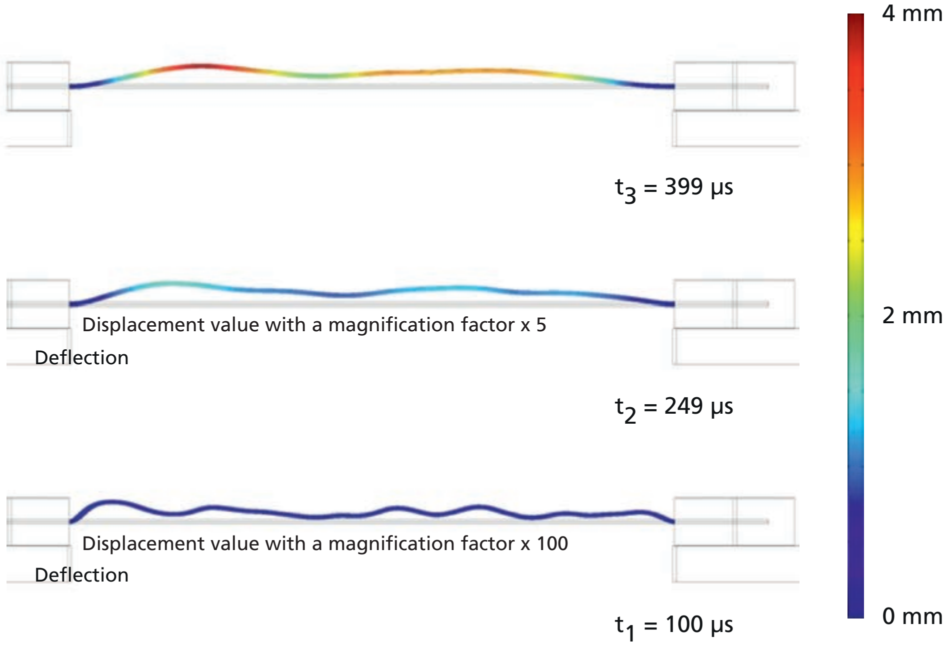


20 Temperature-dependent Young's modulus for copper.

Based on this approach, the time-dependent mechanical structural response can be calculated with the finite element simulation model (see the example in Figure 21). Focusing on the medium electrical current pulse load, you can observe a wave-like modulation of the displacement. At 100 microseconds, the amplitude of this modulation has formed only very little. For this reason, the displacement amplitude in Figure 21 is displayed with a high magnification factor. With increase of time, the magnitude of displacement increases strongly, whereas the number of modulations decreases.

Whereas the earlier work focused on the aspects of wire explosion phenomena, the presented approach addresses modeling the structural mechanical response of the target upon high current pulse loads, which can be used to analyze the effects of such currents on components in a wide range of pulse loads.

The results have been obtained for thin cylindrical samples. The linking of the different physical effects in the model can be used as a base for the analysis of applications such as lightning effects on aircraft structural components, the design of self-opening high current switches, or new protective technologies like electrical armor. In the latter, the framework of a project cooperation for multi-hit-capability of a functional electric armor demonstrator was accomplished for the successful protection against several RPG threats within a short time frame.



21 Time-evolution of the mechanical structural behavior of the copper wire. The colors indicates the displacement of the wire from its center (amplitudes not drawn to scale).

Reaction kinetics modeling of explosives under intense laser irradiation

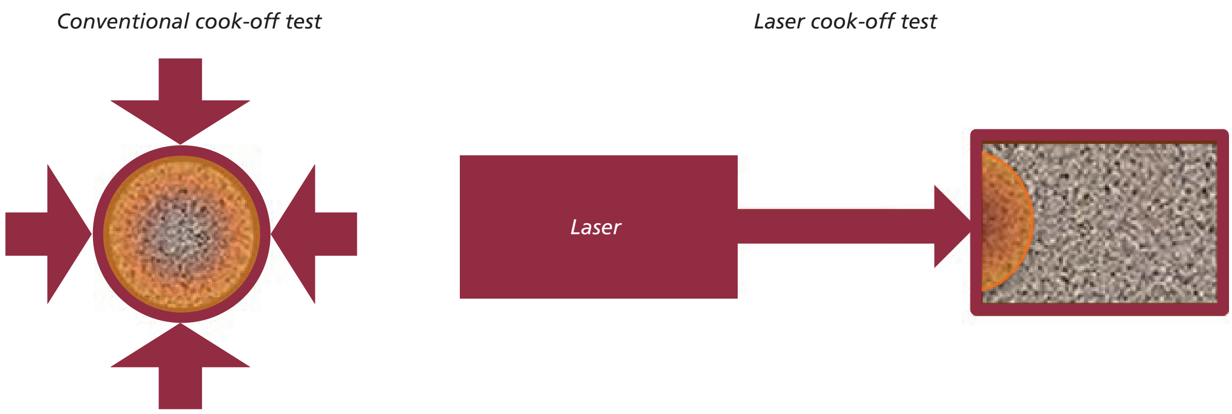
Collimated beams of intense laser radiation allow for the directed transport of energy over long distances and thus render the development of new applications possible. In the context of its activities in security research, Fraunhofer EMI investigates the potential of laser radiation for the neutralization of explosive devices. In military operations, laser-based techniques are already being used for the neutralization of explosive devices, e. g. by intentionally triggering the ignition of the explosive material from a safe distance.

However, for application in a civilian environment, the requirements in terms of safety are stricter, and the risk of a fast reaction leading to an unintended detonation has to be kept as small as possible. For an assessment of this issue, Fraunhofer EMI is investigating the potential of numerical models for predicting the behavior of explosive materials under laser irradiation. The challenge here lies in the requirement that a model should be able to address a broad spectrum of explosive materials with different chemical compositions. Thus, a suitable approach should allow for the application to different explosives as well as the description of different reactions types such as slow burning, deflagration, and detonation.

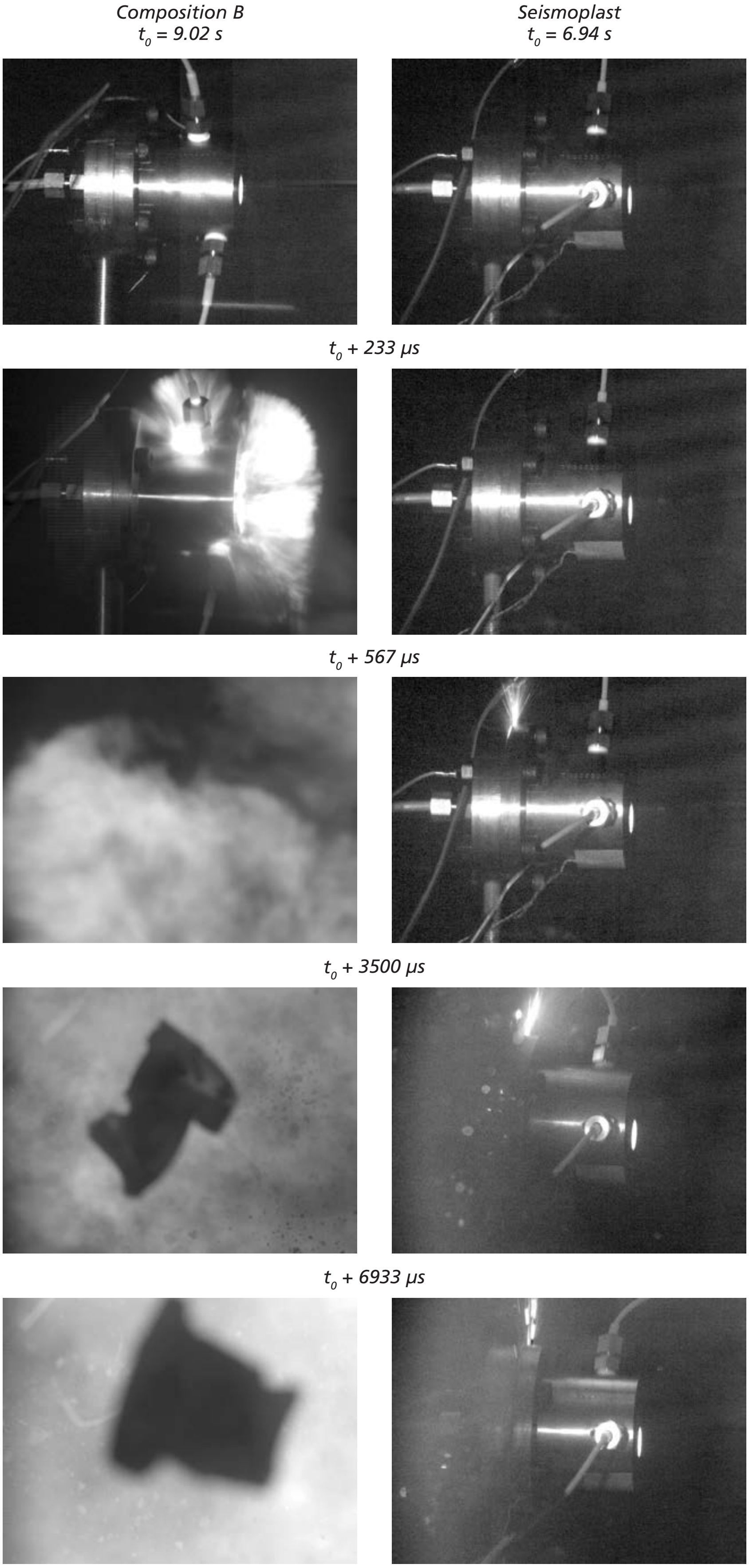
In general, modeling the behavior of explosive materials under thermal loads is a topic of great relevance with regard to the safety of explosives. For the quantitative rating of the sensitivity of explosives against thermal loads, different tests have been developed and are described in literature. In these experiments referred to as cook-off tests, the sample, which consists of a closed metal sheath filled with explosive material, is typically heated by electric heat sources or thermal radiation until an initiation of the explosive is observed. In addition to the temperature, the pressure inside the sample also has a strong influence on the kinetics of the reaction. Consequently, the layout of the confinement plays an important role for the interpretation and reproducibility of the experimental results. Important examples of cook-off tests with a strong confinement are the Scaled Thermal Explosion Experiment (STEX) and the Sandia Instrumented Thermal Ignition (SITI) test.

In recent years, similar experiments have been carried out using intense laser beams as heat sources. A fraction of the energy of the laser beam is absorbed by the sample and is converted to thermal energy leading to a temperature increase at the surface of the metal sheath. Due to thermal conduction, the explosive material in the metal sheath gets heated as well. The increase of temperature and pressure in the inner part of the sample finally results in the ignition of the explosive material. In contrast to a conventional cook-off test, local heating in the immediate area of the laser irradiation has to be considered instead of homogeneous heating over the whole surface of the sample. In addition, the rate of the temperature increase is typically higher by orders of magnitude as compared to conventional cook-off tests. These differences are illustrated in Figure 22.

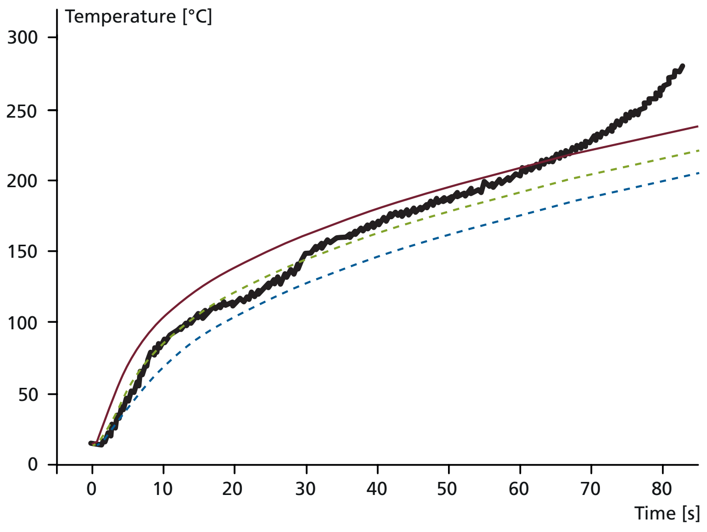
The reaction of the cook-off sample under laser irradiation strongly depends on the explosive material used in the test. This observation becomes very clear in Figure 23 showing a sequence of a high-speed video starting at the time of



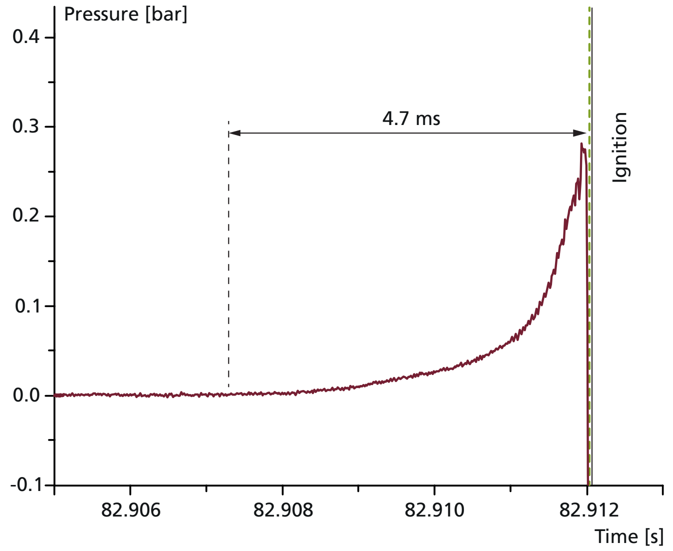
22 Comparison between conventional cook-off test and laser cook-off test.



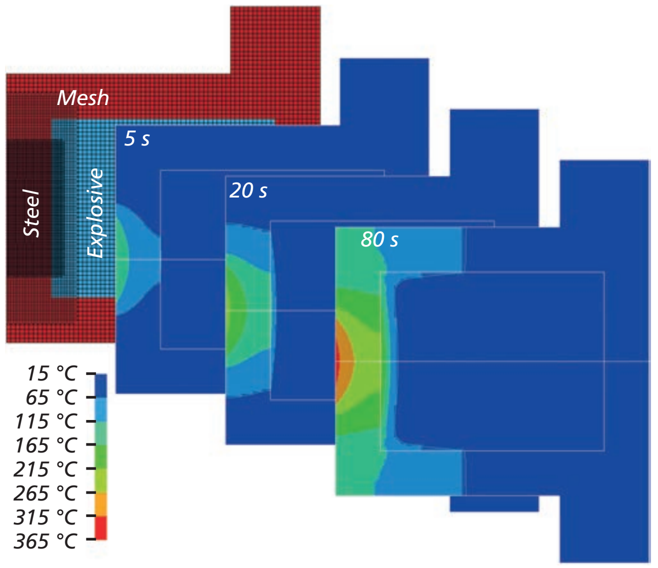
23 Comparison of the reaction of different explosive materials (left: Composition B, right: Seismoplast) during laser cook-off.



24 Comparison of simulated (dashed green line) and measured (solid black line) temperature inside a cook-off sample filled with Composition B during laser irradiation with a power of 1 kilowatt. The red and blue curve indicate the error of the simulation.



25 Pressure increase inside a Composition B cook-off sample. In contrast to the temperature, a pressure increase is not measured until a few milliseconds before ignition.



26 FEM simulation of the temperature distribution in a cook-off sample filled with Composition B irradiated with a laser power of 1 kilowatt for three different points of time (5 seconds, 20 seconds and 80 seconds).

ignition (t_0) of two cook-off samples filled with different explosive materials (Composition B and PETN-based Seismoplast). The tests were carried out under identical conditions with a laser power of 3 kilowatts. The fragmentation of the metal sheath in the case of the Composition B sample indicates a deflagrative reaction, whereas the weaker damage in the Seismoplast sample suggests a slow burning reaction.

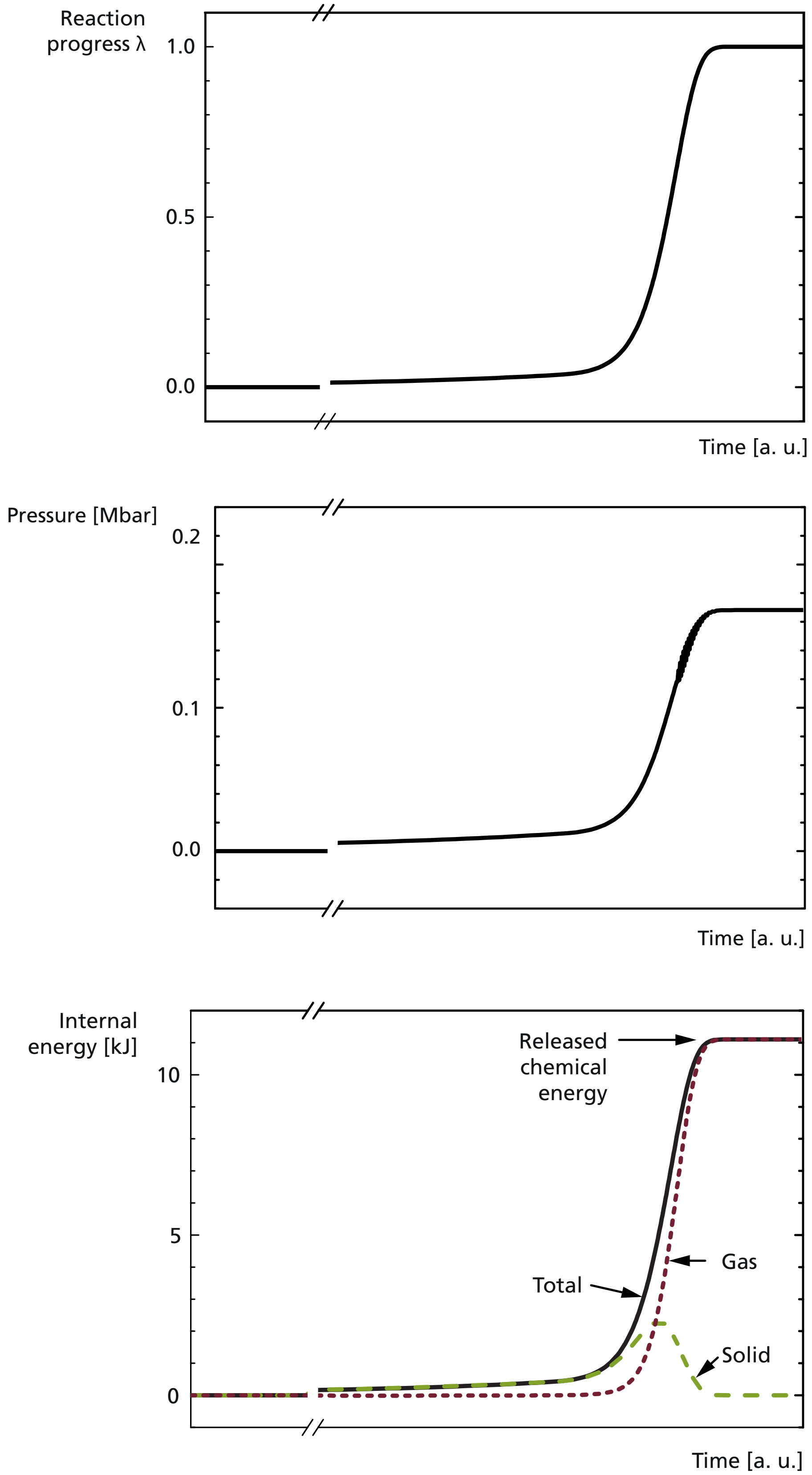
For a quantitative analysis of the underlying processes, the temporal evolution of pressure and temperature were measured inside the cook-off samples during laser irradiation at Fraunhofer EMI. As an example, Figure 24 and 25 show the measured evolution of temperature and pressure inside a cook-off sample filled with Composition B irradiated with a laser power of 1 kilowatt. Time t = 0 seconds corresponds to the beginning of the laser irradiation. It is evident that the plots for pressure and temperature exhibit a different behavior. The increase of temperature inside the sample is observed after a short thermal transit time which depends on the sample geometry and the thermal properties of the metal sheath. In the example in Figure 24, the thermal transit time is of the order of a few seconds. Afterwards, a continuous temperature increase is observed until the ignition takes place approximately 80 seconds after the beginning of the laser irradiation. In contrast, an increase of pressure is not observed until a few milliseconds prior to ignition. For a better visualization, Figure 25 shows the development of the pressure in a time interval beginning a few milliseconds before ignition of the sample. For the Seismoplast sample, a longer value for the period from the onset of the pressure till ignition of about one second was measured. The slower pressure increase in the Seismoplast sample correlates with the weaker damage of the metal sheath observed in Figure 23. This example illustrates that the time scale of the pressure increase is an important quantity for the characterization of the expected reaction type.

For a detailed understanding of the reaction of explosives under laser irradiation with applications in security technology, Fraunhofer EMI also develops simulation models which take into account pressure- and temperature-dependent reaction rates. In a first step, FEM simulations calculating the temperature increase in the samples due to absorption of the laser energy were carried out. Figure 26 shows the result of such an FEM simulation for a sample filled with Composition B irradiated with a laser power of 1 kilowatt. The corresponding temperature evolution inside the sample at the boundary between the metal sheath and the explosive filling is displayed by a dashed green line in Figure 24. The red and the blue line indicate the uncertainty of the simulated temperature and represent the gradient of the temperature over a length scale of 0.5 millimeters corresponding to the diameter of the thermocouple used in the experiment.

For the prediction of the pressure inside the sample, the simulation model is currently being extended by a reaction kinetic material model which calculates the kinetics of the chemical reaction of the explosive material taking into account the pressure- and temperature-dependent rate constants. The model is based on a mixing rule which separates each simulation cell into two regions, where the first region contains the solid reactant (the explosive material) and the second region contains the gaseous reaction products. The progress of the chemical reaction is described by a dimensionless progress variable λ with possible values between 0 and 1. A value of $\lambda = 0$ corresponds to the situation before the reaction when the simulation cell only contains solid reactants, whereas $\lambda = 1$ represents the situation after ignition when the cell only contains the gaseous reaction products. For the implementation of the reaction kinetic model in the FEM simulation, the relation between the thermodynamic state variables pressure p, temperature T, specific volume v, and internal energy e has to be described by an equation of state. In the mixing rule, it is assumed that temperature and pressure of the reactants and the reaction products are equal. Under these conditions, the total internal energy and the total specific volume can be calculated corresponding to the reaction progress variable λ.

As an example, Figure 27 shows the calculated evolution of reaction progress, pressure, and internal energy inside a simulation volume consisting of a single simulation cell. This calculation indicates that important features such as the quick increase of pressure and internal energy at the start of the ignition can already be observed in simple simulation geometries.

In the next step, it is planned to extend the simulation model to arbitrary simulation geometries. Due to the general formulation based on pressure- and temperature-dependent reaction rates, the model allows for the adaption to different explosive materials. It is expected that the model is capable of giving new insight into the behavior of explosive materials under laser irradiation. For application in security research, for example, the model can be used to predict the reaction strength and optimize the laser parameters with regard to the safety during the neutralization of explosive devices. The model can also be extended to the regime of higher laser powers, which is relevant in time-critical scenarios where the neutralization has to be performed at smaller time scales.



27 Calculation of the evolution of reaction progress, pressure and internal energy for the ignition of an explosive material using a reaction kinetic material model.

EXPERIMENTAL BALLISTICS

EXPERIMENTAL BALLISTICS

The combination of a highly instrumented experimental setup and state of the art numerical simulations forms the basis for the innovative research and development work of the Experimental Ballistics Department at EMI.

Under these advantageous condition EMI has successfully developed its uniaxial (1D) high-g sensor further into a revolutionary multiaxial (3D) MEMS. With this new component, the EMI extended its already highly sophisticated diagnostic equipment portfolio by an additional tool with unrivalled measurement capabilities. This sensor exceeds, according to its resonance frequency, sensitivity limit and the monolithic 3D configuration, the US built reference-sensors and most of the sensors presently available on the market by far.

Due to the imminent threat from modern electro-chemical energy sources under mechanical loading, i. e. during impact and penetration, investigation efforts with the focus on lithium-ion-accumulators are proceeded. These investigations include the examination of failure modes and mechanisms as well as the method development for a comprehensive characterization of such systems according to requirements of the Bundeswehr.

An additional key aspect of the department has been put on low energy detonators based on primary explosives. According to new and existing requirements, like the miniaturization of the fuse system, the usage of REACH[1]-compliant chemicals (lead- and chromate-free detonators), and reliability and safety, these components gained scientific attention again. By means of specifically designed experiments, the use of high-end diagnostic equipment and multi-physical simulations, a deepened comprehension about the operating mode of fuse systems has been achieved.

Dr. Manfred Salk
Head of Experimental Ballistics until December 31, 2014
Phone +49 761 2714-120 | manfred.salk@emi.fraunhofer.de

Dr. Marek Dolak
Head of Experimental Ballistics since January 1, 2015
Phone +49 7628 9050-730 | marek.dolak@emi.fraunhofer.de

[1] *REACH = **R**egistration, **E**valuation, **A**uthorisation and Restriction of **CH**emicals, prescription (EG) no. 1907/2006.*

EXPERIMENTAL BALLISTICS

Characterization and modeling of brittle materials for ballistic protection

A reliable protection of soldiers in operational areas around the globe has been given highest priority since the very beginning of out of area operations of the German Federal Armed Forces. This concerns not only the direct personal protection of the soldier himself, but also the protection of the transport vehicles of deployed forces. The most prominent threat to military and to some extent civilian vehicles arises from attacks with Improvised Explosive Devices (IEDs). In this case, different mechanisms come into effect. Beside the mechanical effects of the projectile/fragment impact and penetration, additional blast effects act on the vehicle. During the simultaneous impact of fragments, multi-hit phenomena and the pre-weakening of the protective structure plays an important role. One utmost significant and most vulnerable part of the vehicle's structure are the windows, where the selection of optimized transparent materials gains high priority. An important requirement in this context concerns weight reduction of protective structures with unchanged or even higher protection capability. This is only possible through the use of modern materials with low density and high strength. From this point of view, ceramics and glasses in connection with polymers and fiber reinforced materials are prominently suited for these applications. Only with the combination of different material properties, the desired high protection level can be achieved. On the one hand, ceramics can be used for personal protection, like in ballistic vests, on the other for the protection of transport vehicles. In summary, protection has to be regarded as an integral task and must be effectively designed against a broad spectrum of threats (polyvalent protection), the design of an adequate protective structure requires the detailed understanding of the highly dynamical behavior of the involved materials together with validated material models for the simulation and analysis of the physical processes. Using the example of transparent protective structures, the following section describes how this objective can be achieved; starting from the construction of the test facility for material characterization to the numerical simulation of the protective effectiveness.

Design of ballistic protection in the experiment

For studying the processes in transparent structures, it is necessary to use glass laminates of such lateral dimensions and thickness that on one hand enable conditions similar to those in a real armor system, and on the other hand allow for measuring the values that determine the protective strength during projectile penetration, like damage and deformation of the single glass layers. Figure 1 shows an impacted glass laminate (impact from the left), consisting of four glass layers and a polycarbonate plate at the backside. In the background, the high-speed camera with a telecentric lens can be recognized, which was utilized to observe damage propagation during the interaction with the projectile within the single glass layers of the laminate of lateral dimensions 500 millimeters x 500 millimeters.

Besides the visualization techniques, an optical method was developed, based on Photonic Doppler Velocimetry (PDV), which allows measuring the displacement of single glass layers during projectile penetration. Due to the high number of parameters like number, thickness and type of glass and bonding layers, an optimization based purely on experiments would be too expensive.

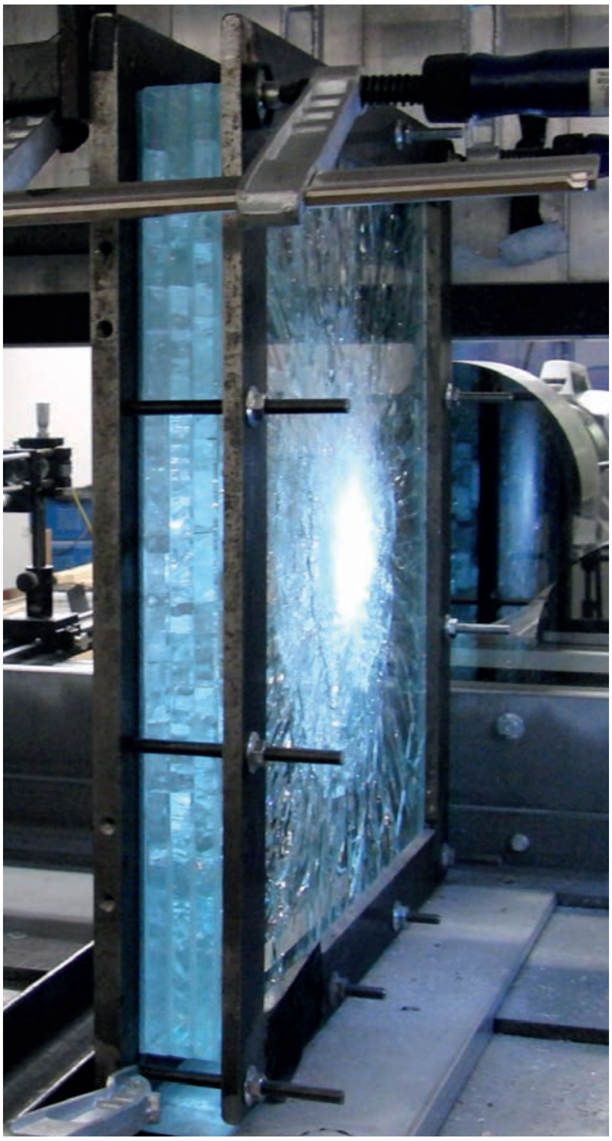
Dynamic behavior of brittle armor materials

A more efficient optimization procedure is achieved by combining experiments with numerical simulations. On one hand, the experimental results form a basis for the validation and development of the simulation. On the other hand, the simulations enable the visualization of experimentally not accessible values and contribute to the understanding of the relevant processes. A validated simulation model additionally provides a cost and time efficient possibility to study the influence of a variety of parameters like thickness and number of glass layers.

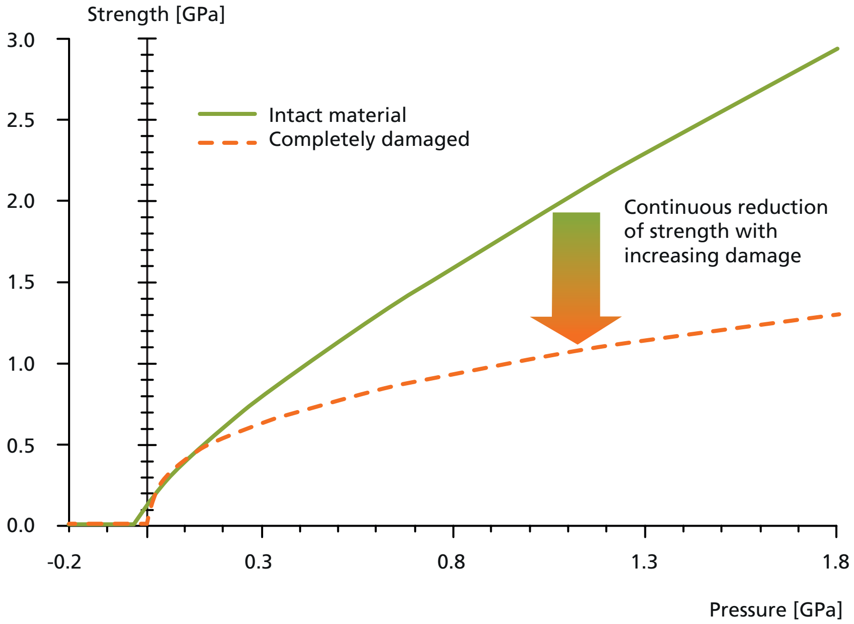
The correct prediction of the processes in the glass is crucial for a realistic simulation result. Therefore, characteristic properties like high strength under pressure, brittle behavior and crack formation have to be represented in the simulation model. Existing models, e. g. JH1, JH2 (Johnson-Holmquist) and JHB (Johnson-Holmquist-Beissel) take into account the mentioned aspects by means of a polynomic equation of state and two analytical functions, which describe the dependency of strength on pressure for the intact and damaged material for pressures up to the GPa range. For the quantification of damage, a parameter D is introduced, which is being calculated and incremented for each time step of the simulation. For intact elements, D is zero, whereas completely damaged material is characterized by $D = 1$. A reduced strength is allocated to partly damaged elements ($0 < D < 1$), which is determined by interpolation between the strength curves for $D = 0$ and $D = 1$ (see Figure 2, next page).

Material characterization at high dynamic loadings

The complexity of penetration processes in glass laminates prevents a direct calibration of all model parameters. However, an excellent method to determine single material properties in the high dynamic loading range is available in form of the planar plate impact test (see Figures 3a and 3b on the next page). Well defined one dimensional loading states can be generated in a glass specimen by plane impact with a projectile plate of a previously characterized material. A velocity measurement of the shock waves with high resolution in time by means of Photonic Doppler Velocimetry (PDV) then allows determining single model parameters like the yield point under one dimensional strain, the so-called Hugoniot-Elastic-Limit (HEL).



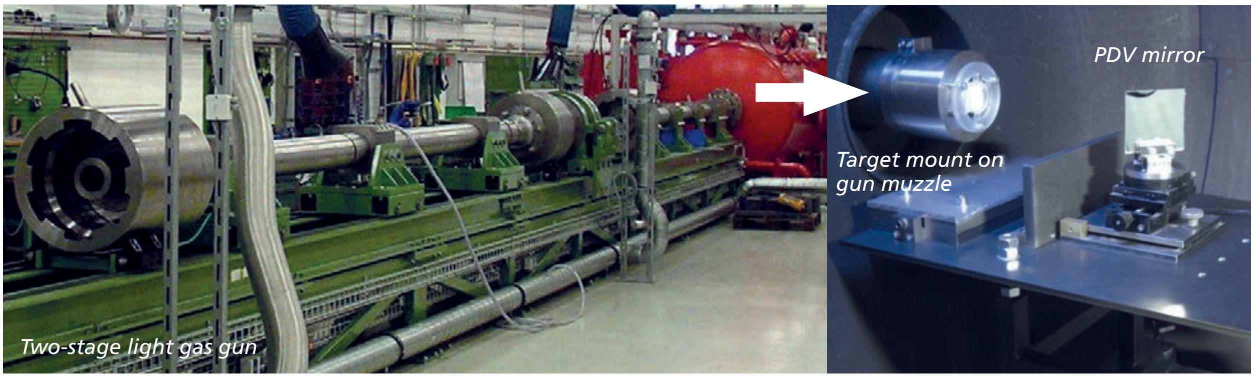
1 Protection effect of a glass laminate at projectile impact.



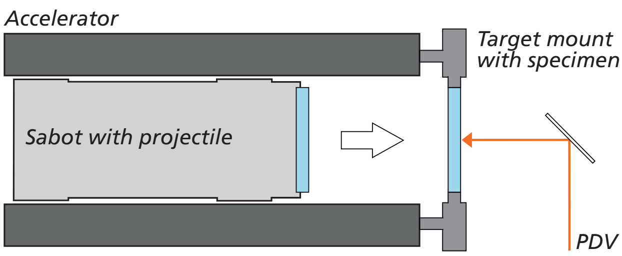
2 *Characteristic strength behavior of brittle materials under high pressure: The von Mises stress increases with pressure in the JH2 model. As the damage increases, the material continuously loses strength. Completely damaged material has no tensile strength.*

Simulation of a glass laminate

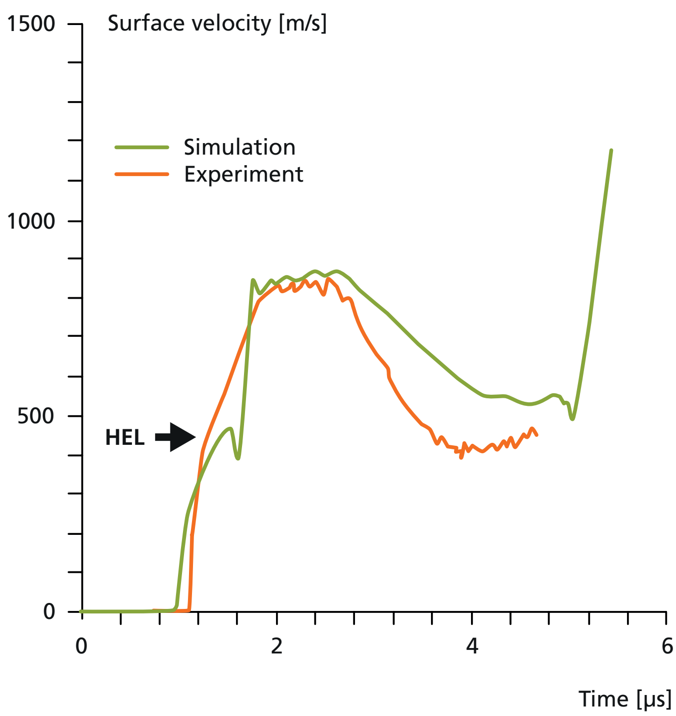
An example of an axisymmetric simulation of a glass-polycarbonate laminate is shown in Figure 5. In this case, a 7.62 mm AP projectile with an impact velocity of 805 meters per second penetrates a glass laminate, consisting of four glass plates and a polycarbonate plate at the backside. Damage in the glass is visualized by a contour plot of the damage parameter *D*. During the penetration of the tungsten carbide projectile (black), damage fronts are propagating radially from the symmetry axis towards the edge of the target. Damage starts from the impact side in the first glass layer, whereas in the other three layers, damage starts at the back side of the single layers and propagates against the impact direction. A similar behavior can also be observed in the experiments; however, the onset of fracture is occurring 8 to 19 microseconds later than in the simulation. Nevertheless, a strong correlation can be found between the onset of fracture in the experiment and the simulated position of the projectile position when damage starts at the impact side of the glass plates.



3a Planar plate impact facility for material characterization in the highly dynamic loading range.



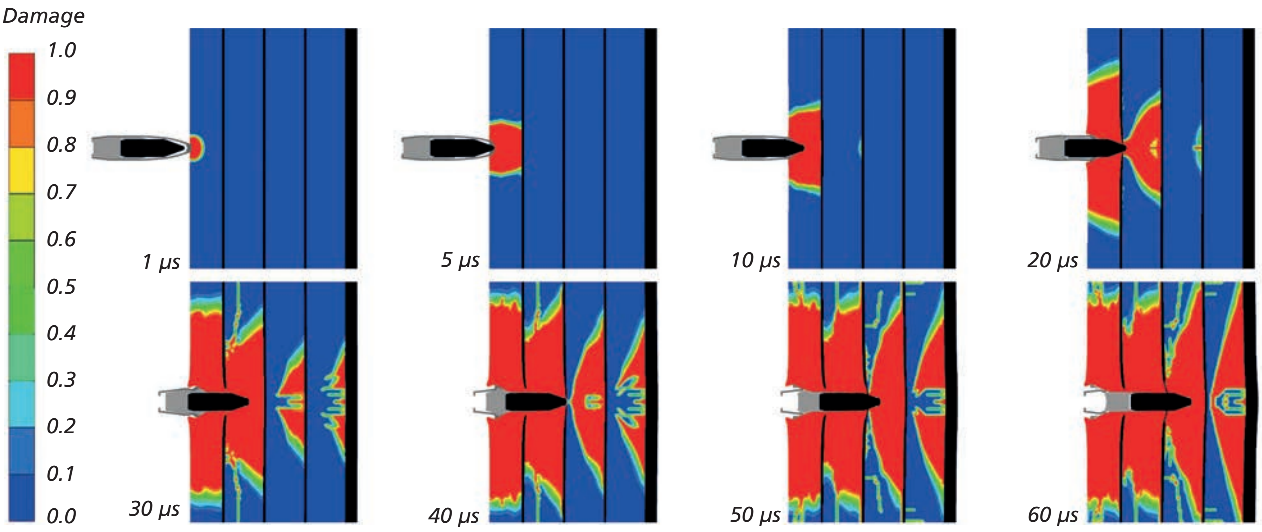
3b Sabot with projectile plate (left) and schematic representation of planar plate impact test (right).



4 Characteristic PDV velocity signal from plate impact test with two glass samples.

Conclusion

The necessary steps for the characterization of brittle materials for ballistic protection have been demonstrated using the example of a transparent protective structure. The knowledge of material properties under high dynamic loadings is the prerequisite for meaningful predictive simulations in order to support the design of ballistic protection. A comparison of experimental and numerical results has indicated that improved models are necessary particularly for the prediction of damage. This is also true for ballistic protection with opaque brittle materials like alumina, silicon carbide and boron carbide.



5 Simulated damage in glass during penetration of an AP projectile in glass laminate; Completely damaged material (D = 1) is represented in red. After 60 microseconds, nearly all glass elements around the shot axis are damaged.

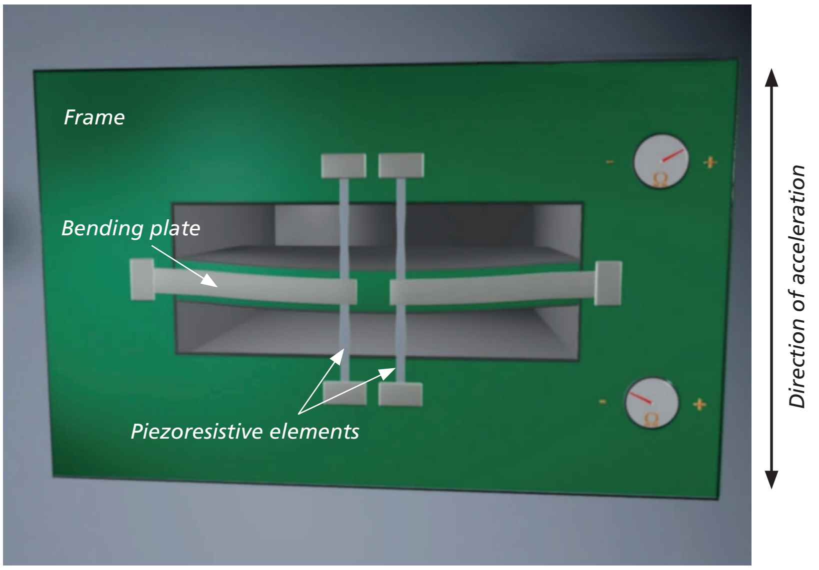
3D accelerometer

For several years, Fraunhofer EMI has been pursuing the development of a highly shock-resistant accelerometer, which is suitable for various measurement tasks in the analysis of highly dynamic processes. This includes, among others, dynamic material characterization, the study of blast and impact events and the development of reliable fuse components. Accelerations of more than 100,000 g, which occur in these processes, can be measured reliably with the new sensor.

In the mentioned measurement tasks, it is usually sufficient if the sensor is able to measure the acceleration in one spatial direction ("1D sensor"). This is mainly due to the laboratory conditions the sensor is used in. The force on the specimen is well defined and thus, the direction of the acceleration is known. In full scale experiments, complex test setups and, of course, in the application, however, the movement of the test object cannot always be predicted. Here, it is important to detect the acceleration in all three spatial directions. One possibility is to mount three 1D sensors perpendicularly to each other on an adapter block and connect it to the test specimen. However, this method requires a lot of space and weight and is relatively expensive. The monolithic integration of the three measuring directions on a single sensor chip, which, however, is accompanied by the need of a corresponding development effort is more elegant. At EMI, the second variant has been targeted and the design of a 3D version was developed based on the existing 1D sensor. Both models are presented in the following section.

1D sensor

Besides using optical methods, high-g acceleration measurements typically use MEMS-sensors (**m**icro **e**lectro-**m**echanical **s**ystems). The EMI sensor is a piezoresistive accelerometer, fabricated with micromechanical methods. Figure 6 schematically illustrates the geometry of the sensor. The main components are the bending plate and the piezoresistors, both of which are machined from the same piece of single crystal silicon, and thus are connected particularly stable. On acceleration, the plate is displaced from its rest position, wherein the deflection in the middle of the front edge is largest. At this point, the self-supporting piezoresistors are spanning the two trenches which define the plate. The measurement signal arises from the fact that due to the deflection of the plate, the piezoresistive elements are stretched or compressed, measurably changing their resistance. They are electrically connected to form a Wheatstone bridge, in order to record the movement of the plate with high accuracy.



6 Schematic representation of the sensor. The resistors are fixed to the point of the largest deflection of the plate in order to achieve maximum sensitivity.

The dimensions of the bending plate are on the order of a few hundred microns and can be adjusted for the desired measurement range. The piezoresistive elements are the most delicate structures of the sensor and have a diameter of a few micrometers. The outer dimensions of the sensor element are in the order of one millimeter. Figure 7 shows a photograph of the silicon chip under a light microscope. One can see the aluminum contacts, which represent the electrical interface to the outside world as well as the trenches defining the bending plate. The sensor chips are manufactured in cooperation with Fraunhofer EMFT.

In order to make the silicon element usable as a sensor, it is packaged with a ceramic multi-layer process (LTCC). The resulting package, which was developed together with Fraunhofer IKTS, meets the requirements for mechanical robustness and allows various contacting solutions, e. g. the use of the sensor as an SMD component (Surface Mounted Device). Figure 8 shows the housing soldered to a test board. It has a height of 2 millimeters and an area of 3 x 6 square millimeters.

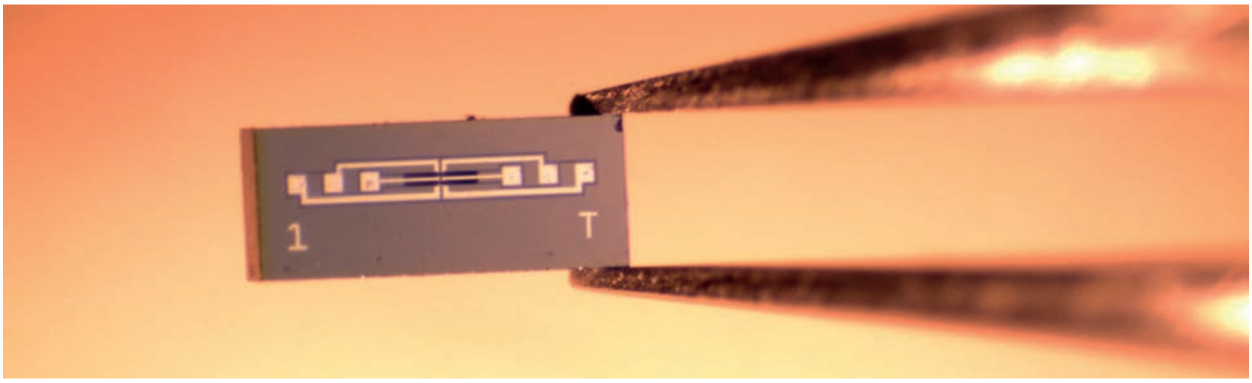
Due to the special geometry of the sensor chip, an innovative method was used to realize the design. It is a new direct-write method for micro conductors. Figure 9 shows an enlarged view of the housing shown in Figure 8 (right), without the lid. The chip is glued to the blue ceramic carrier with its electrical contacts facing forward. Thus, a 90° contacting from the chip-pads to the electrical pads of the ceramic is needed, which is realized with the new direct-write method. The EMI sensor is the world's first upright MEMS, which is contacted with printed conductor paths.

Characteristics 1D sensor

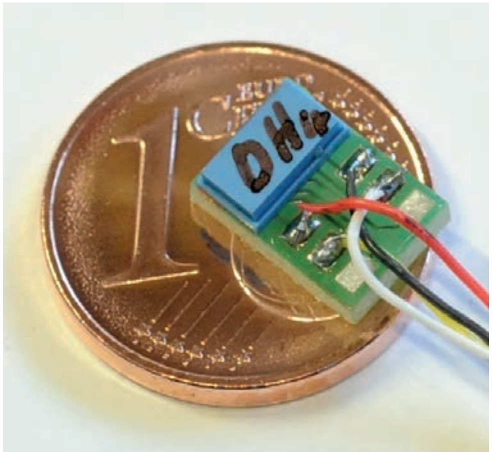
The main characteristics of the 1D sensor were determined. The values, which are obtained for sensitivity and natural frequency are crucial, as these are critical to the quality of the sensor measurement of highly dynamic processes. In Table 1, the properties are compared with two piezoresistive sensors, which are the current references in the shock test area. The EMI design stands out in terms of sensitivity and natural frequency, as it offers higher values in both and is thus superior to the references. In addition, the EMI sensor can relatively easily be extended to a 2D or 3D concept due to its geometry.

	Reference A	**Reference B**	**Fraunhofer EMI**
Sensitivity	0.09 µV/V/g	0.21 µV/V/g	0.50 µV/V/g
Resonant frequency	1.34 MHz	164 kHz	1.50 MHz
Simple 2D/3D integration?	No	No	Yes

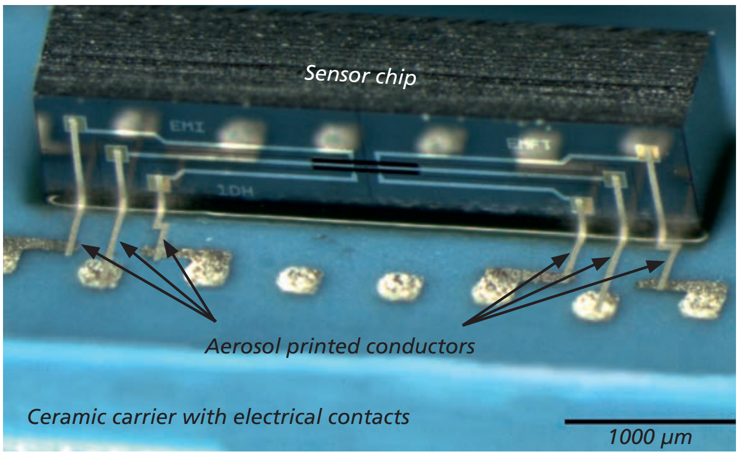
Table 1 Comparison of the characteristics of the EMI 1D sensor and reference accelerometers.



7 Photo of the sensor chip under an optical microscope. The bright surfaces are aluminum-coated and used as electrical contacts. The small dark areas in the center of the chip are the trenches which define the bending plate. The piezoresistive bridges cannot be identified due to their small size.



8 Image of the ceramic package. It is SMD mountable and has a flat and thus mechanically stable design.



9 The chip with direct-write conductor paths. The 90° angles that are crossed by the conductors, in order to connect the forward facing chip pads and the ceramic pads are the unique feature (Image: Fraunhofer IKTS).

3D sensor

With the EMI design, it is possible to monolithically integrate several measurement directions (2D and 3D) onto one chip and thus efficiently increase the measurement capabilities of the sensor. Figure 10 shows the new 3D silicon chip. In the central region, two 1D sensing elements are arranged perpendicular to each other. They measure accelerations in the image plane (X- and Y-directions). To the left and right, elements are integrated that detect the movement perpendicular to the image plane (Z-direction). As for the 1D version, the 3D chip is also packaged in a multi-layer ceramic housing, which is shown in Figure 11.

Experimental characterization of sensors

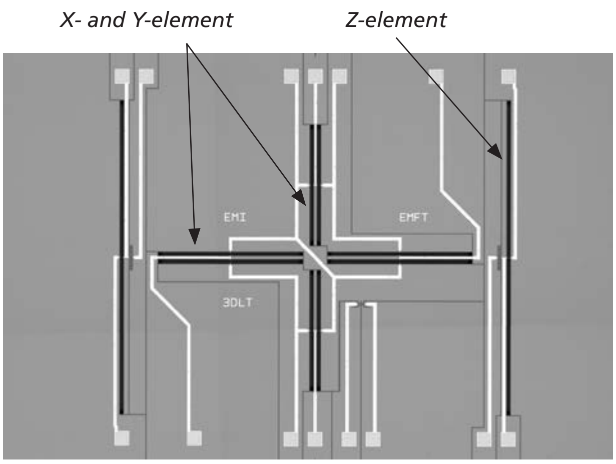
The experimental characterization and calibration of the sensors represent a particular challenge. The only system that can produce sufficiently reproducible and well-defined high-g loads on a laboratory scale for these purposes is the Hopkinson bar. It is the standard method for testing 1D shock sensors and was used to characterize the 1D variant accordingly.

The Hopkinson bar is a long, homogeneous bar (see Figure 12), in which a mechanical wave is induced. The sensor is mounted on the far end of the rod, which in our case is made of titanium. The wave travels through the bar up to the sensor and accelerates it in less than 30 microseconds to a speed of several meters per second. Due to the rapidness of the movement, accelerations of up to 100,000 g occur. This test pulse has a very high reproducibility. Figure 13 shows a measurement of the acceleration with a peak value of more than 100,000 g in both positive and negative measurement direction. The signal of the sensor is referenced with a high precision optical system, a so-called laser vibrometer (see Figure 12). The two measured curves agree very well and prove the high signal quality of the EMI sensor. After the initial acceleration (positive and negative peak), the signals start to differ because of the systems' different resonant frequencies.

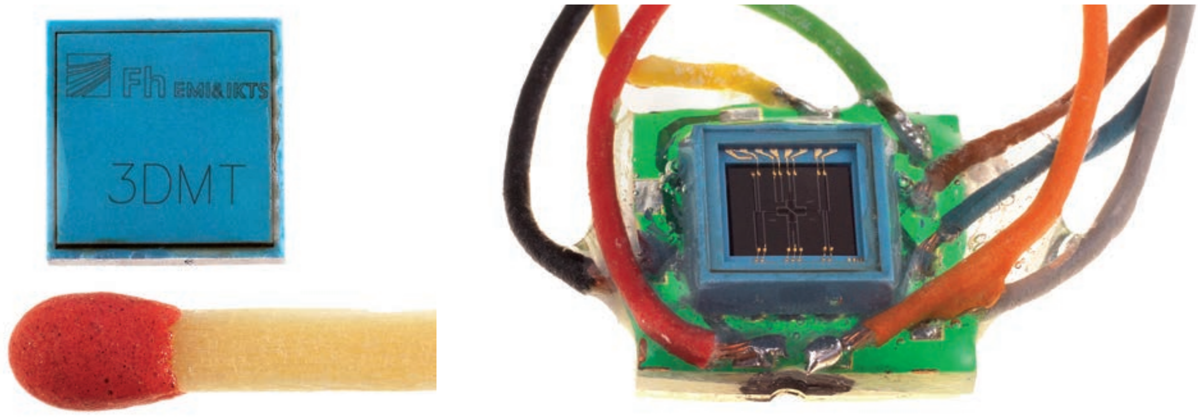
For the 3D sensors, the calibration can in principle be conducted on the same system. The concept is simply to load the sensor once in each axis. If possible, one also measures the acceleration in the transverse direction and receives the transverse sensitivity of the sensor axes as further output.

In practice, however, this approach turns out to be quite difficult. Because the sensor is in an SMD package, it must be soldered to a test PCB, which cannot be fixed onto the Hopkinson bar with its sides. Therefore, an adapter was designed, in which the sensor can be fixed for characterization in all three spatial directions. Figure 14 (next page) shows the structure.

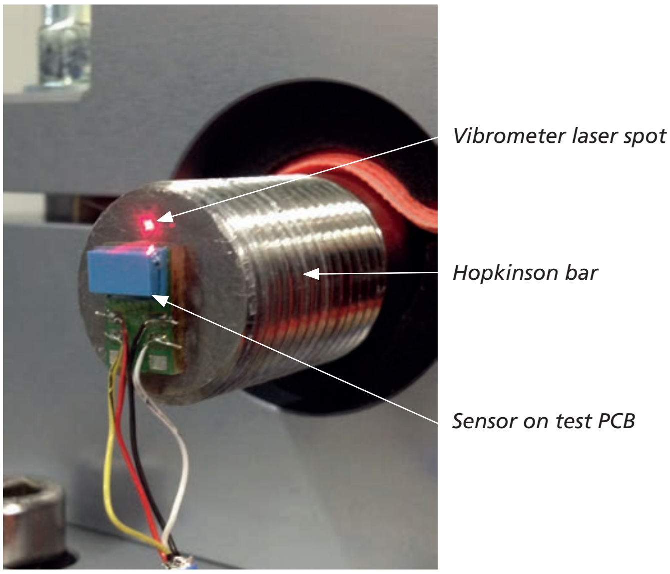
The use of an adapter, however, has the disadvantage that the stress pulse of the bar is no longer homogeneous. The traveling mechanical wave is disturbed by the adapter. Thus, the resulting acceleration is distorted and loses its reproducibility. In addition, stronger lateral accelerations occur in the bar, which are not relevant in the 1D configuration. Figure 15 shows one measurement for each axis of the 3D sensor. The measurement of the Z-axis is carried out in the normal configuration (see Figure 14) and for the X- and Y-axis, the sensor was attached to the side of the adapter. As a reference measurement, a 1D sensor was adhered to the end face of the bar in the second configuration.



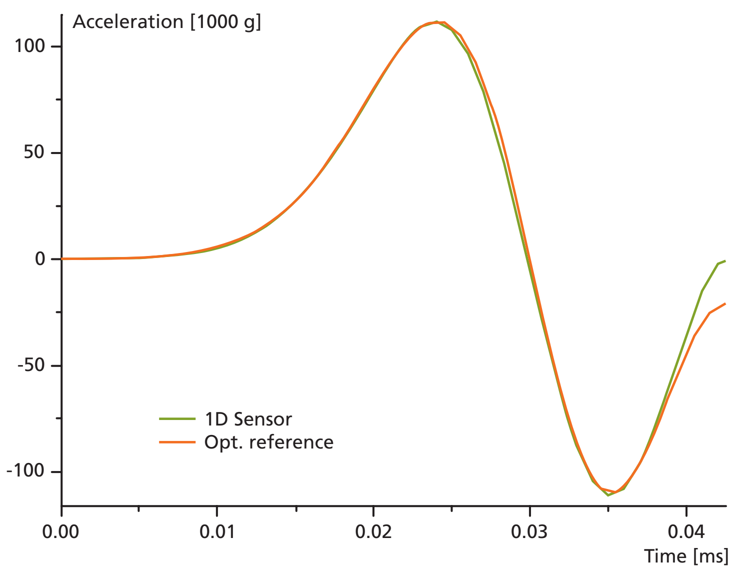
10 Silicon chip oft he 3D accelerometer. In the central region, two 1D elements are used to measure in X- and Y-direction. On the sides, two elements are responsible for the detection of the Z-movement.



11 *3D sensor inside ceramic package (left). Sensor chip in open housing mounted on a test PCB (right).*



12 *1D accelerometer on the Hopkinson bar. This end of the bar makes a rapid movement that is detected by the sensor as a short acceleration. A laser vibrometer is used for a reference measurement.*



13 *Acceleration measurement of the EMI sensor and the optical reference on the Hopkinson bar. The signals agree very well and verify the measurement range of the sensor being larger than 100,000 g in positive and negative direction.*

Despite the problematic behavior of the adapter, first values for the sensitivities of the three sensor axes could be determined. They are shown in Table 2 and are within the design goal of about 0.5 µV/V/g.

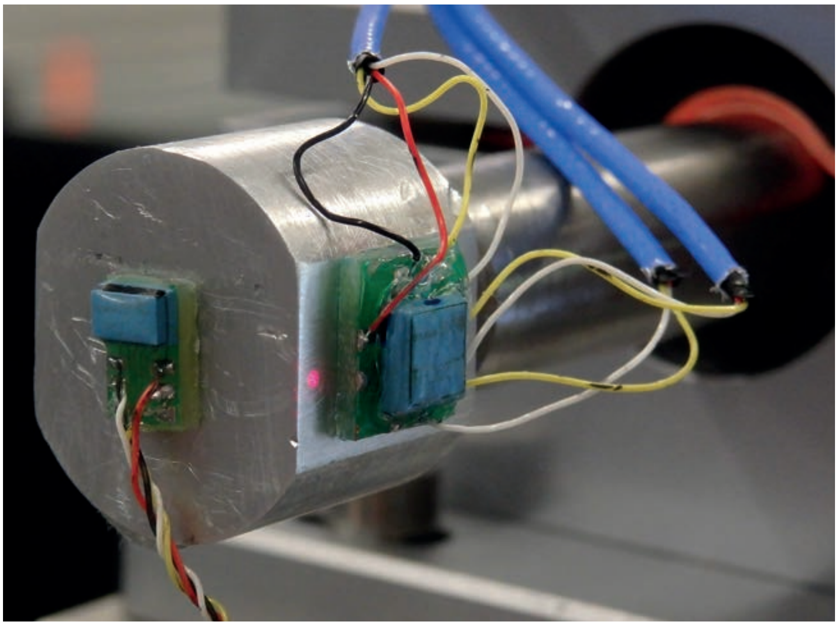
Summary

With the existing high-g sensor and its successful upgrade to a 3D-capable device, the German and European industry and research institutions have a new powerful measurement tool at their disposal. The sensor exceeds the US reference models in terms of natural frequency and sensitivity considerably and has no counterpart as a monolithically integrated 3D high-g sensor on the market.

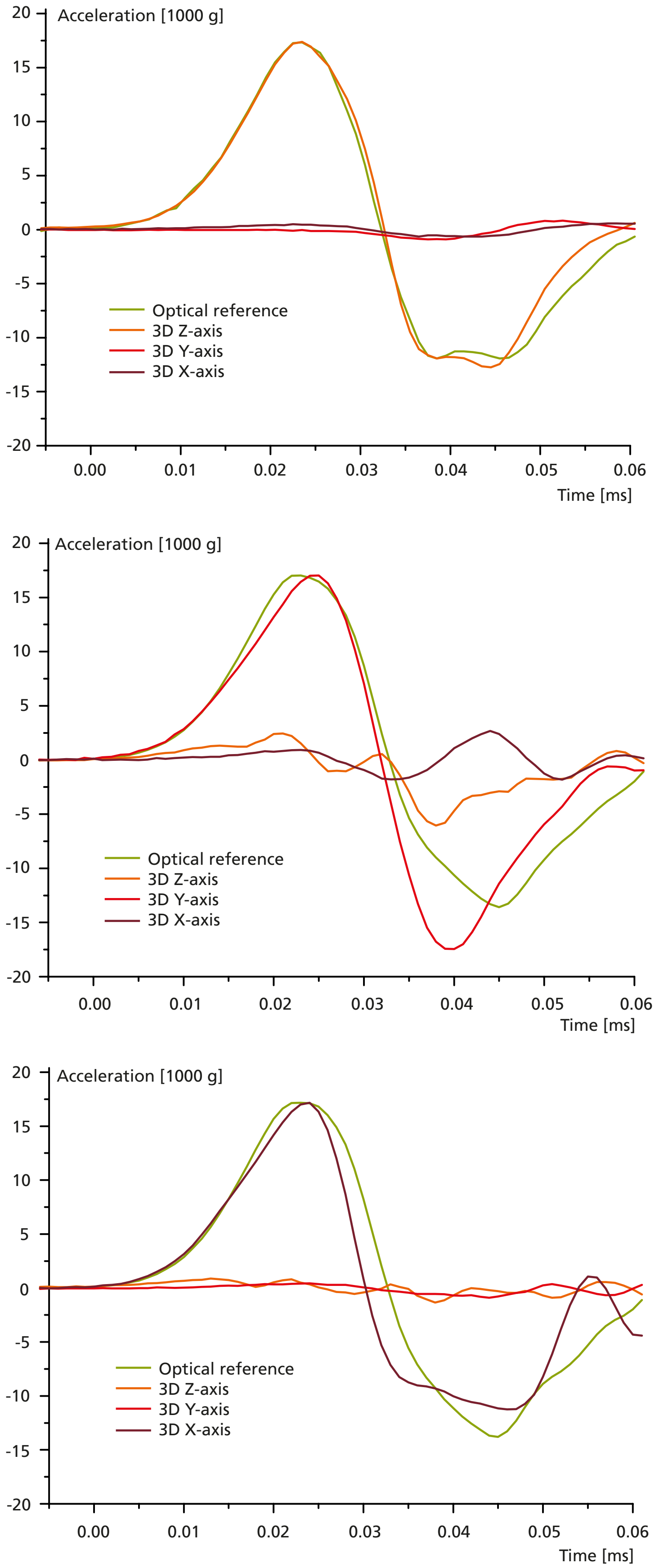
A difficult task is the exact determination of the characteristics of all three axes of the 3D design, since no adequate test systems exist. Especially the quantification of the transverse sensitivity of all axes with respect to each other is particularly challenging.

	X-axis	Y-axis	Z-axis
Sensitivity	0.5 µV/V/g	0.3 µV/V/g	0.6 µV/V/g

Table 2 First values for the sensitivities of the 3D accelerometer.



14 Hopkinson bar with adapter for 3D sensors. A 1D sensor is positioned at the end face of the rod (i. e. in a normal configuration for measuring the Z-axis) and a 3D sensor is fixed on the side of the adapter. This way, the latter can be loaded in X-direction or, rotated by 90°, in Y-direction.



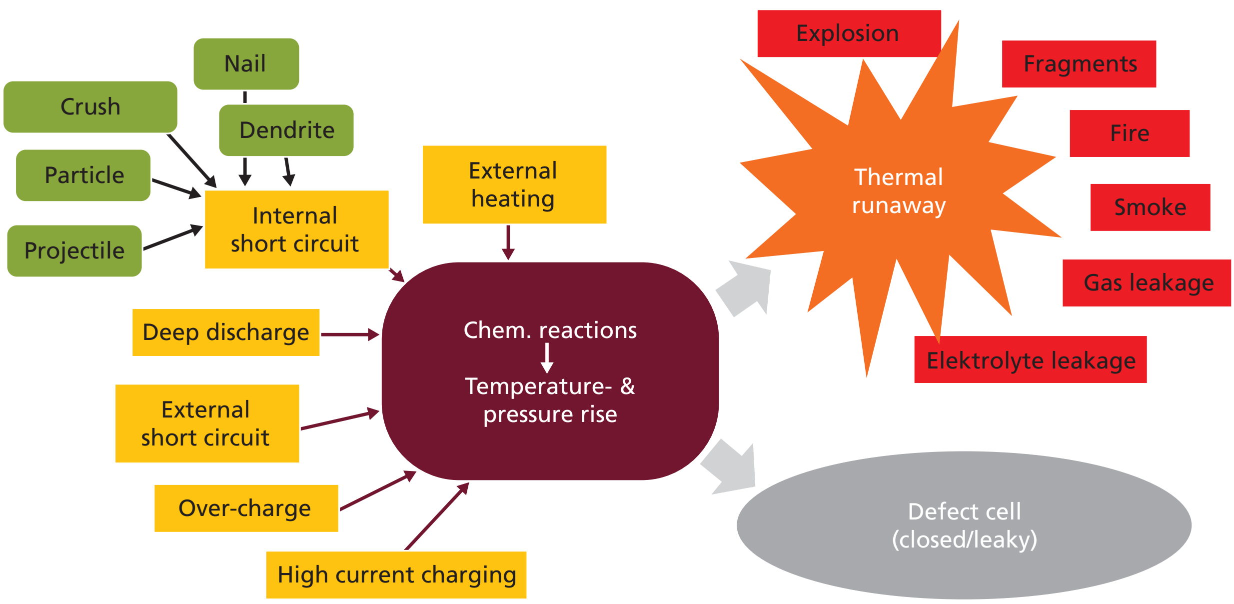
15 Measurement of all three axes of the 3D accelerometer. The signals show disagreement, but are sufficient for a first sensitivity determination.

Safety of electric energy storage systems in case of failure

The rapid development of novel electric energy storage systems in the civil area provides new opportunities for the German Armed Forces as these systems allow for new functionalities and help in sparing weight and space. That is why electric energy storage systems find increased applications on all platforms, from battery packs carried as personal equipment to traction batteries in electric vehicles. However, the increased energy density of these storage systems entails correspondingly higher hazard potentials, which bear special importance in the defense sector as the specific hazards relevant in this sector, caused by firing and high mechanical loads (crash), are mostly not covered by civil test procedures. Accidents with such storage systems or firing hits can result in fire, poisonous gas release, or even an explosion of the whole storage system. Depending on location and dimensions of the storage system as well as surroundings and position of the soldier, substantial hazards may result. Hence, an analysis of the hitherto unknown failure mechanisms and the conditions/loads which lead to specific reactions is of great importance. It has significance for a critical evaluation of potential risks as well as the design of effective safety measures.

Figure 16 schematically depicts possible reaction channels which may lead to uncontrolled energy release of a battery cell. Different exterior events reaching from false handling during the charging process (overcharge) through accidents (mechanical deformation) to projectile impact may induce exothermic chemical reactions inside a Li-ion cell, which can entail temperature and pressure rises. This in turn may trigger further internal decay reactions of the electrodes and finally provoke a so called thermal runaway, the worst case scenario. The danger of such a process becomes apparent from the fact that the releasable chemical energy content of a Li-ion cell is typically an order of magnitude higher than the technically useable electro-chemical energy of that cell.

Currently, at Fraunhofer EMI, different investigations on Li-ion secondary cells are conducted in order to analyze potential hazards and reaction mechanisms of modern energy storage systems in case of failure (crash, projectile impact and penetration). Simultaneously, methods are being developed for the characterization of these systems with respect to the special requirements of the German Armed Forces.



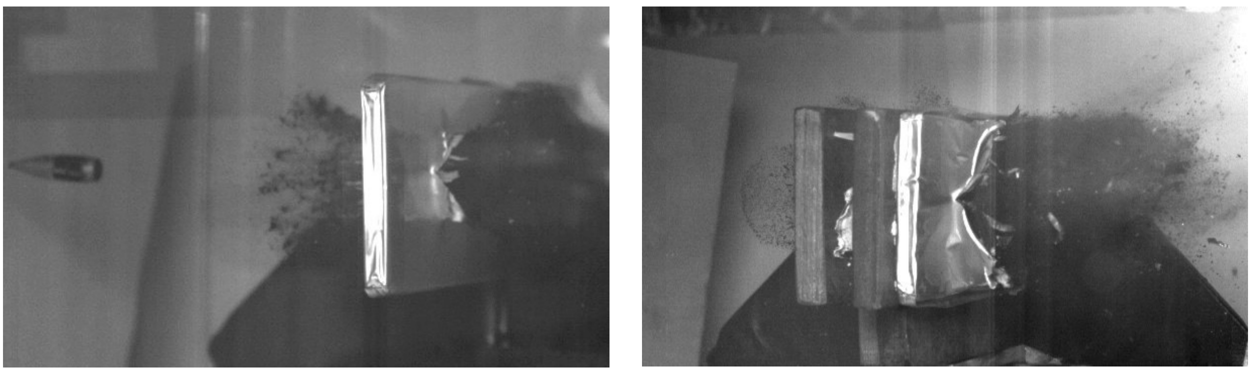
16 Flowchart of possible cell failures. Different exterior or interior events (yellow) can provoke chemical reactions inside the cell, which can entail temperature and pressure rises. With sufficient temperature increase, a thermal runaway results.

In one test series, firing on Li-ion pouch cells was investigated. For this, charged and uncharged cells have been fired at in different configurations. The process was registered by a high-speed camera, and voltage as well as cell temperature were measured. Figure 17 depicts exemplarily two high-speed pictures. On the left side, a penetrating shot of a freely pending fully charged Li-ion pouch cell is shown. On the right side, the same process is shown with a cell fastened to a steel plate as backing. Used projectiles were DM-111-bullets, which hit the target with a velocity of approx. 850 meters per second.

The freely pending cell is penetrated by the projectile, whereupon cell material is blown out (Figure 17, left side). Figure 18 depicts the corresponding voltage time history of the cell during the penetration process. While being penetrated, the cell voltage breaks down. Soon afterwards though, the voltage rises again to the normal charged value. This indicates that no permanent short circuit was formed by the penetration process. The cell keeps its charge after being penetrated and remains functional, even if with reduced capacity. As no permanent short circuit with continuous discharging is formed, no heat is developed and no chemical reactions are initiated. Neither a temperature increase nor smoke or fire were observed in all tests. The hazard in this scenario is limited to the blown out toxic substances.

Very rarely, a discharge of a cell occurred after impact. Even in these cases, no significant temperature increase or chemical reactions have been observed. Yet, this result is relevant only for the hitherto investigated pouch cells which do not have a rigid housing. Other cell types as well as pouch cells with an extra housing as in a real application can entail different hazard potentials. Hence, the investigations will be continued next year.

A second test series comprises fundamental investigations on the reaction mechanisms after an internal short in a cell. In a joint project with the Fraunhofer Institute for Chemical Technology (ICT), miniaturized cells were examined with X-ray technology. The mini-cells, developed by the ICT, contained only one layer of anode, cathode and separator. By this, cells with a width of only 3 millimeters could be realized by the ICT and provided for the EMI investigations. The small dimensions of the cells allow not only a high local resolution during an X-ray analysis. In addition, they enable a detailed numerical modeling of processes inside the cell with full resolution of all relevant structures which is impossible with cells of greater dimensions due to their high number of internal layers. Hence, the mini-cells suit ideally as test objects and for the validation of numerical models.

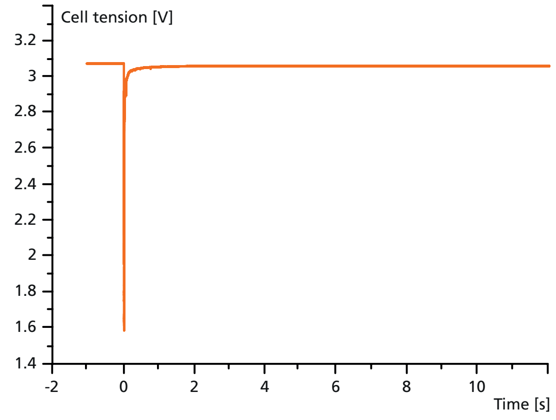


17 High-speed-photographs of the bombardment of charged pouch cells. Left: without backing, right: with steel backing.

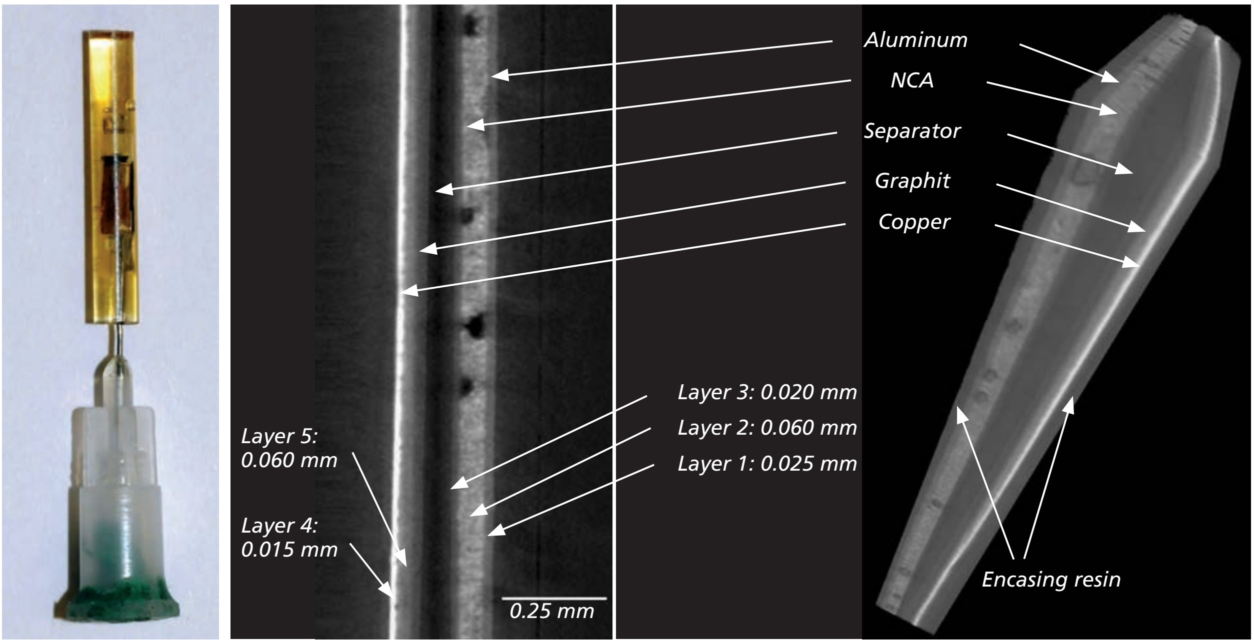
Figure 19 depicts a photograph on the left side, a CT slice image in the middle and a 3D render image of a mini-cell on the right side. Voxel dimensions of approx. 2 micrometers could be realized. Every single cell layer is clearly discernable on the CT-pictures. Correspondingly, internal short circuits with diameters < 10 micrometers should be detectable and could be analyzed dimensionally.

In order to use this technique for the analysis of internal short circuits and corresponding failure mechanisms, further improvements in cell production are necessary as the cells, up to now, are neither sufficiently homogeneous and flat nor electro-chemically operative. The right side picture (render image) of Figure 19 clearly shows the distortion of the copper sheet over the thickness of the cell.

It is planned to investigate improved mini-cells with implanted internal short circuits in the next step. These cells will be surveyed dimensionally by X-rays, electrically analyzed (short circuit resistance and current), and modeled numerically. We expect that a model, validated through detailed tests in the mini-cells, will provide valuable predictions about the hazards of real world Li-ion storage systems in different scenarios.



18 Penetrating shot of a charged Li-ion pouch cell without backing. Only mechanical damage has been observed, no chemical reactions occurred.



19 Left: photography; middle: CT slice image; right: cut 3D render image of a mini-cell.

SAFETY TECHNOLOGY AND PROTECTIVE STRUCTURES

SAFETY TECHNOLOGY AND PROTECTIVE STRUCTURES

The developments and events of the last few years have unfortunately indicated how fast the security situation and the felt security can change. The global political changes as well as the increase of natural phenomena assigned to climate changes prove that it is essential for the preservation and development of the private and public security to address initially unimaginable threat situations and potential hazards at an early stage.

Over the past year, the Department for Safety Technology and Protective Structures has contributed to this by examining the consequences of unplanned, unusual events which have an effect on technical systems or built infrastructures.

Multi-scale consideration levels reach from miniaturized electronic systems, the consideration of multi-technical overall systems to the analysis of buildings and even whole urban areas. Besides that, the analyses not only considers the direct primary consequences of an event, but also, the other effects arising from the primary consequences, which can continue in a cascade-like manner.

The quantitative risk analysis is the common base of the investigations for different systems and consequence levels. Here, based from a hazard and threat analysis (HTA) and a consequence analysis (CA), the risk and vulnerability assessment (RVA) of a system or building is evaluated and determined. If this is above the acceptable limit, it must be reduced to an acceptable limit with countermeasures. This is made clear in Figure 1 (next page) by the non-acceptable damage of the reinforced concrete slab on the right, which can be reduced to a minimum by the use of a ductile concrete with the same load (on the left).

Thereby, the quantitative risk analysis also allows increasing the sustainability of systems and buildings, because with life cycle considerations, the influence of the unusual events becomes detectable and assessable. Due to the increase of the systems' robustness

Dr.-Ing. Alexander Stolz
Head of Safety Technology and Protective Structures
Phone +49 7628 9050-646 | alexander.stolz@emi.fraunhofer.de

through extended utilization periods, ecological and economic resources are saved. In addition, resilience, which is defined as the capability to prepare for, respond to, and recover from an incident, can be increased through a better understanding of vulnerability.

Within this context, different research results of the last year are introduced providing important insights into the different phases of the risk analysis applied on very different systems.

We want to show how decisive load scenarios beyond the standardization for big multi-functional complexes of buildings can be defined by quantitative risk analyses. Following that, the new methods are shown that allow to further improve and adapt to future requirements for the security and passenger's satisfaction at airports by optimized designs of security systems. Besides that, solutions are indicated that can be realized with the help of the developed decision support software IDAS within the scope of urban security analyses. In the area of physical protective structures, the derivation of an assessment method is explained for ductile wall elements made of a high-performance material, which can be used if other preventive measures cannot be used.

1 Process cycle in the risk management when facing extreme events.

SAFETY TECHNOLOGY AND PROTECTIVE STRUCTURES

Load scenarios for multifunctional large-scale buildings

The objective of the research project is to provide a planning basis for multifunctionally used, representative complexes of buildings in urban surroundings, so that these not only comply with usual design situations, but also show a sufficient robustness in relevant extreme loading events. Such load scenarios are not quantified, or only insufficiently, in the appropriate standards on load definition. This is why a consideration through a quantitative risk analysis is required.

An assessment close to the reality of the building loads that on the one hand leads to an unerring dimensioning of load-bearing structural components and, on the other hand, to a sufficient dimensioning of technical equipment elements of the building is essential to achieve the necessary operational safety. Within the scope of the EU project ELASSTIC "Enhanced Large Scale Architecture with Safety and Security Technologies and Special Information", methods are compiled that will allow to carry out such a risk analysis for big, multifunctional buildings.

A way used in quantitative risk analysis to determine extreme load events is the evaluation of past events. Taking into account the temporal development, qualitative statements about the future development of the load events can also be derived.

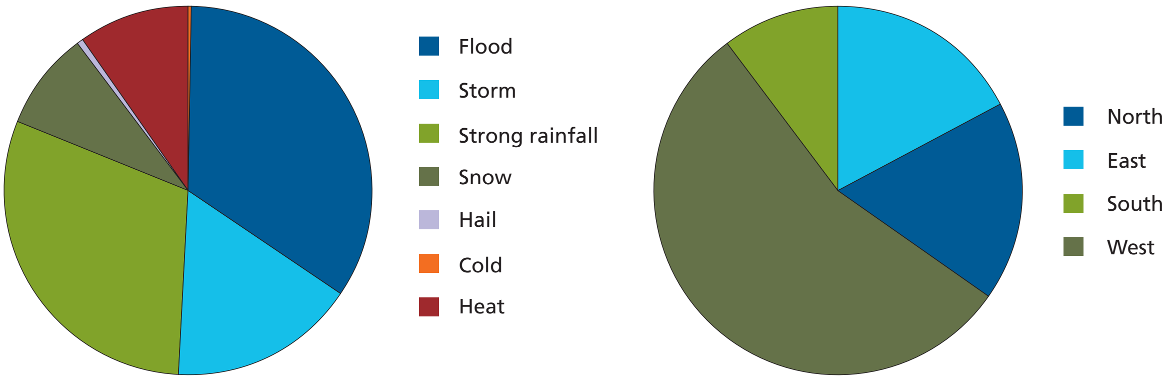
For terrorist events, the Terrorist Event Database (TED), which is used to evaluate relevant loads as a result of man-made events, has been developed at Fraunhofer EMI. Besides, it is just as necessary at the stages of the planning of buildings and structural assessments to consider extreme effects of other sources, as for example results of natural events and accidents.

Hence, extreme natural phenomena were also considered extensively in the research project "Elasstic" for the first time, such as extreme wind loads and extreme precipitation with flood as well as distinctive periods of heat or cold. In addition, an accumulated databank of natural/weather-conditioned events was developed that lists the events that have occured in Europe since the 50s of the last century.

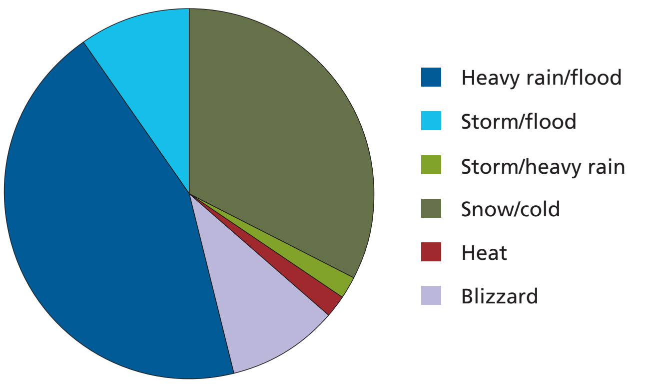
2 Large urban infrastructure.

Category	Events with structural damage	Events without structural damage
Natural phenomena	Strong wind Strong rainfall Snowfall, ice, hail Flood Earth movements	Heat wave Cold wave
Accidents	Explosions Impact Fire	Smoke Air pollution Water pollution Heat
Sabotage and terrorism	Explosions Impact Fire	CBR attack Cyber crime

Table 1 Possible extreme load events on a multifunctional building complex in Europe.



3 Extreme weather phenomena in Europe; left: types of extreme events, right: affected regions.



4 Combined extreme weather phenomena in Europe.

A significant influence on the development of extreme weather events is ascribed to the climate change. Hence, the analysis of such events also aimed to include the future development of precipitation, wind and temperature with the help of forecast models.

The named relevant events (Table 1) must not necessarily have a damaging influence on the architectural structure. They are also considered if they have a direct influence on the users of the building. For example, it is necessary at distinctive temperature events to lay out the system of the technical building equipment according to these demands.

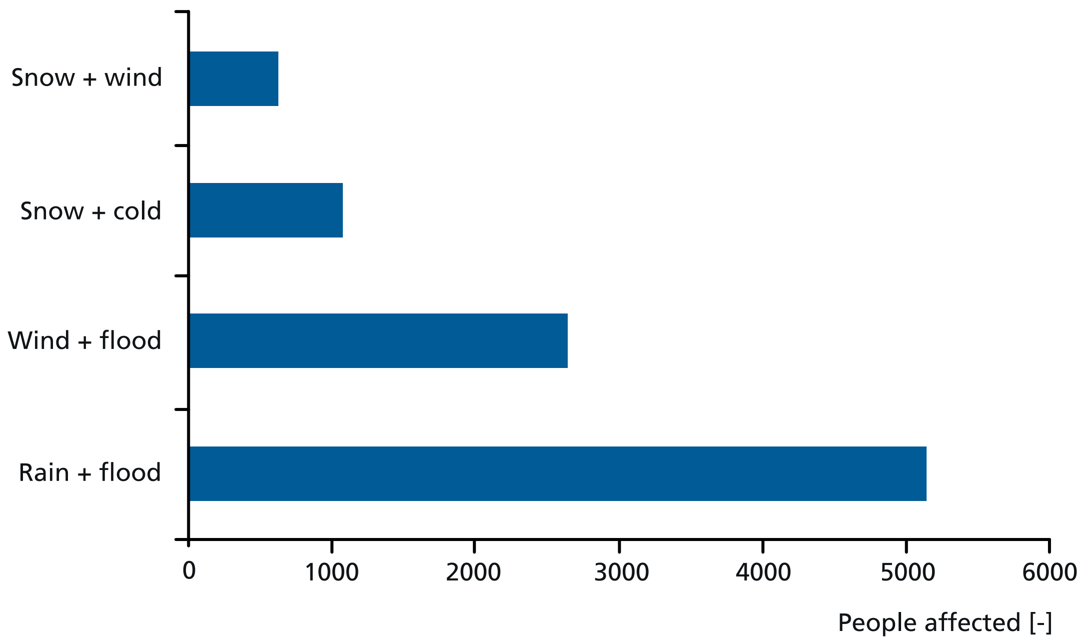
Figure 3 and 4 show the evaluation of the databank for natural phenomena. Figure 3 on the left shows the statistical evaluation of extreme weather events in Europe. The figure on the right illustrates the regional appearance of extreme weather events. It is recognizable that in the past, flood events, strong rain and strong wind were the dominating events.

Due to the geographic situation, most events took place in Western Europe, and strong wind and strong rain, which led to floods in the mountainous area, were dominant here.

Furthermore, we found out that extreme weather events mostly appear as combined weather events. For example, strong rain can lead to floods. In coastal regions, it is often to be reckoned with strong winds and floods and a storm surge originating from it. Figure 4 shows an overview of widespread events. It becomes visible that floods as a result of strong rain take the biggest share in combined events, which requires special preventive measures in terms of the architectural structure.

The numbers of affected persons that has a basic meaning for the calculation of the individual risk are summarized for the most important combined extreme weather events in Figure 5.

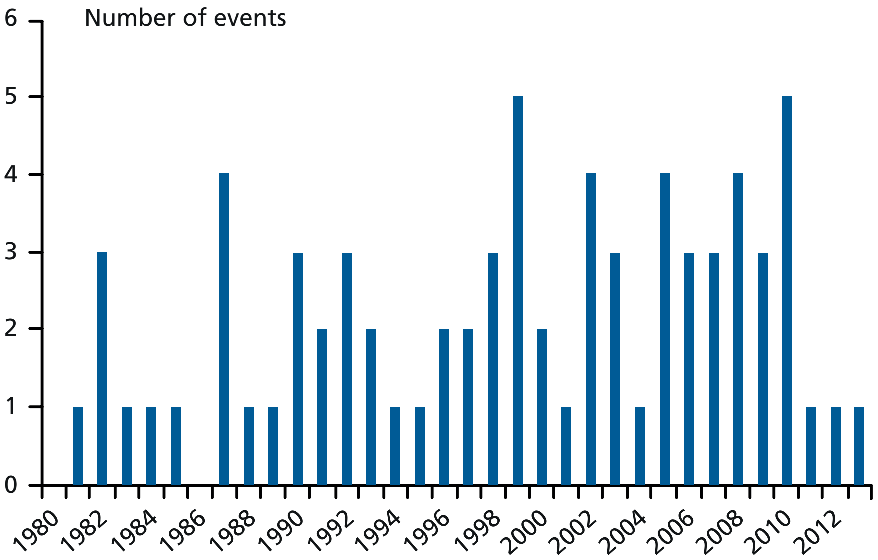
Therefore, the analysis carried out allows quantifying the individual risk of affected persons of a combined weather event in Europe by regions (Figure 6 and 7, following page). The biggest risk for the population in Eastern Europe is being involved in an event with strong wind and strong snowfall (East_Wi_Sn). In Western Europe and Southern Europe, however, dominant flood events as a result of strong wind (West_Fl_Wi) and strong rain (South_Fl_Ra) occur in coastal regions.



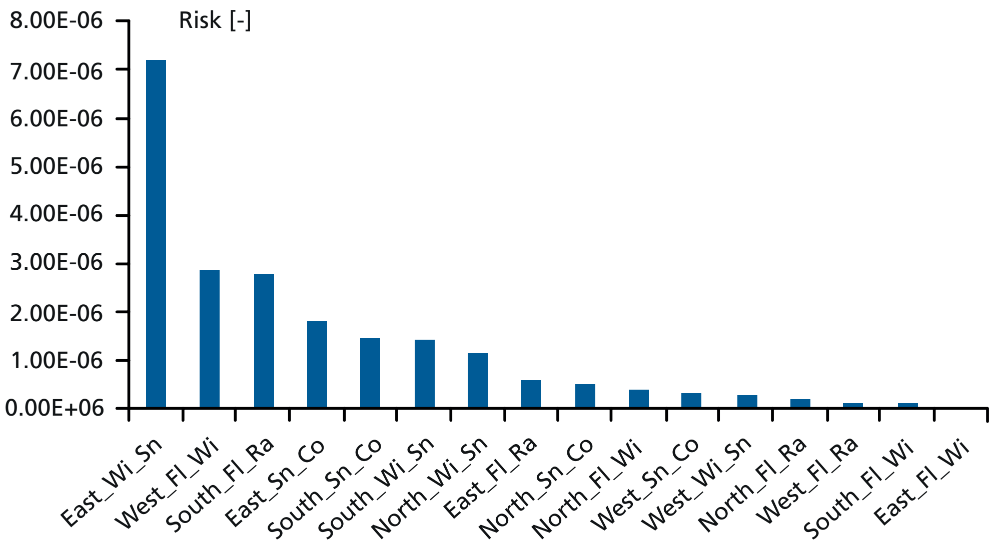
5 Number of people affected by combined weather events in Europe.

The temporal return of extreme events concludes to a qualitative trend which allows estimating the future weather developments with the assistance of climate models and therefore, compiling a forecast of the future. Exemplarily, the appearance of extreme weather events in Europe is summarized in Figure 6. A recognizable trend in weather events since the 80s is visible.

Based on the obtained results, the risk analysis delivers important information for the planning process of such multifunctional building complexes, which allows an integration of architectural measures for the reduction of damaging influences of these events at an early stage.



6 Temporal distribution of extreme weather events in Europe from 1980 to 2013.



7 Risk comparison for extreme weather events in Europe for the identification of relevant load events.
The horizontal axis shows all relevant load events (as combined events).
The identification is made up as follows: Region in Europe_Natural event 1_ Natural event 2
(Example: East_Wi_Sn: Eastern Europe_Wind_Snow: combined event in Eastern Europe with wind and snow.
Further abbreviations mean: Wi = Wind; Fl = Flood; Ra = Rain; Co = Cold.

New concepts for airport security and passenger satisfaction

The civil aviation is constantly facing new challenges for more security and the protection of airplanes and passengers. Since the late 60s, authorities and airports have introduced obliging security examinations of passengers as a reaction to numerous incidents before the entry into an airplane. After the attacks from September 11, 2001, security measures have been tightened several times. This is not least due to the fact that since then, attempts were undertaken over and over again to smuggle new dangerous substances or objects on board of airplanes. However, as a result of the intensification and increasing complexity of the security checks, the raised security standard brings also disadvantages for different interest groups.

Airports have to provide more space for security checkpoints, passengers have to queue up longer. This leads to more missed flights, dissatisfaction among passengers, sales losses for companies at the airport and higher costs for the public authorities, which have to finance the security at airports.

Fraunhofer EMI develops a software for the evaluation and simulation of security checkpoints on the system level. This comprehensive evaluation platform (SEP) should run automated analyses that consider the needs of all stakeholders through an intelligent mix of the performance indicators and indicates thus, in the end, ways to a balance between security and acceptable disadvantages.

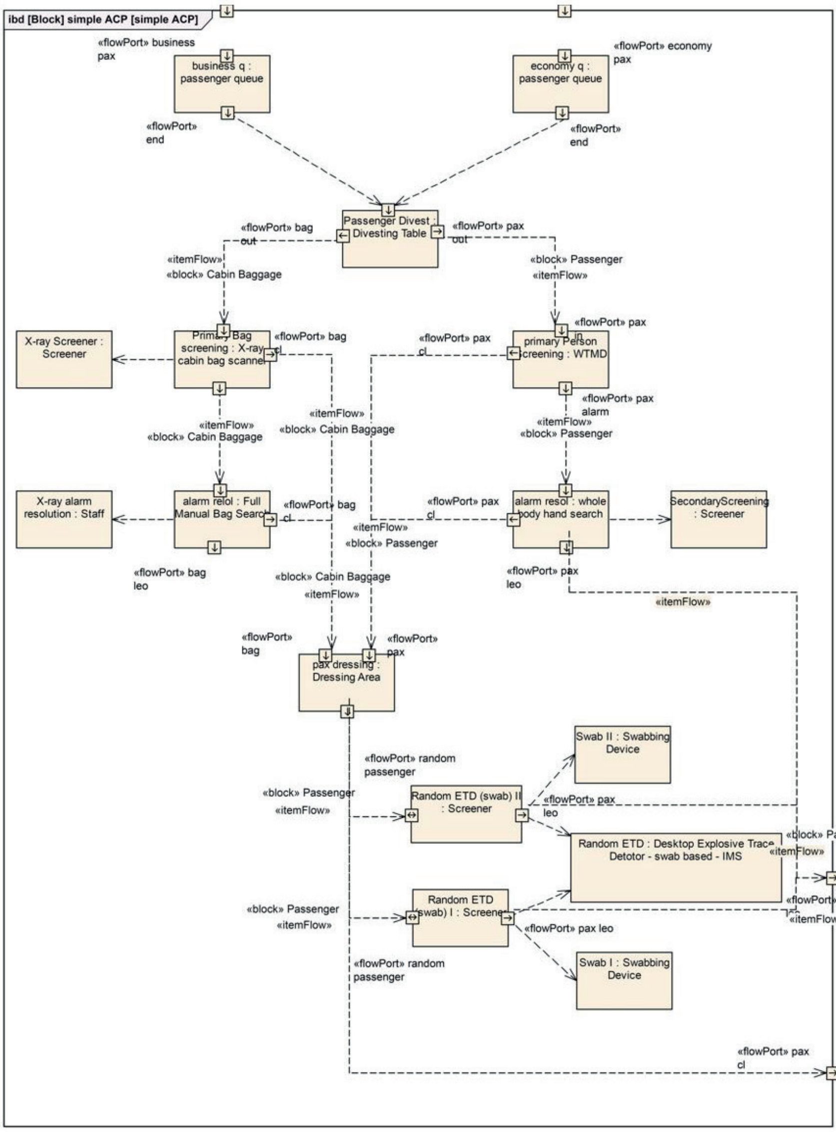
Instead of looking at optimized and accredited components individually, EMI examines the impact of the system security checkpoint in its totality. This new approach allows new optimization procedures that can consider combinatorial and statistical effects. In the analysis and assessment, the SEP evaluates all relevant performance areas according to the stakeholders: Security, passenger's satisfaction as well as operation and costs. By concurrent protection of the security, it is thus better possible to respond to the interests of all interest groups at the airport, i. e. better adaptions to individual airport situations, more dynamism in the innovation of component development as well as ethical tenability and social effects of the passenger controls.

Fraunhofer EMI can draw on experiences and contacts from successful concluded projects such as the EU project COPRA, the BMBF project FluSs as well as the EU project XP-DITE, under which the current research is encouraged. From this, a comprehensive catalogue arose that describes the demands for security checkpoints for current basic conditions as well as for future new security concepts. During interviews and workshops, stakeholders were interviewed and integrated into the project. From this, performance indicators were derived to evaluate the system security checkpoint in terms of security, operation and costs, passenger's satisfaction as well as ethics and society regarding airport security.

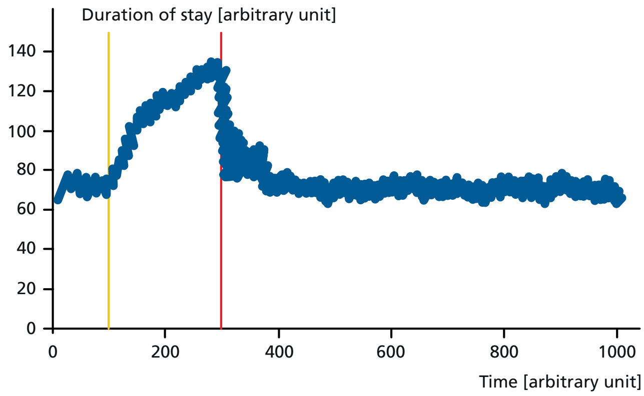
Based on the obtained information, concepts and the possible architectural and functional realizations of different security checkpoints were developed because the focus of the used evaluation methods and procedures in SEP is the application in current and realistically expectable concepts for security checkpoints.

Therefore, security concepts developed in cooperation with experts from the airport could use the semiformal modelling language SysML. The results thus abstracted serve as a basis for the tool development. The models emulate the architecture as well as the function of the security checkpoints with graphic elements, like abstract blocks and their connections (see Figure 8, next page).

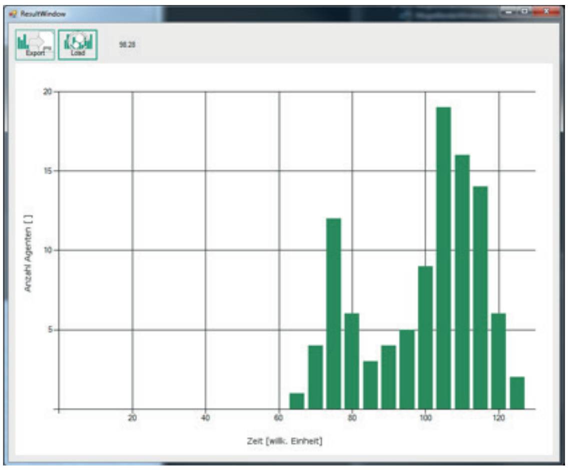
In interaction with a commercial design tool for security checkpoints, the SEP permits comprehensive evaluations and optimizations of a security checkpoint during the design phase before the actual construction after completing the project. Already the draft of a security checkpoint can thus be evaluated with the Fraunhofer software module. Then, with the help of the above mentioned performance indicators, the design can be improved iteratively and be evaluated once more until a mix of performance indicator values ideal for the respective airport is achieved (examples Figure 9 and 10).



8 Semiformal model of an exemplary security checkpoint.



9 Chronological development of the duration of stay of the agents in the test model.



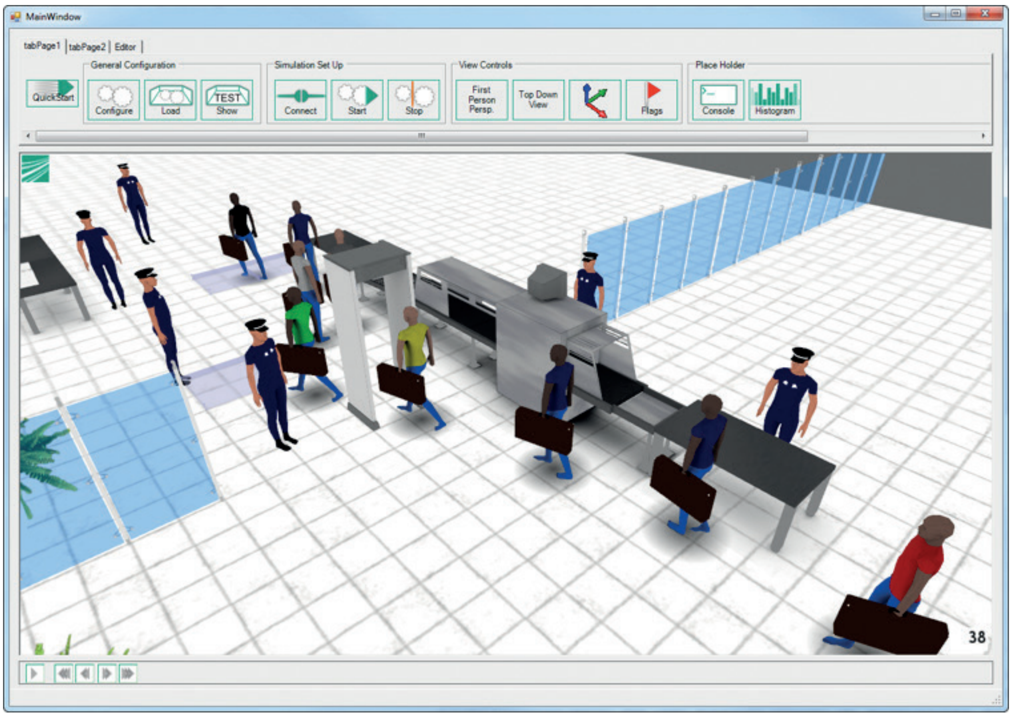
10 Duration of stay statistics of the agents in the test model.

The SEP is therefore adoptable for different configurations of security checkpoints (number and classification of the individual components) and approaches of system analysis. Essential advantages in the evaluation arise by the use of analytic methods on the one hand as well as a Monte Carlo simulation on the other. The analytic method has the advantage to work fast and transparently. With a Monte Carlo simulation, processes in a security check can be considered with more detail. The simulation works with autonomously operating agents that react on the surroundings in the security checkpoint as well as on other agents. Application possibilities for this enhanced evaluation method are such as the capacity and the security of the checkpoint. The simulation is adapted for the analysis of individual areas, processes or problems at the security checkpoint, while analytic results are available very fast, which allows a quick optimization of the design.

Besides, a specially developed, independent input interface permits the import of an airport design, which thus can be viewed as 3D representation and animation.

This happens with the help of the three-dimensional representation of the security checkpoint in which the passengers, devices and security forces are shown in 3D and animated according to the simulation (see Figure 11). The results of the simulation and evaluation can then be analyzed and visualized in detail through further functions of the animation program.

To sum up, a tool is developed that can help to better understand security checkpoints at airports in the future within the system context and thus make the planning process more efficient. The software tools developed at Fraunhofer EMI will provide computer-aided evaluation methods for planning, optimization and performance evaluation of security checkpoints. This and the visualization of the simulation of the calculation results makes in-depth analyses and evaluation of the function of a checkpoint possible; and in prospective, not only in the airport context.



11 Exemplary illustration of a security checkpoint with agents using the EMI visualizing tool.

Decision support for more security in cities

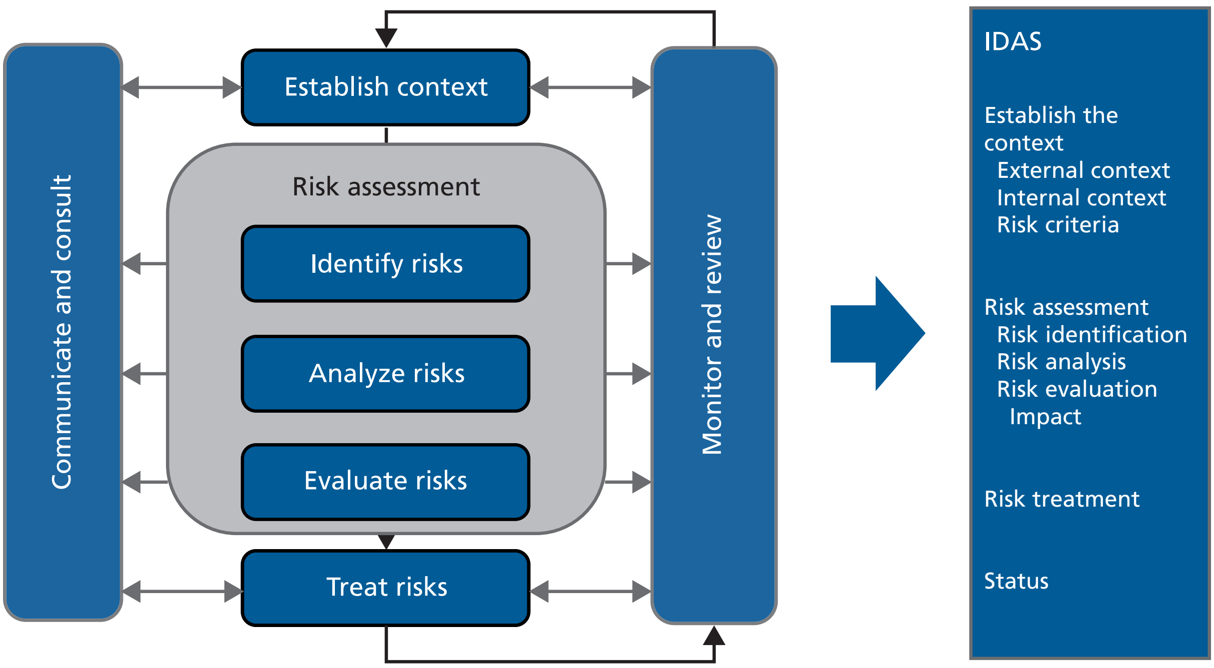
To feel comfortable in a city, we need a certain, individual perception of security. At short notice and in the long term, different measures (i. e. employment of social workers, training programs) can influence the security of inhabitants of a city. Besides, it is a matter of finding a reasonable balance of different measures. Both a too high level as well as a too low level of different security measures can lead to a lower security or a lower security perception of the inhabitants. In this context, complicated decisions often have to be made which can affect many people directly.

At Fraunhofer EMI, the web-based software application IDAS (Issues and Decisions: Analysis and Support) was developed, which supports decision-makers in considering and answering typical questions regarding security in urban areas. Already with development of the software, a lot of value was placed on addressing a wide area of application. Therefore, the application is based on an established process, the risk management process of the international norm ISO 31000:2009.

The basic process can also be exchanged any time in order to be adaptable to the demands of other subject fields.

With the choice of measures for reaching of security-related targets in urban areas, many questions have to be considered, such as: who is affected by present security problems where? Which basic conditions are to be considered? Who could be concerned (negatively/positively) by measures to be implemented? At which points have the mostly limited resources to be used for the solution of security questions first?

The web-application IDAS, developed at Fraunhofer EMI, is a tool to support risk management which can be used in every field of application that requires risk analysis as it implements the generic approach of the ISO 31000. At the example of urban security, it is described in the following which functions are made available to a user, whereas an important element of the risk management is the consideration of involved or affected internal and external stakeholders.



12 Representation of the risk management process using the Software IDAS.

For example, police officers could be internal stakeholders when it comes to the question of pickpocket prevention at events with high visitor amounts, as for example Christmas markets or public festivals, because they would actively be involved in the issue; in this case, the visitors of a market would be external stakeholders.

IDAS supports the user in all phases of the risk management process. Besides, in the first phase of the risk management process, the relevant aspects of the context in which the risk management is pursued are gathered. On this occasion, the indicators can be recorded in the form of data sheets or time rows and then be analyzed.

Referring to the example, the everyday number of the visitors at a market or the number of recorded pickpockets at the market would be the linear dimensions.

Based on established time series analysis methods, warnings can therefore be issued which point out to the user that levels previously defined by himself are probably crossed or deceeded at a certain time.

Thus, a warning can be given if the predicted number of the pickpockets is above a threshold due to observed developments of this indicator over the past time (hours, days, months, years).

Then, in the area of context definition, the risks or chances are defined. In addition to the likelihood of occurence, the consequences are also recorded on an impact scale. This impact scale permits the qualitative comparison of the different contexts. As another key element, the objectives to be achieved have finally to be determined in the phase of the context definition.

The preliminary steps of the risk analysis are concluded with the identification of the stakeholders, the determination of the impact scales and the definition of the objectives to be achieved.

In the next step, IDAS guides the user to the risk identification, in which risks can be assigned to every single object. For the urban context, IDAS already suggests defined risks which are known from the past use of the software. In addition, the user can define risks himself.

Based on the consequence scales and likelihoods identified and defined before, the identified risks can be analyzed in the next step, i. e. the expected probability of occurrence and the expected consequence are assigned. Control mechanisms in IDAS guarantee a certain degree of completeness, which is a clear advantage compared to traditional approaches.

Afterwards, the identified and assumed risks are evaluated, while they are arranged and visualized in a risk matrix. Here it is recognizable whether risks are applicable for the benchmark of the user or not.

Figure 13, next page, shows the step of the risk evaluation in the implemented software application. The related risk matrix contains two risks (abbreviated: r_1 and r_2), which were defined and estimated in advance. With the help of the position and color coding, it is evident whether a risk requires further measures. The necessity to initiate measures increases from left to right or from bottom to top, which is made clear additionally through the color coding from green to yellow and orange to red.

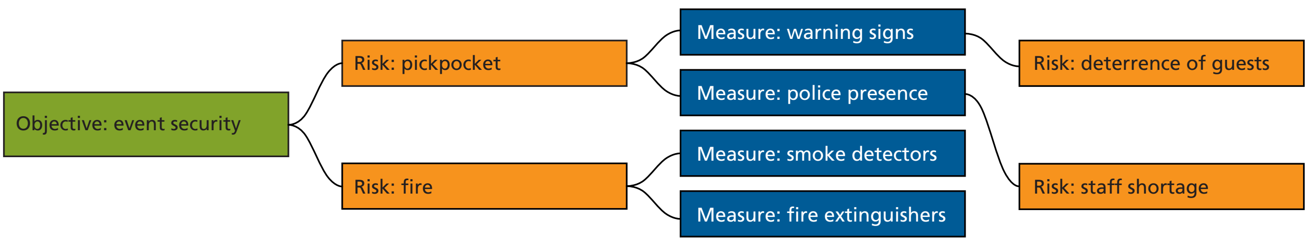
In the last step of the process, the handling of risks is addressed. To every risk, a measure can be assigned which diminishes the risk either because of the reduction of the probability of occurrence or because the consequences are minimized. If every risk which requires a risk-diminishing measure was assigned to one, the risk management process is run through once.

In a graph, IDAS shows the coherence of the objects, risks and measures. Measures are evaluated based on their effect and duration of the effect. Because measures themselves can cause secondary risks again, IDAS permits assigning secondary risks.

Figure 14 (next page) shows a risk identification graph for different objects in the context of urban security for the example introduced above "security at events" with related risks, measures and secondary risks.

In the application that has to be gone through iteratively, certain points in time can finally be set at which risks should be reconsidered and re-evaluated once more if necessary or to identify further measures.

13 Risk matrix with classified risks.



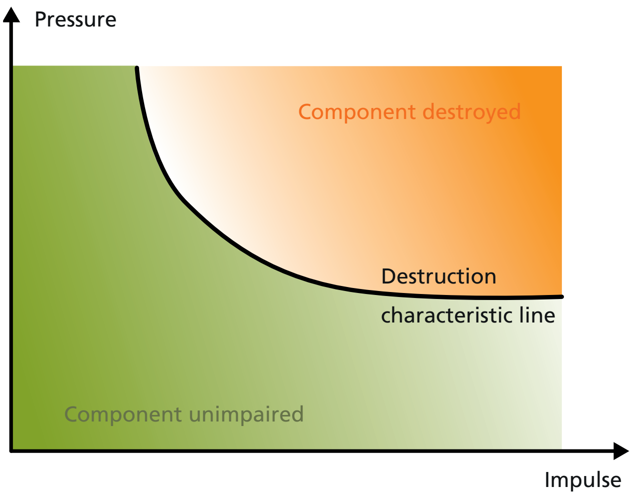
14 Risk identification graph.

Assessment of a high-performance material for extreme cases

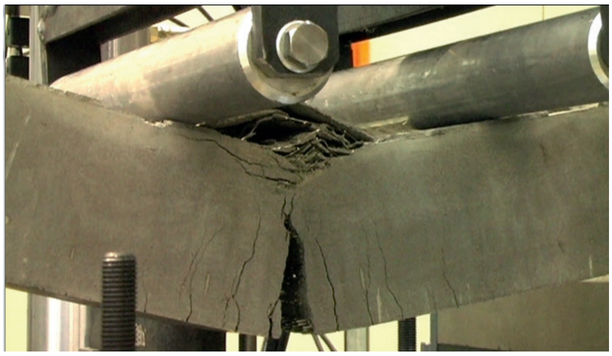
If it becomes obvious within the scope of a risk analysis that the damages of an architectural structure exceeds an acceptable level and this cannot be compensated by simply increasing the material thickness, innovative high-performance materials are an effective and efficient approach. To be able to use these materials for components in buildings in a secure and economic way, it is necessary to also know their load capacity for the considered extreme loads. For the Material DUCON™, the high protective potential had been proved during the last years over and over again by test series. What was still lacking was a consistent mathematical description of the resistance regarding far field explosion scenarios which the slabs can be exposed to with different load parameters according to the distance of the explosion site and type of explosion source. Now a mathematical description was developed which enables to calculate the material specifically.

The controlling parameters that describe the significance of the load at a far field detonation are the pressure peak of the blast and the inherent positive impulse which represents the integral of the time-varying pressure peak proportion. To be able to reflect the load capacity of the DUCON™ wall elements for all possible combinations of those two values, a threshold line must be defined in the peak-pressure impulse area that distinguishes between the still acceptable conditions and conditions that lead to the damage of the building elements. This can occur through a so-called iso-damage curve in a two-dimensional pressure and impulse diagram (Figure 15).

It is important for the definition of this iso-damage curve to better understand the material behavior of the ductile concrete to be able to mathematically forecast its load capacity and deformation under the dynamic loads. Moreover, different test series were carried out to be able to exactly determine these parameters. Here, the material has been subjected to static tensile tests (Figure 16). Due to those tests, the static critical loads and the plastic, i. e. irreversible distortions and the resulting ductility of the different DUCON™ configurations could be identified. Within the test series, the influence of the component thickness and the micro reinforcement degree were examined for these parameters. The analysis of the load deformation diagram shows that the DUCON™ slabs suffer at least 6 times the elastic deformation (Figure 17, next page) than plastic deformation before they totally fail. The determined tensile strengths are in the range of 30 megapascals up to about 40 megapascals depending on the configuration.



15 Destruction characteristic line and interpretation.



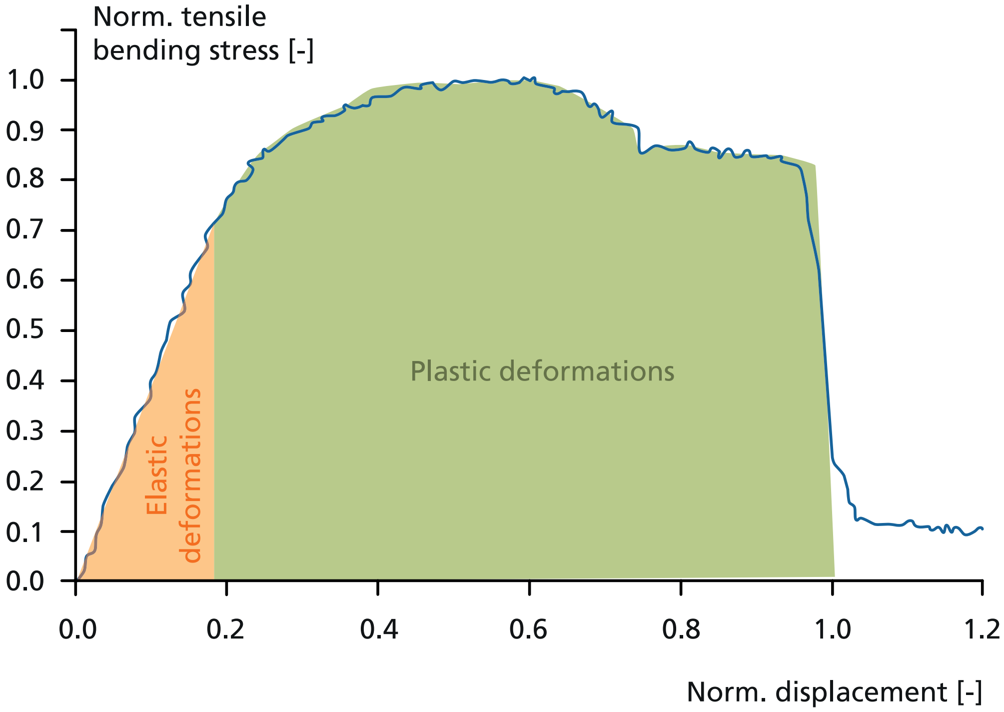
16 DUCON™ element at static tensile test.

Based on these static experiments, the dynamic load behavior of the wall components was examined in several test series by using the EMI shock tube "BlastStar" (Figure 18). With the help of the EMI BlastStar, it is possible to test different areas in the pressure pulse range. Thus, for example, loads can be tested which correspond to those of detonation of high explosives, but also, loads of explosions of gas mixtures as they can occur in the petrochemical industry. Due to the continuous extension of the experimental spectrum of the shock tube, both high, short-term peaks up to 250 kilopascals as well as low pressure ordinates with long exposure times close to one second can be tested.

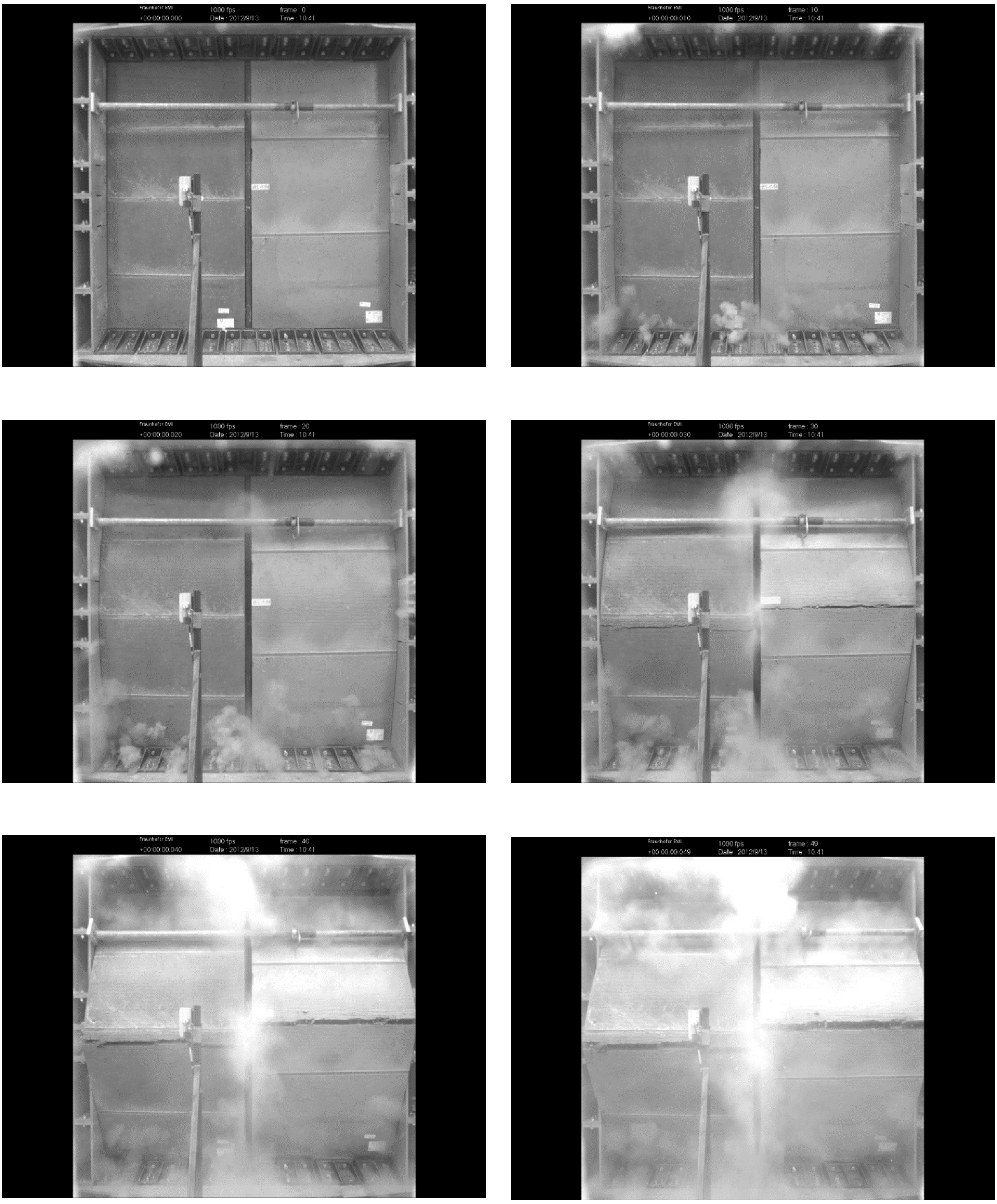
Under the dynamic loading conditions, the ductile concrete shows a high loading capacity in coherence with a high ductility level as well.

Based on the evaluation of the static and dynamic experiments, a mathematical relation between the material resistance of the ductile concrete elements and the load exerted on them could be derived in the form of an iso-damage curve. Then this could be transferred to a dimensionless form which allows determining the resistance of the elements for any dimensions. Besides, initial parameters are easy-to-handle engineering dimensions which require no further investigation.

Thus, there is now a method that makes it possible to assess the resistance of the ductile wall elements with any dimensions in seconds compared with any explosion load.



17 Load versus deflection curve of the DUCON™ element at compressive- and tensile test.



18 Picture sequence of a shock tube experiment on the DUCON™ element at times (from left to right, from top to bottom) t = 0 ms, 10 ms, 20 ms, 30 ms, 40 ms, 50 ms.

DYNAMICS IN MICROSTRUCTURES

DYNAMICS IN MICROSTRUCTURES

One of the focal points of the department is the development of numerical methods allowing predictive simulation of different classes of material subjected to crash and impact loading.

In 2009, a new group was established within the department focusing on the description of fiber reinforced composite materials. The first article describes an innovative multi-scale approach for simulating fiber reinforced composites under impact loading. This model was developed within the framework of the Attract project IMAGINE (**I**nnovative **M**ateri**A**l desi**G**n for **I**mpacted compou**N**d structur**E**s), funded by the Fraunhofer-Gesellschaft.

The second article describes a methodology for simulating the mechanical behavior of granular materials (e. g. sand) based on computer tomography data. The article describes the enhancement of computer tomography images as well as the automated construction of complex simulation models.

In aviation, birds are an ominpresent threat for starting and landing aircraft. The simulation of the impact of a bird onto a windscreen is a difficult task due to numerical instabilities. The Composite Design group has taken on this challenge and has developed enhanced numerical methods allowing a realistic prediction of the extent of damage. This is described in the final contribution of the department.

Dr. Michael May
Head of Dynamics in Microstructures
Phone +49 761 2714-337 | michael.may@emi.fraunhofer.de

DYNAMICS IN MICROSTRUCTURES

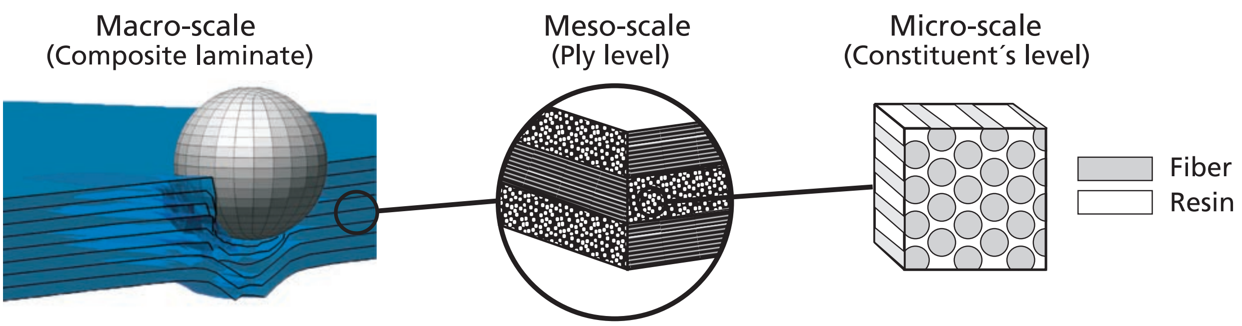
Multi-scale simulation of fiber reinforced composites

Several high technology applications require the increasing use of materials tailored for the desired application and anticipated loading state, in particular regarding the stiffness, strength, and crash properties. Composite materials offer large degrees of flexibility in the design space and are therefore ideal for tailoring the structural properties for complex loading states and geometric shapes. However, there is still a lack of predictive engineering tools that would enable the use of composite materials in safety relevant structures subjected to crash and impact loading. The development of such tools is therefore inevitable for the wide industrial application of fiber reinforced composite materials.

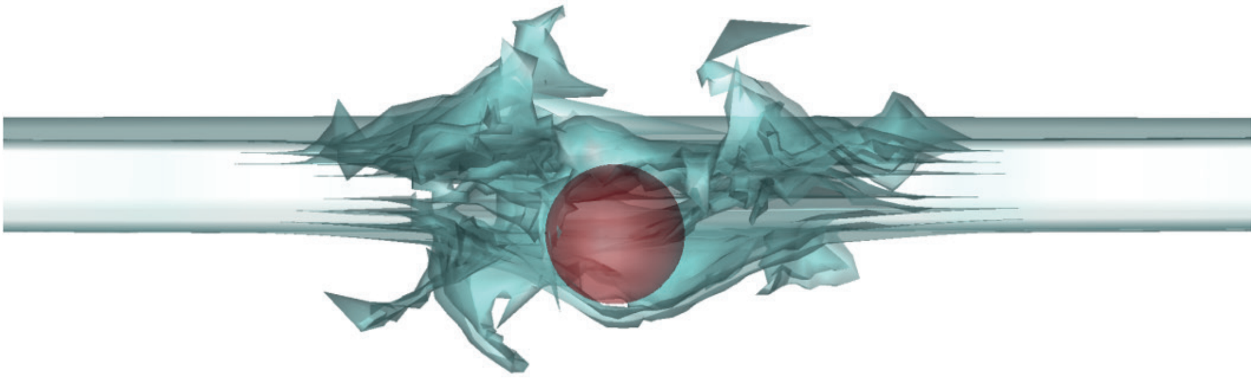
Simulation tools need to account for the heterogeneous structure at several length scales inherent to composite materials. As a consequence of this multi-stage heterogeneity, a predictive, homogenized macroscopic description of composites beyond the initial failure is very difficult, as the non-linear processes occurring at different length scales, their evolution, and interaction cannot be captured accurately during high-rate loading. However, the processes at small length scales must not be neglected as they are the cause for macroscopic observations.

In engineering applications, composite structures are almost exclusively modeled at the macro scale using homogenized properties as, due to the enormous computational effort, it is currently and in the near future not possible to simulate large structures at the microstructure.
However, it is the consideration of processes occurring at smaller length scales that provides the ground for a physically based simulation model. Thus, the behavior of composite materials is modeled such that specific areas of interest are locally refined.

Multi-scale approaches enable the simulation of composite materials at the macro-scale whilst considering meso- or micro-mechanical processes (see Figure 1). Consideration of processes occurring at small length scales is of particular importance if the resin undergoes large deformations, for example close to the vicinity of an impact. Within the course of the Attract program "IMAGINE", we developed a numerically highly efficient method which, based on the micro-mechanical properties of the constituents (fiber and resin), allows predictive impact simulations.



1 Relevant length scales in composite materials subjected to impact.



2 Simulation of the impact of a steel sphere onto a CFRP target at a velocity of 200 m/s. The sphere is stopped in both, the experiment and the simulation.

An analytical modeling approach, the so-called generalized method of cells, is used for deriving homogenized macroscopic properties. The analytical solution avoids the computationally expensive parallel execution of several finite element simulations postulated by other groups of researchers. However, the analytical solution requires the challenging transformation of large matrices, which is also impeding the computational performance. This problem was addressed by including an algorithm capable of identifying whether a finite element is within the damage zone of an impact. The computationally expensive multi-scale approach is only activated if an element is within the damage zone and if nonlinearities occur. For all other cases, a very simple and computationally efficient linear-elastic approach, based on the rule of mixtures, is used.

Using this approach, the computational time was reduced by 70 percent without compromising the accuracy of the predicted results. Figure 2 shows an example of a steel sphere impacting a composite plate at a velocity of 200 meters per second. The projectile is stopped by the target plate.

This was an important step to increase the attractiveness of multi-scale simulation for the industrial user.

Further details can be found in the following publication: Michael May, Matthias Nossek, Nik Petrinic, Stefan Hiermaier, Klaus Thoma; Adaptive multi-scale modeling of high velocity impact on composite panels; Composites Part A 58, pp. 56-64, (2014).

Generation of structures for numerical simulations at the mesoscale

The characterization of materials under dynamic mechanical loading, modeling of material behavior to the point of failure as well as the development of predictive models for numerical simulation at different scales are core competencies of EMI.

For modeling of materials, the underlying physical principles can generally be described at different levels of abstraction. In many cases, the actual issue or application determines the level at which an observation is useful. For instance, the behavior of heterogeneous materials which consist of different parts – such as sandstone (quartz grains and pores) or synthetic energetic material (crystals and plastic matrix) - can be described at a level of abstraction which does not explicitly consider this internal structure (macro scale). However, in order to (better) understand the dependency of material behavior of this inner structure, or to derive models for the description at the macro-scale, the heterogeneous structure at the meso-scale and its influence at material behavior can explicitly be considered at a detailed level of modeling. Based on that, improved material models can be derived for the macro-scale and new materials can be optimized by specific changes of their inner, heterogeneous structure.

For numerical simulations based on continuum mechanics, representative and geometrically realistic models, which contain the heterogeneous structure of the material, are essential. Also suitable material models for the individual components as well as the behavior at material boundaries are necessary.

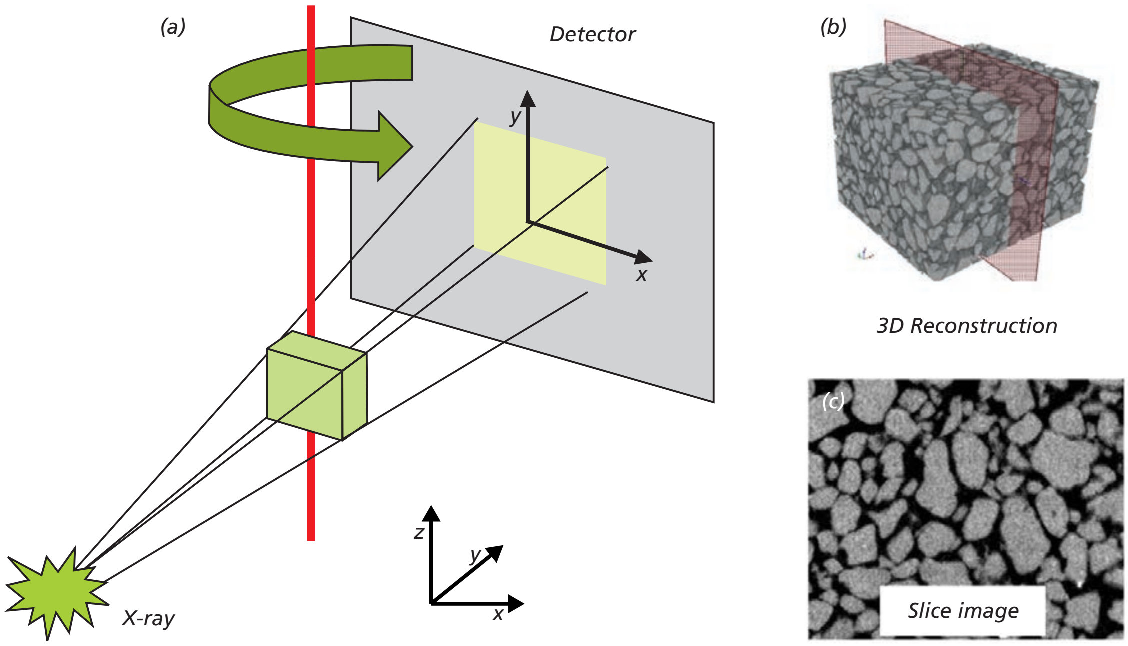
The main focus of this contribution is the description of two methods which have been developed at EMI. Representative geometric models are constructed as a baseline for finite-element-models for numerical simulations. The methods are based on different approaches: The first one uses structural information of real material samples which are obtained by computed tomography (CT). The second approach uses statistical information about the structure – such as grain size distribution and overall density of energetic material – to create geometrical models using algorithms. Both methods are explained in the following.

Structure modeling based on CT Data

Computed tomography was originally mainly used in medical applications. Today, it is also increasingly used for non-destructive analysis of materials. The function principle is shown schematically in Figure 3. The sample is X-rayed. Depending on material density, the X-rays are partially absorbed and measured at a detector screen. Thus, some kind of two-dimensional shadow image is obtained. Using many of these measurements from different angles (here done by stepwise rotation of the sample) a three dimensional density distribution can algorithmically be calculated from the original 2D images (filtered backward projection). The result can be visualized as three-dimensional greyscale-image (Figure 3 (b)) or arbitrarily orientated sectional image (Figure 3 (c)).

Based on the spatial greyscale distribution – mathematically described by a scalar function of the coordinates – the geometrical structures are now to be identified. This is in general complicated and depends both on the data quality and on the examined material, since the structures to be identified are often hardly detectable in the general noise. Therefore, the noise is reduced using a smoothing filter in the first step. Here, each pixel is replaced by a (weighted) mean of its environment. The level of smoothing has to be adjusted accordingly in order to remove as much noise as possible without making the structures of interest undetectable. In the second step, appropriate filters are used to accentuate the material structure. This is achieved by using the first and second derivative of the grey scale distribution. The first derivative (gradient of the scalar field) shows the direction of the strongest change of brightness and can be used for border detection. The second derivative (Hesse matrix) which shows the curvature enables the recognition of further structures.

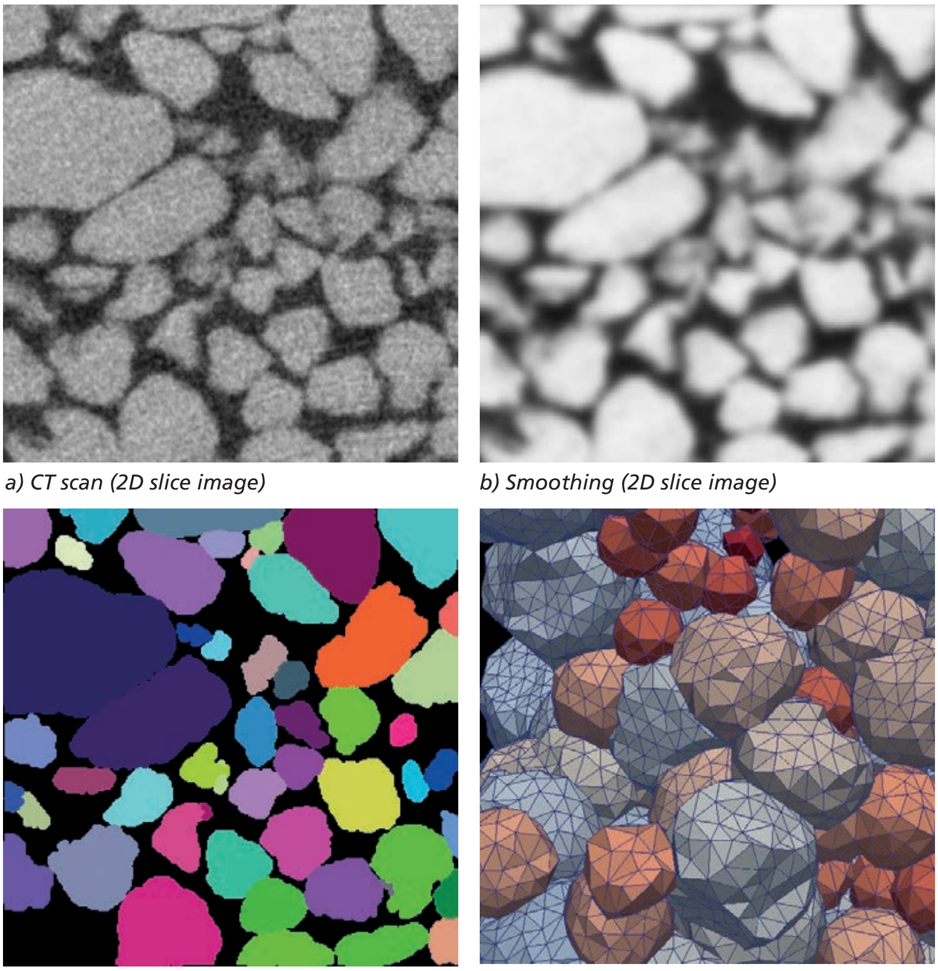
The single steps are exemplarily visualized in Figure 4 for the example of sand. Here, the individual grains as well as their contact areas are to be determined. Figure 4 (a) shows a part of a typical 2D-Section of a CT-Image. Figure 4 (b) shows the same part after applying a 3D smoothing filter (step 1), where a substantial reduction of noise has been achieved while still preserving the essential structures of the image. Afterwards, a series of detection filters is applied (step 2): The borders of grains (next to empty space/air) are identified over the absolute value of the first



3 *Mode of operation of X-ray computed tomography: (a) A large number of X-ray projections on different angles by rotation of the sample; result of a 3D reconstructed volume (b) and a (virtual) 2D slice image (c).*

derivative. A high value shows the transition from light to dark. However, this is not sufficient for the determination of contact zones between grains, where the first derivative is around zero. Here, the second derivative has to be considered (in 3D a 3 x 3 matrix) that describes the curvature of the brightness in all dimensions. Within the slightly darker contact area between two lighter grains, this matrix has exactly one large positive eigenvalue. The corresponding eigenvector shows the direction of the strongest curvature in brightness which is the normal direction of the contact area. In that way, individual voxels (image points) can be assigned to individual grains as shown in image 4 (c). This concludes the structure detection.

To create a finite element model from this, the identified structures have to be meshed, as shown in Figure 4 (d). Here, freely available programs like TetGen or Gmsh can be used. Alternatively, it is also possible to distribute points on the grain surfaces and contact zones which are then connected to a grid. The advantage of using an own grid algorithm is in the possibility of directly applying quality criterions as needed for the simulation afterwards. For example, small elements are often undesirable for dynamical simulations, since those lead to small time steps and therefore much higher computation runtimes.



a) CT scan (2D slice image)

b) Smoothing (2D slice image)

c) Grain recognition (2D slice image)

d) FE mesh of the grains (3D)

4 Generation of structures on the basis of CT data. Different steps starting from raw CT data over 3D image processing and pattern recognition to a finite element mesh.

Algorithmic structure generation

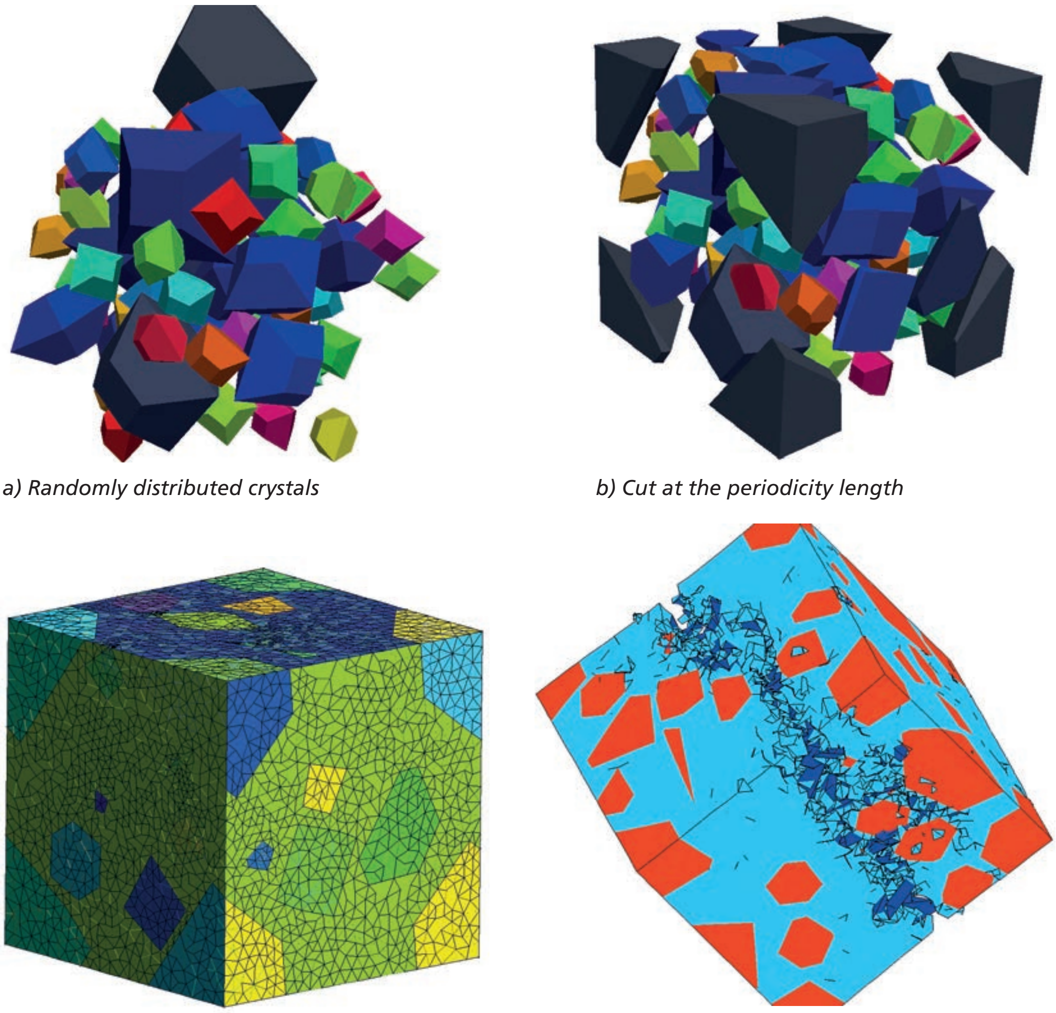
For algorithmic structure generation, statistical information about the heterogeneous material is needed. This information can be based on CT-data or 2D-microsections. For example, information about shape and size distribution of structural elements – such as sand grains or crystals of energetic material – and its density is required. From these specifications, a geometrical model is generated using the algorithm described below. The advantage of the algorithmic approach is that parameters such as the percentage of structural components or their size distribution can easily be modified. Also, spatially periodic models can be generated which are useful for certain applications. In the following, the algorithm is exemplarily described for a heterogeneous mixture of crystals and a homogeneous, surrounding matrix.

A distribution of crystal sizes and shapes is required as input data. We assume a realistic size distribution as shown in Figure 5. The definition of shapes is done using a set of half spaces, the intersection of which results in the crystal shape. These shapes are always convex and can then be described by a set of nodes, edges and plane surfaces. These shapes are first distributed in a periodic space, without overlap and in random spatial orientation and position (Figure 5 (a)). To achieve a higher, given density, the periodic space is then uniformly made smaller. On contact, crystals can move and rotate to avoid any overlap. At last, crystals are being cut at the border of the periodic space (Figure 5 (b)). This concludes the structure generation. A corresponding finite element model is shown in Figure 5 (c). Here, mesh generation was performed using the program Gmsh. It is important to ensure that elements are not too small. This must already be considered during the generation of the structure: crystals should not be too close to each other, and when cutting crystals at the border of the periodic space, this should not create too small elements.

A further challenge for algorithmic structure generation is to achieve a high density. This is a nontrivial problem; just consider packing of spheres of equal size which only fill 74 percent of the available space.

Figure 5 (d) exemplarily shows a simulation with the EMI-hydrocode SOPHIA, where a material sample is under tensile loading until cracks can be seen.

Using those new methods, EMI has new valuable tools for the generation of geometrical structures of heterogeneous materials on the mesoscale. They are the basis of the numerical simulation.



a) Randomly distributed crystals

b) Cut at the periodicity length

c) Meshing with Gmsh

d) SOPHIA model simulation

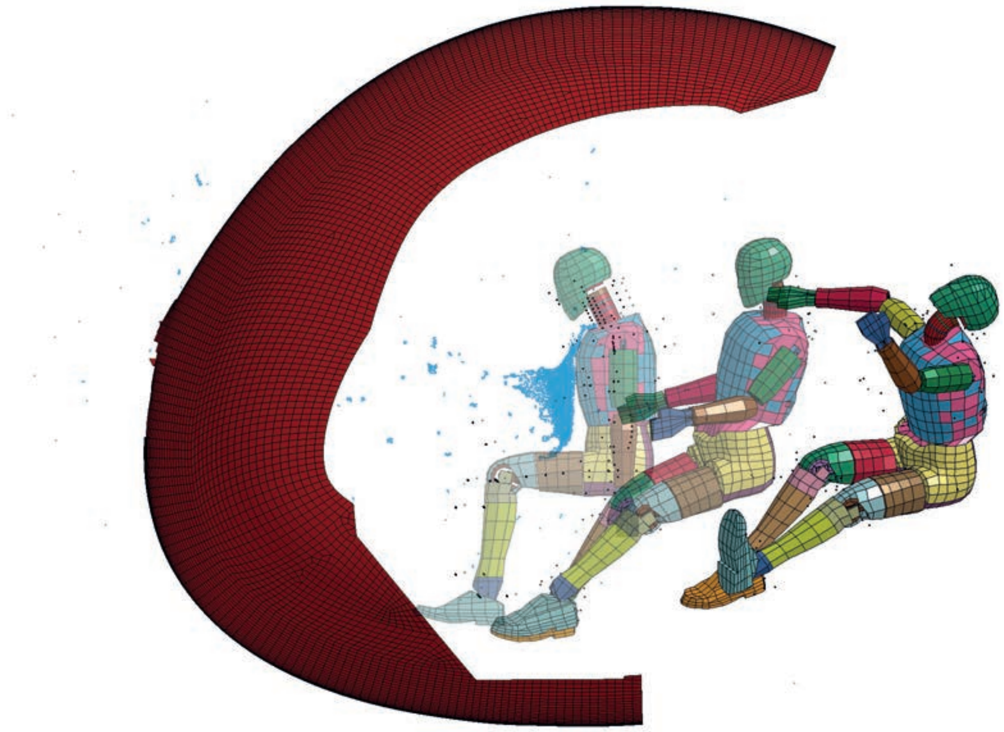
5 Algorithmic generation of structures, FE mesh and SOPHIA model simulation.

Towards better numerical prediction tools for bird-strike

Bird strike is a technical term which describes the collision of a bird with an aircraft. Even though a bird is lighter, smaller, and much softer compared to exposed aircraft parts, a bird becomes a serious projectile at relative velocities up to 300 kilometer per hour. Such velocities are typically attained during landing and takeoff, i. e., at low altitude levels, where birds are most prevalent.

On a global scale, the range of costs inflicted every year on civil air transport due to bird strike is estimated in the range of a few hundreds of millions of US dollars up to a few billion US-$. However, this is not only a relevant problem for civil aircraft with rigid fuselage and wing structures, and comparatively small and stable cockpit windows. Bird strike poses a much larger problem for helicopters, as this type of aircraft permanently operates at low altitude and features much larger window panes with reduced structural stiffness.

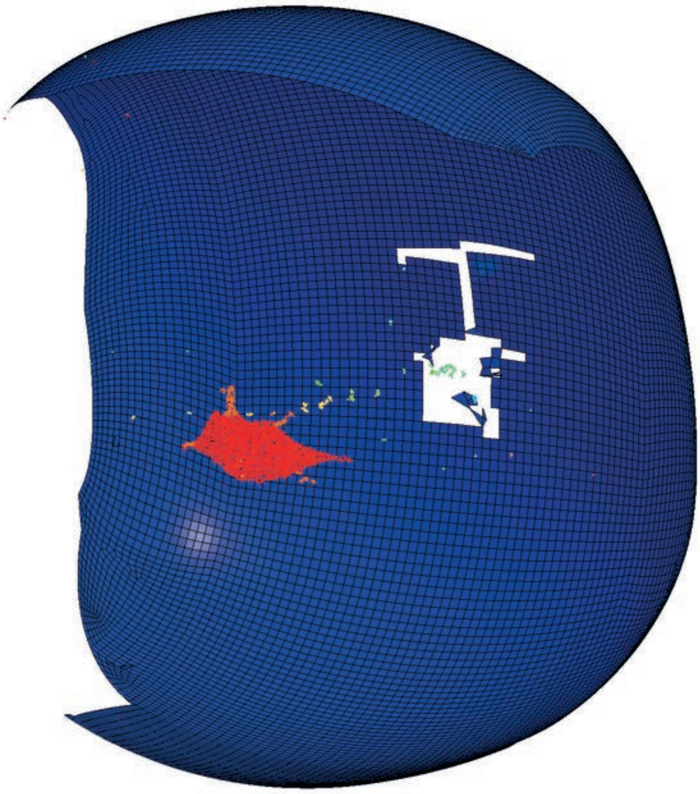
Figure 6 shows an exemplary simulation scenario of bird strike: A bird surrogate penetrates the wind screen of a helicopter. The kinetic energy that remains after penetration is sufficiently high to cause serious and permanent trauma to the pilot. To safely protect against such situations is therefore an important design requirement for the helicopter cockpit. To realize a robust constructive design of a protection system, exact information about the forces which are transferred to the structure during bird strike



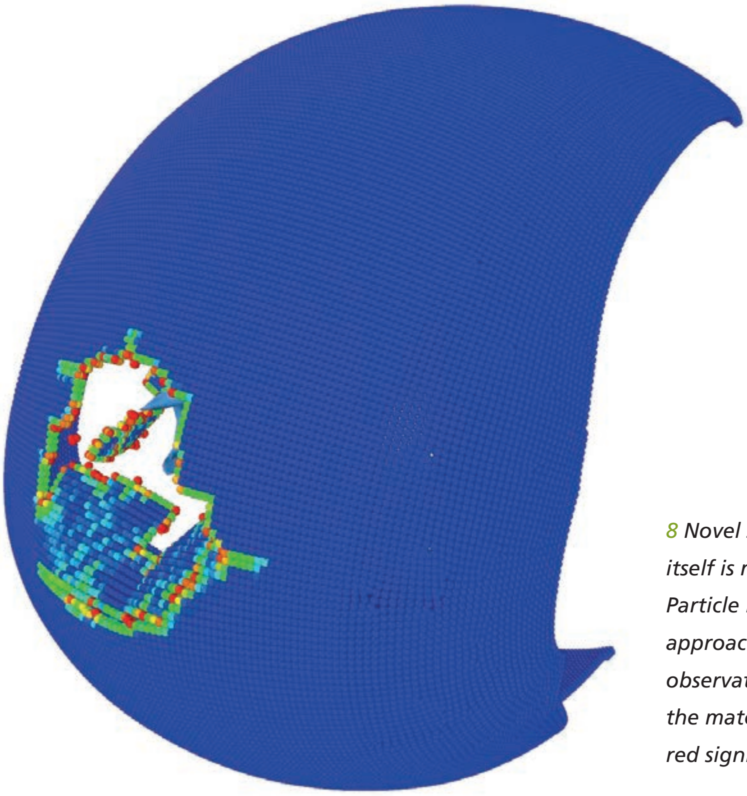
6 Bird-strike scenario. A surrogate model of a bird (blue particles) travels from left to right and penetrates the wind screen of a Bell MH6 "Littlebird" helicopter. The violent acceleration of the crash test dummy serves to visualize the kinetic energy of the bird that remains after penetration of the wind screen.

are mandatory. Such information can only be delivered by a numerical model which takes into account experimental data. Such experiments, in particular impact experiments with birds or bird surrogates, are very expensive, both in terms of costs and time. It is therefore a prime interest to reduce the number of experiments to a small number and substitute testing by as much numerical simulation as possible. However, this desirable situation can only become realistic if the predictive quality of the employed numerical simulation tools is sufficiently high, so that results can be deemed trustworthy.

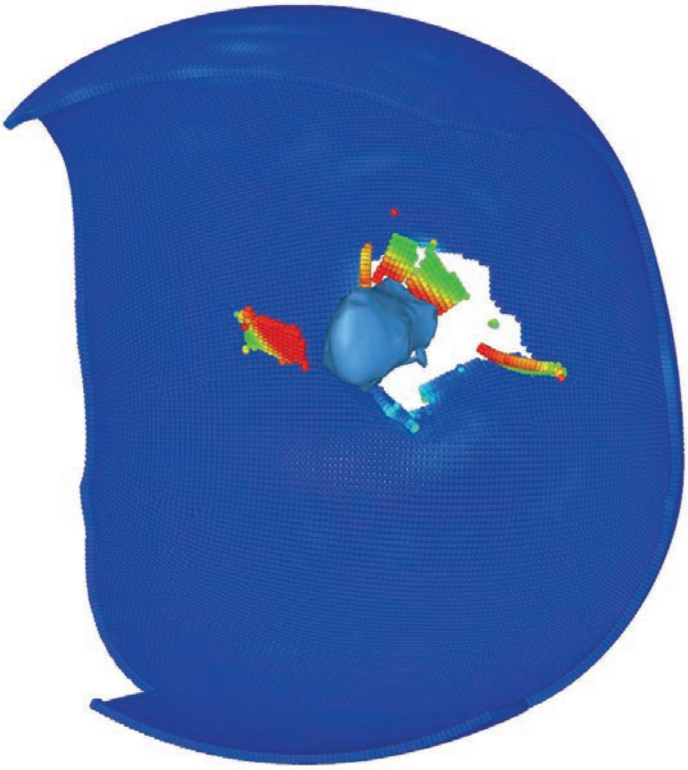
Today's numerical method of choice for simulating loading problems in structural mechanics is the finitie element method. This approach divides the entity to be simulated into a large number of small elements, which are topologically connected to each other, strictly following a set of certain rules. The solution to the underlying continuum mechanics problem of how stress and deformation states are mutually related is determined by Euler's equations, which are a set of coupled differential equations. These equations are solved individually for each element. The topological connection between the individual elements causes the solution to be continuous and smooth for the whole body which is simulated. This approach works indeed well if the deformation sustained by the body is well-behaved with no abrupt jumps in the distribution of stress. However, the method fails precisely for those loading cases which lead to cracks and geometrically non-linear deformation modes, because the assumptions inherent to the method are violated. Most of the commercially available finite element solvers can thus only approximate crack propagation and cracks by deleting entire finite elements if these sustain too large deformations. This approach leads to two undesirable effects: on the one hand, the deletion of an elements corresponds to removal of material, altering the volumetric response of the structure under compressive loading, because the removed volume cannot sustain pressure anymore. On the other hand, cracks may only propagate along edges of elements, which causes very unrealistic predictions of the true crack path and the number and size of fragments of a shattered body. Figure 7 illustrates this problematic behavior using a helicopter wind screen as an example: The pattern of the resulting cracks is dominated by numeric artifacts and fragments of the wind screen, which would travel inwards into the cockpit and towards the pilots, and cannot be tracked anymore, because the corresponding elements have been deleted. This observation permits concluding that the finite element method may not be the best method for dynamic loading structures with extreme deformation mechanics.



7 Traditional simulation approach for bird-strike. The wind screen of a helicopter (blue mesh) is modelled using finite elements. A surrogate bird model penetrates the wind screen, causing a number of cracks to run across the wind screen. In the finite element model, these cracks can only propagate along existing mesh element edges, which cause non-realistic crack patterns. Additionally, no fragments travelling inwards into the cockpit can be identified as the corresponding elements have already been deleted.



8 Novel simulation approach for bird strike. The windscreen itself is modelled using the meshfree method Smooth-Particle Hydrodynamics. The crack pattern observed with this approach is in much better agreement with experimental observations. Color coding represents the damage state of the material, blue corresponds to undamaged material while red signifies fully damaged material.



9 Novel simulation approach for bird strike. A helicopter wind screen is penetrated by a bird surrogate model. In contrast to the finite element method, realistic fragments of the wind screen can be tracked as they fly into the cockpit, because no material points need to be deleted in order to achieve material failure. Color coding corresponds to velocity, with red signifying a velocity of 150 kilometers per hour.

A remedy to the described shortcomings of the finite element method is given by a different approach to solving Euler's equations: meshfree methods. Here, the numerical model of the body to be simulated is not divided into topologically connected individual elements. Rather, the body is discretized using a set of material points, which only serve as a temporary coordinate for the solution of the governing differential equations. One particular class of mesh-free methods is given by Smooth-Particle Hydrodynamics, for which Fraunhofer EMI has played a pioneering role during the method's first application to solids. Throughout the last two decades, the development of Smooth-Particle Hydrodynamics has been actively pursued at EMI because our core research interests call for numerical methods which are well suited to accurately describe extreme deformations and material failure. More recently, a major breakthrough was achieved with the invention of a stabilization scheme [3] which permits accurate simulation of the failure patterns which occur in brittle materials. Figure 8 shows an example of this new numerical method for a bird strike scenario. Crack propagation and failure patterns are obtained which correlate very well with experimental observations. An alternative view of the same scenario from the inside shows fragments of the penetrated wind screen, hurling at high velocities towards different locations within the cockpit. This new simulation method therefore exhibits improved predictive capabilities for performing risk assessments, which in turn allows an easier constructive design of the cockpit with better performance in the case of bird strike.

The meshfree simulation results presented here have been obtained using Smooth Mach Dynamics, a computer code developed at EMI. This code features state-of-the-art implementation of Smooth-Particle Hydrodynamics and the afore mentioned stabilization mechanism which allows accurate solid body deformation and failure modelling. Additionally, the code is targeted at efficient simulation of very large problems on massively parallel computer systems.

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MATERIAL DYNAMICS

MATERIAL DYNAMICS

The sustainable and efficient use of resources gains an ever increasing significance in the automotive sector. The demand for an improved crash safety together with the demand for weight reduction open a challenging field of research. The development and application of new materials and structures is one promising way to address this challenge.

In the aerospace sector, load bearing structures consisting of hybrid material systems have been deployed successfully for some time. A prominent example is the material GLARE – a hybrid material system of alternating layers of thin aluminum and glass fiber reinforced polymers. The idea of multi-material lightweight structures which feature tailored sets of properties according to the respective loading situation by designing structures with the "right material in the right place" is currently a focus of research throughout the automotive industry. The first contribution of the department Material Dynamics presents the results of an ongoing research cooperation with a German car manufacturer investigating the potential of hybrid crash structures composed of metals and fiber reinforced polymers with respect to their crashworthiness.

The technological development and introduction of alternatively powered vehicles necessitates the re-evaluation of current vehicle architectures and gives rise to the development of novel vehicle designs. In parallel to the development of new designs for electrically powered vehicles, currently valid crash regulations have to be evaluated and possibly adjusted leading to new test scenarios like the mechanical testing of battery packs. These and other questions are addressed in the second contribution presenting the results of an international research project where recommendations for the passive safety of future electric vehicles were proposed.

Dr.-Ing. Ingmar Rohr
Head of Material Dynamics until December 31, 2014
Phone +49 761 2714-416 | ingmar.rohr@emi.fraunhofer.de

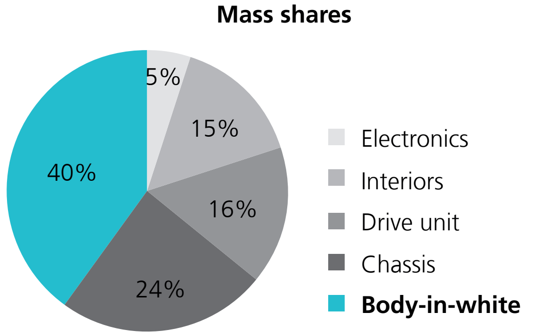
Dr.-Ing. Jens Fritsch
Head of Material Dynamics since January 1, 2015
Phone +49 761 2714-472 | jens.fritsch@emi.fraunhofer.de

Hybrid structures composed of advanced composites and sheet metal for vehicle crash structures

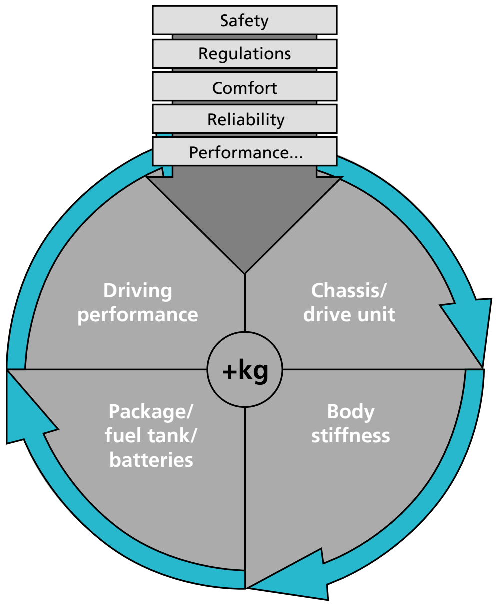
Growingly stringent laws and regulations for the CO_2 emission of vehicles lead to increasing efforts to reduce the fuel consumption of future vehicle models. When looking at the energy balance of a modern vehicle in an urban driving scenario, it can be observed that up to 90 percent of the fuel consumption are directly proportional to the vehicle's mass. Consequently, proper light weight design measures are an effective way to increase the overall efficiency and to reduce the CO_2 emissions of the vehicle. With roughly 40 percent, the automotive body-in-white accounts for the major share in the mass composition of modern vehicle models (Figure 1). This explains the high priority of body-in-white lightweight design measures that is observed throughout the entire automotive sector.

Due to increasing demands concerning driving comfort and vehicle safety, most vehicle models have continuously gained mass from one model generation to the following in the last decades. Especially for electric and hybrid vehicles, interdependencies and mutually reinforcing effects result in a cycle of increasing vehicle mass which needs to be broken in order to enhance the vehicle efficiency (Figure 2). By stringently pursuing the individual lightweight design strategies (integrative, constructive and material lightweight design) in the past years, the potentials for straight forward and cost effective reduction of the body-in-white's mass have been widely exploited. Synergetic combinations of the individual lightweight design strategies as part of a holistic approach now offer the possibility to break the parasitic weight cycle and to even invert it into a cycle of decreasing vehicle mass. These ideas lead to the development of integrative multi-material lightweight structures which feature tailored sets of properties according to the respective loading situation by designing structures with the "right material in the right place".

In the aerospace sector, load bearing structures composed of fiber reinforced plastics (FRPs) or "advanced composites" can be considered state of the art. Through steady optimization of the production and manufacturing processes and through higher lightweight cost tolerance limits for electric vehicles, FRPs are increasingly pushing their way into the automotive sector. While already well established in highly specialized automotive applications, composite-intensive



1 Weight composition of modern vehicles.



2 Parasitic cycle of increasing vehicle weight.

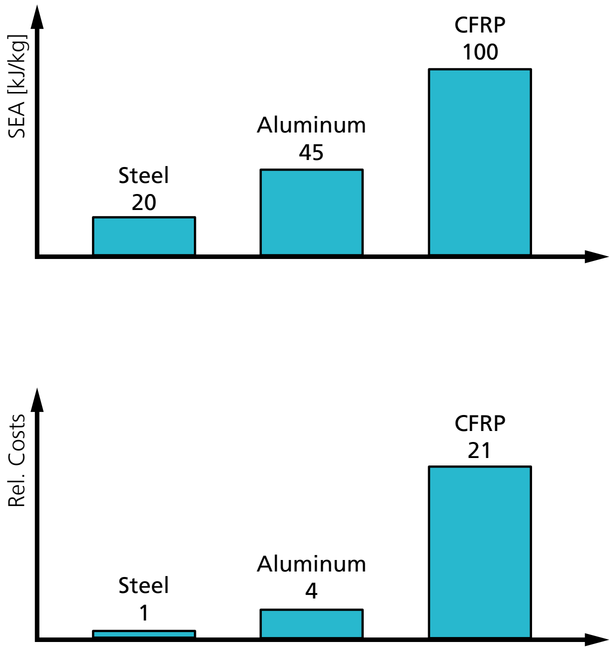
automotive structures are currently proving their feasibility in low and mid volume production series. Although some of the load carrying structures are already largely made of advanced composites, structural areas particularly subject to crash loads are predominantly composed of conventional body-in-white materials such as steel or aluminum due to their mainly stable and robust failure behavior.

The most important features of structures subject to crash loads are their stiffness and energy absorption capability during deformation ("crumple zone"). Depending on the fiber architecture, particularly carbon fiber reinforced plastic (CFRP) features a weight specific energy absorption that massively outrivals that of steel or aluminum under continuous axial compression failure.

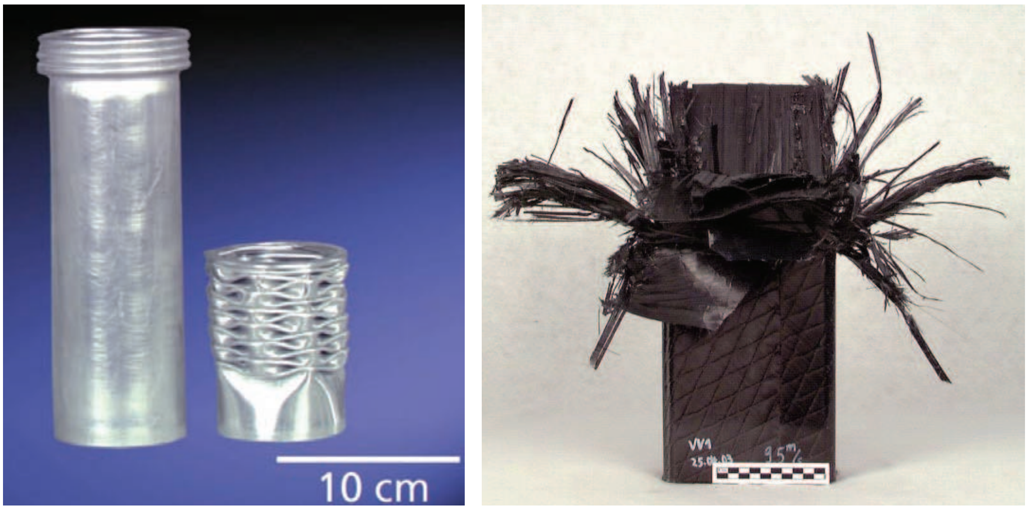
The main hurdles to the broad application of CFRP-crash structures are their instable failure behavior and the enormous material and production costs that cover several times those of conventional metal structures (Figure 3).

Based on the aforementioned developments, Fraunhofer EMI is conducting a research project in cooperation with a major automotive manufacturer, which investigates the potentials of hybrid material systems composed of FRPs and metals for automotive crash structural applications. One major goal is to form synergetic combinations in order to exploit the potentials of the single constituent materials while simultaneously compensating their shortcomings. A hybrid crash structure, which features the stable and robust failure mechanism of steel in combination with the high specific energy absorption of CFRP while reducing costs with respect to the pure CFRP structure and reducing weight with respect to the pure steel solution, would be one ideal example (Figure 4).

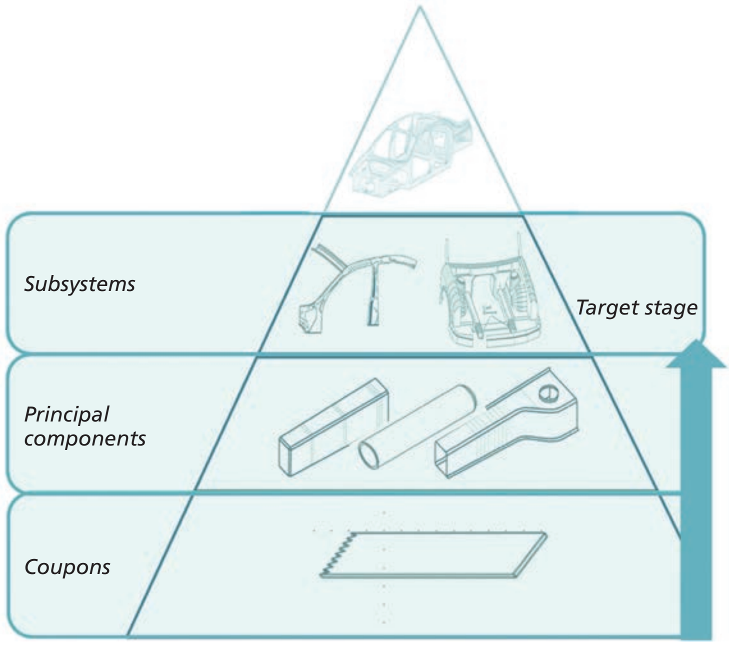
In order to ensure the design of hybrid crash structures according the respective materials' properties and loading specifications, a profound understanding of the materials' mechanical properties as well as their loading and failure mechanisms is essential. A simple superimposition of the major material properties – like stated above – without any side effects or interdependencies is rarely possible.



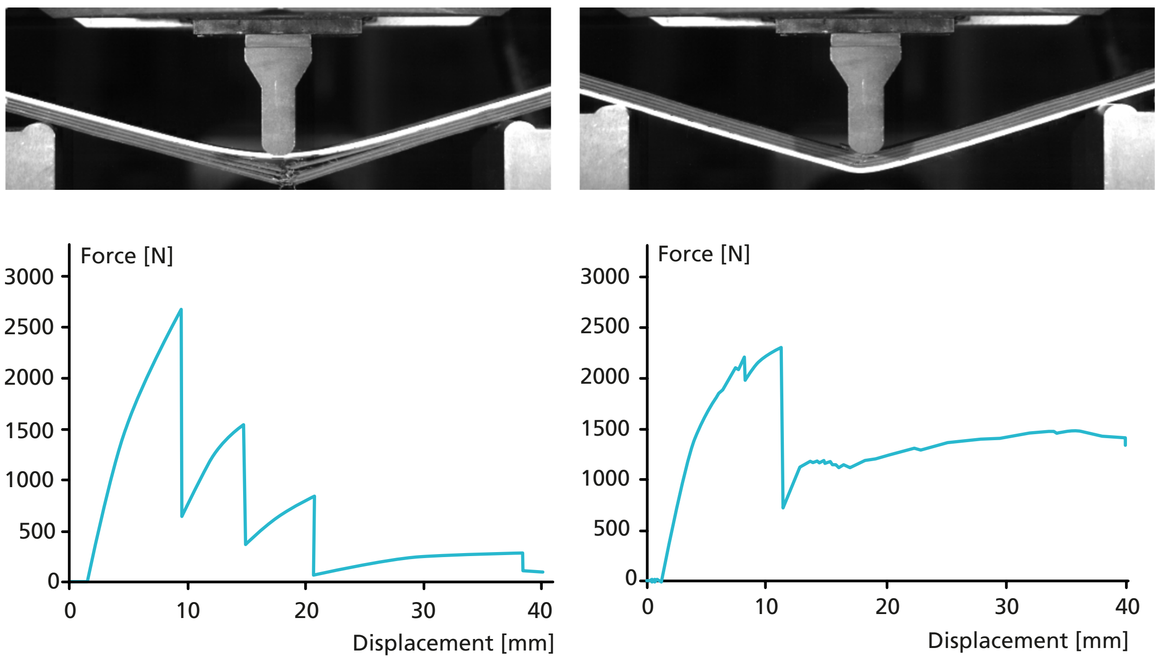
3 Specific energy absorption (SEA) under axial loading (up) and relative costs for components with same function (approximate values).



4 Failure mechanisms of metal and FRPs.



5 *Systematic characterization – Building block approach.*

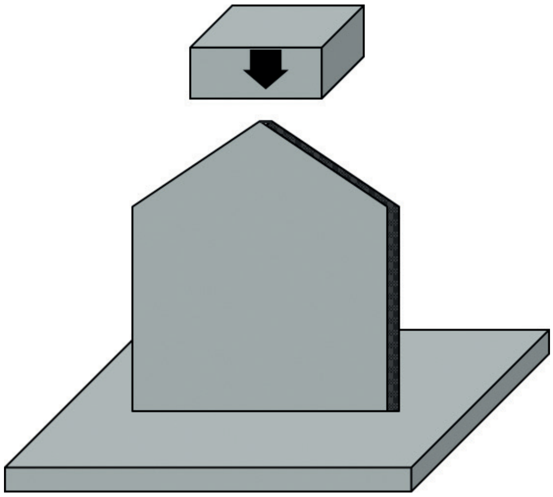


6 *Energy absorption with respect to the loading direction under 3-point-bending.*

A systematic analysis of the major mechanical properties of different hybrid material combinations composed of FRPs and metals is conducted using a building block approach (Figure 5). While the complexity of structures under test increases from one stage to the next, the volume and the number of tested variants decreases taking into account the insights and findings made in the previous stages.

The first stage here is a screening process of a broad spectrum of material combinations. By testing simple coupon specimens, geometric effects are largely ruled out. The study focuses on major basic material parameters such as the stiffness, strength or the maximum strain. Furthermore, combined parameters such as the amount of absorbed energy are evaluated to anticipate crash relevant material characteristics. Next to concrete parameters defining the loading and failure behavior of the hybrid specimens, qualitative aspects and so called "hybrid mechanisms" for the respective material combinations are of central interest. The experimental characterization of the coupon specimens is conducted through quasistatic and dynamic tension and 3-point-bending tests. This screening process leads to the assessment of the potentials of the different hybrid material combinations and helps to quantify the effects of the major material parameters such as the type of steel, the type and orientation of the reinforcing fibers and the number of composite plies. A hybrid mechanism, for instance, is observed when analyzing the energy absorption under 3-point-bending with respect to the loading direction. As depicted in Figure 6, the amount of absorbed energy with CFRP on the tension loading dominated, lower side of the specimen is doubled when loading the specimen with CFRP on the upper and predominantly pressure loaded side. This contradicts general FRP design principles, which prefer to subject FRPs exclusively to tension loading.

In order to anticipate the future crash behavior of the different hybrid material combinations, the coupon program is extended by another type of experiment. One of the most important load cases during a vehicle crash is the axial pressure loading, which at best (particularly in the crumple zone) produces a stable failure of the loaded thin walled sections. For that matter, pentagonal specimens and a special test setup are designed in order to investigate the behavior under axial compression already on the coupon level. Next to the maximum load and the energy absorption, understanding the conditions of transferability of the

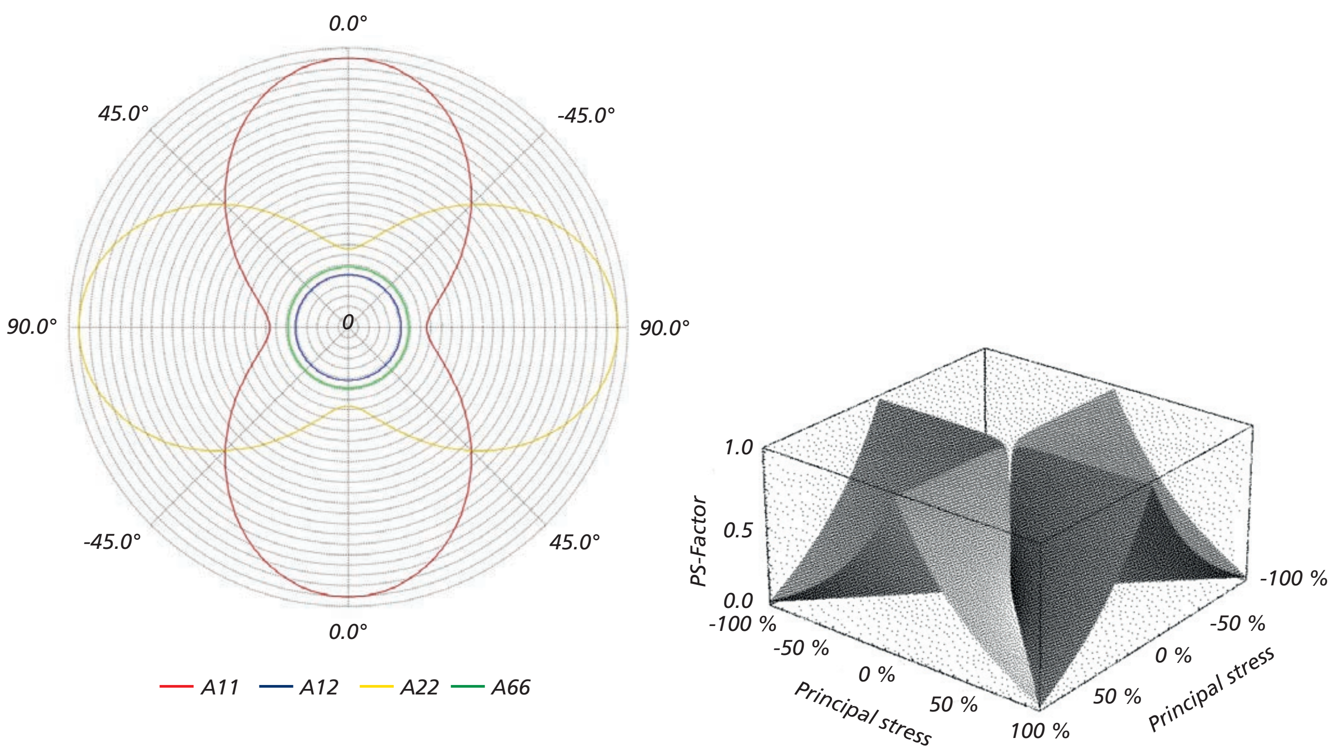


7 Axial compression tests with hybrid coupon specimens.

coupon results to the next stage of principal components is one of the major interest when conducting this type of mechanical test.

The knowledge about the crash specific requirements in the different structural areas of the body-in-white is just as important as understanding the mechanical behavior and the hybrid mechanisms within the hybrid material systems. Thus, a large number of numerical crash simulations with full vehicles is evaluated. In order to derive a global overview of the existing loading situations in the various structural areas, the numerical simulation results of the different crash scenarios are superimposed and analyzed with respect to hybrid specific loading criteria. This could be the degree of global loading anisotropy, for instance. A structural area subject to a rather anisotropic loading situation, meaning there is one single predominant loading direction for all critical load cases, indicates a high potential for rather composite intensive hybrid crash structural applications in this area. This is due to the mostly anisotropic (directionally dependent) mechanical properties of high performance FRPs (Figure 8).

Another focal point of the research project is the development of an efficient method to model hybrid crash structures for numerical simulations in the predevelopment of novel, composite intensive vehicle architectures. One of the major challenges here is to correctly balance the very detailed modeling of the – particularly for composites – highly complex failure mechanisms and a time- as well as computationally efficient modeling technique with an adequate level of detail. Since the development processes in the field of vehicle safety involving many highly complex full vehicle crash simulations are particularly computationally expensive, the efficiency is one of the most important criteria when deciding for or against the implementation of a particular method into the predevelopment processes of automotive crash structures.



8 Anisotropic behavior of FRPs – directional dependency of the mechanical properties and of the loading (Figure left: TU Dresden; Figure right: 1. Auflage Göttingen: Cuvillier, 2008 Audi-Dissertationsreihe Bd. 3) .

Crash simulation for electromobility

New challenges with electric vehicles

The development and introduction of alternatively powered vehicles with modern designs on public roads raises the question whether crash safety issues between conventional and alternatively powered vehicles are still covered by current crash test guidelines, or whether crash compatibility issues between the old and the new car generation can occur. Furthermore, the question arises whether the current regulations regarding these new vehicles meet the safety requirements, or whether they have to be further developed.

Research project EVERSAFE

These questions were addressed by the Fraunhofer EMI together with the Fraunhofer Institute for Chemical Technology ICT, the Swedish Research Institute of Transport and Transportation (VTI), the Federal Highway Research Institute (BASt) and the Volvo Car Corporation (VCC) in a common Research project named "Everyday Safety for Electric Vehicles" (EVERSAFE[1]). The project was founded by the ERA-NET Electromobility + Community through the 7th Research Framework Programme of the EU. Fraunhofer EMI could contribute with important results particularly in the field of passive vehicle safety (Figure 9). Critical load cases for electric vehicles were derived from this study and recommendations were developed for improved crash test guidelines.

Material characterization of lithium-ion battery cells

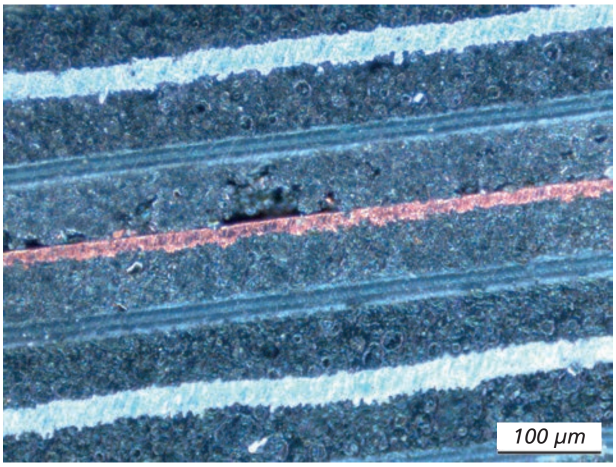
An important step consisted in an appropriate description of the mechanical behavior of current battery cells under dynamic loads. The majority of publications on cell experiments and cell simulations still primarily deal with thermal and electrical issues. However, in the event of a crash, the mechanical properties and deformations of the cell are essential, and these have to be considered for an appropriate crash model.

Therefore, characterization tests of cell materials and experiments on lithium-ion pouch cells were performed at Fraunhofer EMI. Microscopic analyses allowed to determine the essential material layers and their respective thicknesses precisely (Figure 10, next page).

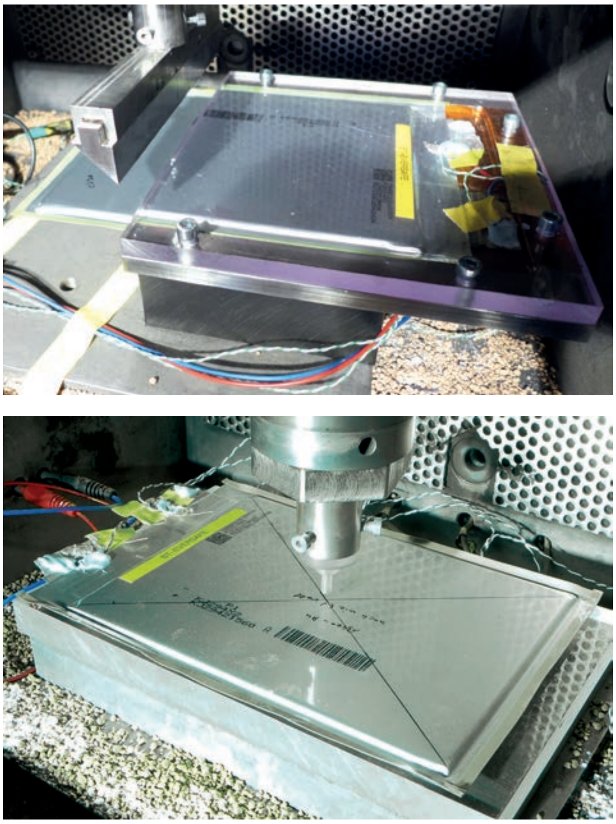
Samples for the tensile tests were directly cut out of the cell, so that each individual layer of the entire laminate and the laminate itself could be characterized. The resulting calibrated model allowed an accurate understanding of the different failure mechanisms in the cell, which is of main interest for predicting possible short-circuits.

9 Tasks of Fraunhofer EMI in the project EVERSAFE: Starting with cell analysis, the modeling of battery cells and cell materials over vehicle batteries to full car crash simulation under various load case was considered.

[1] *More information can be found on the website www.eversafe-project.eu.*



10 Microscopic analysis of the lithium-ion cell to identify the different layers and their thicknesses.



11 Destructive tests performed on fully loaded lithium-ion battery cells. Top: Shear test on cells with a sharp indenter; Bottom: Penetration test with a rounded plastic penetrator.

Additionally, various destructive component tests of charged cells were conducted (Figure 11). In this case, the so-called "abuse tests" consisted firstly of a penetration attempt with a rod-shaped penetrator, and secondly a shear test with sharp-edged cutting. The aim of the shear tests was to study the influence of a separation of the cell body through the cutting of a wide sharp-edged metal sheet that could likely happen in the event of a crash. Surprisingly, these cutting tests caused no chemical reaction or short-circuit.

In addition, penetration tests with thin pointed penetrators were performed both at the standard conditions and according to EMI specifications. In contrary to the standardized test according to SAE J2464, the EMI's penetrator differs in the geometrical shape and also the material used: The in-house penetrator has not a pointed, but a rounded head and is not made of metal like the standardized one, but of plastic, so that its own conducting influence could be excluded.

All tests were performed several times with the same configuration and always lead to the same results: standardized tests with thin pointed metallic head led to no chemical hazards, whereas tests with the wider plastic penetrator led to severe electro-chemical reactions with the resulting consequences.

Modeling and validation of lithium-ion cells

The modeling of the lithium-ion cells and the corresponding simulations made it possible to understand in detail the different failure steps inside the cell (Figure 12, next page). In the case of the standard test, the cell is separated and the individual layers fold, but the separator layers always prevent any direct contact between the electrodes. In the case of the non-standardized test, the individual layers severely deform until the separator is locally damaged and fails, leading to a short circuit.

Modeling and simulation of electric vehicles under crash loading

In order to get inforamtion related to the crash behavior of electrically powered vehicles, a corresponding numerical model was set up. For this purpose, the freely available finite element vehicle model of the Toyota Yaris provided by the US National Crash Analysis Center was modified and improved to fit the experimental results given by the crash database from BASt. A literature study of possible battery locations inside a vehicle and on current design concepts showed that the statistically safest place for car batteries in case of a crash is located in the tunnel area.

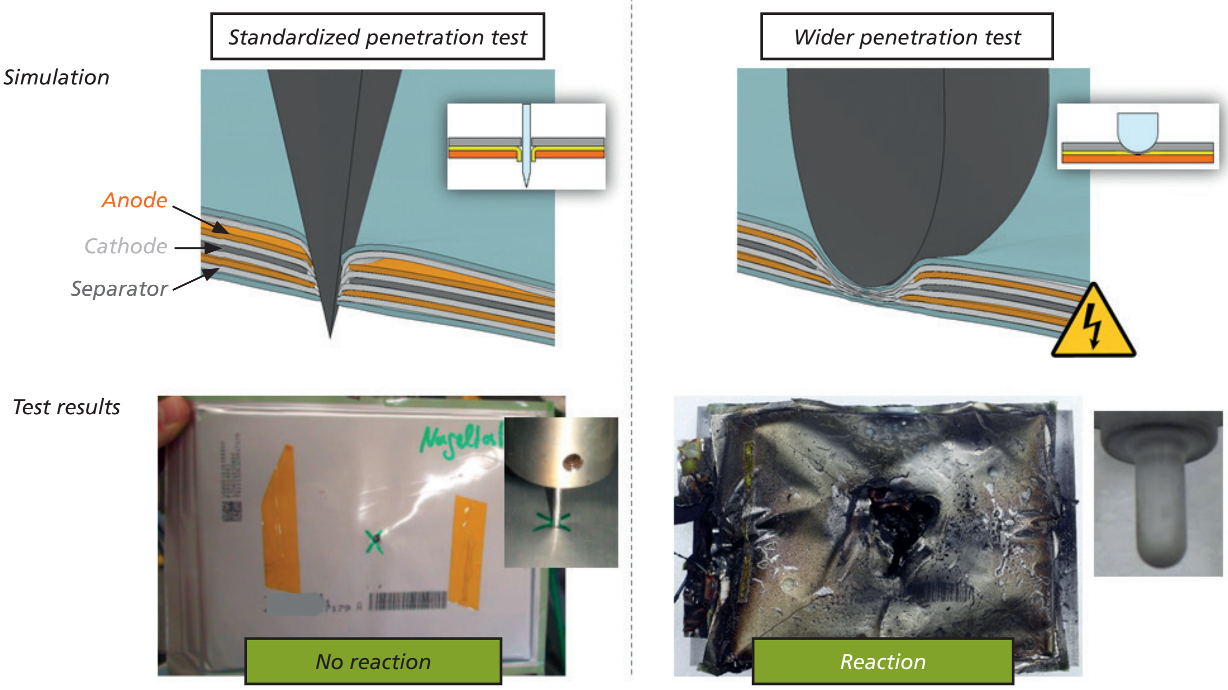
For this reason, the given vehicle model of the Toyota Yaris was converted into an electric vehicle of the first generation, in which an in-house developed tunnel battery was integrated and the combustion engine was removed.
The battery model consists of 192 pouch cells and is divided into eight modules. Both the plastic strain of the battery case as well as the forces and accelerations occurring in the modules were used to assess the severity of the accident scenarios.

The developed vehicle model was tested against a large number of crash scenarios, both coming from conventional crash-test guidelines and also crash conditions that are currently not part of any crash regulation, such as undercarriage impact or multiple traffic collisions. The model showed a very good numerical stability (Figure 13, next page). The results from all simulated load cases were examined quantitatively and sorted.

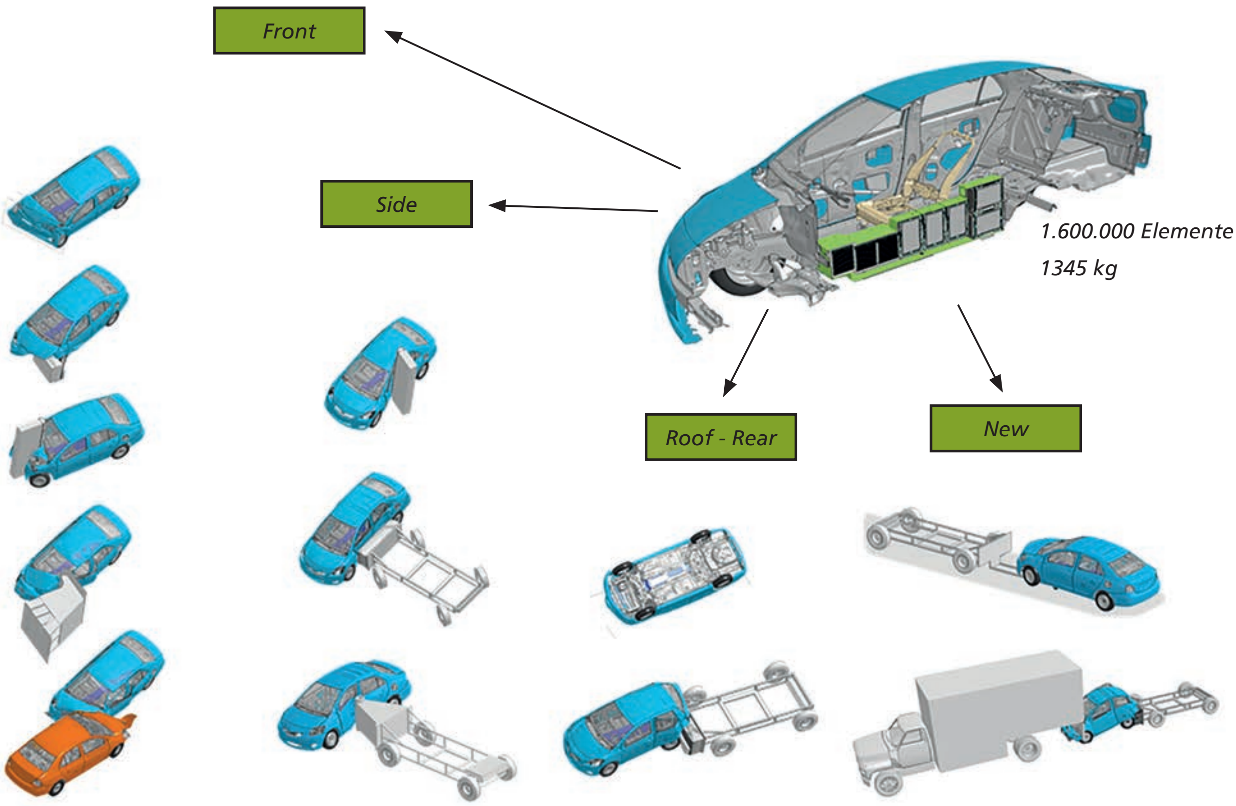
Research results and discussion

Based on both the results of the project EVERSAFE, an extensive literature review and the sharing of experiences with car manufacturers, it was possible to derive recommendations for the passive safety of future electric vehicles. These recommendations are primarily related to the critical load cases identified within the simulation, concerning front pole impact and undercarriage collisions. As a further result, it turned out that the crash compatibility between existing vehicles and electric ones is less a matter of battery integrity, but rather a matter of occupant safety.

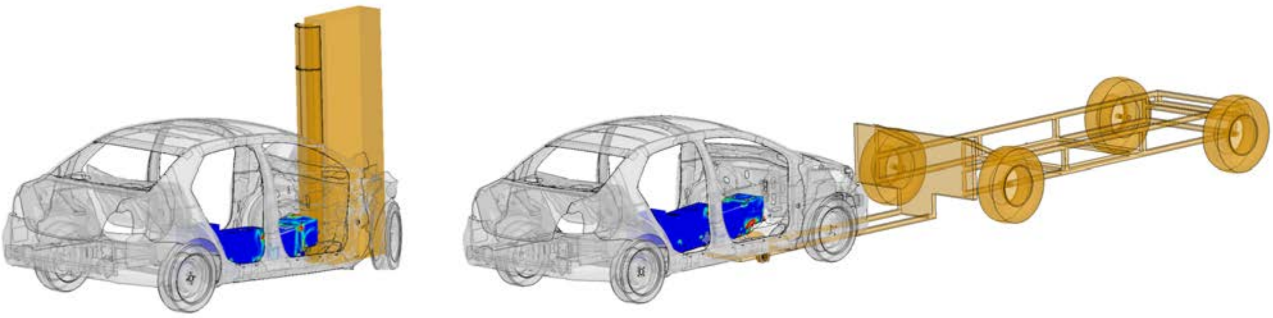
Today's battery cells are optimized so that they can usually overcome any standardized test methods. However, small deviations from these test procedures have shown electrochemical reactions with important damages for the battery and its surroundings.



12 Penetration tests according to standardized procedure (left) and according to in-house requirements (right).



13 Simulated load cases involving the electric version of the Toyota Yaris in project EVERSAFE.



14 *Load cases especially critical for the battery, for the specific car concept simulated in the project. Left: Front pole impact with 50 kilometers per hour. Right: Undercarriage impact with 40 kilometers per hour. Contour plots of plastic deformation amount are represented.*

The simulations on vehicle level have not only delivered concept-specific results, but also a method to evaluate and rank the severity of an electric vehicle accident. Recommendations concerned the improvement of the current crash test standards and the design of future electric vehicles. The worst cases were identified as the frontal pole impact with 50 kilometers per hour and the undercarriage impact with 40 kilometers per hour, which do not belong to any crash test guideline today and are not prescribed by law (Figure 14).

For the frontal pole impact a maximum pulse of more than 100 g was registered in the frontal battery module. The space gained in the front area by the conversion of the engine into a smaller electric motor must therefore be optimized to fit this scenario.

Since in many electric vehicles the vehicle batteries are located in the underbody area, undercarriage collisions should be considered. The influence of a protective structure in front of the battery that could avoid a direct impact of road debris on the battery was significant in simulations, as the primary crash pulse of almost 90 g could be reduced to more than half of its original value.

It is currently planned to investigate the impact of dynamic loads and the influence of different penetrator shapes on battery cells. The numerical model of the battery cell will also be further improved and refined. Surrounding battery components such as cables and electronic components should be considered, as these may be potential sources of hazards in a crash.

GROUPS, ALLIANCES AND COOPERATIVE ENTERPRISES

SCIENTIFIC NETWORK

GROUPS, ALLIANCES AND COOPERATIVE ENTERPRISES WITH THE INVOLVEMENT OF FRAUNHOFER EMI

Pooling expertise

The Fraunhofer EMI has a wide-ranging portfolio of research topics. Within the Fraunhofer-Gesellschaft, the institute is interconnected in a very complex way. Through profitable cooperative enterprises with other Fraunhofer Institutes, synergies are used and inter-institutional topics are made transparent and visible to the outside. Demands of public and private clients are met with comprehensive solutions from applied research.

Institutes of the Fraunhofer-Gesellschaft that are specialized within the same domain bundle competences in groups which present themselves together on the national and international market. Fraunhofer EMI is a member of the Fraunhofer Group for Materials and Components– MATERIALS as well as of the Fraunhofer Group for Defense and Security VVS.

With its wide variety of competences in the areas of characterization and modeling of highly complex materials, Fraunhofer EMI contributes to the Fraunhofer Group for Materials and Components – MATERIALS. Together with partner institutes, technologies and concepts are developed close to the market and converted into system solutions.

The Fraunhofer Group for Defense and Security VVS is the key actor and contact for politics and economy concerning civil and military security research in Germany and Europe.

The Fraunhofer EMI is thematically focused within four Fraunhofer Alliances – where institutes or departments with different competences are perfectly linked in order to work together on a business segment and to place it on the market.

GROUPS

- Fraunhofer Group for Materials and Components – MATERIALS
- Fraunhofer Group for Defense and Security VVS

ALLIANCES

- Fraunhofer Battery Alliance
- Fraunhofer Building Innovation Alliance
- Fraunhofer Lightweight Structures Alliance
- Fraunhofer Numerical Simulation of Products, Processes Alliance
- Fraunhofer-Alliance Space

COOPERATIVE ENTERPRISES

- »Centre for Security and Society«: in cooperation with the University of Freiburg for a joint security research
- Sustainability Center Freiburg In cooperation with Freiburg’s five Fraunhofer Institutes, the Albert-Ludwigs-Universität Freiburg and the industry (p. 117)
- Resilien-Tech: Resilient-technical cooperation project with acatech – Deutsche Akademie der Technikwissenschaften – in ordert o develop strategic topics of the future in the area of resilient infrastructures (p. 127)
- Leading edge cluster Electromobility South-West (p. 129)
- Clean Sky 2 Joint technology initiative in the aerospace sector. Fraunhofer is one of the 12 founding member Clean Sky (p. 131)
- Training program “safety system technology” in cooperation with the University of Freiburg (p. 133)

SUSTAINABILITY CENTER FREIBURG

Sustainability Center Freiburg

The Sustainability Center Freiburg has been inaugurated on March 6, 2015 during a gala in the "Historisches Kaufhaus". For the first time, researchers from the five Freiburger Fraunhofer Institutes and from the University of Freiburg are working side by side with the industry to improve resource conservation and climate protection. This constellation is new and promising in this form: The different points of view on the topic of sustainability create new, application-oriented solutions.

This exceptional form of cooperation has been made possible by the collaboration between the University of Freiburg and the Fraunhofer-Gesellschaft. Professor Hans-Jochen Schiewer and Professor Reimund Neugebauer recognize the potential that lies in the pooling of the different strengths of the institutes. The industry as well has been convinced by this and is now able to introduce its questions and profit from the results of the research. This became evident in the panel discussion on the opening day, during which industry representatives stressed the priority of sustainable development.

"Sustainability is one of the German economy's key issues", says Professor Reimund Neugebauer, President of the Fraunhofer-Gesellschaft. "We have to consolidate our strengths. With this pilot scheme for a national sustainability center, we pave the way to harness the region's potential more intensively. Freiburg will be a location for top level research for sustainable development, but this can only be achieved if we get the economy on board", Neugebauer added. Recent projects of the Sustainability Center Freiburg examine how the resource efficient LED-technology can be established with blanket coverage via lower manufacturing costs, whether and how CO_2 could be used as a raw material, and what we can learn from the self-repair-mechanisms of plants. The financing for these pilot projects and The Sustainability Center is provided by the Ministry of Science, Research and Arts Baden-Württemberg, the Ministry of Finance and Economy Baden-Württemberg, and the Fraunhofer-Gesellschaft. 7.2 million euros will be available over the next three years: among other things, the pilot projects, the annual conference "Sustainability Summit" (the former "Solar Summit" of the Fraunhofer Institute for Solar Energy Systems ISE) will be financed with these funds. Partners from the industry additionally participate with 6 million euros in work transferring the findings into praxis.

"With our funding, we support the University of Freiburg and Fraunhofer's strategic objective of establishing a globally respected center for sustainability research. Young scientists from all around the world as well as established top researchers, innovative company founders and established companies will be working together in the Sustainability Center Freiburg. Here and today, we will begin the realization of the vision of a location for top research, teaching and further education for sustainable development, a room for innovation, and a place for the dialogue with the society about the future topic of sustainability", says Baden-Württemberg Minister for Research Theresia Bauer.

Fraunhofer's and the University of Freiburg's future plans will be synchronized via a roadmap. Targeted advancement of the main topics sustainable materials, energy systems, resilience research, and how society deals with processes of change are part of these plans in the Sustainability Center Freiburg. The planned Institute for Sustainable Systems Engineering (ISSE) at the faculty of Engineering will be the engineering-oriented core of the sustainability center. "The ISSE will expand our university by a further future-oriented key topic and will provide many important impulses for research and teaching" says Professor Hans-Jochen Schiewer, rector of the Albert-Ludwigs-Universität Freiburg.

It is only when we look beyond our own scientific horizon that we can find the correct answers. "This is what we aim for", explains Schiewer. "We bring together application-oriented scientists from Fraunhofer and the natural scientists, the social scientists, and scientists of the humanities from the University." Six pilot projects have already started.

"The challenges that the topic of sustainable development poses are very diverse and require technological, ecological and economical expertise as well as profound knowledge of societal relations. A center that fully approaches relevant issues of the future comes into being in Freiburg due to our funding. This strengthens the economy-oriented research and will accelerate the cooperation between the disciplines and between the institutes in Freiburg" Minister of Finance and Economics Dr. Nils Schmid stresses.

The dialogue with the society is particularly important to the research community. "Our scientific findings should find their way into practice as soon as possible", says Professor Reimund Neugebauer. "This can only be made possible if we know what is important to the people and if we know how we can help them." Thus, the new Sustainability Center Freiburg will also offer possibilities for an exchange between science and society.

The Georg H. Endress-Stiftung was the first important partner from the industry to contribute to the Sustainability Center Freiburg together with the University and the Fraunhofer Institute for Physical Measurement Techniques IPM. The project encountered a broad resonance with companies in the region and beyond, who want to integrate the aspects of sustainability into their product development. Further projects are i. a. planned with the Daimler AG, EnBW and the Robert Bosch GmbH. The partners of the Sustainability Center Freiburg thus establish a broad network with a focus on companies from Baden-Württemberg.

Photo 1: *The two coordinators of the Sustainability Center Freiburg, Professor Gunther Neuhaus, vice-rector/prorector for research at the Albert-Ludwigs-Universität Freiburg and Professor Stefan Hiermaier, director of the Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI;* ***Photo 2:*** *More than 200 guests attended the opening ceremony in the "Historisches Kaufhaus";* ***Photo 3 und 4:*** *In the panel moderated by Heike Schmoll (FAZ), Prof. Dr. Reimund Neugebauer, President of the Fraunhofer-Gesellschaft, talked with Prof. Dr. Dr. h.c. Hans-Jochen Schiewer, Rector of the University of Freiburg, Dr. Gisela Splett, Member of the Parliament and Secretary of State in the Ministry for the Environment and Transport Baden-Württemberg, Dr. Robert Bauer, Chairman of the SICK AG, Dr. Klaus Dieterich, former Chief Executive Officer in Research And Advance Development, Robert Bosch GmbH and Dr. Ulrich Kaiser, Director Technology Endress + Hauser Management GmbH.* ***Photo 5:*** *The exhibition of the pilot projects;* ***Photo 6:*** *Hartmut Klein informs the press about the project "bio-inspired self-repairing materials for a sustainable development".*

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The pilot projects with contributions from Fraunhofer EMI in the Sustainability Center Freiburg

Bio-inspired self-repairing materials
The pilot project "bio-inspired self-repairing materials for a sustainable development" is thematically assigned to the Sustainability Center Freiburg's research-topic Sustainable Materials.

It deals with the examination of processes of self-repair in special species of plants, the development of the functional principles and the generation of a suitable numerical model. It will be examined whether and how natural self-repair-mechanisms can be transferred onto materials. A critical assessment of a self-repairing material's potential with regard to an improvement of sustainability is also part of the research.

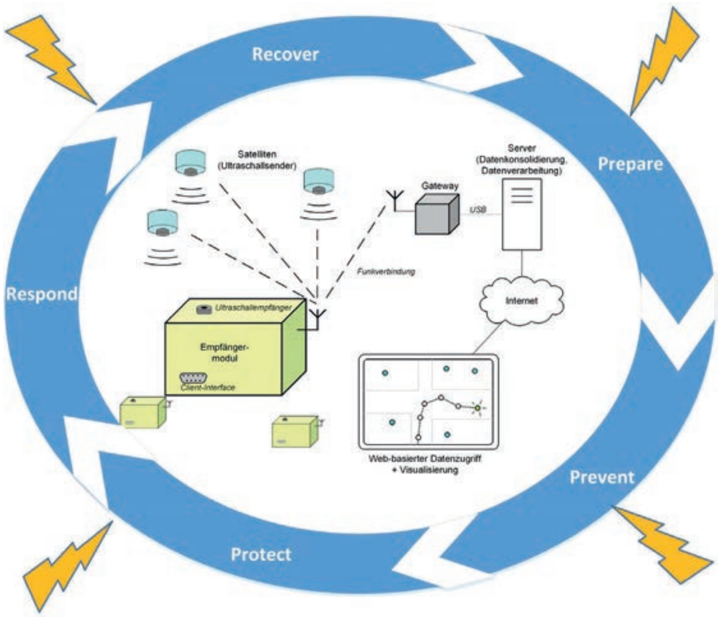
The usage of materials with a self-repair-function in technical products is interesting for all applications. Self-repairing materials allow an extension of the operability while diminishing the maintenance costs. Especially for building materials or components difficult to access in permanently running systems, self-repairing materials are of great interest. The project is carried out by a team of biologists and bionic scientists of the University of Freiburg's Plant Biomechanics Group (Dr. Olga Speck, Prof. Dr. Thomas Speck) and engineers of the Fraunhofer EMI's Material Dynamics Department (Dr. Matthias Boljen, Hartmut Klein).

The project especially excels due to its interdisciplinary approach from and via the supplementary scientific competences from the fields of biology, bionic sciences, material modeling and material testing as well as sustainability assessment.

Malleable plastics made from Lignin: A by-product of the timber industry replaces fossil raw materials
Lignin is a constituent of wood and occurs in vast quantities as a by-product in paper production. Lignin is actually a valuable raw material due to its chemical structure, from which a bio-based plastic could be won. Due to difficulties in processing, lignin is not used in a value-added chain to make a synthetic, but serves as fuel for the paper production's energy demand. Each year, 50 million tons of a principally valuable raw material are destroyed this way.

In this research project, the EMI, together with the University of Freiburg's center for Material Research, examines how the processing characteristics of lignin can be significantly improved by adding a second bio-based component.

Degrees of resilience to optimize technical systems
In the pilot project "Degrees of Resilience to Optimize Technical Systems", technical resilience levels and metrics will be determined that describe the failure of functions on a system level and their temporal change. Especially after the occurrence of disruptive events (environmental influences, partial system failure, human mistakes). The objective is the development of a holistic and systematic approach for evaluation and comparison of different system designs with regard to relevant disciplines of resilience, such as reliability, security, or availability in consideration of the phases of the resilience cycle. In this context, new verifiable degrees of resilience have to be introduced, especially for the determination of the optimization potential of technical systems. To assess these degrees, new methodical and experimental analyses are necessary as well. The project partners Fraunhofer EMI, the three institutes IMTEK (Department of Microsystems Engineering), IIF (Department of Computer Science) and IFS (Department of Sociology) of the University of Freiburg as well as the HSG-IMIT (Institute of Micro- and Information Technology of the Hahn-Schickard-Gesellschaft) provide the corresponding methodical fundamentals and the experience in their



Schematic illustration of technical systems in the resilience cycle.

practical implementation. By developing a new interdisciplinary method of analysis, they also ensure the transferability onto systems of different technology and application. An energy self-sufficient and autonomous sensor system for the cost-efficient indoor-localization for mobile objects in the field of inventory logistics (controlling and monitoring of interactions between goods and robots) serves as a first example. The disruptive partial system failures that are to be examined for example include the disruption of data links, the failure of entire transmitter- and receiver-components, as well as the disruption of grid areas. The forum INTRALOGISTIK e. V. supports the project with regard to the construction of a test- and praxis-environment. With further case studies in the area of airport security and construction site logistics, the independence from technology and the transferability onto further application areas will eventually be verified for the developed methodical approach to determine resilience.

Central Office
Benjamin Scharte, Fraunhofer EMI
Phone +49 761 2714-538

Sorana Kamla, University of Freiburg
Phone +49 761 203-6803

Eckerstraße 4
79104 Freiburg, Germany

geschaeftsstelle@leistungszentrum-nachhaltigkeit.de

SUSTAINABILITY CENTER FREIBURG

For more information, visit
www.leistungszentrum-nachhaltigkeit.de

FRAUNHOFER GROUP FOR MATERIALS AND COMPONENTS – MATERIALS

The Fraunhofer Group for Materials and Components – MATERIALS pools the expertise of those Fraunhofer institutes which are focused on materials science.

Fraunhofer research in the field of materials science and engineering covers the entire value chain from the development of new materials and the improvement of existing ones to manufacturing technology on a semi-industrial scale, the characterization of materials' properties and the assessment of their performance. This work extends to the components produced from the materials and their performance in systems. In addition to experimental tests in laboratories and pilot plants, numerical simulation and modeling techniques are applied in all these areas and in all dimensions, on molecular scale as well as on component scale and with respect to processes. The Fraunhofer Group for Materials and Components – MATERIALS encompasses the entire field of metallic, inorganic-nonmetallic, polymer and sustainable materials, as well as semiconductor materials.

The Group concentrates its expertise mainly in the Energy & Environment, Mobility, Health, Machinery & Plant Engineering, Construction & Living, Microsystems Technology, and Safety business sectors. System innovations are achieved by means of tailor-made material and component developments and customer-specific performance assessment. With strategic forecasts the group supports the development of future materials and technologies.

Key objectives of the Group are:

- To increase safety and comfort and to reduce the consumption of resources in transport, mechanical engineering, plant construction and building industry
- To raise the efficiency of systems for generating, converting, storing energy and distributing
- To improve the biocompatibility and functioning of materials used in medical engineering and biotechnology
- To increase the integration density and improve the utility properties of components in microelectronics and microsystem technology
- To improve the use of raw materials and the quality of the products made from them
- Recycling concepts

Fraunhofer MATERIALS

For more information, visit
www.materials.fraunhofer.de

The Group comprises the Fraunhofer Institutes for
Applied Polymer Research IAP
Building Physics IBP
Structural Durability and System Reliability LBF
Chemical Technology ICT
Manufacturing Technology and Advanced Materials IFAM
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Ceramic Technologies and Systems IKTS
High-Speed Dynamics, Ernst-Mach-Institut, EMI
Silicate Research ISC
Solar Energy Systems ISE
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ursula.eul@lbf.fraunhofer.de

FRAUNHOFER GROUP FOR DEFENSE AND SECURITY VVS

The VVS continues being the national authority in the field of security and defense research. The first major science conference in cooperation with DWT sets an example. After two terms in office, Prof. Thoma passes the chairmanship of the Group to his successor.

Security and defense research are anchored in the scientific identity of Fraunhofer-Gesellschaft

Since its founding, the Fraunhofer-Gesellschaft has been obliged to the Federal Ministry of Education and Research (BMBF) as well as to the Federal Ministry of Defence (BMVg). Due to its vast portfolio, Fraunhofer covers the largest part of the institutional research conducted for the BMVg.

The prosperity and growth of our developed industrial societies already depend on globally highly linked critical infrastructures. The massive disturbance or, worse, destruction of these infrastructures carries the potential to trigger economic and societal secondary damage that cannot be calculated.

Furthermore, fading borders between interior and exterior, and between public and private security confront our state institutions, which are responsible for security measures, with so far unknown challenges when facing modern phenomena such as internationally operating terrorism, transnationally organized crime, as well as local natural catastrophes and major accidents with possibly global impacts. In order to early detect and possibly prevent the vast number of possible hazards from occurring and to minimize the consequences, the VVS is developing thorough technological security solutions and the accompanying methodological, procedural, and tactical concepts.

1st science conference »Applied research for defense and security« in cooperation with the German military technology society (DWT)

From February 3 to 5, 2014, this science conference took place in Berlin for the first time. It was organized upon request of the BMVg and was co-hosted by Fraunhofer VVS and DWT. Alongside a variety of scientific presentations, there was an accompanying exposition which offered a broad overview of the research development. The 304 participants were informed about research efforts of the application-oriented research organizations, meaning primarily representatives of Fraunhofer, DLR and ISL Saint-Louis. This was complemented with contributions by assigned departments of the BMVg, e.g. the Technical and Research Centers of the Bundeswehr (WTDs). The civil safety authorities have also shown interest and wide response with representatives of the Federal Criminal Police Office, the GSG9, the Deutsche Hochschule der Polizei (German Police University), and of the State Offices of Criminal Investigations participating in the conference.

Prof. Thoma passes the chairmanship of the Fraunhofer Group VVS to Prof. Dr.-Ing. Jürgen Beyerer and Prof. Dr. Peter Martini

Since the founding of the Fraunhofer Group VVS in 2002, Prof. Thoma held the office of chairman and competently led the Group through times that were sometimes rather turbulent. Along with the Group's outstanding position within the scope of national and international security and defense research, Prof. Thoma managed to supervise and moderate the FGAN institutes' integration into the Fraunhofer-Gesellschaft. The former FGAN institutes are now Fraunhofer FHR, Fraunhofer FKIE and Fraunhofer IOSB.

Besides the consolidation of German defense research with respect to growing challenges of the structural and political change in the research landscape, the existence of a national and European research program in the field of civil security research is significantly Prof. Thoma's achievement. After twelve years in office, Prof. Thoma passed the chairmanship of the Group to Prof. Jürgen Beyerer, Director of the Fraunhofer Institute for Optronics, System Technologies and Image Exploitation IOSB, on January 1, 2015. New deputy chairman is Prof. Peter Martini, Director of the Fraunhofer Institute for Communication, Information Processing and Ergonomics FKIE.

Figure above: Group photo during the VVS-meeting in November 2014 at Fraunhofer EMI.

Member institutes are the Fraunhofer Institutes for

High-Speed Dynamics, Ernst-Mach-Institut, EMI
Applied Solid State Physics IAF
Chemical Technology ICT
Technological Trend Analysis INT
High Frequency Physics and Radar Techniques FHR
Communication, Information Processing and Ergonomics FKIE
Optronics, System Technologies and Image Exploitation IOSB
Systems and Innovation Research ISI (guest institute)
Integrated Circuits IIS (guest institute)
Telecommunications, Heinrich-Hertz-Institut, HHI (guest institute)

Chairman of the Group:
Prof. Dr.-Ing. Jürgen Beyerer
Fraunhofer IOSB

Deputy Chairman of the Group:
Prof. Dr. Peter Martini
Fraunhofer FKIE

Central Office:
Caroline Schweitzer
Fraunhofer IOSB
caroline.schweitzer@iosb.fraunhofer.de

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For more information, visit www.vvs.fraunhofer.de

RESILIEN-TECH: COOPERATION PROJECT WITH ACATECH FOR THE DEVELOPMENT OF STRATEGIC FUTURE TOPICS REGARDING RESILIENT INFRASTRUCTURES

Adaptation instead of isolation: resilience is the security concept of the 21st century

Fraunhofer EMI defines the requirements future technological solutions will have to meet in order to increase the resilience of society.

"Modern infrastructure cannot be fully protected from natural disasters, terrorism, cyber attacks or accidents. This is why resilience is the security concept of the future: the fast adaptation complements existing strategies, such as isolation through robust, but rigid protection mechanisms, to a holistic entity.

After a first test and analysis of existing approaches, three workshops with renowned experts were realized, in which national, European, and non-European (specifically, US American) perspectives of resilience were discussed. At the end of the workshop, the focus was on "resilient companies", including an analysis of those aspects of resilience which have already found their way into long term company strategies. Based on the workshop presentations and discussions, ten recommendations were formulated:

Resilience aims at a new definition of security: critical infrastructures will also function reliably during unexpected interferences and will return to an operable state as quickly as possible. Resilience is not a static state, but a characteristic feature of adaptive, flexible systems. In order to minimize the economic and ecologic damage as much as possible, citizens will have to prepare for the unpredictable as well.

Especially the resilience of critical infrastructures is of growing importance, because those infrastructures are increasingly interconnected and thus, new vulnerabilities emerge. Even minor, seemingly harmless interferences can, in a chain reaction, lead to severe damage or even total system failure. Since natural disasters, accidents or terrorist attacks cannot be fully averted, we have to think security in new ways: According to the principle "bend, not break", modern infrastructures must learn to better adjust to the unpredictable. Humans and infrastructures can only be efficiently protected in the future if we realize in society that prevention as well as adequate crisis response and the ability to learn from past events are important tasks and have to be implemented.

Prof. Thoma presented the results of Resilien-Tech to Dr. Wolf Junker from the German Federal Ministry of Education and Research (BMBF) in the framework of the second BMBF innovation forum "civil security" on May 8, 2014 in Berlin. They have been published in the acatech study "Resilien Tech – Resilience-by-design: strategies for the technological topics of the future" (download at www.acatech.de/de/publikationen/studie.html).

acatech NATIONAL ACADEMY OF SCIENCE AND ENGINEERING | Fraunhofer EMI

For more information, visit www.acatech.de

Contact
Daniel Hiller
daniel.hiller@emi.fraunhofer.de

Figure left: Prof. Thoma presents the results of Resilien-Tech to Dr. Wolf Junker from the German Federal Ministry of Education and Research.

LEADING EDGE CLUSTER
ELECTRIC MOBILITY SOUTH-WEST

Leading edge cluster Electric Mobility South-West: Fraunhofer EMI develops diagnostics concepts in the after-sales for electric vehicles

Germany pursues ambitious climate change objectives – to reach these, the CO_2 emissions in the transport sector have to be reduced drastically. One applicable measure is the introduction of electric vehicles in large quantities. This poses new challenges for suppliers, automotive manufacturers, service stations and technical service providers. Those challenges include the safe operation, the safe and precise identification of defects and faults – especially in the high voltage system – and the safe maintenance of electric vehicles. Consequently, a decisive factor for the commercial breakthrough of electric vehicles is a competitively viable maintenance concept in the after-sales sector. Only if the complex HV system can be repaired after a car crash or a defect in a safe and cost efficient way, a positive customer acceptance can be achieved.

For this reason, the project DINA – diagnostic and maintenance in after-sales – was launched. Fraunhofer EMI cooperates with the Robert Bosch GmbH, DEKRA and the Research Institute of Automotive Engineering and Vehicle Engines Stuttgart (FKFS) until autumn 2015 in conducting research on efficient and reliable diagnostic methods and cost-effective maintenance concepts and solutions in the after-sales sector. Fraunhofer EMI's research focus is on the analysis of components within the complete system and on understanding the resulting interactions, correlations and the fault patterns. This way, complex fault correlations are detected and modeled. The models and fault patterns subsequently serve as starting point for the design of symptoms-based diagnostic algorithms (on board- and off-board diagnosis) and are integrated into a comprehensive diagnostic concept. This will be an essential part of the service concept for electric vehicles that is being developed in the framework of the project.

The project DINA is one of the central projects of the leading edge cluster "Electric Mobility Southwest", which has successfully participated in the third round of the Leading Edge Cluster Competition initiated by the German Federal Ministry of Education and Research (BMBF) in 2012. With more than 80 renowned large, medium and small sized businesses, universities and research institutes, the cluster combines competences from the fields of automotive engineering, energy management, ICT (information and communication technology) and manufacturing. Fraunhofer EMI as a partner in the leading edge cluster is especially active in the cluster's field of innovation: "vehicle".

With innovative technologies and methods, the cluster partners are significantly shaping the basis for new, economically sustainable business models which secure the regional economic value added and the jobs in the cluster region and in all of Baden-Württemberg. The cluster's objective is to advance electric mobility, to establish Germany as the leading supplier and leading market of e-mobility with international attention, and to make Baden-Württemberg a leading region for electro-mobile solutions on the global market.

Contact
Benjamin Scharte
benjamin.scharte@emi.fraunhofer.de

elektromobilität süd-west

Fraunhofer EMI

For more information, visit
www.e-mobilbw.de

CLEAN SKY

Participation in the most ambitious aeronautical research program in Europe

75 percent less CO_2, 90 percent less NO_x, 65 percent less aircraft noise: Clean Sky has set its sights on developing technologies which contribute significantly to more sustainable airplanes and to air traffic with less emission.

With an expected increase of global air traffic of 4 to 5 percent per year, a reduction of noise and emissions marks an important contribution to environmental sustainability of aircrafts and to air itself, and therefore to the quality of living, especially around airports. More efficient fuels with a simultaneous reduction of fuel consumption through the use of lighter materials in airplane manufacture aim at making air traffic more affordable.

In order to achieve these ambitious goals, the largest industrial companies of the European aviation sector and the European Union have formed a partnership, the Joint Technology Initiative "Clean Sky". This public-private partnership is part of the EU's 7th Framework Programme for Research and Innovation and has been running since 2008. In 2014, the CO_2- emission could be reduced by 20 percent compared to the year 2000. But Clean Sky is to continue: In addition to the results of Clean Sky, environmental impacts due to air traffic are to be reduced further and European aviation shall become even more competitively viable.

The new technologies are planned to be driven further: a 20 – 30 percent reduction in fuel consumption and related CO_2 emissions compared to the level of 2014, reductions in NO_x of at least 30 percent, and at least a 30 percent reduction of noise. The partnership of industry and European Union is continued in "Clean Sky 2". Within the scope of Horizon 2020, the new Framework Programme for Research and Innovation, the Joint Undertaking Clean Sky 2 will run from 2014 to 2020 with a total budget of 4 billion euros.

Along with large European airline companies like Airbus, Airbus Helicopters, AgustaWestland, Alenia Airmacchi, Dassault Aviation, DLR, EADS-CASA, Evektor, Liebherr, MTU, Piaggio-Aero, Rolls-Royce, SAAB, Safran, and Thales, Fraunhofer is also involved in this partnership. Within the scope of Clean Sky 2, Fraunhofer EMI is one of seven key institutes of Fraunhofer Aviation which are working actively on the development of aerospace technology in direct cooperation with the industry. Among the competences and contributions of the Ernst-Mach-Institut are the simulation of lightning and bird strike, debris impact, manufacturing of light-weight components with laser sintering, analysis of crash behavior of small and large aircraft parts, and on-site diagnosis of potential damage on the airplane through mobile X-ray machines.

Contact
Dr. Stephanie Günther
stephanie.guenther@emi.fraunhofer.de

For more information, visit www.cleansky.eu.

KICK-OFF OF THE CONTINUING EDUCATION TRAINING “SICHERHEITSSYSTEMTECHNIK” (SECURITY SYSTEMS ENGINEERING) FEBRUARY 27 AND 28, 2014

CONTINUING EDUCATION TRAINING DIPLOMA OF ADVANCED STUDIES (DAS)

SICHERHEITSSYSTEMTECHNIK (SECURITY SYSTEMS ENGINEERING)

CERTIFICATES OF ADVANCED STUDIES

CAS RISK ANALYSIS
CAS TECHNICAL SAFETY
CAS SECURITY SYSTEMS ENGINEERING

The Ernst-Mach-Institut's research topics as a blended learning continuing education training

The courses "Risk Analysis" and "Technical Safety" of the continuing education training "Security systems engineering", which are developed and conducted within a cooperation between the Ernst-Mach-Institut and the University of Freiburg, started with an opening ceremony in the Ernst-Mach-Institut in Freiburg on February 27 and 28, 2014. Current and concluded topics of research from the Department of Safety Technology and Protective Structures are part of the training. They include risk analysis schemes, risk assessment, examples of qualitative and quantitative risk analyses, systems analysis methods such as Failure Modes and Effect Analysis (FMEA,) and Fault Tree Analysis (FTA), the semi-formal modelling of safety-critical systems, and how to deal with security related standards such as the IEC 61508.

For a better balance of the training with family and work, the courses are carried out in the blended learning format. The participants meet three times in Freiburg during the one-year course and work on their own on an internet platform for five hours a week between the meetings. The self-learning stages are complemented by regular online-meetings with experts from the Ernst-Mach-Institut. The continuing education training is embedded in the continuing education program of the University of Freiburg.

The courses are developed according to the classification and quality standards of the Swissuni. They are assessed with the established Bologna-process ECTS points (European Credit Transfer System, 1 ECTS point matches 30 working hours) and can be combined (10 ECTS Points, 30 ECTS Points). The development of the continuing education training took place within the joint project "Freiräume für Wissenschaftliche Weiterbildung" (Windows for Continuing Education) with the University of Freiburg and the Fraunhofer Institute for Solar Energy Systems ISE, which is sponsored by the Federal Ministry of Education and Research Baden-Württemberg in the competition "Aufstieg durch Bildung: Offene Hochschulen" (Advancement through Education: Open Universities).

The courses will likely be offered again in 2016. In the course of the second phase of the BMBF joint project, further courses will be developed and piloted in the subproject "Resiliente Technische Systeme" (Resilient Technical Systems) of Fraunhofer EMI in cooperation with the University of Freiburg from 2015 to 2017: CAS Structural Security, CAS Resilience Analysis and CAS ApplicationTool Development. Every CAS will, in turn, consist of two courses of 5 ECTS points each.

For more information please visit www.offenehochschule.uni-freiburg.de/sicherheits-systemtechnik

Contact
Dr. Ivo Häring
ivo.haering@emi.fraunhofer.de

Figure above:
Group photo during the opening event in Freiburg.

NAMES, DATES, EVENTS
HIGHLIGHTS
2014/15

"FUTURE SECURITY", BERLIN
SEPTEMBER 16–18, 2014


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9th Future Security conference in Berlin

The 9th edition of this conference was visited by important representatives from the USA and put special focus on certain topics: The concept of resilience was discussed in several expert panels and presentations. The question was to what extent resilience introduces a new dimension to the current understanding of classic safety. Prof. Thoma, chairman of the Fraunhofer VVS and the conference's organizer, was honored for his life-time achievement.

From September 16 to 18, 2014, the Fraunhofer Group for Defense and Security VVS' 9th "Future Security" conference took place in the Berlin Representation of the Federal State of North Rhine-Westphalia. 237 participants from the fields of research, industry and government were discussing current research results and were seeking new solutions for existing and upcoming challenges in order to contribute to a secure future.

The conference was opened by Thomas Rachel, Parliamentary Secretary of State at the Federal Ministry of Education and Research (BMBF). Then, Richard A. Serino, former Vice-Head of the American Federal Emergency Management Agency, offered fascinating insights into the United States' recent efforts to fill the concept of resilience with novel topics through new partnerships with various players. Serino was, for example, commander-in-chief of the entire disaster relief crew in New York and New Jersey during hurricane Sandy in 2013. On the second conference day, a panel with representatives from the United States provided useful insights into the transfer of resilience to policy initiatives and rules within the USA. This was also addressed in a keynote by Caitlin A. Durkovich, Assistant Secretary for Infrastructure Protection in the Department of Homeland Security DHS.

In a total of 75 expert presentations, the scientific program gave a broad insight as well as an overview of current research activities and results. The conference was again complemented by a poster exhibition. For the first time, all participants could vote for their favorite poster and the winner was granted the Best Poster Award. The winning poster showed the detection of hazardous substances in freight containers using X-ray tomography and was made by employees of Fraunhofer IIS. This research project was also supported by employees of Fraunhofer EMI.

A special highlight was the conference dinner, which took place at the German Museum of Technology in Berlin. Surrounded by real airplanes and vehicles, the participants enjoyed excellent food and an entertaining program, which included a humorous speech by Henning Beck called "Neuro-Security – How to protect data in biological systems".

The 9th Future Security Conference, however, was also a place to say goodbye. Prof. Klaus Thoma, co-founder and Chairman of the Fraunhofer Group VVS, is retiring and leaves Fraunhofer EMI at the end of 2014. He was honored for his life-time achievement by high-ranking representatives from politics and industry. They also expressed appreciation and gratitude for his work.

***Photo 1 and 2:** Keynote I "Resilience – Success Through Partnerships", Richard A. Serino; **Photo 3:** Caitlin A. Durkovich; **Photo 4:** The participants at the poster session; **Photo 5:** Conference dinner at the German Museum of Technology Berlin; **Photo 6:** Lauren Alexander Augustine.*

Future Security
Security Research Conference

For information on the next "Future Security", visit www.future-security2015.de

SCIENTIFIC CAMPUS, FREIBURG
OCTOBER 6–9, 2014

Scientific Campus 2014 in Freiburg:
The steppingstone for women to research

Female students of mathematics, computer science, natural sciences and engineering from the 4th semester upwards had the opportunity to extend their knowledge, to be counselled and to look behind the curtain of research facilities with workshops and lectures for four days in October 2014. Organizers of this varied program were the Fraunhofer-Gesellschaft and the University of Freiburg.

The participants got an in-depth view into the latest advances in aerospace technology in seminars, lectures and visits to laboratories, they learned which methods and systems help to make the "Energiewende" possible, how characteristics of materials can be improved, and much more. And they had the opportunity to discuss their career questions with coaches and representatives of the institutes. In workshops, the students learned more about their own creativity and strengths and how they can use them in applied research.

The participants learned what everyday working life looks like and which career plans are possible in research when visiting the Fraunhofer Institutes for Applied Solid State Physics IAF, for High-Speed Dynamics EMI, for Physical Measurement Techniques IPM, for Solar Energy Systems ISE and for Mechanics of Materials IWM, as well as the University of Freiburg's Faculty of Engineering. It was possible for them to talk with experts from all involved facilities. "'More women into applied research' is an important objective of the Fraunhofer-Gesellschaft. We want to inspire young women for careers in research and thus raise the amount of female scientists at Fraunhofer. The additional value of mixed teams has been proven long ago", Michael Vogel, Head of Department of the Fraunhofer recruitement marketing states. "Fraunhofer offers excellent development opportunities for young researchers. Here, female graduates of technical fields or the natural sciences are given the opportunity to qualify themselves for a responsible position in the Fraunhofer institutes and in the industry". Employer rankings prove: In the fields of engineering and natural sciences, the Fraunhofer-Gesellschaft ranks among the most popular employers in Germany. The Universum study 2013, for example, ranks Fraunhofer on the third place when it comes to natural sciences.

At EMI, the participants gained an insight into the institute's research areas. On the so called "Fachtag" they had the opportunity to visit institutes according to their fields of study and to deepen their scientific knowledge. The Space Technology Group opened their laboratories and was present to answer scientific questions. In workshops about the topics of security and the EMI Business Unit Transport, they had the opportunity to advance to the practical implementation of project work at EMI. The event concluded in an interesting discussion session with real role-models:

Dr. Bärbel Thielicke, Central equal rights officer of the Fraunhofer-Gesellschaft, who worked as a physicist and group manager at Fraunhofer for many years, Dr. Lena Schnabel, group manager and expert for heat transfer in technical building equipment at the Fraunhofer ISE and Nicola Heidrich, group manager "Diamond technology" at the Fraunhofer IAF, were present on the podium. Silvija Kauric (Femtec) moderated the panel. The feedback after the scientific campus in Freiburg had ended was positive throughout. The involved colleagues from the institutes as well as the participants themselves gained rewarding experiences, and there were first conversations about starting a career at Fraunhofer. With such activities, Fraunhofer takes another step in order to win more women for a job in science, especially in leading positions.


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__Photo 1:__ At the science quiz on the first day, there was a general lecture at each institute and at the university. After that, questions about these had to be answered in a quiz. __Photo 2:__ In the control room of the Spacecraft Technology Group; __Photo 3 and 4:__ Martin Schimmerohn explains how the EMI light gas gun accelerator works and how it can be used in the area of protection in space. __Photo 5:__ Dr. Bärbel Thielicke, Central equal rights officer of the Fraunhofer-Gesellschaft (on the right) with Silvija Kauric, Femtec (on the left) at the panel of the closing event.


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“MESSE BAU”, MUNICH
JANUARY 19–24, 2015

The trade fair BAU 2015 in Munich

The growth and change of cities will noticeably influence the development of the 21st century, since the race concerning ecologically sustainable future will mainly take place in urban centers. Innovative solutions regarding the way of dealing with resources and energy are in great demand by private households as well as by companies. Considering the increasing raw materials prices and energy costs, companies have to apply materials and energy efficiently in order to prevail on the market. The construction industry, employing more than 700,000 people, is an important sector of the German national economy.

Its innovative ability will be a decisive factor for whether the climate aims concerning CO_2 reduction and energy saving can be achieved through further improvements in the fields of energy efficiency and sustainability. Furthermore, the construction industry has to respond to the constantly changing requirements that arise from future living conditions and the demand for convenience. At the special exhibition "ForschungsWerkStadt", 18 research facilities of the Fraunhofer-Gesellschaft employed in the fields of building materials, building systems and security presented 44 product and system solutions of applied building research. These solutions will contribute to a realization of a CO_2 neutral and energy-efficient city.

Fraunhofer
BAU

For more information, visit www.bau.fraunhofer.de

Figure: Oliver Millon explains the exhibit of Fraunhofer EMI. Board member Prof. Alexander Verl, Klaudia Kunze (head of communications) and Franziska Kawalewski (central administration) are listening with considerable interest.

At this special exhibition, the visitors learned how intelligent joining technology can be used to build multistory wooden constructions earthquake-proof and how multifunctional façade solutions reduce renovation costs and thus contribute to energy supply. Furthermore, they were informed on building materials made from renewable resources that increase the recycling ability of buildings. Further explanations were given on building information modeling (BIM) that provide sustainable assistance in building processes. The EMI presented its competency in security and resilience research. An exhibit illustrating hazards and possible protective measures gained considerable attention.

This model illustrates the effects of an extreme impact on building structures in a city after an automobile accident. The concepts, which were developed by Fraunhofer EMI in order to improve resistance behavior of buildings (e.g. façades made of masonry, of high performance concretes and of glass), are applied on particular buildings. The model visualizes the effect of the protective measures on the buildings' load bearing capacity in relation to the distance of the accident location. The visitor can individually simulate the present protection concepts and can thus actively explore the model. The effectiveness of the particular protective measures can be perceived visually through these logical illustrations.

The next trade fair BAU will take place from January 16–21, 2017 on the exhibition grounds of the Messe Munich.

BAU 2017

January 16–21 · Munich

World's Leading Trade Fair for
Architecture, Materials and Systems

www.bau-muenchen.com

NAMES, DATES, EVENTS

Girls' Day 2014 March 27, at EMI

A research institute is usually an unknown field for girls attending ninth grade. During this year's "Girls' Day" at EMI, eight participants got the chance to explore the different working places in such an institute. Especially in the technical area, there are almost no females employed. This is one of the reasons why girls usually decide not to study STEM subjects (science, technology, engineering, and mathematics).

At EMI, the girls met Deborah Mohrmann, a real role-model. Her career and the topic of her doctoral studies – "sustainable materials" – considerably differ what from the girls are surrounded by in their private life. After presentations on the Fraunhofer-Gesellschaft and on the various fields of work at EMI, the girls could see the laboratories where scientific experiments are conducted.

During the guided tour through the material laboratory, the workshop manager Helmut Zettl showed how tools are produced and additionally explained to them what trainees of precision mechanics learn. At the end, they could watch how EMI key rings were produced with the aid of a CNC machine, and each girl was given one of them.

During the second part of the day, they could also gain practical experiences. Under the professional guidance of Kevin Kreklow, Ulrike Clausen, Max Ortlieb and Melina Haller (apprentice), each girl successfully made a flashlight with LED lights, thus learning how to handle the soldering iron.

On Girls' Day, companies, research centers and institutes all over Germany open their doors for school girls from fifth grade upwards. That way, girls can explore technology and natural sciences and experience that women can also be successful in "typically male" professions. Simultaneously, there is also a Boys' Day in Germany. The boys are introduced to fields of work in which commonly only few men are employed, e. g. social, educational or nursing jobs.

It is the declared objective of the Fraunhofer-Gesellschaft to raise the interest of more women, especially for expert or leading positions. Events such as Girls' Day contribute to lessen the girls' reservations about science and engineering and to motivate them to take up a technical course of studies or apprenticeship.

Photo 1: *The participants of Girls' Day with Birgit Bindnagel;* ***Photo 2:*** *The EMI key rings;* ***Photos 3, 4 and 5:*** *The girls manufacturing a LED flashlight in the EMI electronic laboratory;* ***Photo 6:*** *At the end, a loud experiment was conducted: At EMI, there has to be a bang!*

GIRLS' DAY AT FRAUNHOFER EMI
MARCH 27, 2014

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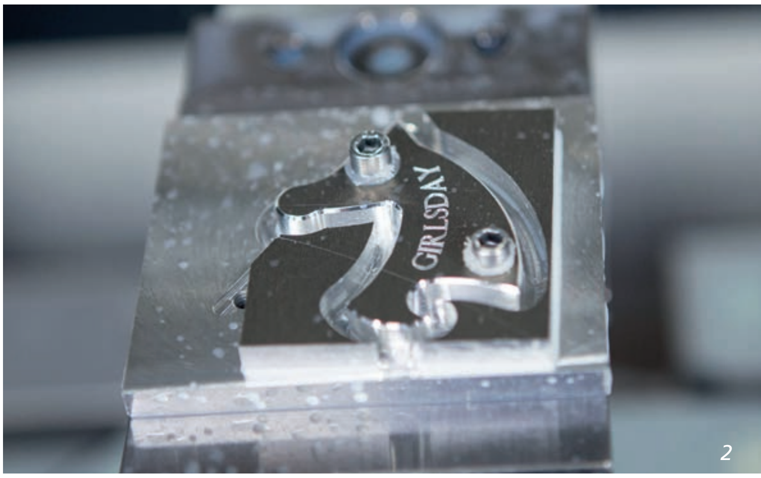

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COLLOQUIUM IN HONOR OF DR. CHRISTOPH MAYRHOFER APRIL 23, 2014

Retirement of Dr. Christoph Mayrhofer on April 23, 2014

"From destroying to simulating – the development of security research at EMI during the Mayrhofer era" was the title of Dr. Alexander Stolz' speech, in which he and invited colleagues, partners and companions looked back on Dr. Mayrhofer's long and successful career. Christoph Mayrhofer was scientist at the Ernst-Mach-Institut for 39 years. On April 23, he started his retirement amongst his family – with a smile!

His successor Alexander Stolz spoke about the impressive development of the former testing ground Efringen-Kirchen, where a wooden meeting bungalow in 1975 became a Fraunhofer branch with a shock pressure chamber, a shock-tube facility, a production hall for concrete, and later, a technical center (1999), laboratories for construction, sensor technology, micromechanics, crash testing, high-velocity impacts, blast testing, and blast loading.

In his laudatory speech, Prof. Thoma emphasized the significance of Christoph Mayrhofer for the Efringen-Kirchen branch. He established and expanded the Security Business Unit at the Ernst-Mach-Institut, first as a scientist and later as head of the Department "Safety Technology and Protective Structures". He coped with all of this impressively while mastering the double challenge of being Head of Department and Head of Administration at the same time for many years.

The laudators Prof. Norbert Gebekken and Rainer Gündisch have looked back at the excellent scientific collaboration of "Südschiene", a cooperation between EMI, the University of the German Federal Armed Forces Neubiberg and the Bundeswehr Technical Center (WTD) 52 in Oberjettenberg. In his speech, Andreas Bach of the engineering company Schüßler Plan, emphasized Christoph Mayrhofer's close relations with the industry.

Christoph Mayrhofer was a highly respected colleague and an outstanding leader who was appreciated professionally and as a person both at EMI and within the Fraunhofer-Gesellschaft, especially at the Building Innovation Alliance.

This was reflected by the gifts and gestures he received at his farewell celebration. With pleasure, he accepted a t-shirt with his motto "breathe in, breathe out" and a last "target agreement" by his successor. The newly formulated goals are now the time for hobbies and spending time with family, which requires a strategic approach by all means. The new target agreement concludes with Arthur Schopenhauer's words: "Retirement carries the cheerfulness of someone who has lost his chains and is now moving freely".

Photo 1: *Dr. Alexander Stolz during his speech;* ***Photos 2 and 6:*** *Colleagues, partners, clients and companions are saying goodbye to Christoph Mayrhofer;* ***Photo 3:*** *Prof. Klaus Thoma thanks the longtime Head of Department for his work;* ***Photo 4:*** *Prof. Dr.-Ing. habil. Norbert Gebekken speaks about the cooperation "Südschiene": UniBW, WTD 52, EMI, using the example of BauProtect;* ***Photo 5:*** *Breathe in, breathe out. Christoph Mayrhofer's motto was printed on a t-shirt which was the gift from his colleagues in Efringen-Kirchen.*

RETIREMENT IS WHAT YOU HAVE WORKED FOR YOUR WHOLE LIFE – AND WHEN IT IS THERE, YOU BECOME A BIT FRIGHTENED.


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BUSINESS RUN FREIBURG
JUNE 5, 2014

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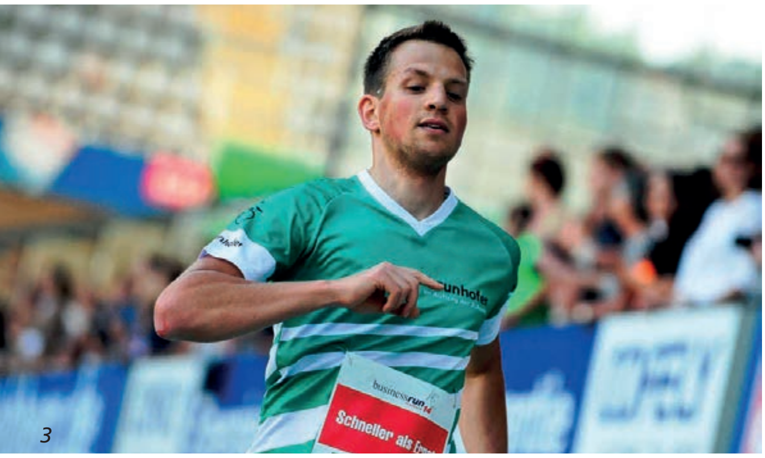

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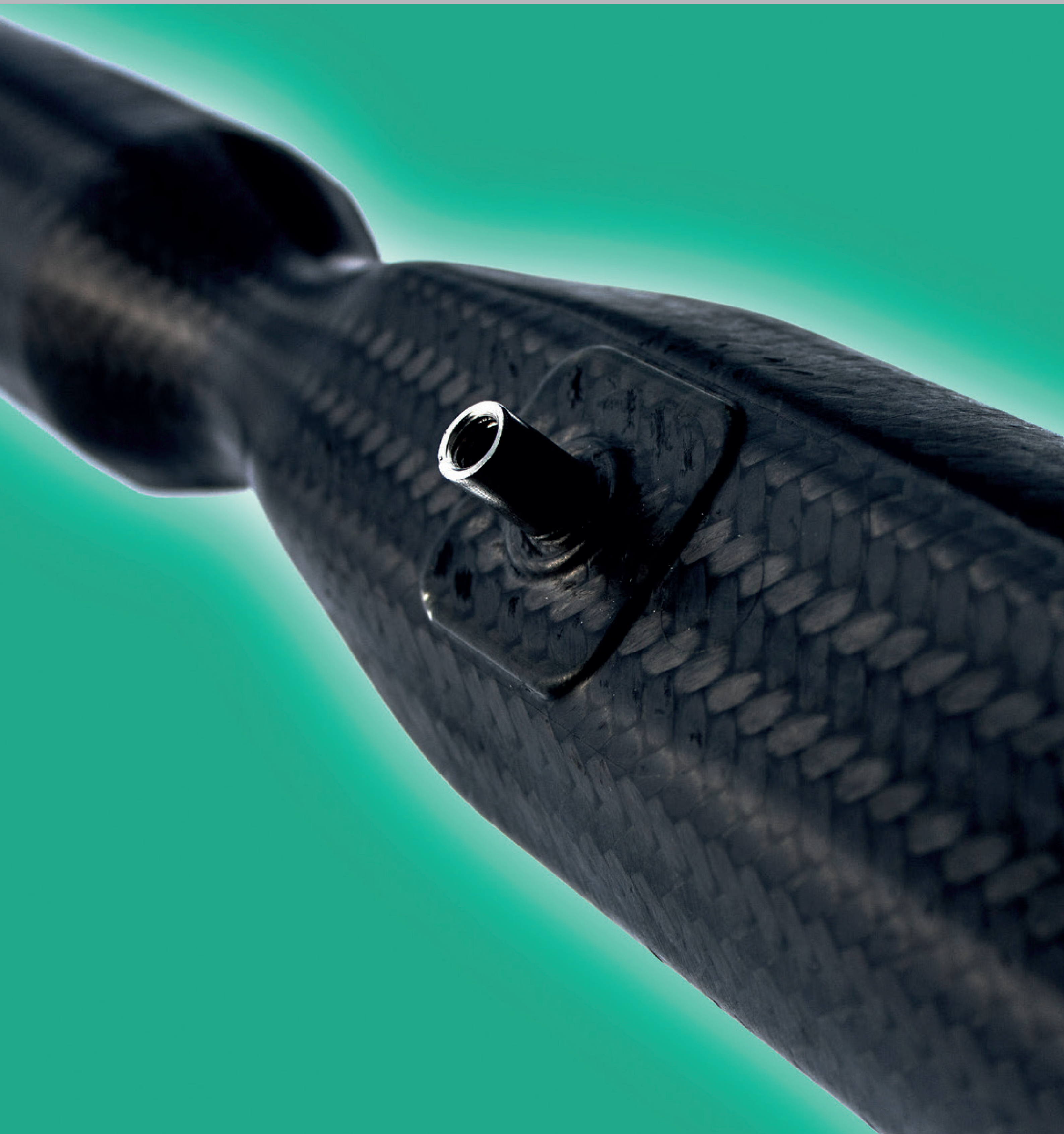
BusinessRun Freiburg 2014

On June 5, 2014 the Ernst-Mach-Institut participated for the first time in Freiburg's BusinessRun. No less than five teams started to compete in the run which was 6 km long and took place around the Schwarzwald-Stadion. The most successful EMI team, consisting of Frank Buraus, Manuel Beck and Markus Jung, made it to a respectable 7th place in the team rankings and therefore was the most successful Fraunhofer team.

The next BusinessRun will take place on June 11, 2015. For more information, visit www.business-run-freiburg.de

***Photo 1:** A strong team for the BusinessRun; **Photo 2:** Good spirits in the team "Lazy Space"; **Photo 3:** He ran the fastest: Markus Jung at the finishing line, he took 2nd place in his age group and 7th place with his team "Schneller als Ernst" in the team rankings; **Photos 4 and 5:** A spectacular start: More than 3,800 runners were at the starting line; **Photo 6:** Fraunhofer Freiburg was strongly represented: Employees of Fraunhofer ISE, IAF und IWM participated.*

AVK INNOVATION AWARD
OCTOBER 6, 2014



AVK Innovation Award for the group Composite Design

During the reinforced plastics industrial association's (AVK) conference on October 6, 2014, the group Composite Design of Fraunhofer EMI and their project partners received the bronze medal of the AVK Innovation Award in the area of research/science.

The prestigious AVK Innovation Award is being awarded since 1995 from the AVK for outstanding innovations in the composite industry. Purpose of the Innovation Award is the promotion of new products/components or applications made of fiber-reinforced plastics (FRP) as well as the promotion of new procedures or processes in manufacturing FRP products.

The award was given to the Composite Design Group and its project partners (Fraunhofer Institutes ICT and IPM, IFB University of Stuttgart, FAST Karlsruhe Institute of Technology, ASCS and Porsche) for papers on the "Transferprojekt Porsche" of the Technology Cluster Composites Baden-Württemberg TC².

In the context of this transfer project, the crash structures of carbon fiber reinforced plastic (CFRP) mesh were examined to advance their use in simulation and manufacturing engineering. A focus of the project was on the progression of manufacturing technology in high-pressure RTM processes for the production of integral hollow structure components. The objective was a reduction of the cycle times to meet the economic requirements of automotive engineering, while maintaining the high characteristics in structure- and crash-behavior of the CFRP composite. EMI's researchers in particular worked on characterizing the composites as well as developing methods in the area of "crushing" and thus contributed significantly to the success of the project.

Figure left: Exemplary component made of CFRP braided composite which was manufactured using the high-pressure RTM-process. Figure above: Dr. Sebastian Kilchert (middle) receives the award representatively for the group.
From left to right: Dr. Gerd Esswein, Senior Vice President of AVK; Florian Gnädinger, University of Stuttgart; Alexander Walser, ASC.S; Dr. Sebastian Kilchert, Fraunhofer EMI; Michael Karcher, Fraunhofer ICT; Prof. Dr. Frank Henning, Fraunhofer ICT; Heike Wolfangel, Senior Vice President AVK. Not present were the project partners Dr. Julian Schöpfer, Porsche AG and Timm Kuhlmann, Fraunhofer IPA.

SUCCESSFUL START INTO THE PROFESSIONAL LIFE: HONORING THE BEST NOVEMBER 11, 2014

Successful start into the professional life
Honoring the best

On completion of their training, Fraunhofer honors apprentices who achieved exceptional performances – together with their instructors – each year.

Training at Fraunhofer is always characterized by research. Thus, a tour through the Fraunhofer IBP took place in the context of honoring the apprentices. They had the opportunity to visit the flight laboratory together with their instructors. Afterwards, there was a panel on sustainability in every-day life and in the professional environment.

The best apprentices of their respective year were welcomed to a ceremonial act in the Fraunhofer-Haus. Stefan Scherer was awarded a magna cum laude for his qualification as an electronics engineer.

Susanne Woltering, head of human resource development at Fraunhofer (B1), handed over the certificates and steles with the image of a sail setting ship under the motto "Full speed ahead!" to the young talents. "Our apprentices are important to us. Almost all of those honored today will continue working at Fraunhofer while doing a course of study or train to become a technician. This is a reason to celebrate", says Woltering. One reason for the success of the apprentices was the instructors' commitment. They also celebrated their apprentices' success and were also awarded a price. Kevin Kreklow received an honorary certificate and a stele.

Apprentices were honored in the Fraunhofer-Haus for their exceptional performance – the certificates were handed out by Susanne Woltering, head of human resource development at Fraunhofer. Stefan Scherer (middle) was honored because of his magna cum laude qualification, Kevin Kreklow (left) received an honorary certificate for his work as an instructor.

HONORARY PROFESSORSHIP FOR DR. FRANK SCHÄFER MARCH 11, 2015

Honorary Professorship for Dr. Frank Schäfer

On March 11, 2015, Frank Schäfer was appointed honorary professor by the rector of the University of Freiburg, Prof. Dr. Hans-Jochen Schiewer. Schäfer gives a lecture on "Shockwaves in Geomaterials" at the Faculty of Environment and Natural Resources of the University of Freiburg. One aspect of the lecture is the "Introduction to the theory of shock waves", is directed at students of geology and mineralogy. With this honorary professorship, the network between Fraunhofer EMI and the University of Freiburg is strengthened further, as bachelor- or master-theses, and even dissertations can be written at the Ernst-Mach-Institut.

As a member of the Faculty of Environment and Natural Resources, Frank Schäfer is now in a position to encourage content related cooperations. In addition to a connection with the Technical Faculty, this creates the opportunity for cooperations, in which EMI takes the role of a technological interface. Furthermore, this offers prospects regarding the joint acquisition of new projects. The new Sustainability Center Freiburg, in which Prof. Frank Schäfer conducts research together with Prof. Dr. Thomas Kenkmann from the Institute of Earth and Environmental Sciences – Geology on geo-hazards through extreme events, plays a key role. Topics will range from the effects of the impact of celestial objects on our geo system, but also, issues concerning lightning strikes or landslides will be treated.

Prof. Frank Schäfer and Prof. Klaus Thoma at the golden doctoral cap ceremony.

Prof. Frank Schäfer with the rector of the University of Freiburg, Prof. Hans-Jochen Schiewer (left) and Prof. Stefan Hiermaier (right) on March 15, 2015, receiving his certificate of appointment to the honorary professorship.

PHD STUDENTS

Seminar for PhD students at EMI

In 2014, Jens Fritsch and Matthias Boljen celebrated their successful doctorate together. The two young scientists supported each other while working on their theses – During the celebration, they both had a look back on the tough times, but the joy of success was all the better. The thesis of Matthias Boljen titled "Ein kontinuumsmechanisches Materialmodell für das Verformungs- und Schädigungsverhalten textiler Gewebestrukturen bei dynamischen Lasten" was published in the series "Schriftenreihe $\dot{\varepsilon}$ – Forschungsergebnisse aus der Kurzzeitdynamik".

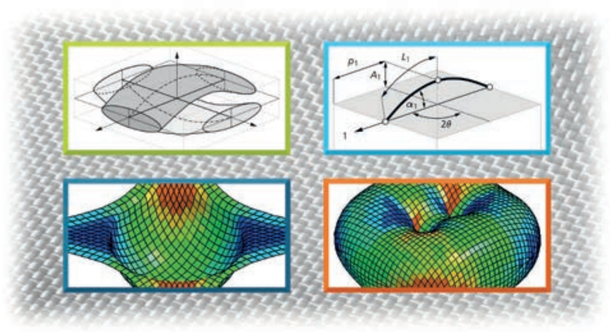
Textile fabrics are very suitable materials for lightweight constructions due to their high flexibility and their tensile strength. Because of their characteristic yarn structure, their behavior is usually strongly characterized by nonlinear features, which could only be captured rudimentarily by continuum-mechanical material models. In Matthias Boljen's dissertation, a material model is developed which derives the stress calculation on the macroscale from observing a representative volume cell on the mesoscale. This scale-independent approach enables the effective combination of efficient modeling techniques with the detail level of high-resolution numerical models. In the present case, important yarn interactions with suitable constitutive relations can equally be captured at multiple distortion rates. The model has been implemented as a user-defined material routine into the explicit finite element code LS-DYNA and has been validated by means of an extensive characterization of real fabrics.

Jens Fritsch's thesis is titled "Charakterisierung und Modellierung glasfaserverstärkter Thermoplaste unter dynamischen Lasten" (characterization and modeling of glass fiber reinforced thermoplastics under dynamic loading) and had already been finished in 2012. Synthetic materials that are reinforced by long glass fibers not only have good mechanical properties, but also an enormous potential for lightweight constructions – with simultaneous cost-efficient manufacturing processes. Today, they are often used for large components in the automotive industry, for example as structural elements for dashboards.

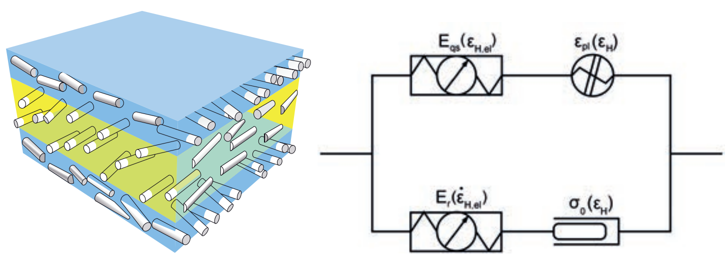
In the event of a crash, these components can be strongly deformed, which may even lead to failure. To display these processes predictably in a numerical simulation, appropriate material models are necessary that can display the complex mechanical properties of the long glass fiber reinforced plastics. Commercial calculation programs for crash simulation are not able to combine the mentioned phenomena and dependencies as desired, nor can they be used simultaneously.

In his dissertation, a material for a long glass fiber reinforced polypropylene PP/LGF is developed which can display the dominant material properties regarding the crash simulation with sufficient accuracy. To this end, a procedure is developed which specifies the necessary characterization experiments as well as the derivation of material constants of the material model from these experiments. Jens Fritsch's dissertation was also published in the series "Schriftenreihe $\dot{\varepsilon}$ – Forschungsergebnisse aus der Kurzzeitdynamik".

The EMI PhD students 2014.



Ein kontinuumsmechanisches Materialmodell für das Verformungs- und Schädigungsverhalten textiler Gewebestrukturen bei dynamischen Lasten
Schriftenreihe $\dot{\mathcal{E}}$ – Forschungsergebnisse aus der Kurzzeitdynamik, Band 26, Matthias Boljen
Hrsg.: Fraunhofer EMI, Freiburg/Brsg.;
Klaus Thoma, Stefan Hiermaier
2014, Fraunhofer-Verlag
ISBN 978-3-8396-0747-3



Charakterisierung und Modellierung glasfaserverstärkter Thermoplaste unter dynamischen Lasten
Schriftenreihe $\dot{\mathcal{E}}$ – Forschungsergebnisse aus der Kurzzeitdynamik, Band 22, Jens Fritsch
Hrsg.: Fraunhofer EMI, Freiburg/Brsg.;
Klaus Thoma, Stefan Hiermaier
2012, Faunhofer-Verlag
ISBN 978-3-8396-0333-8

The PhD festivity of Matthias Boljen and Jens Fritsch was a time of celebration for their families but also for their doctoral supervisors and colleagues. A thesis is a challenge not only for the PhD students but also for their social environment. This challenge had apparently been well met!


Dr.-Ing.
Jens Fritsch
27.05.2011

EMI ALUMNI
VISITING SCIENTISTS AT EMI

EMI *Alumni* – staying in contact

Alumni networks have gained importance at the Fraunhofer-Gesellschaft. The word "alumnus" derives from Latin and can be literally translated to "pupil". It stems from alere "to nourish, to raise". Our alumni worked at EMI and many of them did their doctoral studies here. At EMI, they have laid the foundation of their future career and have established friendly contacts.

The spirit of Fraunhofer "knowledge transfer through heads" also means that the alumni leave Fraunhofer in order to occupy important positions in economy and science. We want to keep in touch with them and build networks profitable for both sides.

This target has been pursued for 10 years within the alumni program of Fraunhofer EMI. Our alumni pass on their knowledge acquired at EMI to their new work places in industry, in different research centers or in the authorities and they develop it further there.

The scientifc and personal contact contributes to the development of new ideas for projects and enables a fruitful exchange. We look forward to meeting our alumni at the institute festivities and scientific events in order to discuss recent developments and ideas with them.

PUBLISHING NOTES

Editors
Birgit Bindnagel
Tobias Leismann
Stefan Hiermaier

Editorial Assistance
Johanna Holz

Layout and Graphics
Sonja Weber

Photo Editorial Department
Birgit Bindnagel
Sonja Weber

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Fraunhofer Institute for High-Speed Dynamics,
Ernst-Mach-Institut, EMI
Eckerstrasse 4
79104 Freiburg, Germany
Phone +49 761 2714-366
birgit.bindnagel@emi.fraunhofer.de
www.emi.fraunhofer.de

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Fraunhofer Institute for High-Speed Dynamics,
Ernst-Mach-Institut, EMI
Eckerstrasse 4
79104 Freiburg, Germany
Phone +49 761 2714-0
info@emi.fraunhofer.de
www.emi.fraunhofer.de

Locations
Freiburg, Efringen-Kirchen and Kandern