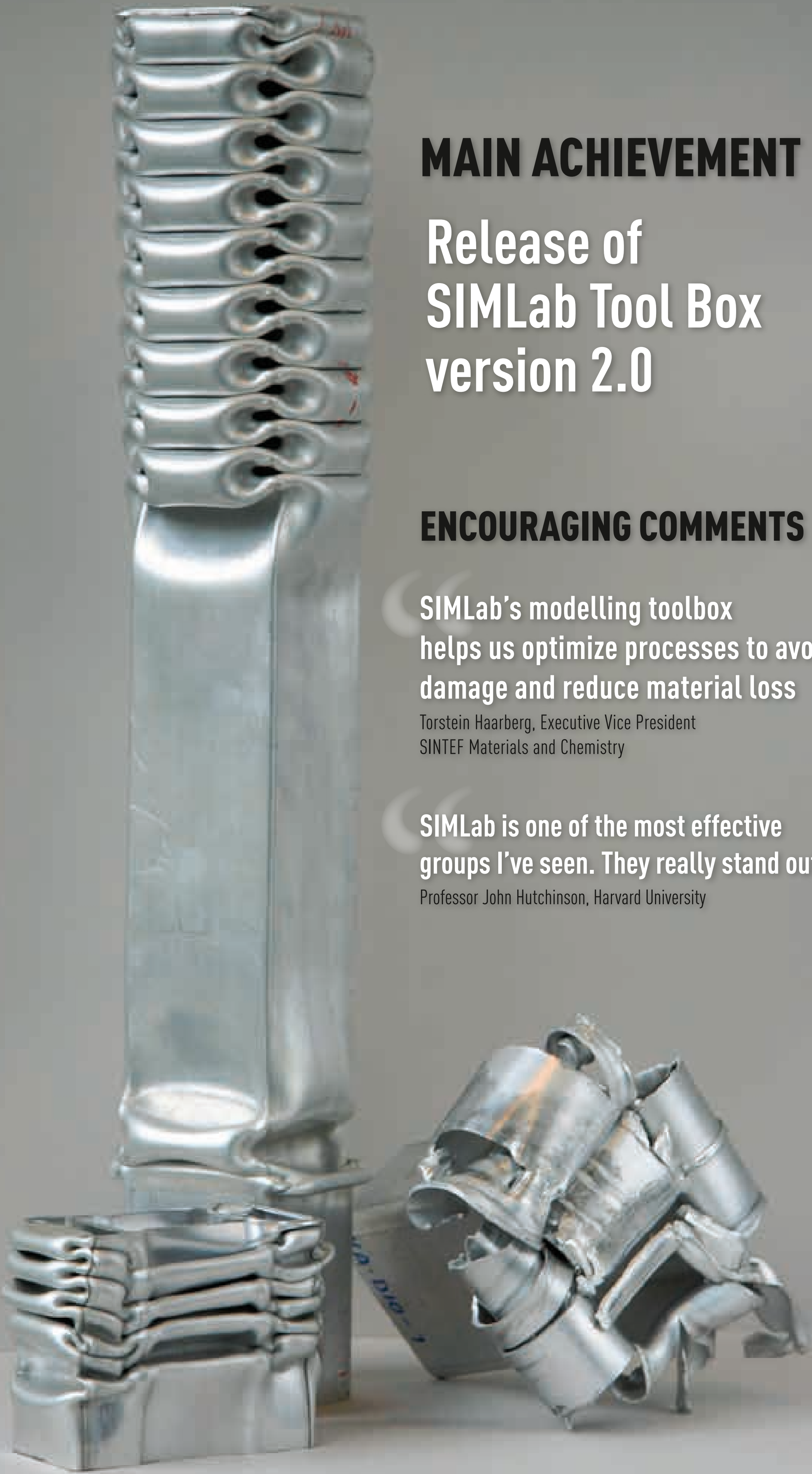
SIMLab

Centre for Research-based Innovation

Annual Report 2013



MAIN ACHIEVEMENT

Release of SIMLab Tool Box version 2.0

ENCOURAGING COMMENTS

"SIMLab's modelling toolbox helps us optimize processes to avoid damage and reduce material loss

Torstein Haarberg, Executive Vice President
SINTEF Materials and Chemistry

"SIMLab is one of the most effective groups I've seen. They really stand out

Professor John Hutchinson, Harvard University

sfi Centre for Research-based Innovation

SINTEF

NTNU – Trondheim
Norwegian University of Science and Technolog

Contents



Industrial partners in 2013

Summary

SIMLab (Structural Impact Laboratory) - Centre for Research-based Innovation - is hosted by the Department of Structural Engineering, Norwegian University of Science and Technology (NTNU) in cooperation with the Department of Materials Science and Engineering, NTNU, and SINTEF Materials and Chemistry.

The main objective of the Centre is to develop a technology platform for safe and cost-effective structures in aluminium, high-strength steels and polymers through advances in the following research areas: *materials, solution techniques* and *structures*. The ability of lightweight structures to withstand loads from collisions and explosions is a key issue in the Centre. Examples of applications are safety innovations in the automotive and offshore industries, improved highway safety as well as protective structures for international peacekeeping operations.

The industrial partners in the Centre in 2013 were Hydro, Audi AG, Renault, Toyota Motor Europe, BMW Group, Benteler Aluminium Systems, Statoil, SSAB, the Norwegian Public Roads Administration and the Norwegian Defence Estates Agency.

The overall management structure of the Centre consists of a board comprising members from the consortium participants. A director is in charge of the operation of the Centre, assisted by a core team which together with the research programme heads run the research in the Centre. Furthermore, a Scientific Advisory Board of international experts provides scientific and strategic advice based on a defined mandate.

The research group

Photo: Ole Morten Melgård

The defined research areas for 2013 are linked with research programmes with focus on *Fracture and Crack Propagation (F&CP)*, *Connectors and Joints (C&J)*, *Polymers (Poly)*, *Multi-scale Modelling of Metallic Materials (M^4)* and *Optimal Energy Absorption and Protection (OptiPro)*. For each research programme, annual work plans are defined with contributions from PhD candidates, post docs and scientists from the partners. The *Demonstrator* activity serves as a link between the basic research and the industrial needs for the technology developed. All technology developed in the Centre is gathered in a SIMLab Tool Box for implementation at the industrial partners.

Workshops and seminars are organized in order to strengthen the idea generation in the Centre and ensure transfer of technology from the Centre to the user partners. In this context the Polymers programme organized a seminar at Toyota Motor Europe in Brussels on 24 October 2013 in order to give the partners hands-on information about the new polymers model in the SIMlab Tool Box. In addition on 13-14 November 2013 a SIMLab Tool Box seminar was held at NTNU with participation from all partners. There was a demonstration for the partners in material testing of steel, aluminium and polymers for parameter identification of the SIMLab Metal and Polymer models. Professor David Embury and Mr Francois Moussy held a short course on steels for automotive applications on 27-28 August 2013. Finally, SIMLab in cooperation with the Norwegian Defence Estates Agency organized a course entitled Modern Protective Structures on 17-21 June 2013 with Professor Ted Krauthammer as a lecturer.

The annual SIMLab conference and the board meeting were hosted by Hydro in Bonn, Germany on 6-7 May 2013. During the conference, the presentations were focused on how the activities in the research programmes supported the development of the SIMLab Tool Box. The partners again expressed that they were pleased with the high quality and productivity of the work carried out as well as with the implementation of the SIMLab Tool Box for innovation and value creation.

In 2013, research work in the Centre resulted in 16 papers published in peer reviewed journals. In addition, 5 journal papers have been accepted, but not yet published. The research group has given 7 conference and seminar contributions and 5 invited lectures. The research in the Centre is carried out through close cooperation between master's, PhD candidates, post docs and scientists. In 2013, 16 male and 3 female master's students, 14 male and 2 female PhD candidates have been connected to the Centre. Further, 1 female and 2 male post docs are employed at SIMLab. One international student from Germany stayed at the Centre during 2013. PhD candidates Anizahyati Alisibramulisi and Knut Gaarder Rakvåg have defended their respective theses on the *"Through process Modelling of Welded Aluminium Structures"* and *"Combined Blast and Fragment Loading on Steel Plates"*.

International cooperation and visibility are success parameters for such a Centre. Thus the Centre has had cooperation (attended through common publications, Cotutelle agreements for PhD candidates and visiting scientists) with the following universities/research laboratories in 2013: Ecole Normale Supérieure de Cachan/Laboratoire de Mécanique et Technologie (ENS/LMT), France; University of Savoie, France; University of Liverpool, UK; University of São Paulo, Brazil; European Commission, Joint Research Centre, Institute for the Protection and Security of the Citizen, Ispra, Italy; Karlsruhe Institute of Technology, Germany; Impetus Afea Sweden; Harvard University, USA; University of Virginia, USA; University of Cambridge, UK; and Purdue University, USA.

With respect to visibility the activities in the Centre have been presented in Norwegian newspapers and magazines as well as on Norwegian television. Several concurrent research projects have been run in parallel with the Centre's activities. Furthermore, the Centre is involved in a EUROSTARS project on the development of a new nonlinear simulation tool for mechanical and multi-physics problems using graphics processing units (GPU).

Finally, a new SFI Centre (Centre for Advanced Structural Analysis - CASA) is proposed on multi-scale testing, modelling and simulation of materials and structures for industrial applications. The leading group behind the application is SIMLab at the Department of Structural Engineering, NTNU. Cooperating units are the Department of Physics and the Department of Materials Science and Engineering at NTNU, and SINTEF Materials and Chemistry.

Our **vision** is to establish SIMLab as a **world-leading** research centre for the design of **Crashworthy and Protective Structures**

Objective

Within the field of structural impact SIMLab is concentrating on research areas that are of common interest to its industrial partners and hence create a link between Norwegian industry and some of the major actors in the global market, i.e. the automotive industry.

However, in order to meet the requirement for innovation and value creation in an international market, Norwegian industry has to adopt new and original knowledge in product development. Here, efficient modelling of the whole process chain, through process modelling, is a key requirement for success where a strong coupling is made between materials, product forms, production process and the structural behaviour. In order to meet the future challenges in product development foreseen by these partners, a multidisciplinary approach is used where researchers from the partners and academia contribute. This is only achievable through activities at the Centre with long-term objectives and funding.

Thus, the main objective of the Centre is to provide a technology platform for the development of safe and cost-effective structures.

Goals

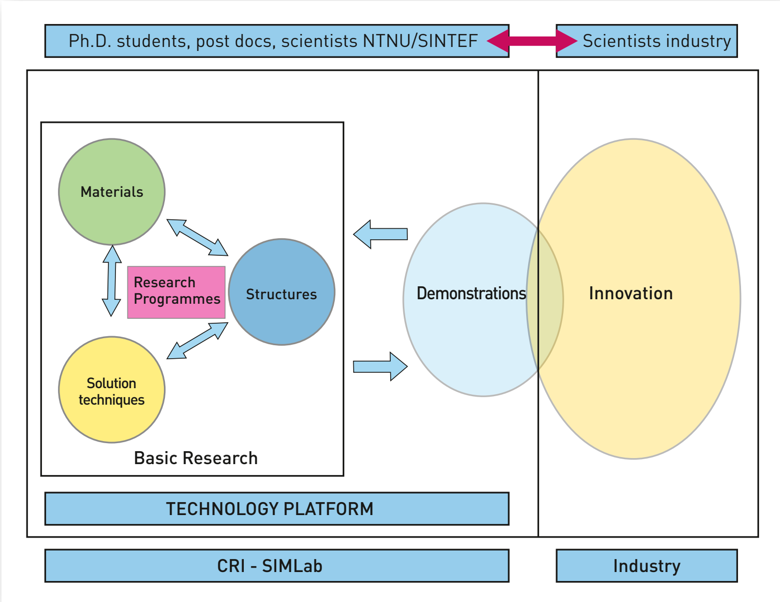
The main quantitative goals of the Centre are as follows:

- **Industrial**: 1) To implement the developed technology by mutual exchange of personnel between the Centre and the industrial partners. 2) To arrange annual courses for these partners. 3) To facilitate employment of MSc and PhD candidates at the industrial partners.
- **Academic**: 1) To graduate 22 PhD candidates where at least four are female. 2) To graduate at least 10 MSc students annually. 3) To attract at least 5 non-Norwegian professors/scientists during the duration of the Centre. 4) To publish on average 15 papers in international peer reviewed journals annually in addition to conference contributions. 5) To arrange one international conference between 2007 and 2014.

Research areas

The technology platform is developed through advances in the following basic research areas:

- **Materials:** Development of improved quantitative constitutive models and failure criteria for large-scale analyses as well as identification methods.
- **Solution techniques:** Establishment of accurate and robust solution techniques for the simulation of impact problems.
- **Structures:** Investigation of fundamental response mechanisms of generic components and structures as well as the behaviour and modelling of joints.



Research areas.

The research area 'Structures' serves as a link between 'Materials', 'Solution techniques' and the "Demonstrators" activities, see the figure below. The selection of demonstrators/ benchmark tests for validation is carried out in close cooperation with the industrial partners. Included in the "Demonstrators" activity is also the development of a SIMLab Tool Box where all the technology and models developed are gathered in order to facilitate the transfer of research carried out to the industrial partners. The interaction between the activities denoted 'Basic Research' and 'Demonstrators' is crucial with respect to validation and possible refinement of the technology developed at the Centre as well as the transfer of technology to the industrial partners.

The Centre is dealing with aluminium extrusions and plates, aluminium castings, high-strength steels and polymers.

The basic research areas **Materials**, **Solution techniques** and **Structures** are linked by Research programmes. The following research programmes have been running in 2013:

- ***Fracture and Crack Propagation (F&CP):*** Validated models for fracture and crack propagation in ductile materials including rolled and extruded aluminium alloys, high-strength steels, cast aluminium and polymers will be developed. Formulations for shell structures and solid bodies will be established for verification and validation. Accuracy, robustness and efficiency are considered to be the major success criteria.

- ***Optimal Energy Absorption and Protection (OptiPro):*** A basis for the design of safer, more cost-effective and more lightweight protective structures for both civilian and military applications subjected to impact and blast loading will be developed. This also includes road restraint systems as well as submerged pipelines subjected to impact.

- ***Polymers (Poly):*** Development of validated models for polymers subjected to quasi-static and impact loading conditions. An important prerequisite is to establish a set of test methods for material characterization and to generate a database for validation tests. The programme for the time is limited to thermoplastics.

- ***Multi-scale Modelling of Metallic Materials (M4):*** Phenomenological constitutive models of metals are available in commercial FE codes, but they do not provide any information about the physical mechanisms responsible for the observed material response. Thus, in this programme the material response is described on the basis of the elementary mechanisms governing the macroscopically observed phenomena. This approach is required for the design of optimized process chains, for the development of next-generation phenomenological models, and for reducing material characterization costs.

- ***Connectors and Joints (C&J):*** Information about the behaviour and modelling of self-piercing rivet and bolted connections subjected to static and dynamic loading conditions is obtained. Special focus is placed on the establishment of a model to be used for large-scale shell analyses.

Research organization

Structure of the organization

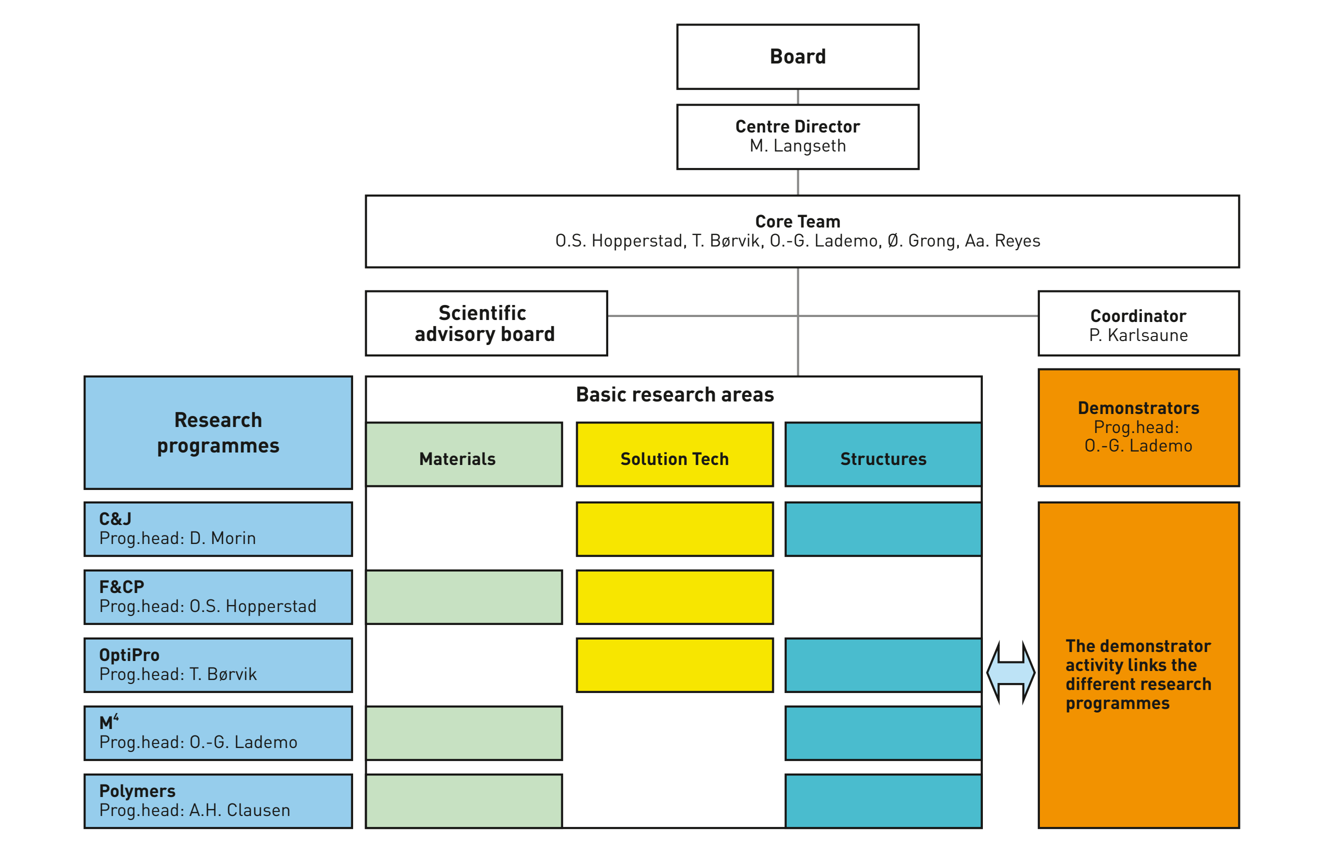
The overall management structure of the Centre consists of a board comprising members from the consortium participants. The Centre Director is in charge of the operation of the Centre, assisted by a core team and the research programme heads. In each research programme, research projects are defined with a project leader. Furthermore, an advisory scientific board of international experts provides scientific and strategic advice.

The Board

- Karl Vincent Høiseth, Professor/Head of Department, Department of Structural Engineering, NTNU (Chairman)
- Thomas Hambrecht, Head of Functional Design, MLB, Audi AG
- Torstein Haarberg, Executive Vice President, SINTEF Materials and Chemistry
- Håvar Ilstad, Manager Pipeline Technology, Statoil
- Hans Erik Vatne, Head of Technology, Hydro
- Helge Langberg, Head of National Centre for Protection of Buildings, Norwegian Defence Estates Agency
- Per Kr. Larsen, Professor Em., Department of Structural Engineering, NTNU
- Joachim Larsson, Head of structural technology, Knowledge Service Center, SSAB
- Tsukatada Matsumoto, Senior Project Manager, Toyota Motor Europe
- Sigurd Olav Olsen, Special Advisor to the Director General, Norwegian Public Roads Administration
- Thorsten Rolf, Team Leader – Simulation methods Body in White, BMW Group
- Anders Artelius, Head of Aluminium Technology, Benteler Aluminium Systems Norway
- Eric Vaillant, Department Manager Analysis, Behaviour and Environmental Materials Engineering, Renault
- Astrid Vigtil, Head of Research Section, Faculty of Engineering Science and Technology, NTNU

Centre Director

- Magnus Langseth, Professor, Department of Structural Engineering, NTNU



Structure of the organization in 2013.

Photo: Max Malsch

The Board

From left: Tore Tryland (representing Benteler Aluminium Systems), Rudie Spooren (representing SINTEF), Arjan Strating (representing Audi), Trond Furu (representing Hydro), Tsukatada Matsumoto (Toyota Motor Europe), Eric Vaillant (Renault), Per Kr Larsen (NTNU), Helge Langberg (NDEA), Astrid Vigtil (NTNU), Magnus Langseth (SIMLab), Thorsten Rolf (BMW), Karl Vincent Høiseth (NTNU), Henning Fransplass (representing NPRA).

Core Team and programme heads

- Tore Børvik, Professor, Department of Structural Engineering, NTNU
- Arild Holm Clausen, Professor, Department of Structural Engineering, NTNU
- Øystein Grong, Professor, Department of Materials Science and Engineering, NTNU
- David Morin, Post doc at SIMLab
- Odd Sture Hopperstad, Professor, Department of Structural Engineering, NTNU
- Odd-Geir Lademo*, Dr. ing., SINTEF Materials and Chemistry
- Aase Reyes, Professor, Department of Structural Engineering, NTNU
- Peter Karlsaune, SIMLab coordinator

* Adjunct Professor at Department of Structural Engineering (20% position)

Scientific Advisory Board

- Professor Ahmed Benallal, LMT-Cachan, France
- Professor Em. David Embury, MacMaster University, Canada
- Professor John Hutchinson, Harvard University, USA
- Professor Em. Norman Jones, University of Liverpool, UK
- Professor Larsgunnar Nilsson, University of Linköping, Sweden
- Professor Klaus Thoma, Ernst Mach Institute, Germany

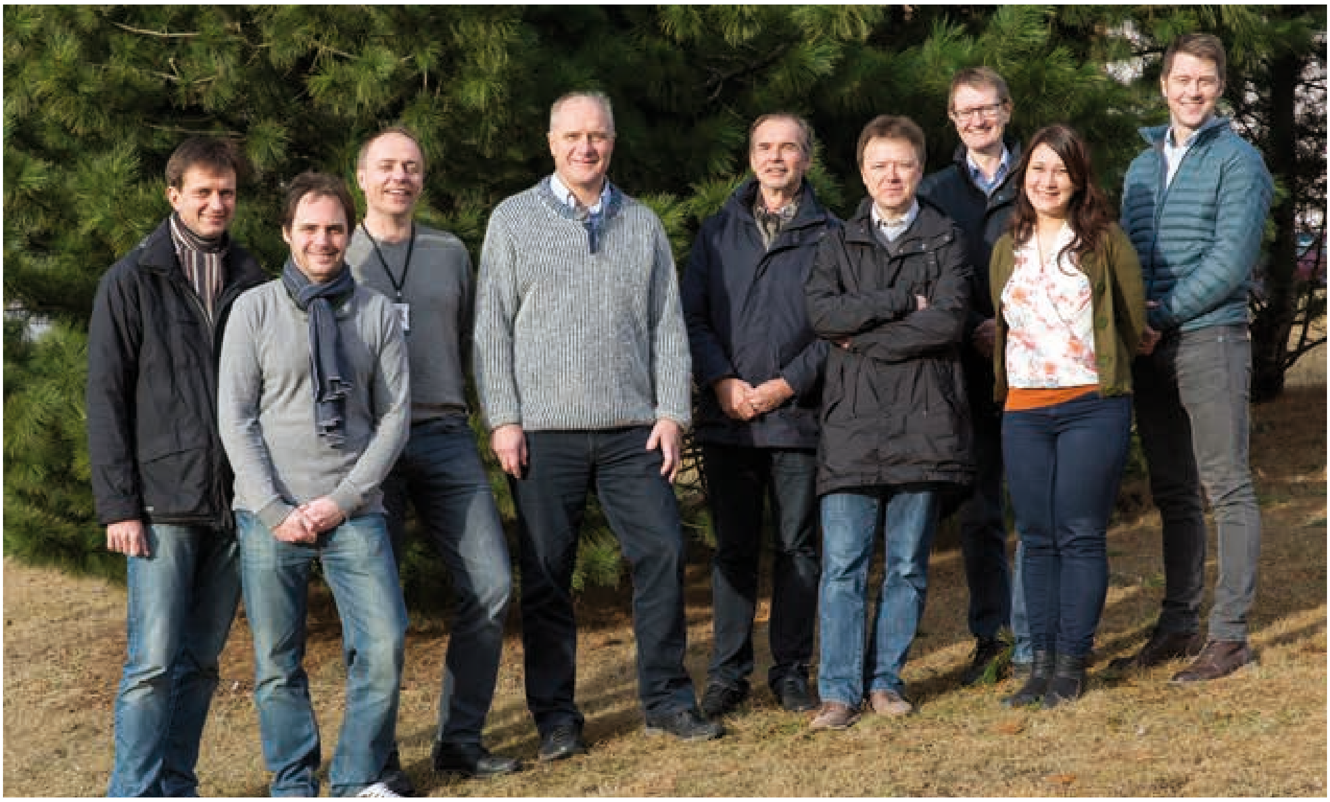


Photo: Ole Morten Melgård

Core Team and programme heads
From left: Arild Holm Clausen, David Morin, Odd-Geir Lademo, Magnus Langseth, Øystein Grong, Tore Børvik, Odd Sture Hopperstad, Aase Reyes, Peter Karlsaune.

Photo: Benedikte Skarvik

Scientific Advisory Board
From left: Klaus Thoma, Larsgunnar Nilsson, Norman Jones, David Embury, Ahmed Benallal and John Hutchinson.

Partners

- Host institution
  - NTNU
- Research partner
  - SINTEF Materials and Chemistry
- Industrial partners
  - Audi AG
  - Benteler Aluminium Systems
  - BMW Group
  - Hydro
  - Renault
  - SSAB
  - Statoil
  - Toyota Motor Europe
  - The Norwegian Public Roads Administration (NPRA)
  - The Norwegian Defence Estates Agency (NDEA)

Core competence of the research team

The core competence of the research team is related to material modelling of metallic materials and polymers, material and component testing at various loading rates and development and implementation of material models suited for large scale structural analyses. This competence serves as a basis for the research activities on materials and structures, taking into account the interaction between material behaviour, structural geometry and the manufacturing process. To support these modelling activities, the Centre has developed extensive experimental facilities for the testing of materials at elevated rates of strain and impact and crashworthiness testing of components and structural subsystems.

Cooperation within the Centre and interaction with the industrial partners

The annual work plans for each programme were defined with contributions from each partner. Scientists from NTNU and SINTEF and PhD candidates and post docs have been the main contributors to perform the work, while each industrial and public partner has participated based on their defined contribution in kind. The contributions in kind for NPRA and Audi are mainly taken care of by PhD candidates working both at the Centre and at the respective industrial partner. Furthermore, NDEA, Hydro and Benteler Aluminium Systems are supporting professorial positions at SIMLab ensuring an excellent link between our master's students and the industrial partners as well as with the PhD candidates. The cooperation and spread of information in the main research group (NTNU and SINTEF) and between the industrial partners and the research group has been based on using programme and project meetings as well as seminars.

Once a week, the Centre Director has had a meeting with the programme heads and the core team members. These meetings are used to coordinate the activities in the research programmes and to ensure that the progress and cost plan as well as the deliverables are in accordance with the defined annual work plans. In addition, specific project meetings and seminars were held in each research programme when necessary with participation from all involved partners. In this context the Polymers programme organized a seminar on 24 October 2013. The seminar was hosted by Toyota Motor Europe in Brussels and focused on the status of the SIMLab Tool Box for polymers; the verification and validation programme set up for the polymer model and the partners experience so far when using the Tool Box. In addition post doc Anne Serine Ognedal at SIMLab and PhD student Holger Staack from Audi gave presentations on Response of thermoplastics at high level of triaxiality and Experimental Characterization and parameter simulation of polymer components for pedestrian protection, respectively.

On 13-14 November 2013, a SIMLab Tool Box workshop was held at NTNU with all user partners present. After a welcome address, an overview of the Tool Box was given which was followed by an in-depth theoretical presentation of the Metal and Polymer models. The introductory presentations were followed by hands-on training with Tool Box including experimental work in the laboratory for parameter identification. Material tests were carried out on steel, aluminium and polymers. The final part of the seminar was dedicated to numerical analysis and case studies coupled with validation. At the end the partners were asked to evaluate the workshop and to indicate their needs for help during the implementation of the developed technology at the Centre. All partners expressed that the workshop was very useful with excellent presentations. It was especially mentioned that the hands-on training gave an excellent insight into the use of the Tool Box in order to establish material cards for large scale numerical simulations. However, the partners indicated that it was very important to have focus on user-friendliness in the development of the Tool Box.

Polymer seminar at Toyota Motor Europe, Brussels on 24 October 2013.

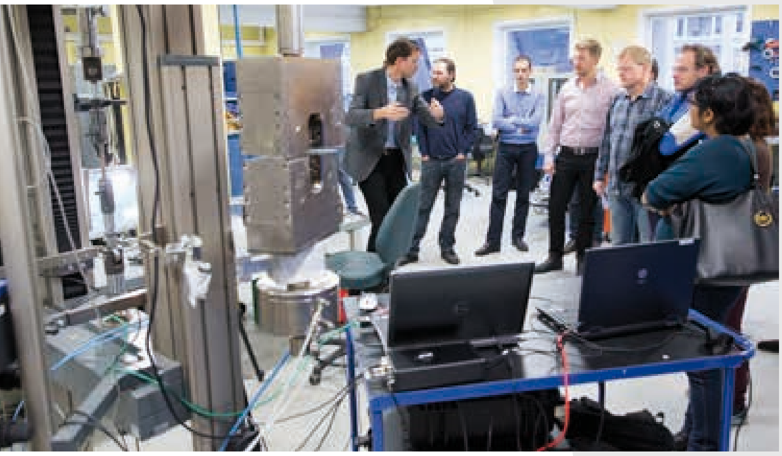
The project meetings, seminars and workshops were also supported by telephone meetings with our partners 1-3 times a year. In order to strengthen the spread of information in the Centre, a seminar was held each second week including a short presentation of a research topic by one of the Centre members (professors, scientists, PhD candidates and post docs).

Tool Box seminar 13-14 November 2013 at SIMLab

PhD candidate Octavian Knoll is waiting for the fracture of the specimen.

Testing in the laboratory.

Test set-up and user partners.



Professor Clausen explains the testing procedure.

Photos: Ole Morten Melgård

Seminar and board meeting at Hydro in Bonn

The Centre's annual seminar and board meeting was held at Hydro in Bonn, Germany, on 6-7 May 2013. After a presentation of Hydro Aluminium Rolled Products and presentation of the annual report for 2012, technical presentations from each of the research programmes were given. Again the partners were impressed by the quality of the research carried out and the way the research in the centre is implemented at the partners through the SIMLab Tool Box.

The board meeting this time focused on the wind-up plan for the Centre and future research after 2014. The proposed wind-up plan was approved by the Board. The wind-up process is run by a dedicated group of partners elected by the Board, i.e. Statoil, Benteler Aluminium Systems and Hydro. The discussion about the future revealed that it was important to continue the development of the SIMLab Tool Box and that the tool could be used as a foundation for a new centre application. NTNU and SINTEF have the owner-

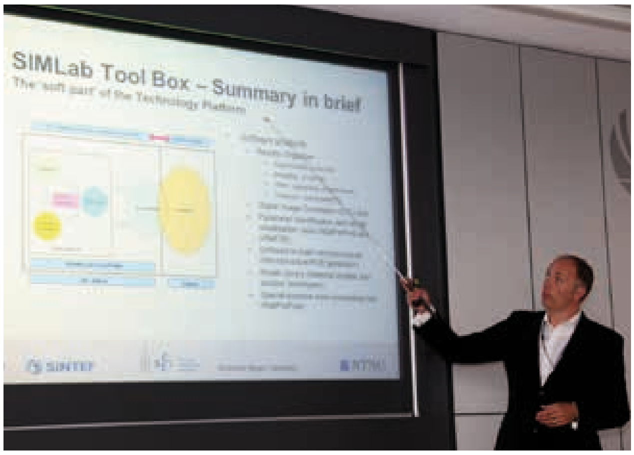
Participants at the seminar and board meeting in Bonn.

The participants seem to be comfortable!

ship of the Tool Box (50/50) and an agreement will be worked out which regulates the use of the results in the future. It was interesting to learn the strong need all partners have for the future development of tools to be used in Computer Aided Engineering contexts, i.e. behaviour and modelling of materials and joints.

Venue – Hydro Bonn.

During the seminar.



Odd-Geir Lademo presents the SIMLab Tool Box.

Photos: Max Malsch

Research programmes and demonstrators

Research in the Centre is based on annual work plans. Thus each research programme and demonstrator activity is composed of several research projects. The following highlights some of the activities carried out.

Fracture and Crack Propagation (F&CP)

Head of Programme: Odd Sture Hopperstad

The main objective of the F&CP programme is to develop mathematical models and numerical algorithms for damage, fracture and crack propagation in ductile and semi-brittle materials. The models are validated against laboratory tests. The materials considered are rolled, extruded and cast aluminium alloys and high-strength steels. Research activities in 2013 have been in the following fields:

- Fracture in high-strength aluminium alloy
- Fracture in cast materials – mechanisms and modelling
- Fracture in age-hardening aluminium alloys – mechanisms and modelling

A PhD project has been defined in each of these research projects. Marion Fourmeau and Octavian Knoll have studied fracture in high-strength and cast aluminium alloys, respectively. Marion Fourmeau defended her thesis on 31 January 2014, while Octavian Knoll is expected to defend his thesis in autumn 2014. Lars Edvard Dæhli started his PhD work in autumn 2013: His topic is micromechanical modelling of ductile fracture in aluminium alloys. The research work of Marion Fourmeau and Octavian Knoll is briefly described in the following.

Marion Fourmeau's thesis is entitled "Characterization and modelling of the anisotropic behaviour of high-strength aluminium alloy". In her work, Marion Fourmeau has shown the importance of accounting for the plastic anisotropy in the modelling of fracture in high-strength, age-hardening aluminium alloys. It was further shown that the complex microstructure of these alloys leads to marked anisotropy in the fracture strain in addition to the strong influence of stress state. A phenomenological anisotropic fracture model was developed to describe the observed fracture behaviour and applied in simulations of ballistic impact, Figure 1. The anisotropic fracture model is implemented in the SIMLab Metal Model but needs further evaluation. Fourmeau concludes that the modelling of ductile fracture in age-hardening aluminium alloys is still a topic for further research.

Octavian Knoll's thesis is entitled "Behaviour and modelling of aluminium cast parts". Knoll has carried out an experimental investigation of the stress-strain response and fracture characteristics of a cast aluminium alloy. Owing to the casting process, the ductility exhibits spatial variations within the cast part, and due to casting defects, substantial statistical variations in ductility is found at a given location. Based on the experimental data, Knoll has developed a probabilistic fracture model for cast materials, including a method for regularization to improve mesh convergence, implemented the fracture model in the finite element code LS-DYNA, and validated the approach against tests on generic automotive parts, Figure 2. The probabilistic fracture model will be implemented in the SIMLab Metal Model in 2014.

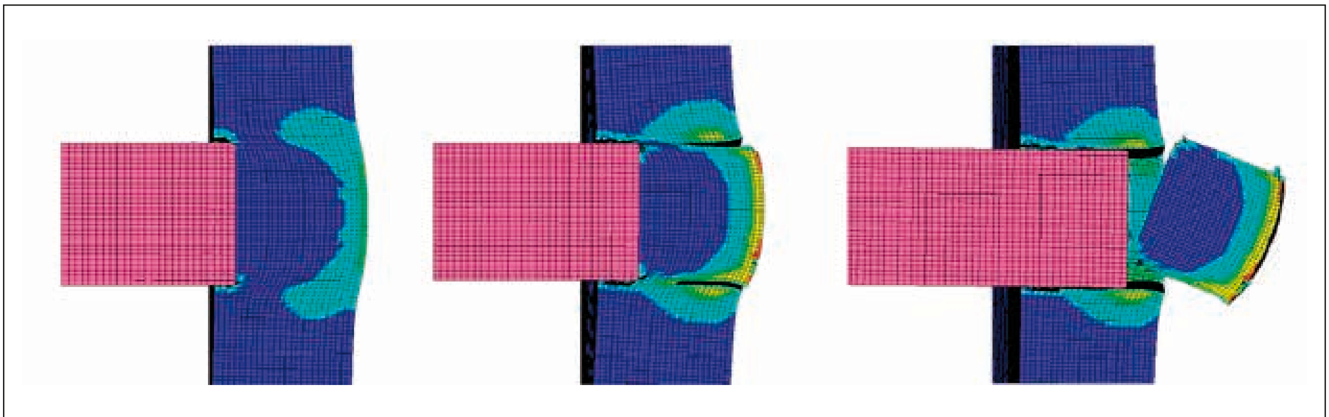


Figure 1 – Finite element simulation of ballistic impact of high-strength aluminium plate using solid elements, anisotropic plasticity model, and anisotropic fracture criterion.

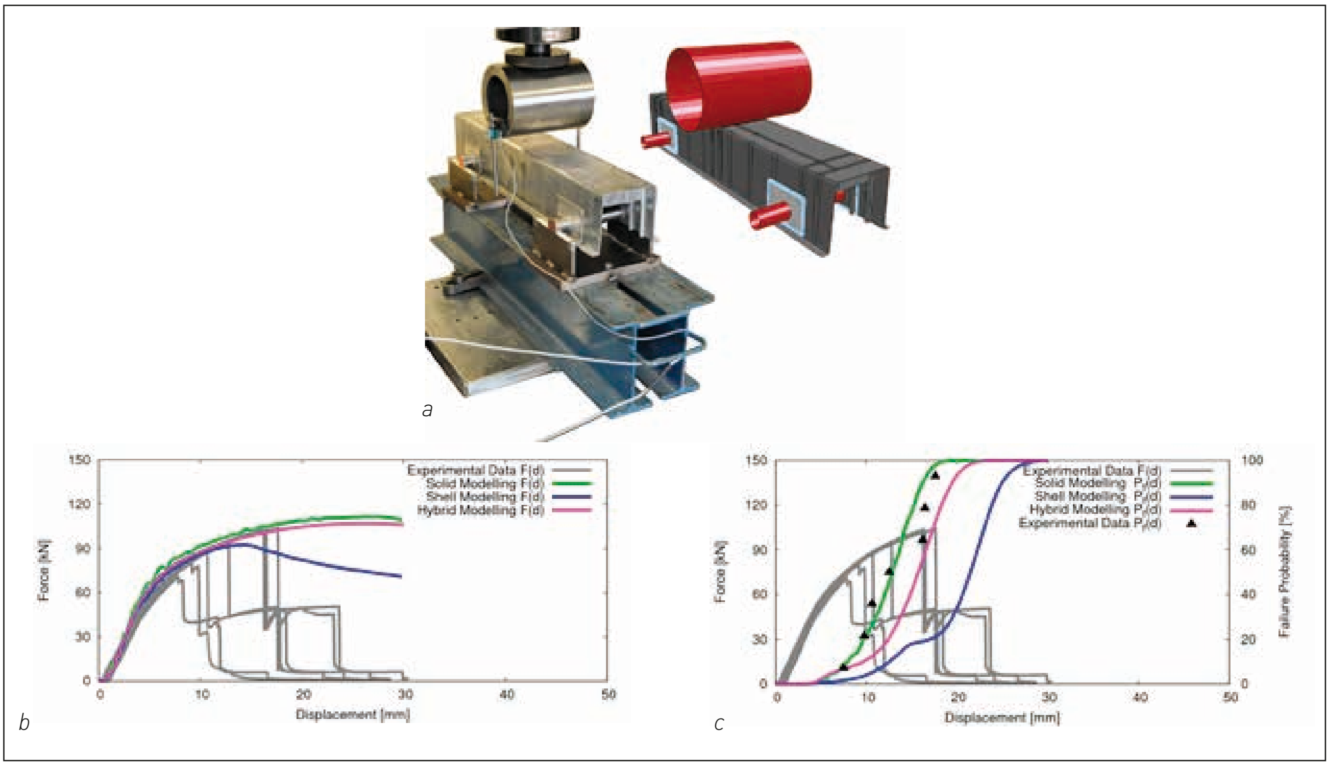


Figure 2 – Three-point bending of cast U-profile in aluminium: (a) Experimental set-up and finite element model; (b) force-displacement curves from tests and simulations; (c) Predicted failure probability versus displacement.

Optimal Energy Absorption and Protection (OptiPro)

Head of Programme: Tore Børvik

The main objective of the OptiPro programme is to design safer, more cost-effective and more lightweight protective structures. To meet these challenges, product development is increasingly carried out in virtual environments by use of FEM in order to improve the protection. The new designs also need to be checked, improved and validated through high-precision experimental tests. Research activities in 2013 have mainly focused on the following fields:

- Lightweight protective structures
- Fragmentation during blast and impact
- Impact against pipelines
- Blast loading on structures

A PhD project has been defined in the three last research areas. The PhD project by Knut Gaarder Rakvåg on fragmentation during blast and impact loading was completed in December 2013, while the PhD project by Martin Kristoffersen on impact against pipelines will finish during autumn 2014. These research projects are briefly described below. The PhD project by Vegard Aune on blast loading on structures was initiated in 2012, and a main activity is to establish a new shock tube facility at SIMLab, see section below. All research activities have been run in collaboration with a number of master's students.

The PhD project by Knut Gaarder Rakvåg investigated the effects of combined blast and fragment loading on protective structures. Based on several experimental and numerical investigations of the fragmentation modes occurring in steels during blast and impact loading, it was shown that numerical simulations without a proper failure description could give very misleading results in computer-aided design of protective structures. The PhD project by Martin Kristoffersen investigates how to design subsea pipelines subjected to interference by trawl gear or anchors. The load scenarios cover the impact, pull-over, hooking and release of the pipe. The main objective with this project is to show how technology developed at SIMLab can be used to calculate the response of a pipeline subjected to impact loading conditions. Component tests are performed on pipes in various testing machines. These component tests serve as a basis for validation of numerical simulations to predict local plastic deformations and fracture initiation and propagation. Material tests are performed to calibrate suitable constitutive relations and fracture criteria, and metallurgical investigations are carried out to better understand the underlying physical reasons for the fracture and crack propagation in impacted pipes. Figure 3 is a photo of one of the activities

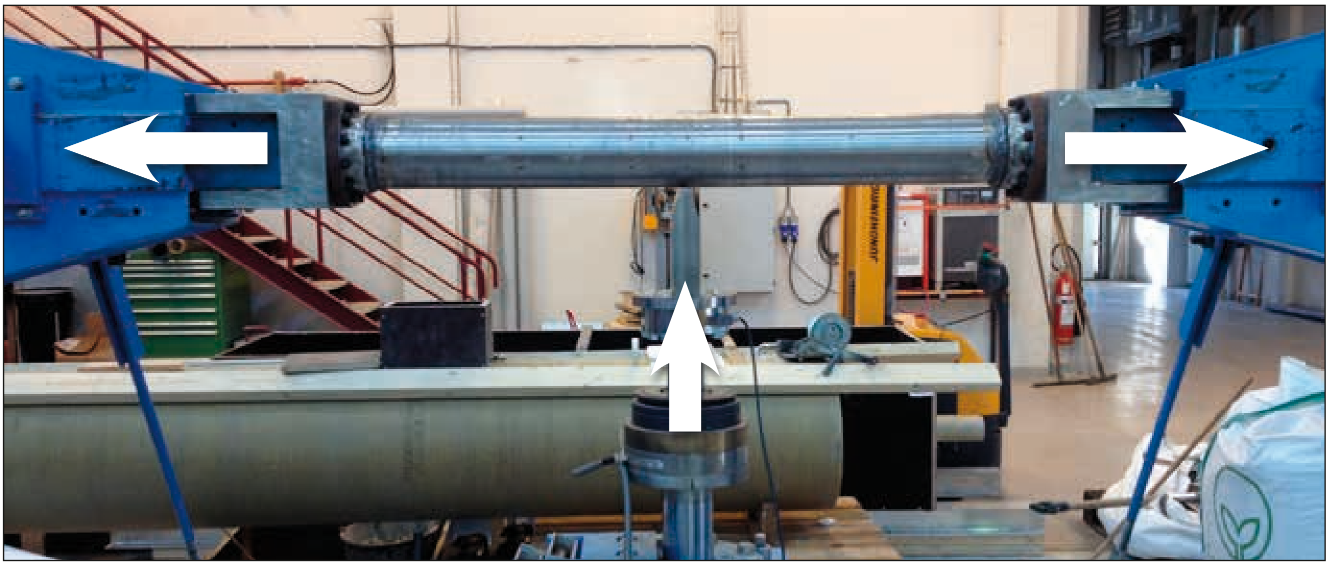


Figure 3 – Stretch-bending of pipes with and without internal overpressure.

that started in 2013, namely stretch-bending of steel pipes with and without internal overpressure of up to 100 bar to study the response of empty or water-filled pipes under such loading conditions.

The SIMLab Shock Tube Facility (SSTF)

Explosions may occur in military conflicts as well as in various industrial applications such as in the petrochemical, chemical or nuclear industries. In recent years, there seems to be a trend that explosive devices have become the weapon of choice for the majority of terrorist attacks, resulting in an increased threat of explosions also against civilians. Norway experienced this trend on 22 July 2011, when a car bomb comprising a mixture of 950 kg ammonium nitrate and fuel oil exploded within the Executive Government Quarter in Oslo, Norway. Eight people were killed and at least 209 injured. The shock wave from the explosion caused severe damage to the surrounding buildings, especially those within a radius of 100 m, and windows were shattered within a radius of 500 m resulting in an affected zone of approximately 750 km^2.

As a consequence, structural impact problems involving fast transient dynamics and explosions have become increasingly important for both industry and society and

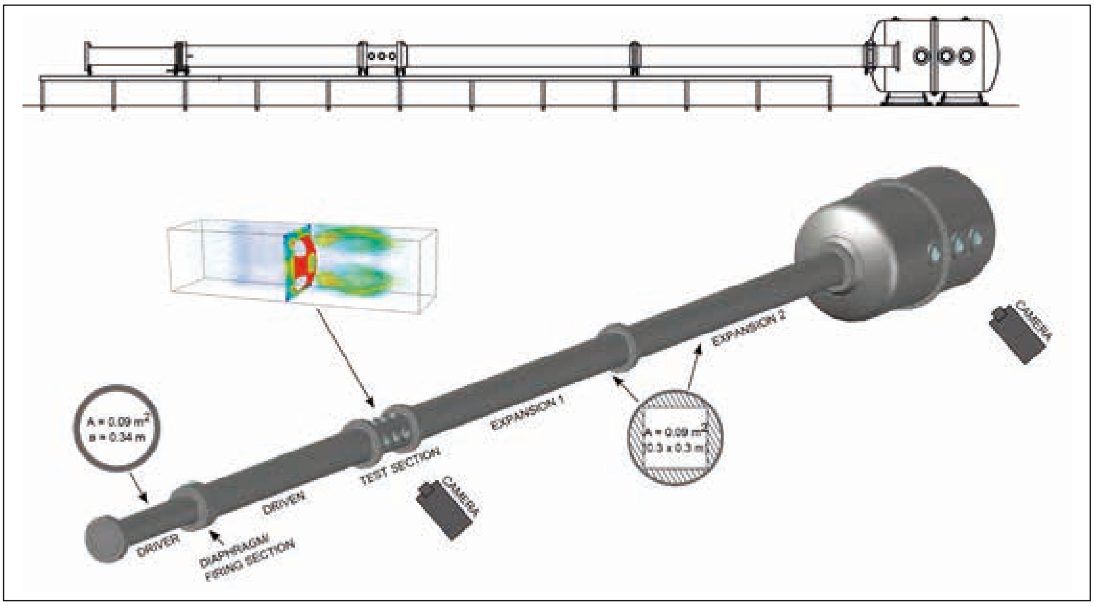


Figure 4 – Shock tube facility.

more research is needed to better understand the consequences of such loading conditions. These conditions often involve Fluid-Structure Interaction (FSI) due to complex geometries, large deformations and potential failure and fragmentation. Current protective design of blast resistant structures is based on the a priori specification of the pressure history acting on the structure and does not account for the interaction between the shock loading and structural response. However, such an approach can result in a non-physical structural response due to the non-linearities in both the material and geometry. Thus the characteristics of the pressure acting on the structure are a function of the structural response and will therefore be significantly influenced by the displacement and possible failure of the structure. Due to the complexity of these problems, controlled experiments are needed to evaluate the available computational methods for FSI in terms of robustness and effectiveness.

A well-known experimental set-up in gas dynamics to investigate the characteristics of shock waves is the shock tube. By performing shock tube experiments it is possible to generate shock waves under controlled conditions, where the shock strength is determined by the initial pressures and temperatures. Therefore, it was decided to establish such a test facility at SIMLab to study the FSI effect from a shock wave impacting a test object. The SIMLab Shock Tube Facility (SSTF) consists of a tube with internal cross-section 0.3 x 0.3 m and an overall length of 20.5 m, see Figure 4. The tube ends in a tank of 5.1 m^3, closing the system and enables an expansion in volume to decrease the overall pressure in the facility after the experiment. The SSFT is basically divided into six parts, i.e. the driver section, diaphragm/firing section, driven section, test section, expansion section and dump tank. The operating pressure in the driver is 170 bar. The experiment starts by filling the driver with compressed air. When puncturing the diaphragm a shock wave will be released, and the characteristics of the wave can be studied by measuring the shock velocity and pressure downstream the diaphragm. The square cross-section downstream of the diaphragm is chosen to simplify the optical measurements through the windows in the test section, where high speed cameras will be used to measure the structural response of the test object. It is also possible to install test objects at the end of the expansion section. The pressure can be measured at 20 various locations downstream of the driver section enabling the measurement of the shock velocity.

The shock tube will be used to obtain experimental data on structures exposed to shock loading. These experiments will then be used to validate computational methods in terms of robustness and effectiveness. The shock tube will be in operation summer 2014 and is a part of a PhD project for Vegard Aune. The project is sponsored by the Research Council through the SFI-SIMLab Centre, NTNU and the Norwegian National Security Authority.

Polymers

Head of Programme: Arild Holm Clausen

The main objective of the Polymers programme is to develop validated material models for polymers subjected to impact. Most of the research has been related to ductile thermoplastics, but there has also been some work on fibre-reinforced polymers. Main attention has been paid to constitutive models representing the evolution of stress as a function of the strain and strain rate, but simple fracture models are also implemented. The main result of 2013 is that some generic models for polymers have been incorporated in the SIMLab Tool Box.

Research activities in 2013 have been in the following fields:

- Implementation, verification and validation of models in the SIMLab Tool Box
- Damage and fracture of polymers, in particular deformation mechanisms around particles
- Crashworthiness of glass-fibre reinforced polymers

The first of these projects has attracted major attention in 2013. The polymer part of the Tool Box includes now a visco-hypoelastic–viscoplastic model. Depending on the material and problem at hand, the viscoelastic and viscoplastic parts may be switched on or off. Anisotropic elasticity, which is relevant for fibre-reinforced polymers, is also implemented in the model. Three damage models are also included. The verification process has mainly been coordinated with researchers from SINTEF.

Figure 5 – Ruptured tension test sample of PP, exhibiting skin and core layers.

For validation, there has been cooperation with Toyota. Heine Røstum's master's thesis which was done at Toyota Motor Europe's Technical Centre in Brussels from September 2013 to February 2014, dealt with a PP material having skin and core layers, see Figure 5, and explored the capability of the Tool Box to model this material. Discretizing the sample with brick elements having different properties in the skin and core parts, Figure 6 shows that the model captures the behaviour of the specimen in the experimental test. The Tool Box was used to adapt the material properties of the skin and core layer to the test

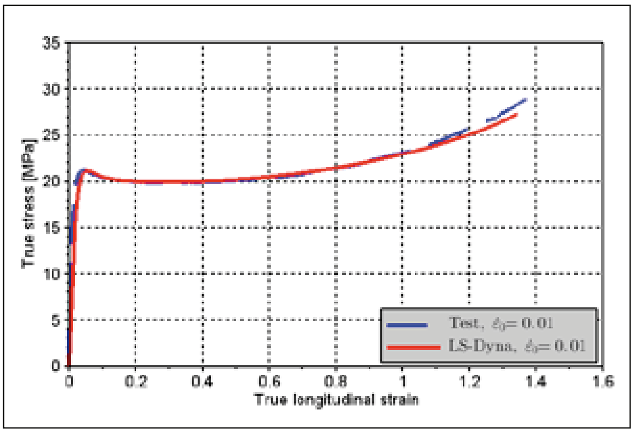


Figure 6 – Stress-strain curve for sample with skin and core layers. Comparison between test data and numerical prediction.

results. This joint master's thesis enhanced the application of the Tool Box at Toyota, and is a useful way to implement technological advances at the user partners.

The research activity on materials with mineral particles has continued in 2013 through the post-doc project of Anne Serine Ognedal. This has mainly been concerned with numerical investigations of the mechanisms for decohesion between particles and the matrix material, and the subsequent void growth. This response at a micro-scale can be related to macroscopic features such as softening and increase of volume. Also related to the response of thermoplastics, one of our PhD candidates Marius Andersen has looked at experimental techniques for determining the material response, i.e. the stress-strain curve, at large deformations (exceeding a true strain of 2).

Andreas Koukal's PhD thesis on glass-fibre reinforced polymers was finished late in 2013, and it will be defended in 2014. Petter Holmstrøm started his PhD project on the modelling of fibre-reinforced materials in August 2013.

Multiscale Modelling of Metallic Materials (M^4)

Head of Programme: Odd-Geir Lademo

The main objective of the M4 programme is to develop a multi-scale modelling framework that enables an integrated design of material, process and product in a virtual process line. At the macro level the modelling relies upon and contributes to the development of the phenomenological SIMLab Metal Model. At a lower (meso-/crystalscale) level, a framework for single- and polycrystal plasticity has been developed (including the SIMLab Crystal Plasticity Model). At the microscale, a precipitation-based modeling procedure (NaMo) is developed that can describe strength and work hardening as function of the chemical composition of the alloy and the thermal history.

Various developments have been done for rolled and extruded aluminium alloys and high-strength steels. Research activities in 2013 have been in the following four fields and projects, each involving a PhD candidate:

- Fundamentals of multi-scale modelling
- Formability of sheet materials
- Capacity and ductility of welded structures
- Behaviour of aluminium at wide ranges of strain rate and temperature

The first project aims to provide qualitative insight and quantitative estimates on the effects of meso- and micro-scale properties on the macroscopic behaviour of the material. One activity, initiated in 2013, which explored the use of multi-scale tools to study the effect of the micro- and crystal structure on the ductility of aluminium alloys used in crash box application, has led to concurrent activities focusing on the modelling of precipitate free zones. The activity also aims to strengthen the hierarchical coupling between the Nanostructure Model (NaMo) and the crystal plasticity

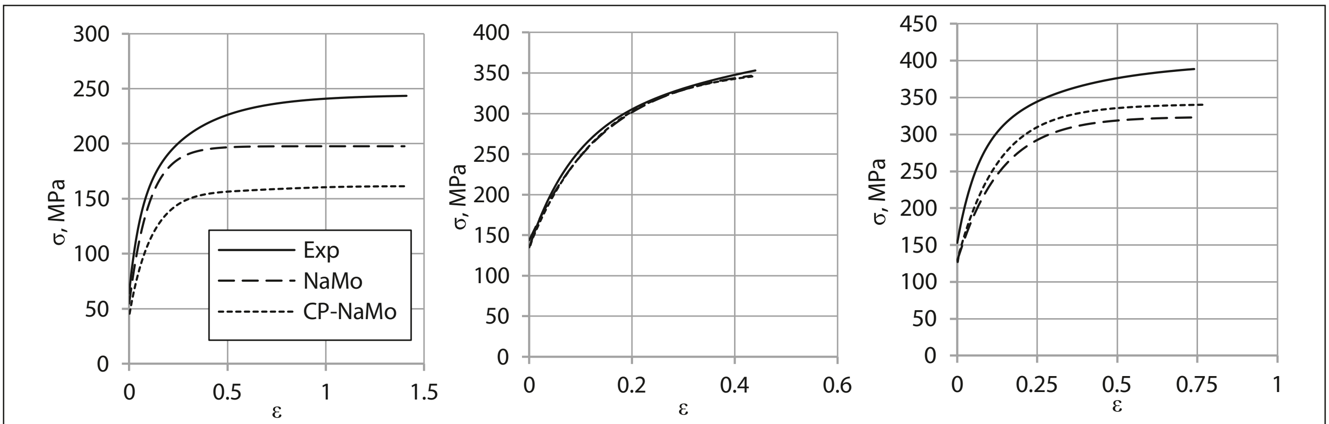


Figure 7 – Comparison between NaMo, CP-NaMo and experimental data for three different alloys 6060 (left), 6082A (middle) and 6082B (right), all in T4 temper.

FEM (CP-FEM) approach and a combined precipitation and CP model has been proposed, see Figure 7.

In the second project, work is done to i) establish experimental procedures to study and characterize strain localization and failure in sheet materials and ii) to perform targeted development of the model framework to represent the observed phenomena. In 2013, a broad experimental campaign on aluminium alloy AA6016 has been documented. Further, a stand-alone software tool for automated processing of DIC-based strain measurements has been established. The tool supports a number of algorithms for this purpose. Work has been initiated to develop guidelines for experimental FLC detection.

The third project aims to refine the established "virtual process line" for integrated design of welded aluminium structures (alloys, welding and Post-Weld Heat Treatment (PWTH) process parameters, and product geometry). The concept makes use of the precipitation-based modelling procedure (NaMo) to feed a precipitate-based strength and work hardening model formulated at the macro-scale. In 2013, Anizahyathi Alisibramulisi defended her PhD thesis on the subject. Her thesis contains an extensive experimental database and a numerical study that guides further research in this area. Model revisions have been undertaken by Hydro Aluminium.

The last project aims to i) establish methods for testing metallic materials at wide ranges of temperature and strain rate; ii) enhance the understanding of the underlying material mechanisms; and iii) evaluate and further develop the model framework for these conditions. The work focuses on aluminium alloys, and is being done by a PhD candidate. At elevated temperatures, necking occurs at an early stage of deformation. The classical technique for the treatment of test data from high strain-rate tests in a split-Hopkinson test rig is based on strain gauges, but this approach is not valid after the onset of necking. One challenge is to determine the area of the necked section, but also the curvature of the neck is of importance to calculate the equivalent stress at large deformations. A method based on the analysis of digital pictures has been developed for determination of the true stress-strain curve after necking until fracture for samples subjected to high strain-rates and high temperature, see Figure 8.

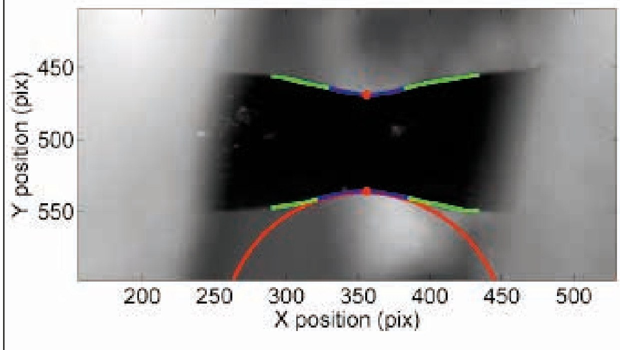


Figure 8 – Determination of minimum diameter and radius of curvature in the necked section of a tensile specimen.

Connectors and Joints (C&J)

Head of Programme: David Morin

Modelling of structural assemblies requires proper modelling of connections, such as rivets, welds, bolts and adhesives. The level of detail in the modelling is again dependent on the model scale of interest. For large-scale impact analysis, simplified and computationally efficient models have to be used. However, the models should represent the large deformation behaviour and connector failure with a fair degree of accuracy.

In this research programme, the behaviour and fracture of connections are handled from experimental and numerical points of view. The experimental activities involve both studies on the behaviour of single connectors as well as the assembly of connectors used in structural joints. The following research activities have been run in this programme in 2013:

- Behaviour and modelling of flow drilling screws
- Bolted connections subjected to dynamic loading

In the first activity, focus has been placed on a rather new joining technology used in the automotive industry; flow drilling screws (FDS). A thorough experimental characterization has been carried out to investigate the strength of FDS relative to self-piercing rivets (SPR). Figure 9 shows a comparison between aluminium specimens joined with FDS and SPR. The critical strength and ductility are assessed by means of a modified Arcan test set up. Figure 9 also shows the difference in terms of joint configurations.

The second activity is a PhD project for Erik Grimsmo and is dedicated to the behaviour of bolted steel connections under quasi-static and dynamic loading conditions. The main objective with the project is to determine if existing design recommendations are able to predict the behaviour when a typical connection used today is exposed to

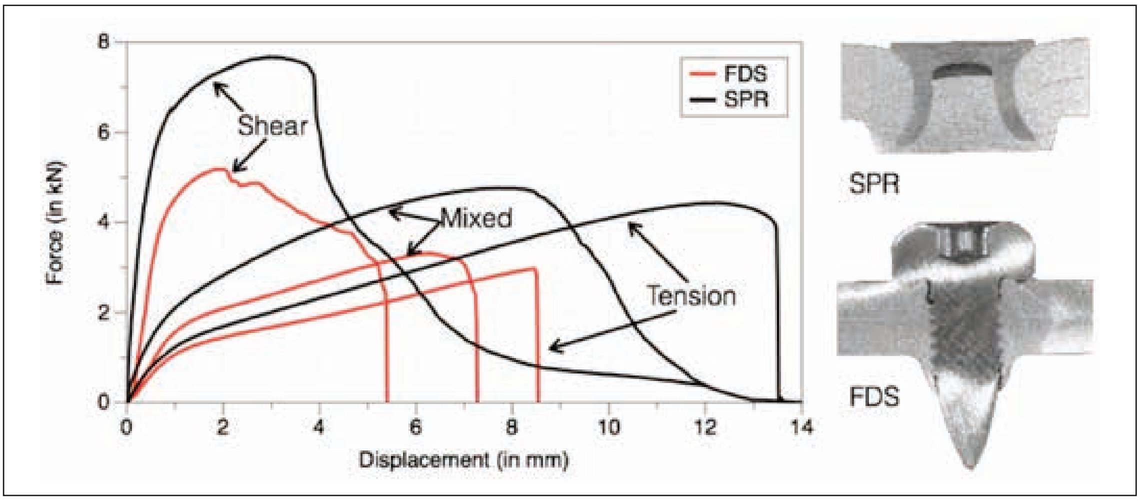


Figure 9 – Comparison between FDS and SPR connecting aluminium sheets.

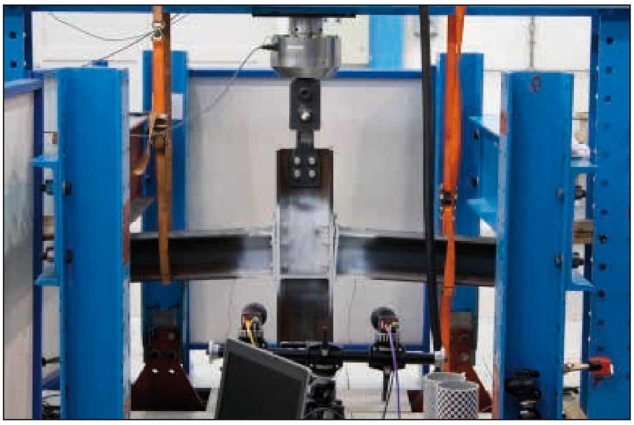


Figure 10 – Beam-column connection at failure subjected to quasi-static loading.

impact loading caused for instance by an accidental event or terrorist act. Static and dynamic tests will be carried out as a basis for validation of a numerical model. The validated model will then be used to carry out parametric studies as a basis for modifications of the present design regulations. Figure 10 shows a bolted steel connection at failure subjected to quasi-static loading.

Industrial Demonstrators (Demo)

Head of Programme: Odd-Geir Lademo

In brief, the main objective of this research programme is to facilitate industrial implementation of the results produced in the Centre (e.g. experimental procedures and modelling concepts). In 2013, the work on the various software products and modelling guidelines has continued. To support industrial pick-up, various meetings and workshops with the user partners have been arranged. Here the SIMLab Tool Box is presented in some detail along with progress made in 2013.

SIMLab Tool Box

In the annual report for 2011 a value chain for non-linear numerical analyses was defined and a number of software products were introduced; 'ResOrg', 'DIC', 'MatPrePost', and a 'Model Library' (consisting of 'SolT(s)' and 'UMAT(s)'). The SIMLab Tool Box, as illustrated in Figure 11, was defined as the resulting cluster of software products. The components in the SIMLab Tool Box may be used as separate software-products or in combination with each other.

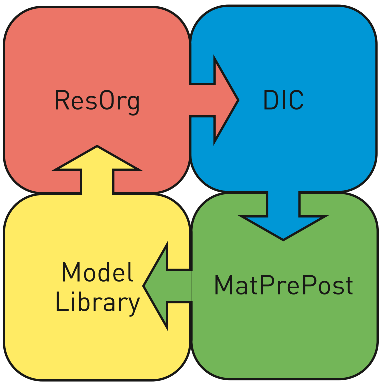
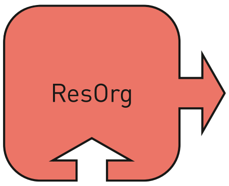
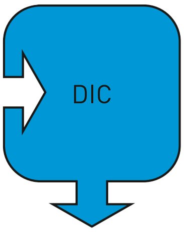


Figure 11 – SIMLab Tool Box software products.

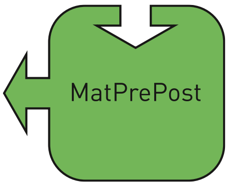


ResOrg (Results organizer) is a software component that is designed to support experimental planning, execution and processing. The software includes order forms for machining of specimens, specimen geometries in the form drawings and CAD files and test protocols. The software represents a Graphical

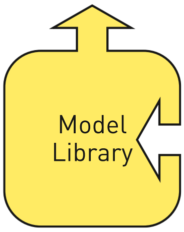
User Interface (GUI) that runs on Windows platforms, but the underlying files can also be accessed without this GUI through an accessible sub-directory structure.



DIC (Digital Image Correlation) allows determining the displacement field on material/structural tests based on digital images. The SIMLab DIC software is able to handle 2D as well as 3D measurements using what is termed a Q4 formulation. Unique features to deal with crack propagation are implemented, like element erosion and node splitting techniques. The computational part of the DIC software is heavily parallelized to get very efficient computation times. The comprehensive GUI runs on Windows platforms.



MatPrePost is a tool for parameter identification and tailored pre- and post-processing. The outcome of the pre-processing utility includes visualizations of the model concept, predicted Forming Limit Diagrams (FLDs) and fracture locus plots, and formatted and quality assured input for the user-defined material models. The tool supports output to various FE codes used by the partners in SIMLab. This comprehensive GUI runs on Windows, Mac OS and Linux platforms.



The Model Library is a collection of customized, user-defined material models, UMAT(s), and Solution techniques, SolT(s), see annual reports 2009 – 2011. The three most important UMAT(s) are the SIMLab Metal Model (SMM), the SIMLab Crystal Plasticity Model (SCPM), and the SIMLab Polymer Model (SPM). Each is built upon a modular strategy, includes options for speed and accuracy, and is thought to fit the needs for all partners in the consortium.

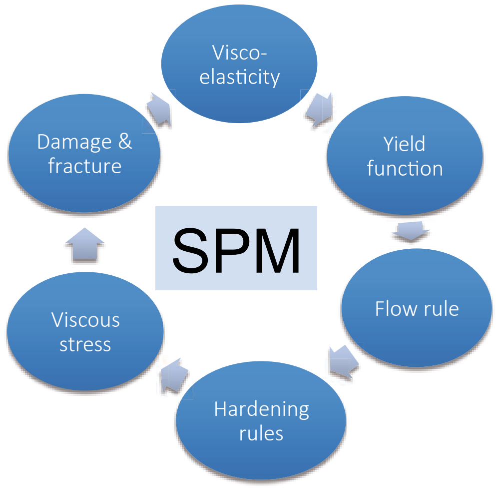


Figure 12 – SIMLab Polymer Model structure.

The SIMLab Polymer model is illustrated in Figure 12 and allows the user to easily include or exclude physical features whenever they are required depending on the application area and load case. This structure further allows for a gradual shift in company-specific 'recommended practise': by modifying a few parameters in the input, the regular industrial approach (generally J2 plasticity) is replaced by more realistic representation of e.g. non-isochoric plasticity. The model is applicable to shell and brick elements. The Model Library can be linked to several FE codes, e.g. LS-DYNA, ABAQUS, PAM-CRASH and IMPETUS.

Highlights 2013

The DIC software has been extended and improved with respect to its functionality and ease-of-use. The coupling of the DIC software with the model library has been a main task. The resulting software can be used to obtain stress fields directly from mechanical experiments, and also create a platform for evaluation and optimization of material model parameters, see Figure 13.

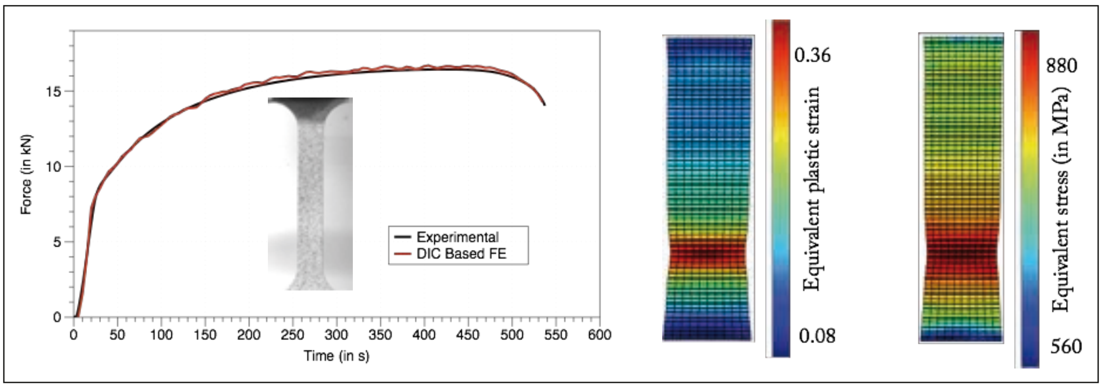


Figure 13 – Application of the DIC code linked to the SIMLab Model Library on a dual-phase steel under tension; results from inverse analysis including stress and strain fields.

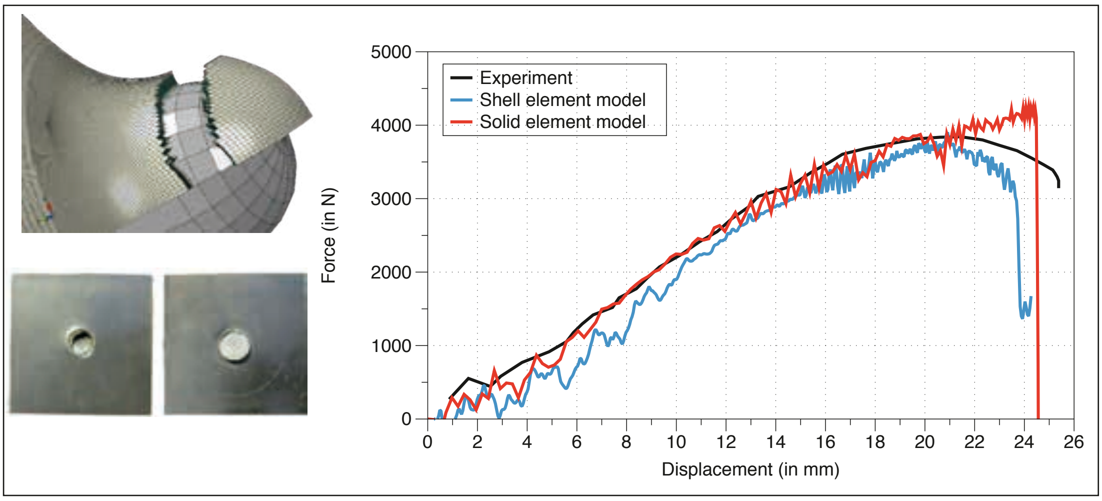


Figure 14 – Dynamic drop tower test simulated with the SIMLab Polymer Model.

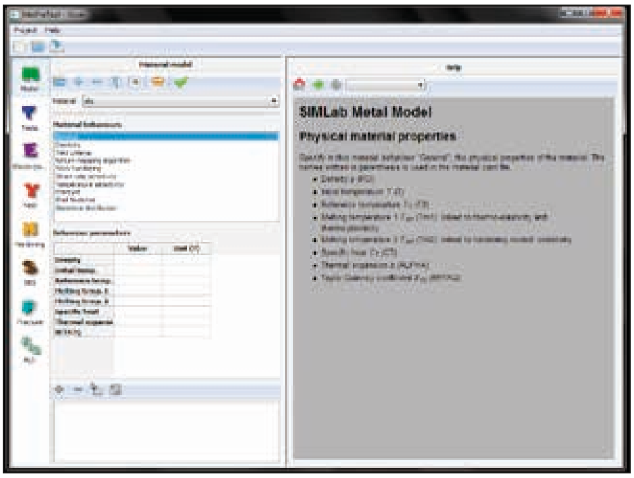


Figure 15 – GUI for MatPrePost 2.0 supporting both the SIMLab Metal Model and the SIMLab Polymer Model.

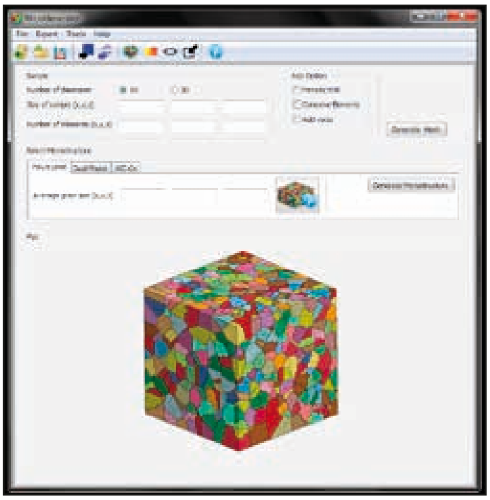


Figure 16 – GUI for SIMLab MicroGenerator.

Considerable focus has been placed on the maturity of the SIMLab Polymer Model as well as its support by MatPrePost. An extensive validation programme based on the experimental data collected through the research programme Polymers was carried out to assess the benefits and limits of the SPM. Particular attention was paid to the prediction of fracture in several polymeric materials (polypropylene type) under complex load paths. Figure 14 illustrates the response of an FE model representing a dynamic drop tower test. Both solid and shell elements were used and provide a good correlation to the experimental data in terms of force and fracture prediction.

All models in the Model Library have been revised during 2013 and have been offered to the user partners of the Centre. MatPrePost 2.0 has been released, fully supporting the SIMLab Metal Model and the SIMLab Polymer Model, Figure 15.

To carry out lower scale analyses, a micro-structure generator has been developed. The SIMLab Micro Generator efficiently builds micro-/crystal- structures of single- and dual-phase materials. This allows numerical mechanism studies on the composition and grain morphology of complex materials. The new GUI and results from studies of dual-phase steel materials are shown in Figure 16 and Figure 17.

Industrial implementation

A workshop on the SIMLab Tool Box was arranged in Trondheim on 13-14 November 2013. This workshop gave a general training, and dedicated introduction to version 2.0 of the SIMLab Tool Box.

Based upon the workshops and meetings, several part-

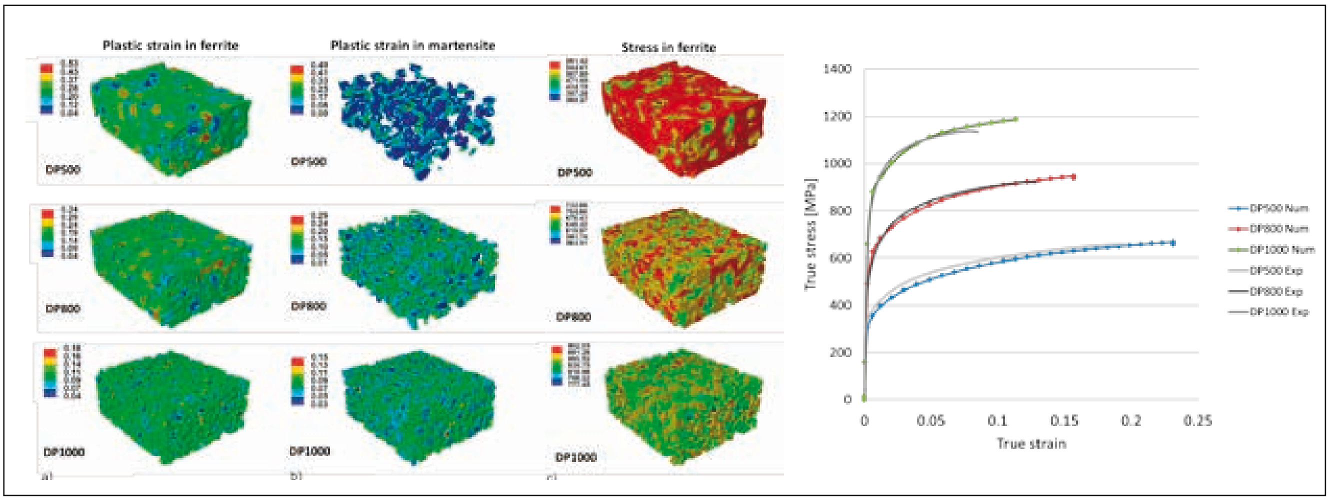


Figure 17 – Numerical studies of dual-phase steel materials.

ners have initiated dedicated projects to implement the SIMLab Tool Box at their own premises, for instance:

- Yann Claude Ngeuveu from Toyota Motor Europe has spent three weeks at SIMLab to characterize a polymeric material and to follow intensive training on the use of the SIMLab Tool Box with a particular focus on polymers. In addition, a master's student from NTNU has spent 4 months at Toyota Motor Europe in Belgium working on the modelling of injection-molded polypropylene under large deformations using the SIMLab Tool Box.
- Arjan Strating from Audi has spent one week at SIMLab to follow a training session on the use of the SIMLab Tool Box with particular focus on the modelling of aluminium alloys. His major responsibilities in 2014 are to disseminate information and facilitate the broad utilization of the tools in Audi.
- A one-day internal workshop has also been arranged to train the MSc and PhD candidates at SIMLab, in the theoretical background as well as practical use of the various tools. This facilitates the long-term, broad dissemination of the results at the Centre to Norwegian and international industry.

Concurrent research projects

Utilizing the high level of expertise at the Centre, a selection of research projects that have been run in 2013 is presented. These include:

- ***FME BIGCCS (2009-2016)***: In the research task CO_2 Pipeline Integrity, the main objective is to develop a coupled fluid-structure model to enable safe and cost-effective design and operation of CO_2 pipelines. Further, requirements to avoid running ductile fracture in pipelines pressurized with CO_2 and CO_2 mixtures will be established.

- ***FME Centre for Solar Cell Technology (2009-2017)***: The overall objective is to give current and future companies in the Norwegian photovoltaics industry long-term access to world leading technological and scientific expertise.

- ***Joint research project with Honda R&D Americas (2013-2017)***: The objective of the project is to model the behaviour and failure of flow drilling screws submitted to crash loadings. One PhD candidate works on the project supervised by personnel from the Centre.

- ***Joint research project with Aker Solutions (2013-2016)***: The objective is to model the behaviour of rubber seals. One PhD candidate works on the project supervised by personnel from the Centre.

- ***EUROSTARS GEPEU (2012-2015):*** This project works with the development of a new non-linear simulation tool for mechanical and multi-physics problems using graphics processing units (GPU) for computations. This is a new use of hardware technology for high computational speed. NTNU's role is to carry out validation of the proposed software. The partners in the project are Impetus Afea Norway (coordinator), Impetus Afea Sweden, NVIDIA Corporation, Centro Ricerche Fiat and NTNU.

- ***Aker Solutions and SIMLab Tool Box (2013):*** Supported by SIMLab, Aker Solutions have used the SIMLab Tool Box to model the impact between a ship and an oil and gas platform.

- ***Validation programme for Sapa (2013):*** SINTEF has been running a project together with Sapa on validation of the SIMLab Metal Model.

'Quite a COMBINATION'

What on earth is the link between wave speed in heart walls and the Liberty Ships of World War II? How does Pasteur connect with Toyota?

We're not going to tell you just like that, are we? Rather, we invite you to indulge in the popularized part of this year's annual report and find out for yourself.

Text: Albert Collett
Photos: Ole Morten Melgård

John W. Hutchinson

The initial questions are an indication of the myriad of elements that form the basis of SIMLab's work. They offer a glimpse of a truly intriguing universe.

On the following pages you'll meet John Hutchinson; Harvard professor, advisor to the US Armed Forces, member of SIMLab's scientific advisory board and an important voice when SIMLab's new path was chosen. He'll touch on Sputnik as well as rigour mortis.

You'll also meet Torstein Haarberg of SINTEF, the largest independent research organization in Scandinavia. Haarberg heads SINTEF's Materials and Chemistry unit. He is a board member with clear ambitions on SIMLab's behalf. He also speaks about quadrants and visible leaders.

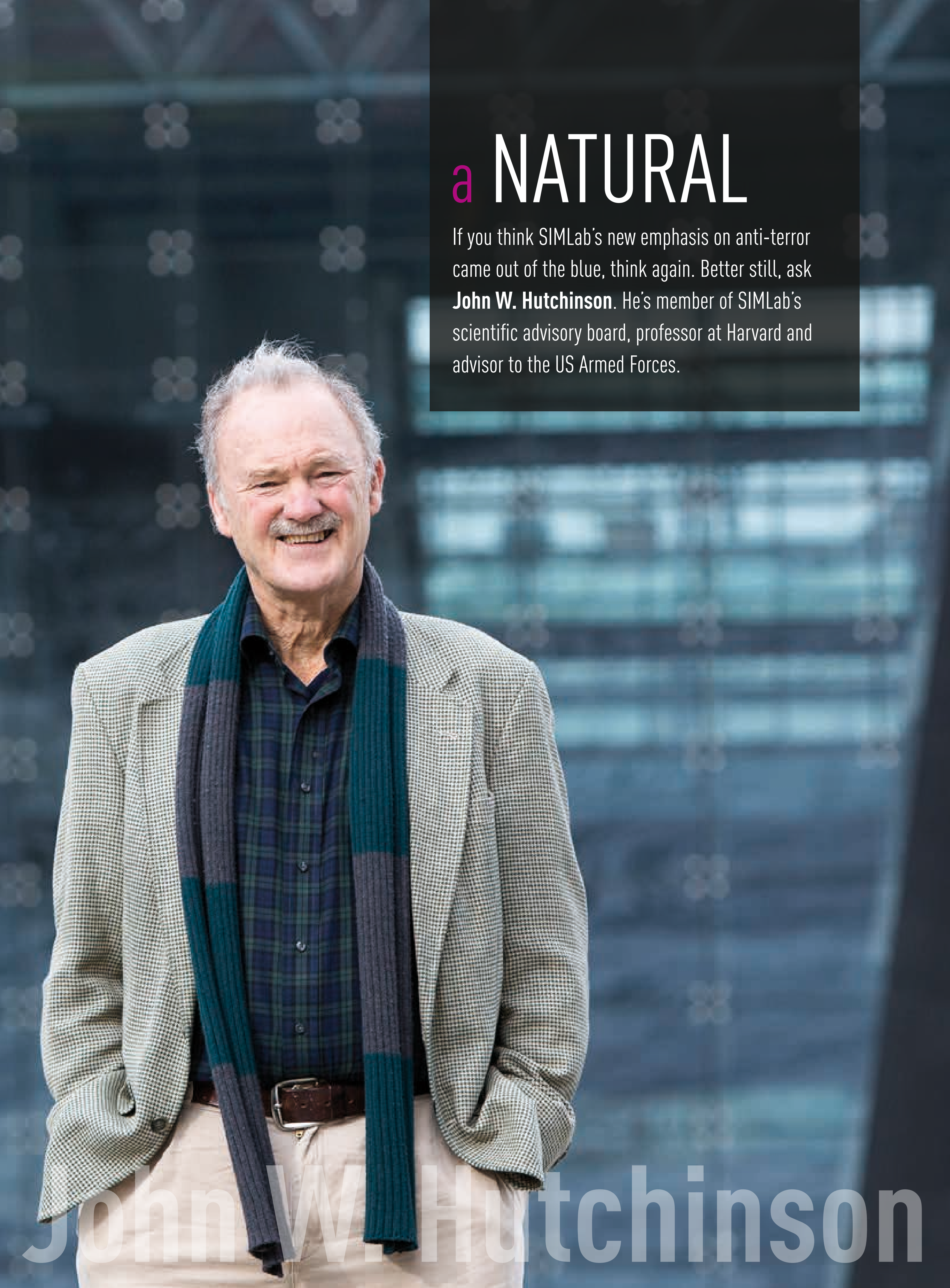
PhD

Finally you'll get to know six aspiring PhD candidates who are about to crush some myths about the behaviour of young Norwegians. On the way you'll pass methods for categorizing tumours, modelling of rubber seals and their common verdict: "What we do at SIMLab is sexy research!"

Enjoy!

a NATURAL

If you think SIMLab's new emphasis on anti-terror came out of the blue, think again. Better still, ask **John W. Hutchinson**. He's member of SIMLab's scientific advisory board, professor at Harvard and advisor to the US Armed Forces.



Flashback, spring, 2011: director Magnus Langseth challenged his highly international board of advisors about the future: where should SIMLab go next?

Spooky

John Hutchinson has decades of experience from various advisory positions to the US Armed Forces. In 2011 he had just joined the Board of Army Science and Technology. Among the topics he had worked on, were blast resistant structures.

Hutchinson and the rest of the board were fully aware of SIMLab's work in fields like projectile penetration, ballistic simulation and blast impact. They knew SIMLab had the expertise needed to give anti-terror measures top priority, so the answer to professor Langseth's challenge was quite easy. In Hutchinson's own words: "It was a natural".

The recommendation soon got a half spooky déjà vu character: it was given only months ahead of the July 22nd terrorist attack that left 77 people dead at the government headquarters in Oslo and the youth camp at Utøya.

No rigour mortis

The relationship between John Hutchinson and SIMLab is also a natural:

"Some engineers are taken primarily with the beauty of the underlying mathematics. They are more interested in formality than application. Then you have people like Magnus Langseth, Odd Sture Hopperstad, Tore Børvik and me: we are heavily motivated by real engineering concerns. There is a lot of overlap between the SIMLab people and me in interest and in style.

Often there is a tension between the formality and application in engineering science with researchers split into two camps. We have a famous saying in our camp about the others that "too much rigour leads to rigour mortis". At times, we love our field more than we love our university. It is so exciting to see a good implementation of will!"

They do it all

Still, the common interest is not sufficient to explain why John Hutchinson happily joined SIMLab's scientific advisory board. There's more to it than that:

"SIMLab is one of the leading groups in the world. They have very strong people with broad technical knowledge and complementary expertise, good leadership and drive, and they work very effectively together as a team with a common purpose. This is worth emphasizing because in my experience this is the exception rather than the rule with large projects. SIMLab is one of the most effective groups I've seen.

Equally important is that they deal with basic mechanics, fundamental tests, development of models, implementation of simulation models and validation tests, and they are at the forefront of incorporating failure in simulating tools; they do it all, that's what's so unusual. They really stand out," says Hutchinson and goes on:

"Their work is at the core of engineering science, particularly in failure, where we need a lot more knowledge. We also need to learn more about structural integrity in transportation and buildings; the whole area of secure structures against blasts and other kinds of loads."

He explains with the help of a historic example:

"When the first Liberty ships in the Second World War sailed to the north, some of them snapped in two. They were made of cheap steel that became brittle and fractured in the cold."

A Sputnik behind

John Hutchinson grew up in southern New Jersey. His mother was a schoolteacher, his father an Irish farm boy who didn't want to be a farmer at all. Instead he became a Presbyterian minister.

On October 4th 1957 a spectacular event took place. The Soviets launched Sputnik. For the first time, a satellite was sent into outer space.

"It had enormous impact and sparked a huge growth in science and engineering", says Hutchinson. He was 18 and his destiny was sealed. At 29 he was the youngest full professor at Harvard. Since then he has acquired enormous expertise in structural and applied mechanics and mechanical engineering from the tiniest micro level to the applied product. Very few are as well informed and have such oversight over the entire field.

The last six years of his career he has split between Harvard and the Technical University of Copenhagen, where he is an adjunct professor.

Absolutely!

SIMLab's scientific advisory board is truly international, with members from France, Germany, Sweden, UK, Canada and USA. Every member overlaps. They are asked to criticize particularly the overall vision of SIMLab and to function as a sounding board to get SIMLab in the direction it should be heading.

John Hutchinson is one of the world leaders in his field and has been a very valuable member. His questions are extremely precise and he has had SIMLab rethink their stances more than once.

Therefore we expect cheers from the SIMLab leadership when they read his answer to our last question:

"Would you be ready to join the scientific advisory board of the next program?"

"Absolutely!

At the core of Pasteur's QUADRANT

Are you familiar with Pasteur's Quadrant? If not, here's a quick introduction. The term seeks to distinguish between three types of research: basic (Niels Bohr), applied (Thomas Edison) and use-inspired (Louis Pasteur).

Pasteur's Quadrant was introduced by Donald Stokes in 1997 in his book by the same name. Stokes' message was the need to come around the asserted dichotomy between basic and applied science. Roughly speaking, where basic research looks for fundamental understanding and ignores considerations of use, applied research does the opposite. Use-inspired research combines the two. To Stokes, Pasteur is the ideal use-inspired researcher.

SINTEF's man on board

The man who introduces us to Pasteur's Quadrant with impressive enthusiasm, is **Torstein Haarberg**. He's been a board member at SIMLab since the very start, representing SINTEF, the largest independent research organization in Scandinavia. Haarberg heads SINTEF Materials and Chemistry with 450 employees. SIMLab's research constitutes a mere fraction of his unit's intake. Nevertheless, Haarberg is very enthusiastic:
"SIMLab is right at the core of Pasteur's Quadrant. They are certainly driven by a quest for fundamental understanding but always keep usefulness in mind."

Wafers...

"SIMLab's findings are useful to us in a whole range of matters. Their expertise on fracture is very helpful in our work with renewable energy in that we learn how to avoid cracks in solar cell panels. The wafers are sawn from silicon blocks with diamond thread. They are extremely delicate and sensitive to even the tiniest shocks. SIMLab's modelling toolbox helps us optimize processes to avoid damage and reduce material loss," Haarberg continues.

... and drill bits

In the oil industry, SINTEF makes use of SIMLab's expertise on what happens in a crash. The generic nature of the research is highly visible in that findings from car crashes can be used to understand what happens when wolfram carbide drill bits hit rock 50 times per second.
SIMLab knowhow is also crucial in the critical parts of oil installations where there is absolutely no tolerance for accidents. In some areas there has to be immediate reaction systems in place in the event that something that theoretically shouldn't be able to happen does happen.

A feather in the hat

To Haarberg, SIMLab's excellence is visible from a number of angles:
"The halfway evaluation of the SFI pointed out their qualities as an exciting and powerful centre when it comes to highly qualified personnel as well as good strategy development and strong, visible leadership.
Another important indicator is their extremely able partners. It says a lot when BMW decides to re-join after having pulled out during the crisis. It is certainly also a feather in SIMLab's hat that Toyota, with 25 000 researchers in Tokyo and 1 200 in Europe join. This goes to prove that SIMLab's level of research has a very high standing among the most prestigious players in the business."

Lab needs

While Torstein Haarberg is both content with and impressed by SIMLab's achievements, he also has views on their needs and potentials to improve:
"Interaction between hypothesis and iterative testing is what scientific method is all about. Therefore the co-existence between experiments and modelling will never become unfashionable. That is where SIMLab is so strong. That's where the quality of their researchers really shines through.
However, in order to maintain this position, the need for a cutting-edge lab will always be fundamental. In the time ahead, SIMLab will need to strengthen their experimental infrastructure. The application for a new CRI with more emphasis on offshore and societal security makes this all the more important."

EU potential

Haarberg also thinks SIMLab has the potential to attract more projects from the European Union:
"I think it would do them good to compete more on the international arena. Having joint projects with PhD programs would give advantages in international cooperation and improve cultural understanding. This could open exciting opportunities.
When you look at the extremely strong consortium SIMLab has been able to build in the automotive industry, this definitely should be within reach."

Clear and visible

As a board member throughout the present SFI programme, Torstein Haarberg hasn't been burdened with loads of serious challenges. He sees this as sign of strength: "There are SFIs and SFIs. Some are dominated by very demanding conflicts that need a lot of attention from the board. Others, like SIMLab, have a clear direction and a visible leadership that everybody relates to. The focus is always on good work, quality and excellence. In these cases there is less need for support from the board. That said, a board still may be useful in strategic matters. I'll certainly keep following SIMLab's development with great interest, whether on future boards or not," Haarberg adds.

THE GANG of Six

In the autumn of 2012 SIMLab announced first one,
then another vacancy for PhD candidates.
Six top students expressed interest.
What to do?
Recruit them all.

PhD candidates

Which is easier said than done, of course. Not for lack of topics in need of further research. That has never been a problem at SIMLab. But there has to be funds.

A lucky combination of creativity, drive and fame secured support from Honda, Aker Solutions and SIMLab's partners at NTNU. Now all six candidates are busy at work.

Myth busters

The Gang of Six are true myth busters. In Norway, popular belief has it that most PhD candidates in engineering are non-Norwegian as the Norwegian master's students are supposedly head-hunted by business long before graduation day and prefer to earn good money from day one.

As we shall see, the myth is not entirely true. **Erik**, **Arne**, **Lars Edvard**, **Petter**, **Jens Kristian** and **Johan** are unmistakably Norwegian names. They have all chosen to pursue academic careers, turning down well paid positions in industry to do so.

Sexy research

Ageing rock geeks will remember The Kinks and their hit "Dedicated follower of fashion".

The text was a satirical comment on London fashionistas in the 1960s. The reference springs to mind when wanting to explain the motives of The Gang of Six: far from being fashionistas they might rather be described as "Dedicated followers of science". It is the urge to do research that drives them, the desire to be part of a scientific environment with top international standing.

"We all very much want to understand and learn more. We want to achieve something useful. At SIMLab we feel that our findings are relevant at once. This is motivating and comforting at the same time," they explain. Then they add:

"What we do at SIMLab is sexy research!"

Hearts and bolts

Erik Grimsmo is the perfect example of a candidate for whom the usefulness and attraction of research itself is more important than the particular field of study. His master's degree was in biomechanics and focused on the connection between wave speed and stiffness in the heart wall. For his doctoral thesis he has switched to bolts and steel connections exposed to dynamic loads. The jump might seem extraordinary. Not to Grimsmo: "The background theory is the same. Both cases deal with mechanics," he argues.

Arne Ilseng has shown the same ability to switch fields. As a master's student he investigated the impact of explosions on laminated glass. Now he's into the modelling of rubber seals exposed to pressure and temperature changes. These are real challenges that Aker Solutions and other providers of subsea equipment face and Arne is on a programme where he has committed himself to working for Aker Solutions after finishing his degree.

Versatile brains

Lars Edvard Dæhli, like Erik, wrote a master's thesis in biomechanics. He is currently studying ductile fracture in aluminium alloys. In this work, he uses the same type of computer program that he used to simulate the propagation of ultrasound waves for discovering and categorizing tumours in breast tissue; a perfect example of the generic nature of research.

Petter Holmstrøm did his master's degree on screws and rivets. Now he has moved to material modelling of fibre-reinforced plastics.

Jens Kristian Holmen left his job as a structural engineer to investigate steel and aluminium protective structures and how to model impact and perforation. Johan Kolstø Sønstabø continues the work he started in his master's thesis; behaviour and modelling of flow-drilling screws for the automotive industry in cooperation with Honda R&D Americas.

Fumbling phase

Much of the first year on the way to a doctoral thesis is spent fumbling, the Gang of Six admits:

"We have to update ourselves on the state of the art, learn to manage the tools and get a grip on theory. We also have a bit of compulsory work that slows us down, so it is normal to fumble."

In the process, friendship helps. Erik, Lars Edvard, Johan and Arne met during the first days at the university; Petter joined the gang after a summer job at Statoil while Jens Kristian met everyone at the beginning of the PhD programme. Common interests gradually developed into friendship.

"Of course, one doesn't necessarily need to have friends at the workplace to enjoy oneself, but it certainly helps," they agree.

Start early

The six stress the importance of good recruitment work and early efforts to trigger interest for further research:

"Arild Holm Clausen's lectures were crucial to attract our interest. He was very active in his approach. He was our tutor during summer jobs with Statoil and encouraged us to apply for the vacant PhD positions," Johan and Petter express.

The gang of six emphasizes that advertising PhD positions is not sufficient. "We need to have a relationship with the people that recruit. In that sense Arild Holm Clausen and Tore Børvik's personal efforts made a whole lot of difference to us."

SIMLab test facilities

The laboratory at SIMLab/Department of Structural Engineering is equipped with a number of special-purpose test facilities. Some of these are applied to material characterization at elevated rates of strain and different stress states. Other test rigs are used for quasi-static or impact testing of components and structures for the validation of numerical models.

Material testing at elevated rates of strain

Split-Hopkinson tension bar (SHTB)

The split-Hopkinson tension bar, see Figure 18, is a device for material testing at strain rates in the range between 100 and 1500 s^{-1}. It consists of two steel bars with 10 mm diameter. They are denoted input and output bars, having lengths of 8 m and 7 m, respectively. The sample is mounted between the two bars. Before the test, the input bar is clamped by a locking mechanism located 2 m from the sample. Thereafter, the external 6 m of this bar is pre-stressed by means of a jack attached at the end of the bar. By releasing the lock, an elastic stress wave is released, propagating towards the sample with a velocity of 5100 m/s. Applying one-dimensional wave theory, the response of the specimen, i.e. stress, strain and strain rates, is determined from records of strain gauges glued to each bar. High-speed camera instrumentation is also feasible. Moreover, an induction heater also facilitates tests at elevated temperatures.

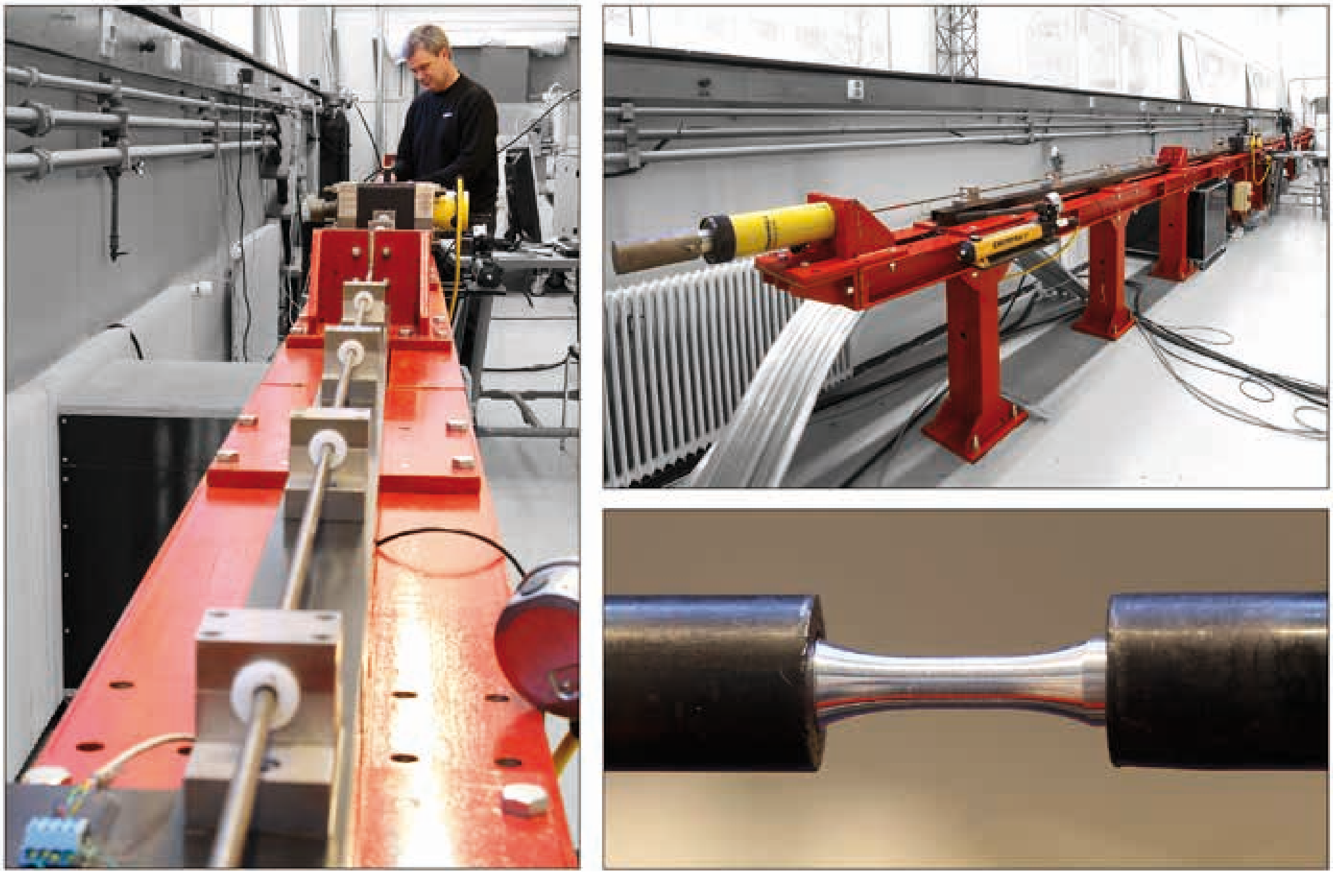


Photo: Melinda Gaal

Figure 18 – Split-Hopkinson tension bar.

The rig has been used for strain-rate characterization of different steel, aluminium and magnesium alloys. High and low temperature tests have been carried out for steel and aluminium. Two designs of the test samples are possible; axisymmetric with diameter 2-3 mm in the gauge part, or sheets with thickness 1-2 mm and width 3 mm.

For more information:
Chen Y., Clausen A.H., Hopperstad O.S. and Langseth M.: *Application of a split-Hopkinson tension bar in a mutual assessment of experimental tests and numerical predictions*. International Journal of Impact Engineering 38 (2011) 824-836.

Split-Hopkinson pressure bar (SHPB)

The split-Hopkinson pressure bar at SIMLab, Figure 19, consists of a high-pressure chamber unit that can accelerate a projectile against the end of the input bar. The diameter of the projectile and thus the input and output bars, which are made of steel, are in the range 16-32 mm. The length of the projectile is 1750 mm, giving a maximum pulse length of 70 ms. The high-pressure chamber has the capacity to accelerate a projectile with

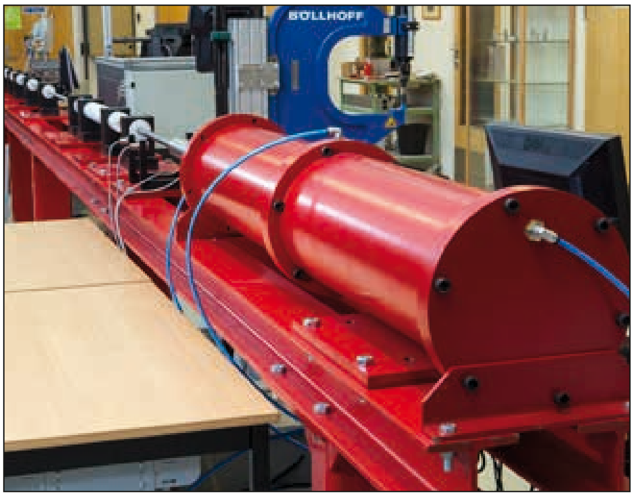


Photo: Ole Morten Melgård

Figure 19 – Split-Hopkinson pressure bar.

a diameter of 32 mm up to an impact velocity of 20 m/s. The data acquisition of the new bar is the same as for the split-Hopkinson tension bar, i.e. the relative deformation of the compressed specimen as a function of time can be calculated from strain gauge measurements on the input and output bars and one-dimensional stress wave theory.

Hydro-pneumatic machine (HPM)

The hydro-pneumatic machine (HPM), see Figure 20, is a device for tensile material testing. It operates in the strain–rate range between 1-100 s-1. The specimen, which has the same dimensions as the sample applied in the split-Hopkinson tension bar, see Figure 18, is connected to two bars with diameters in the range 8-12 mm. The facility is mainly operated by gas and water with a lightweight movable piston made of steel or aluminium. The movement of the piston is controlled by the difference in pressure between the two chambers. Prior to testing, both chambers are brought to equal pressure by introducing

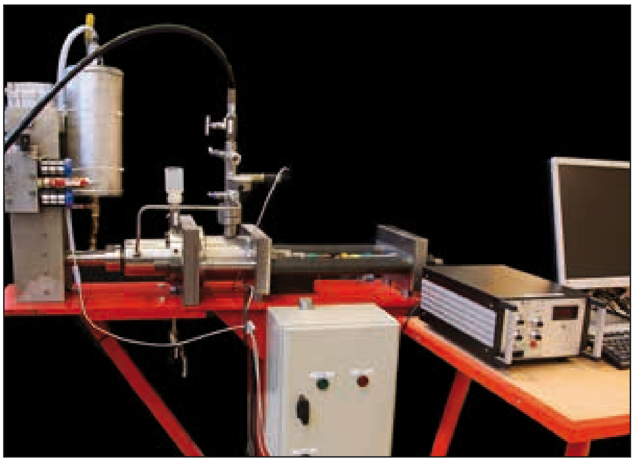


Photo: Melinda Gaal

Figure 20 – Hydro-pneumatic machine.

nitrogen gas in one chamber and water in the other. The pressure difference is established by firing a rapid valve located in the exhaust line to the water chamber causing rapid evacuation of the water through an orifice, thus allowing the piston to move at a constant velocity and stress the test specimen to fracture. The piston velocity and hence the rate of loading is controlled by the size of the orifice. The load applied to the specimen is measured by using strain gauges on the bars. The specimen elongation is measured by means of a displacement transducer sensing the displacement of a metallic strip connected to the piston shaft.

The facility can be operated at low and high temperatures with the same instrumentation as for the SHTB. So far the test rig has been used to characterize steel and aluminium alloys at elevated rates of strain and temperature.

For more information:
Tarigopula V., Albertini C., Langseth M., Hopperstad O.S., Clausen A.H.: *A hydro-pneumatic machine for intermediate strain-rates: Set-up, tests and numerical simulations.* 9th International Conference on the Mechanical and Physical Behaviour of Materials under Dynamic Loading, Brussels, Belgium 7-11 September. DYMAT2009 381-387.

Component and structural testing

Sheet metal testing machine (BUP 600)

This fully PC-controlled multi-purpose hydraulic sheet metal forming machine, see Figure 21, is designed for testing the formability of sheet metals in accordance with the most common standards and procedures. Its main advantages are easy and rapid inter-changeability of the test tools, availability of tools for all well-known test standards and procedures, low cylinder-piston friction delivering accurate measurement acquisitions and excellent reproducibility, and numerous modular possibilities of extensions. These features make this machine an excellent means for performing advanced research to study forming processes and for the validation of numerical models. The machine has a 600 kN load capacity, a maximum clamping force of 50 kN, a maximum test stroke of 120 mm and a maximum test speed of 750 mm/min. It is compact with a volume of 1000x1485x1280 mm^3. The machine at SIMLab has currently tooling for earing tests, Nakajima and Marciniak-Kuczynski formability test set-ups, square cup drawing tests and bulge tests.

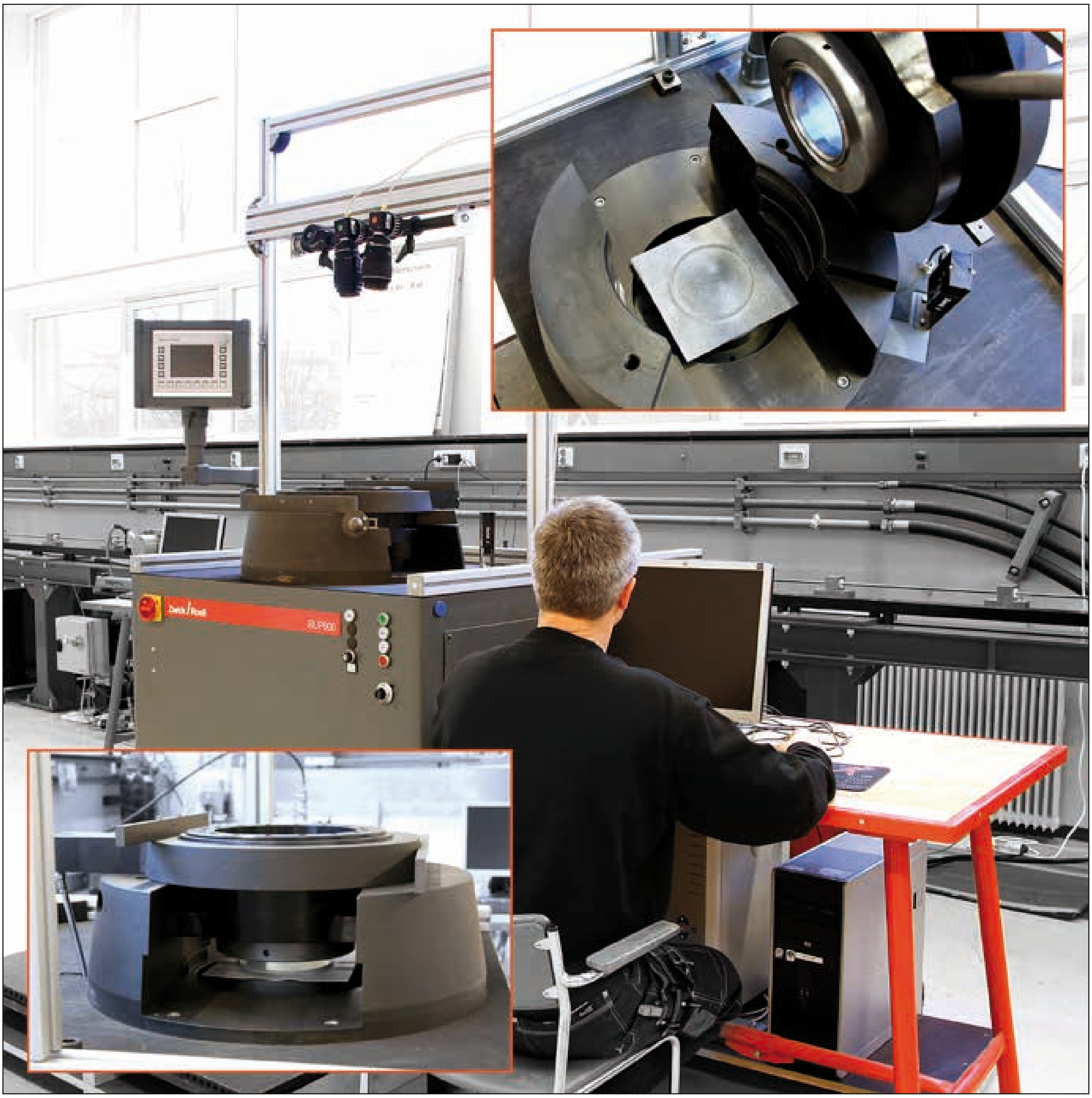


Photo: Melinda Gaal

Figure 21 – BUP 600 machine.

The machine has been equipped with a pair of high resolution black and white Prosilica cameras GC2450, with a resolution of 2448×2050 pixels, and a frame rate of 15 fps at full resolution. The cameras are PC-controlled by software for image acquisition. A frame has been built on the machine that allows easy positioning of the cameras and image acquisition during testing, thereby providing the opportunity for strain field measurement on the upper surface of the test pieces.

For more information:

Lademo O-G., Engler O., Keller S., Berstad T., Pedersen K.O., Hopperstad O.S.: *Identification and validation of constitutive model and fracture criterion for AlMgSi alloy with application to sheet forming*, Materials & Design 2009; 30: 3005-3019.

Gruben G., Vysochinskiy D., Coudert T., Reyes A., Lademo O-G.: *Determination of Ductile Fracture Parameters of a Dual-Phase Steel by Optical Measurements*. Strain 49:3 (2013) 221-232.

Pendulum accelerator (Kicking machine)

The pendulum accelerator is a device for impact testing of components and structures, Figure 22. The test rig accelerates a trolley on rails towards a test specimen fixed to a reaction wall. The reaction wall has a total weight of 150 000 tonnes and is floating on the laboratory floor by using special-purpose designed shock absorbers. The accelerating system consists of an arm that rotates around a set of bearings. The arm itself is connected to a hydraulic/pneumatic actuator system which provides the moving force and accelerates the trolley up to the desired velocity. The connection of the actuator piston rod to the arm introduces a 1/5 lever action, i.e. the force acting on the trolley is 1/5 of the piston force, but the velocity is 5 times greater. Based on the maximum working pressure in the hydraulic piston, the maximum energy delivered to the trolley is approximately 500 kJ. At present the mass of the trolley is in the range between 800 -1500 kg, giving a maximum velocity between 35 m/s and 26 m/s. The velocity is measured by a photocell system. In case the specimen does not have sufficient energy absorption capabilities to stop the trolley, a secondary energy absorbing system is installed.

During testing, the trolley and the reaction wall can be equipped with load cells where each of the axial forces as well as two orthogonal bending moments can be recorded. The deformations of the specimen during testing can be recorded by two simultaneous high-speed cameras.

For more information:

Hanssen A.G., Auestad T., Tryland T., Langseth M.: *The Kicking machine: A device for impact testing of structural components*. IJCrash 2003 Vol. 8 No. 4 pp. 385-392.

Photo: Ole Morten Melgård

Figure 22 – Pendulum accelerator.

Pneumatic accelerator

In this test rig, see Figure 23, a projectile with a mass of 50 kg can be accelerated up to a velocity of 25 m/s. The rig consists of an accelerator tube (with an internal diameter of 160 mm) which is connected to a compressed air chamber at the top and a projectile which is designed to act as a piston inside the accelerator tube during testing. The projectile consists of a central rod, a replaceable nose and is equipped with guides and an interchangeable mass.

During testing the interface force between the projectile and target is measured with strain gauges and by double integration the force vs. displacement time curve is obtained. The test rig has been used to study the behaviour of plated structures subjected to large mass projectiles in the low velocity regime as well as the behaviour of aluminium tubes under axial compression.

Photo: Melinda Gaal

Figure 23 – Pneumatic accelerator.

For more information:
Langseth M., Larsen P.K.: *Dropped Objects' Plugging Capacity of Steel Plates: An Experimental Investigation*. International Journal of Impact Engineering, Vol. 9, No. 3, 289-316, 1990.

Compressed gas gun

A schematic drawing of the compressed gas gun is shown in Figure 24. The main components of the gas gun are the 200 bar pressure tank, the purpose-built firing unit for compressed gas, the 10 m long smooth barrel of calibre 50 mm and the closed 16 m3 impact chamber. Due to the size of the impact chamber, large structural components can be tested full scale. The gas gun is designed to launch a 250 g projectile/sabot package to a maximum velocity of 1000 m/s when helium is used as propellant. The projectile is mounted in a sabot, allowing a variety of striker geometries and masses to be used, and the package is inserted into the rear end of the barrel. When the package leaves the muzzle, the sabot is immediately separated from the projectile due to aerodynamic forces. A sabot trap allows the projectile to pass freely while the sabot parts are stopped. The projectile passes the initial velocity measurement station before it impacts the clamped target after about 2 m of free flight. To allow high-speed photography during impact, the clamping system is equipped with a framing window. If the projectile perforates the target, residual velocities are measured before all free flying bodies are stopped without further damage in a rag-box. After testing, the impact chamber can be opened for final inspection and measurements.

For more information:
Børvik T., Langseth M., Hopperstad O.S., Malo K.A.: *Ballistic penetration of steel plates*. International Journal of Impact Engineering 1999; 22: 855-886.

Børvik T., Hopperstad O.S., Langseth M., Malo K.A.: *Effect of target thickness in blunt projectile penetration of Weldox 460 E steel plates*. International Journal of Impact Engineering 2003; 28: 413-464.

Photo: Melinda Gaal

Figure 24 – Compressed gas gun facility.

Photo: Melinda Gaal

Stretch-bending rig

The stretch-bending rig, see Figure 25, applies a combined bending and axial tensile/compressive loading to the test component. The length of the specimens is 1-2 m, and they are bent around an exchangeable die with a defined curvature. The main components of the test rig are a rigid steel frame, two horizontally mounted servo-hydraulic actuators giving the axial action, and a vertical loading device supported on a servohydraulic actuator. All actuators have a capacity of 330 kN. The rig has complete instrumentation including load cells, displacement transducers and clinometers. Cameras may also be attached.

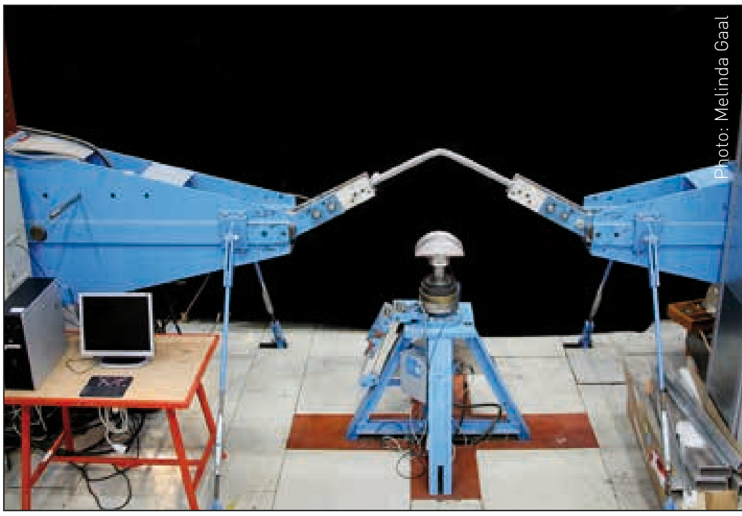


Figure 25 – Stretch-bending rig.

It can be operated in force as well as displacement control, and a broad variety of loading sequences can be defined.

The rig has been employed in tests where the bending operation of car bumpers is studied. It has also been used to study the behaviour of pipelines subjected to impact and subsequent stretching.

For more information:
Clausen A.H., Hopperstad O.S., Langseth M.: *Stretch bending of aluminium extrusions for car bumpers*. Journal of Materials Processing Technology 102 (2000) 241-248.

Figure 26 – Droptower impact system.

Droptower impact system

In this machine, see Figure 26, impact testing of materials and small components can be carried out at low and high temperatures. The mass of the projectile ranges from 2-70 kg and gives an impact velocity in the range 0.8-24 m/s. All tests can be carried out with an instrumented nose which gives the impact force as a function of time. The machine has been purchased from Instron and is denoted CEAST 9350.

For more information:
www.instron.com

Joining machine

Self-piercing riveting machine

In this machine, see Figure 27, self-piercing riveting can be carried out of sheets under industrial conditions. The machine has been purchased from Böllhoff in Germany.

For more information:
http://www.boellhoff.com/en/de/assembly_systems/riveting/rivset.php

Figure 27 – Self-piercing riveting machine.

Photo: Melinda Gaal

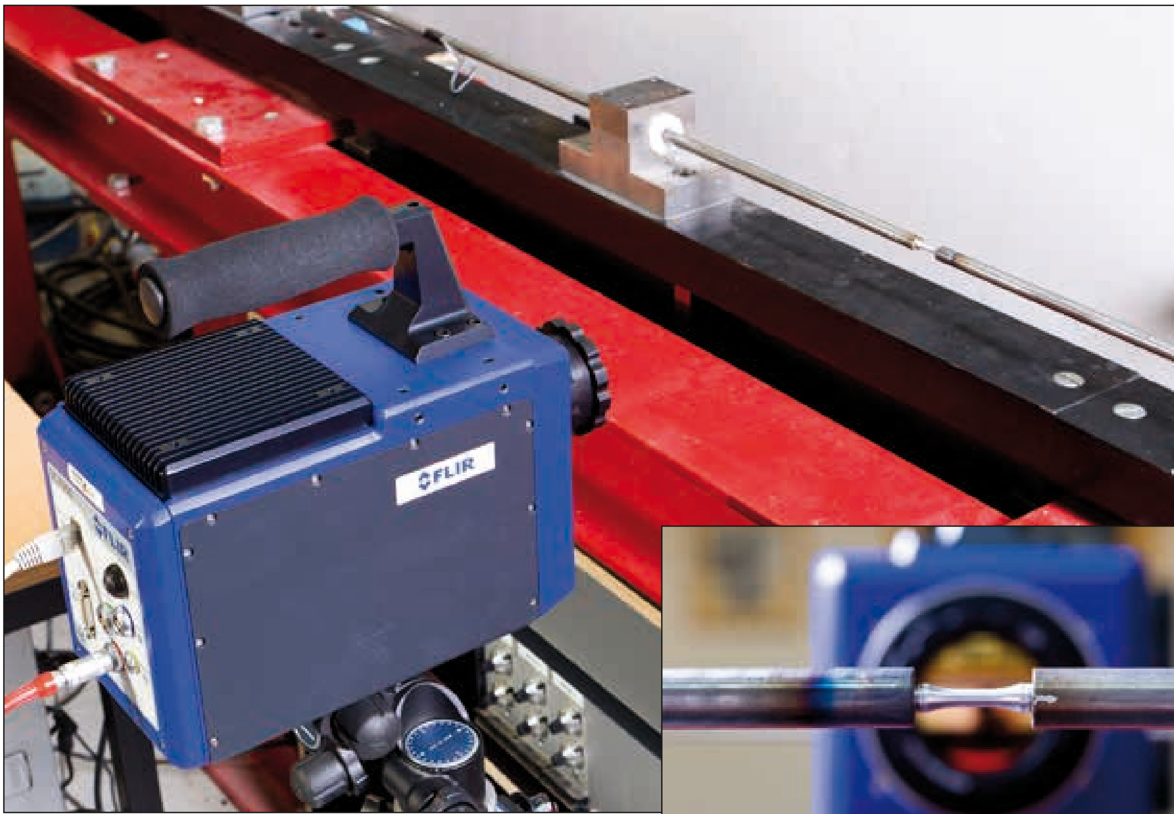


Photo: Ole Morten Melgård

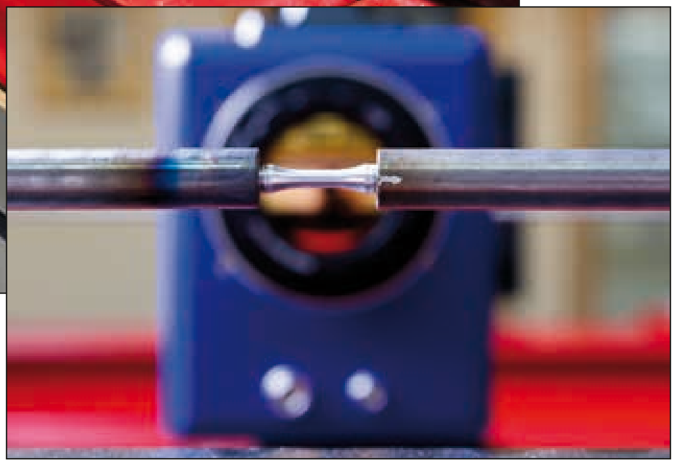


Figure 28 – Infrared camera.

Cameras

Infrared camera

The infrared camera shown in Figure 28 can convert infrared radiation to a visual image that depicts thermal variations across an object or scene. Thus it can be used to measure the surface temperature of a specimen under inelastic deformations. With a resolution of 320×256 pixels the maximum frame rate is 380 per second, while at a resolution of 48×4 pixels the maximum frame rate is 31 800 per second. The camera is a FLIR SC7500 and was purchased in 2011.

> ***For more information:***
> www.flir.com

Cameras for DIC measurements

Two Prosilica GC2450 cameras support the developments of the DIC technique at SIMLab. The cameras have a maximum speed of 15 FPS.

High-speed cameras

During impact testing of materials and structures, the events are recorded using high-speed cameras. The research group has access to 2 Photron and 2 Phantom cameras.

Figure 29 shows a test where the Phantom V1610 high-speed camera has been used. A 7 mm laminated safety glass is hit by a 7.62 calibre lead bullet at a speed of 800 m/s. The camera is set to a frame rate of 60 000 FPS and exposure time 0.452 μs.

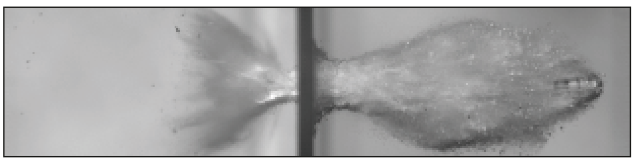


Figure 29 – Impact on laminated glass.

Modern Protective Structures - Course participants.

Workshops and seminars

- SIMLab in cooperation with the Norwegian Defence Estates Agency organized a course entitled Modern Protective Structures in Trondheim on 17-21 June 2013. The course was given by Professor **Ted Krauthammer** from the Center for Infrastructure Protection and Physical Security (CIPPS), University of Florida, USA. The course was attended by SIMLab personnel, people from the Norwegian and Swedish authorities and Norwegian engineering companies.

- Visiting Professor **Adnan Ibrahimbegovic** from ENS Cachan, Paris, France, held a course at SIMLab on 18 and 19 March 2013. The course had the title *Nonlinear Solid Mechanics: Theoretical Formulation and Finite Element Solution Methods*.

- Professor **David Embury** and Mr **Francois Moussy** gave a short course on the selection of steels for automotive applications on 27-28 August 2013. The lectures gave an overview of modern steels including ferrite/pearlite steels, Dual Phase, Trip and TWIP steels. A discussion about microstructure was included and linked to yield strength, work hardening and the Bauchinger effect. Finally an overview of mechanical testing of steels was given including methods to describe damage and porosity development during deformation.

Invited and guest lectures

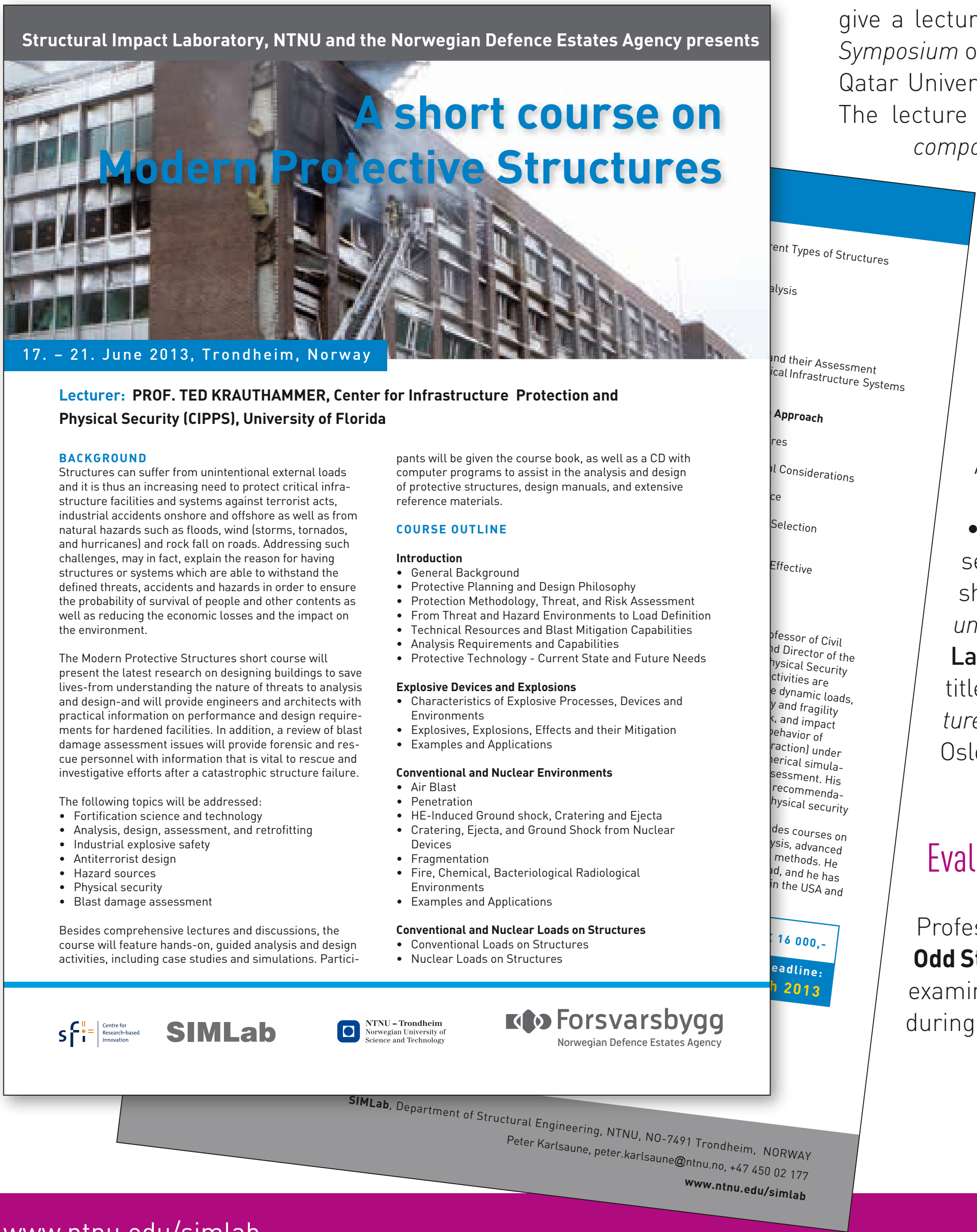
- Professor **Odd Sture Hopperstad** was invited to give a lecture at the Royal Institute of Technology (KTH), in Stockholm, Sweden, on 18 March 2013. The lecture was entitled *Challenges in the modelling of the behaviour of aluminium alloys for structural applications*.

- Professor **Odd Sture Hopperstad** gave a lecture titled *Challenges in the modelling of the behaviour of aluminium alloys for structural applications* at Viggo Tverrgaard Symposium: New Horizons in Materials Mechanics, 5-7 June 2013, Lyngby, Denmark.

- Professor **Magnus Langseth** was invited to give a lecture at the conference *Aluminium Symposium* organized by Hydro, Qatalum and Qatar University on 22 January 2013, Qatar. The lecture title was *Design of Aluminium components for structural and engineering applications*.

- Professor **Magnus Langseth** gave a lecture with the title *Forskning som redder liv* at *Sikkerhetskonferansen* on 19-20 March 2013. This is an annual conference on security, organized by the Norwegian Security Authority.

- Hydro Aluminium organized a seminar about aluminum for off-shore applications titled *Aluminium til havs*. Professor **Magnus Langseth** gave an invited lecture titled *Design of aluminium structures; basic principles*, 17 April 2013, Oslo, Norway.



Structural Impact Laboratory, NTNU and the Norwegian Defence Estates Agency presents

A short course on Modern Protective Structures

17. – 21. June 2013, Trondheim, Norway

Lecturer: PROF. TED KRAUTHAMMER, Center for Infrastructure Protection and Physical Security (CIPPS), University of Florida

BACKGROUND
Structures can suffer from unintentional external loads and it is thus an increasing need to protect critical infrastructure facilities and systems against terrorist acts, industrial accidents onshore and offshore as well as from natural hazards such as floods, wind (storms, tornados, and hurricanes) and rock fall on roads. Addressing such challenges, may in fact, explain the reason for having structures or systems which are able to withstand the defined threats, accidents and hazards in order to ensure the probability of survival of people and other contents as well as reducing the economic losses and the impact on the environment.

The Modern Protective Structures short course will present the latest research on designing buildings to save lives-from understanding the nature of threats to analysis and design-and will provide engineers and architects with practical information on performance and design requirements for hardened facilities. In addition, a review of blast damage assessment issues will provide forensic and rescue personnel with information that is vital to rescue and investigative efforts after a catastrophic structure failure.

The following topics will be addressed:
- Fortification science and technology
- Analysis, design, assessment, and retrofitting
- Industrial explosive safety
- Antiterrorist design
- Hazard sources
- Physical security
- Blast damage assessment

Besides comprehensive lectures and discussions, the course will feature hands-on, guided analysis and design activities, including case studies and simulations. Participants will be given the course book, as well as a CD with computer programs to assist in the analysis and design of protective structures, design manuals, and extensive reference materials.

COURSE OUTLINE

Introduction
- General Background
- Protective Planning and Design Philosophy
- Protection Methodology, Threat, and Risk Assessment
- From Threat and Hazard Environments to Load Definition
- Technical Resources and Blast Mitigation Capabilities
- Analysis Requirements and Capabilities
- Protective Technology - Current State and Future Needs

Explosive Devices and Explosions
- Characteristics of Explosive Processes, Devices and Environments
- Explosives, Explosions, Effects and their Mitigation
- Examples and Applications

Conventional and Nuclear Environments
- Air Blast
- Penetration
- HE-Induced Ground shock, Cratering and Ejecta
- Cratering, Ejecta, and Ground Shock from Nuclear Devices
- Fragmentation
- Fire, Chemical, Bacteriological Radiological Environments
- Examples and Applications

Conventional and Nuclear Loads on Structures
- Conventional Loads on Structures
- Nuclear Loads on Structures

SIMLab — NTNU – Trondheim, Norwegian University of Science and Technology — Forsvarsbygg, Norwegian Defence Estates Agency

SIMLab, Department of Structural Engineering, NTNU, NO-7491 Trondheim, NORWAY
Peter Karlsaune, peter.karlsaune@ntnu.no, +47 450 02 177
www.ntnu.edu/simlab

Evaluation committees

Professor **Tore Børvik** and Professor **Odd Sture Hopperstad** have both been examiners at PhD defences abroad during 2013.

Magazines/Newspapers/TV

Gemini no. 1 2013 – SIMLab's work on security related research was presented in an article in the research magazine Gemini.

Photo: Ole Kaland, NRK

Norwegian Broadcasting Corporation - 29 March 2013
Norwegian comedians Øystein Bache and Rune Gokstad visited SIMLab's laboratoratories as a part of their annual Easter quiz, **Påskenøttene**, for the national TV station NRK.

10 | Nyheter — Mandag 15. april 2013 | Adresseavisen

Splintregn: Overåkningskamera viser hvordan glassplinter regner ned fra Y-blokka i regjeringskvartalet.
Foto: Sikkerhetsavdelingen DDS, 22.juli rapporten.

NTNU bygger kanon for tryggere glass

NTNU bygger en gasskanon for å teste vindusglass. Splintret glass var årsak til de aller fleste menneskelige skadene fra 22. juli-bomben.

Sjokket fra den 950 kilo tunge terrorbomben i Oslo blåste ut vinduer 500 meter unna eksplosjonsstedet.
Alle de åtte som ble drept døde som følge av at de ble truffet av sjokkbølgen og glass og gjenstander. Når høyblokka i regjeringskvartalet skal gjenoppbygges, eller erstattes, er sikring av vinduer meget viktig.

– Vi trapper opp forskningen på sikring av vinduer og bygninger. Dette er et område vi trenger å bygge opp kompetanse på, sier professor Tore Børvik ved Simlab, Senter for forskningsdrevet innovasjon ved NTNU.

Laboratoriet investerer i utstyr spesielt for å teste vindusglass. NTNU har lagt 800 000 kroner på bordet til bygging av gasskanonen.

Sjokk på boks
– Kanonen kan skape sjokkbølger som tilsvarer en bilbombe. Gjennom praktiske forsøk får vi kunnskap om hva som skjer med glasset ved en eksplosjon, sier Børvik.

Når laboratoriet utfører sine tester brukes høyhastighetsfilm for å registrere nøyaktig hva som skjer. Målet er finne ut hvilke konstruksjoner, materialer og dimensjoner som gir maksimal sikkerhet.

– Er ikke dette et område der for eksempel amerikanerne har stor kompetanse?

– Det vil jeg tro. De store glassleverandørene har også egen forskning og utvikling. Men Norge trenger nasjonal kompetanse, blant annet når vi skal bestemme hva vi skal bruke penger på. Ved laboratoriet ønsker vi å bygge opp den grunnleggende kunnskapen.

Folie reduserte skadene
Etter en sikkerhetsgjennomgang av regjeringskvartalet i 2004, ble det slått alarm om at vinduene måtte sikres, spesielt med tanke på en bilbombe. 22. juli-rapporten slår fast at det tok nesten syv år før det var lagt folie på alle vinduene i høyblokka der statsministeren sitter. Da bomben gikk av, hindret folien at mye av det knuste glasset sprutet innover i bygget. Rapporten slår fast at folien bidro til å redusere skadeomfanget. Omkring 250 mennesker oppholdt seg i blokka på tidspunktet.

– Glass er av de største truslene, ikke minst i forbindelse med bilbomber, sier Helge Langberg, leder for Kompetansesenter for sikring av bygg.

– Trykket fra bilbomber blåser ut vinduer og sender splinter i høy hastighet innover i rommet. Det er stort behov for å forske på gode løsninger. Sterkere glass og film som holder fragmentene samlet er noe av det som kan bedre sikkerheten.

Mens Simlab kan levere den grunnleggende kunnskapen, er det opp til Kompetansesenteret å ta det videre til innovative løsninger, mener Langberg.

Kompetansesenter for sikring av bygg ble opprettet av regjeringen i 2012. Senteret ble lagt til Forsvarsbygg, som før bare hadde ansvar for militære bygninger og anlegg. Kompetansesenteret skal jobbe med statlige bygg og eiendommer som trenger beskyttelse mot terror, spionasje og eksplosjonsulykker. Senteret samarbeider blant annet med Nasjonal sikkerhetsmyndighet, Statsbygg og Politiets sikkerhetstjeneste og forskningsmiljøer som Simlab.

SVEIN INGE MELAND 951 98 688
svein.inge.meland@adresseavisen.no

– Kanonen kan skape sjokkbølger som tilsvarer en bilbombe.
TORE BØRVIK,
professor ved Senter for forskningsdrevet innovasjon ved NTNU

Ulovlig mobilbruk øker kraftig
Oslo: Antallet som ble tatt for ulovlig bruk av mobiltelefon på veiene, firedoblet seg mellom 2005 og 2012, ifølge Utrykningspolitiet. – Vi skrev ut 20 000 forelegg i fjor for ulovlig mobilbruk, det er fire ganger så mange som i 2005, sier UP-sjef Runar Karlsen til VG. – Vi har større fokus på dette, men vi er også sikre på at folk, i takt med mobilutviklingen, bruker mobiltelefonen mer ulovlig i trafikken enn før, sier Karlsen videre. Han understreker at det er ekstra alvorlig at sjåfører av tungtransport bruker telefon mens de kjører. NTB

Strid om Sigrid-siktet er tilregnelig
Oslo: De sakkyndige er uenige om den 37 år gamle mannen som er siktet for drapet på Sigrid Giskegjerde Schjetne (16), er tilregnelig eller ikke. Fredag overleverte de tre sakkyndige en rapport med to ulike konklusjoner. Spesialistene i psykiatri Andreas Eirik Hamnes og Kjersti Narud har konkludert med at 37-åringen var tilregnelig og kan straffes, melder TV 2. Nevropsykolog Anne Lill Ørbeck er uenig og konkluderer med at mannen var paranoid schizofren og strafferettslig utilregnelig. NTB

Polakker tatt for alkoholsmugling
Moss: Fem polske sjåfører er pågrepet og 14 biler beslaglagt etter at politiet i Østfold stanset et større forsøk på smugling av alkohol og sigaretter inn i Norge søndag morgen. Ifølge politiet kan flere biler enn de 14 ha vært med i smuglerkolonnen, men de kom seg imidlertid unna. NTB

Rettssak om bruk av logo
Oslo: Firmaet Walk-in Clinic nekter å betale en bot på 40.000 kroner for å ha brukt en logo som politiet mener lett kan forveksles med Røde Kors' logo. Mandag møter firmaet i Oslo tingrett. Walk-in Clinic brukte logoen på nettsider og skilt utenfor lokalene på Aker Brygge i Oslo i perioden 2010-2012. Firmaets forsvarer, advokat Ingvild Opøien, avviser overfor NTB at firmaets varemerke er i strid med Røde Kors-emblemet. – Ulikhetene er for store til det, sier hun. NTB

The local newspaper ***Adresseavisen*** pulished an article about SIMLab's plans for a new shock tube rig on 15 April 2013.

6 Nyheter Mandag 22. juli 2013 Aftenposten

INNOVASJON PÅ UNIVERSITETENE

SERIE Aftenposten presenterer en nyvinning fra hvert av Norges åtte universiteter. I dag: Universitetet for miljø og biovitenskap (UMB) i Ås.

Nå utlyses flere milliarder til innovasjon. Men nye tiltak fører nødvendigvis ikke til at nye kreative nettverk oppstår.

Etablerte nettverk får mest penger

på ulike steder. Som et kroneksempel trekker Forskningsrådet frem SIMlab ved NTNU i Trondheim, som med sine datasimulerte biler og kollisjons-dukker er blitt en ettertraktet samarbeidspartner for internasjonale bilprodusenter. Arvid Hallén opplyser at midt-

In an article in the national newspaper ***Aftenposten*** on 22 July 2013, Director General of the Research Council of Norway, Arvid Hallén, mentioned SIMLab as a prime example of a Centre for Research-based Innovation.

The national newspaper ***Aftenposten*** presented SIMLab in an article focusing on how SIMLab's work can improve computer simulations on 24 October 2013.

12 Økonomimagasinet Torsdag 24. oktober 2013

Nye tider Bilindustri

Før brukte Renault og Audi millioner av kroner for å teste sikkerheten til én bil. Nå har de funnet en billigere løsning i Trondheim.

Datakræsj lønner seg

The release of SIMLab Tool Box version 2.0 was covered by local TV station ***NRK Trøndelag*** and ***TV2 Nyhetskanalen*** on 15 November 2013.

Photo: Ole Morten Melgård

FORSVARSBYGG

NTNU får 10 millioner til terrorforskning

Hvis terroren rammer igjen og en bombe går av ved en bygning, skal forskning fra NTNU sørge for at bygget er sikkert.

The Norwegian Security Authority (NSM) announced in a press release that they intend to support SIMLab with NOK 10 million over a period of eight years. NOK 2 million will be used to fund the planned shock tube rig and NOK 8 million is NMS's contribution to the SFI-CASA application. The local newspaper ***Adresseavisen*** and the weekly technical journal ***Teknisk Ukeblad*** published articles about NSM's support to SIMLab on 23 December 2013.

Visits

- Representatives from the Norwegian National Security Authority, the Norwegian Police Security Service, Statoil and Gassco visited SIMLab on 19 September 2013.

Demonstration of impact on safety glass.

Demonstration of the stretch bending rig.

Tested steel pipes.

Crushed specimens.

Photos: Ole Morten Melgård

- Representatives from the Norwegian Directorate for Civil Protection, Ministry of Justice and Public Security (Justis- og beredskapsdepartementet) and the Norwegian Police Security Service visited SIMLab on 14 October 2013.

International cooperation

International cooperation is one of the success criteria defined by the Research Council of Norway for an SFI centre. For SIMLab, this is taken care of by both international partners as well as strong interaction with universities and research organizations abroad. The latter is mainly initiated by the high quality research carried out by the Centre which is published in peer reviewed journals as well as the fact that three of the Centre professors are editors in top international journals. The international cooperation has resulted in several joint research projects with common publications. Thus, the cooperation with top international research groups as well as the publication work carried out ensures that the Centre transfers leading-edge technology to the partners and at the same time is able to define new and innovative research areas of importance to the partners.

Visiting scientists/professors

The following researchers visited SIMLab in 2013:

- Dr Rafael Traldi Moura, University of Saõ Paolo, Brazil. 3-31 January 2013.
- Professor Adnan Ibrahimbegovic, ENS Cachan, Paris, France. 18-21 March and 17-31 June 2013.
- Professor Robert McMeeking, University of California, Santa Barbara, USA. 1-5 July 2013.
- Reseacher Yann Claude Ngueveu, Toyota Motor Europe, Brussels, Belgium. 2-22 September 2013 and 11-14 November 2013.
- Professor Shaker Meguid, University of Toronto, Canada. 2-29 October 2013.
- Researcher Arjan Strating, Audi AG, Neckarsulm, Germany. 4-8 November 2013.
- Associate Professor Jonas Faleskog, Royal Institute of Technology (KTH), Stockholm, Sweden. 5-8 November 2013.

Research cooperation with organizations

The Centre has strong international cooperation due to its five international partners, i.e. Audi, BMW, Toyota Motor Europe, Renault and SSAB. In addition, the following organizations took an active part in the Centre projects in 2013:

- ***Cotutelle agreements for PhD candidates***
  - LMT-Cachan (Professor Ahmed Benallal), France.
  - Karlsruhe Institute of Technology (Professor Karl Schweizerhof), Germany.
- ***Other organizations involved in Centre activities***
  - University of São Paulo (Professor Marcílio Alves), Brazil. University of Savoie (Professor Laurent Tabourot), France. Impetus Afea (Dr Lars Olovsson), Sweden. European Commission, Joint Research Centre, Institute for the Protection and Security of the Citizen, Ispra (Dr Folco Casadei), Italy. Harvard University (Professor John Hutchinson), Purdue University (Professor Weinong Chen), and University of Virginia (Professor Hayden Wadley), USA. University of Liverpool (Dr Graham Schleyer) and University of Cambridge (Professor Vikram Desphande), UK.
- ***Research visits abroad by our PhD candidates and SIMLab staff***
  - Professor Aase Gavina Reyes spent her sabbatical year at University of Florida, USA, from August 2012 until June 2013.
  - Professor Odd Sture Hopperstad stayed at ENS Cachan, Paris, France, as a visiting professor for four weeks during spring and summer of 2013.
  - PhD candidate Mikhail Khadyko spent four weeks at Ecole des Mines, Paris, France, in the period 25 March-22 April 2013.

Guest lectures at SIMLab

The following guest lectures were given at SIMLab in 2013:

- Dr Rafael Traldi Moura, University of Saõ Paolo, Brazil: *Low to high strain-rates visco-elasticity: tests and modeling*.
- Professor Torger Reve, Norwegian Business School (BI), Oslo, Norway: *Et kunnskapsbasert Norge: Implikasjoner for forskning og næringsliv*.
- Professor Adnan Ibrahimbegovic, ENS Cachan, Paris, France: *Multiscale methods for dealing with localized failure of quasi-brittle materials*.
- Professor Robert McMeeking, University of California, Santa Barbara, USA: *The generation of stress in the storage particles of lithium-ion batteries*.
- Professor Shaker Meguid, University of Toronto, Canada:
  - *Multifunctional nano-tailored composites for aerospace applications: Trends and prospects*.
  - *Energy absorption in axial crushing of foam filled thin walled circular and conical columns*.
  - *Best practice in engineering education: Does it mean replacing chalk with chip*?
- Researcher Arjan Strating from Audi AG, Neckarsulm, Germany: *Computer-aided engineering at Audi*.
- Associate Professor Jonas Faleskog, Royal Institute of Technology (KTH), Stockholm, Sweden:
  - *Porous plasticity and ductile failure*.
  - *Strain gradient plasticity*.

Students

PhD candidates and post docs. From left: Petter Henrik Holmstrøm, Johan Kolstø Sønstabø, Arne Ilseng, David Morin, Marion Fourmeau, Egil Fagerholt, Marius Andersen, Vincent Vilamosa, Mikhail Khadyko, Erik Løhre Grimsmo, Anne Serine Ognedal, Vegard Aune, Lars Edvard Bryhni Dæhli, Espen Myklebust, Martin Kristoffersen, Jens Kristian Holmen, Dmitry Vysochinskiy.

PhD candidates

The following PhD candidates have been linked to the Centre in 2013:

Name	Start	Planned exam	Programme	From	Male/Female
Henning Fransplass*	Spring 2005	Winter 2014	C&J	Norway	Male
Octavian Knoll*	Summer 2009	Autumn 2014	F&CP	Germany	Male
Marion Fourmeau**	Autumn 2009	Winter 2014	F&CP	France	Female
Knut Rakvåg**	Summer 2009	Autumn 2013	OptiPro	Norway	Male
Dmitry Vysochinskiy**	Spring 2010	Autumn 2014	M4	Russia	Male
Mikhail Khadyko**	Autumn 2010	Autumn 2014	M4	Russia	Male
Martin Kristoffersen*	Autumn 2010	Autumn 2014	OptiPro	Norway	Male
Espen Myklebust**	Autumn 2009	Autumn 2014	F&CP	Norway	Male
Marius Andersen*	Autumn 2011	Autumn 2015	Polymers	Norway	Male
Vincent Vilamosa*	Autumn 2011	Autumn 2014	M4	France	Male
Anizahyati Alisibramulisi**	Autumn 2007	Autumn 2013	M4	Malaysia	Female
Vegard Aune**	Autumn 2012	Autumn 2016	OptiPro	Norway	Male
Lars Edvard Bryhni Dæhli*	Autumn 2013	Autumn 2017	F&CP	Norway	Male
Erik Løhre Grimsmo**	Autumn 2013	Autumn 2017	C&J	Norway	Male
Jens Kristian Holmen**	Autumn 2013	Autumn 2016	OptiPro	Norway	Male
Petter Henrik Holmstrøm**	Autumn 2013	Autumn 2017	Polymers	Norway	Male

* = Salary and operational costs from the Centre
** = Operational costs from the Centre – salary from other sources

New PhD candidates in 2013

- Lars Edvard Dæhli, Erik Grimsmo, Jens Kristian Holmen and Petter Holmstrøm started with their PhD work in August 2013. They are all former master's students at the Department of Structural Engineering at NTNU.

Related PhD candidates in 2013

- Andreas Koukal is a PhD student at the Technische Universität München. He was recruited by Audi to work on the behaviour and modelling of polymers and is thus linked to the Centre through Audi.
- *Behaviour and modelling of elastomers subjected to a wide range of pressures and temperatures* is the topic of the thesis of PhD candidate Arne Ilseng. The project is under the industrial PhD scheme supported by the Research Council of Norway. Ilseng is employed by Aker Solutions and supervised by personnel from Aker Solutions and SIMLab.
- Johan Kolstø Sønstabø works with SIMLab on a concurrent project funded by Honda R&D Americas. He started his PhD work in August 2013. The project has the title *Behaviour and modelling of flow drilling screws*.

Post docs

The following post docs were linked to the Centre in 2013:

Name	Start	End	Programme	From	Male/Female
David Morin	Autumn 2010	Autumn 2016	C&J	France	Male
Egil Fagerholt	Autumn 2012	Autumn 2014	F&CP	Norway	Male
Anne Serine Ognedal	Autumn 2012	Autumn 2014	Polymers	Norway	Female

Visiting students

The following international students have stayed at the Centre in 2013:

- PhD student Holger Staack from Technische Universität München, Germany, stayed with SIMLab for one week on 11-15 November 2013. His project is funded by SIMLab partner Audi AG.

Master's students

The following master's students (16 male and 3 female students) were associated with the Centre in 2013:

STUDENT	TOPIC
K.H. Andersen and F.B. Hernandez*	Numerical Simulations of Docol 600 DL Steel Plates Subject to Blast Loading
T.I. Asheim and I. Mogstad*	Impact Against Offshore Pipelines
B.E. Egeland and I-M. Torstvedt*	Stiffness of end plate joints in hollow sections
H.O.S. Eide and E.A. Melby*	Blast Loaded Aluminium Plates
K.C. Falao	Block Tearing Failures in Aluminium Plates
P.H. Holmstrøm and J.K. Sønstabø*	Behaviour and Modelling of Self-piercing Screws and Self-piercing Rivet Connections
A. Ilseng	Mechanical behavior of laminated glass exposed to blast loading
V.B. Kristensen	Visco-elastic response of thermoplastics
K. Lauknes	End Plate Joints in High-Strength Steel
H. Røstum**	Behaviour and modelling of injection molded PP
E. Semb	Behaviour of Aluminum at Elevated Strain Rates and Temperatures
H. Urseth	Design of Beam Ends with Copes
A.S. Vium	Behaviour of Plate Panel with transverse Stiffeners
R. Zahlquist	Buckling of stiffened Plates subjected to axial Load

* Joint thesis

** Master's student Heine Røstum wrote his master's thesis for SIMLab and Toyota Motor Europe during the period September 2013 - February 2014.

PhD disputations

ANIZAHYATI ALISIBRAMULISI defended her thesis on 27 November. The thesis had the title *Through Process Modelling of Welded Aluminium Structures*. Her supervisors were Odd-Geir Lademo from SINTEF Materials and Chemistry and Professor Em. Per Kristian Larsen from the Department of Structural Engineering, NTNU. The evaluation committee consisted of the following persons: Cato Dørum from the Norwegian Defence Research Establishment, Kjeller, Norway and Professor Mats Oldenburg from Luleå University of Technology, Sweden. Aase Reyes from NTNU acted as administrator of the committee.

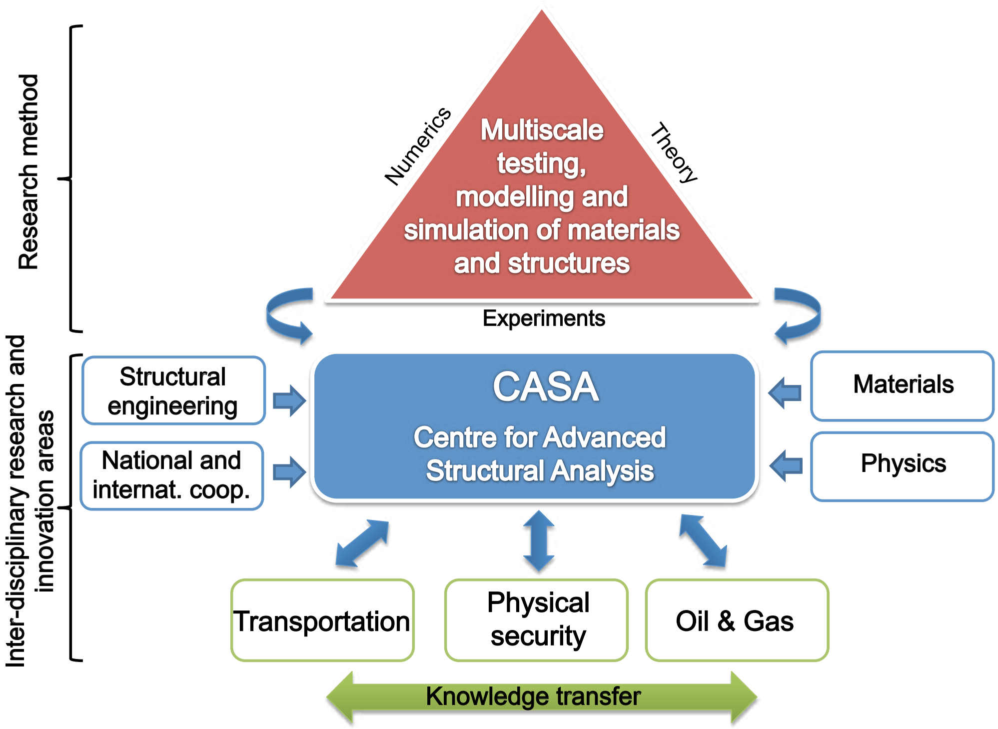
PhD disputation for Anizahyati Alisibramulisi – the committee. From the left: Aase Reyes, Anizahyati Alisibramulisi, Mats Oldenburg and Cato Dørum.

KNUT GAARDER RAKVÅG defended his thesis on 10 December. The topic of his thesis was *Combined Blast and Fragment Loading on Steel Plates*. His supervisors were Professor Tore Børvik and Professor Odd Sture Hopperstad, both from Department of Structural Engineering, NTNU. The evaluation committee had three members; Professor Hans-Åke Häggblad from Luleå University of Technology, Sweden, Professor Alexis Rusinek from the National Engineering School of Metz, France, while Odd-Geir Lademo from SINTEF Materials and Chemistry was the administrator.

PhD disputation for Knut Gaarder Rakvåg –the committee. From the left: Hans-Åke Häggblad, Alexis Rusinek, Knut Gaarder Rakvåg and Odd-Geir Lademo.

New SFI Application

An SFI Centre (Centre for Advanced Structural Analysis - CASA) is proposed on multi-scale testing, modelling and simulation of materials and structures for industrial applications. The research in this centre will be multidisciplinary and interdisciplinary in order to create a platform for credible numerical simulations of products and structures for innovation and value creation in the transportation industry, the oil and gas industry, and industry and public enterprises working with physical security. The research is intended to cover structures made of steel, aluminium alloys and polymers, hybrid structures and protective structures. The core group of professors and scientists behind this application is Tore Børvik, Arild Holm Clausen, Odd Sture Hopperstad, Odd-Geir Lademo, Magnus Langseth and Aase Gavina Reyes from the Department of Structural Engineering, Randi Holmestad from the Department of Physics and Knut Marthinsen from the Department of Materials Science and Engineering. Professor Odd-Geir Lademo is working at SINTEF and has at the same time an adjunct professorship, i.e. a 20% position at NTNU. The user partners in the Centre, each representing one or more of the defined business sectors, are Aker Solutions, Audi, Benteler Aluminium Systems, BMW Group, Det Norske Veritas (DNV), Gassco, Honda R&D Americas, Hydro, Norwegian National Security Authority (NSM), Norwegian Defence Estates Agency (NDEA), Norwegian Public Roads Administration (NPRA), Sapa, Statoil, and Toyota Motor Europe.



Annual accounts

The annual work plans for each research programme have to present a detailed description of the activities to be carried out in the Centre, allowing the Research Council of Norway (RCN) to monitor that that the research activities are within the ESA requirements. Thus the funding plan for each programme shows the funding from each of the partners in the form of "Fundamental research (F)" and "Industrial research (I)" and how funding from RCN contributes to funding of each project. The cost plan describes each partner's participation in each of the programmes. The funding and cost plans for 2013 are shown below.

SIMLab: Funding 2013 (All figures in 1000NOK)

Research Programmes	Type of research	State aid			Industry										Total State Aid	Total Funding	State aid/ total funding
		RCN Grant	Host (NTNU)	SINTEF	NDEA	NPRA	AUDI	BMW	Renault	Toyota	Statoil	SSAB	Benteler	Hydro			
C&J	F	2142	312			870									2454	3324	0.74
C&J	I																
F&CP	F	2151	712		200		100							239	2863	3402	0.84
F&CP	I																
M4	F	861	212	1100										2200	2173	4373	0.50
M4	I																
OptiPro	F	1059	712		1540										1771	3311	0.53
OptiPro	I																
Poly	F	2276	1573				100		200						3849	4149	0.93
Poly	I																
Demo	F		801												801	801	1.00
Demo	I	60	212		120	120	420	120	420	120	120	420	320	520	272	2972	0.09
Equipment					127		132	132	132	132	132	132	132	264		1315	
Adm		254	1000		213	130	248	248	248	248	398	248	48	877	1254	4160	
Total		8803	5534	1100	2200	1120	1000	500	1000	500	650	800	500	4100	15437	27807	

F = Fundamental research, I = Industrial research RCN = Research Council of Norway NPRA = Norwegian Public Roads Administration
NDEA = Norwegian Defence Estates Agency

SIMLab: Cost 2013 (All figures in 1000NOK)

Research Programmes	Host (NTNU)	SINTEF	NDEA	NPRA	AUDI	BMW	Renault	Toyota	Statoil	SSAB	Benteler	Hydro	Total
C&J	1829	625		870									3324
F&CP	2002	900	200		100							200	3402
M4	1073	1300										2000	4373
OptiPro	2001	310	1000										3311
Poly	3209	640			100		200						4149
Demo	1073	1200			300		300			300	200	400	3773
Equipment	1315												1315
Adm	3475	685											4160
Total	15977	5660	1200	870	500	0	500	0	0	300	200	2600	27807

Publications

The following lists journal publications and conference contributions generated from the Centre in 2013:

Journal publications

1. Dumoulin S., Hopperstad O.S., Sène N.A., Balland P., Arrieux R., Moreau J-M.: *Numerical modelling of plastic forming of aluminium single crystals*. International Journal of Material Forming 6 (2013) 13–27.
2. Fagerholt E., Børvik T., Hopperstad O.S.: *Measuring discontinuous displacement fields in cracked specimens using Digital Image Correlation with mesh adaptation and crack-path optimization*. Optics and Lasers in Engineering 51 (2013) 299–310.
3. Fourmeau M., Børvik T., Benallal A., Hopperstad O.S.: *Anisotropic failure modes of high-strength aluminium alloy under various stress states*. International Journal of Plasticity 48 (2013) 34–53.
4. Fransplass H., Langseth M., Hopperstad O.S.: *Numerical study of the tensile behaviour of threaded steel fasteners at elevated rates of strain*. International Journal of Impact Engineering 54 (2013) 19–30.
5. Gruben G., Hopperstad O.S., Børvik T.: *Simulation of ductile crack propagation in dual-phase steel*. International Journal of Fracture 180 (2013) 1–22.
6. Gruben G., Vysochinskiy D., Coudert T., Reyes A., Lademo O-G.: *Determination of Ductile Fracture Parameters of a Dual-Phase Steel by Optical Measurements*. Strain 49 (2013) 221-232.
7. Hoang N-H., Hopperstad O.S., Langseth M., Westermann I.: *Failure of aluminium self-piercing rivets: An experimental and numerical study*. Materials & Design 49 (2013) 323–335.
8. Holmen J.K., Johnsen J., Jupp S., Hopperstad O.S., Børvik T.: *Effects of heat treatment on the ballistic properties of AA6070 aluminium alloy*. International Journal of Impact Engineering 57 (2013) 119–133.
9. Johnsen J., Holmen J.K., Myhr O.R., Hopperstad O.S., Børvik T.: *A nano-scale material model applied in finite element analysis of aluminium plates under impact loading*. Computational Materials Science 79 (2013) 724–735.
10. Kristoffersen M., Børvik T., Westermann I., Langseth M., Hopperstad O.S.: *Impact against an X65 steel pipe – an experimental investigation*. International Journal of Solids and Structures 50 (2013) 3430–3445.
11. Leacock A.G., Howe C., Brown D., Lademo O-G., Deering A.: *Evolution of mechanical properties in a 7075 Al-alloy subject to natural ageing*. Materials and Design 49 (2013) 160–167.
12. Rakvåg K.G., Børvik T., Westermann I., Hopperstad O.S.: *An experimental study on the deformation and fracture modes of steel projectiles during impact*. Materials and Design 51 (2013) 242–256.
13. Rakvåg K.G., Underwood N., Schleyer G.K., Børvik T., Hopperstad O.S.: *Transient pressure loading of clamped metallic plates with pre-formed holes*. International Journal of Impact Engineering 53 (2013) 44–55.
14. Saai A., Dumoulin S., Hopperstad O.S., Lademo O-G.: *Simulation of yield surfaces for aluminium sheets with rolling and recrystallization textures*. Computational Materials Science 67 (2013) 424–433.
15. Tabourot L., Balland P., Vautrot M., Hopperstad O.S., Raujol-Veillé J., Toussaint F.: *Characterization and modeling of the elastic behavior of a XC68 grade steel used at high strain rates and high temperatures*. Key Engineering Materials 554–557 (2013) 1116–1124.
16. Wadley H.N.G., Børvik T., Olovsson L., Wetzel J.J, Dharmasena K.P., Hopperstad O.S., Deshpande V.S., Hutchinson J.: *Deformation and Fracture of Impulsively Loaded Sandwich Panels*. Journal of the Physics and Mechanics of Solids 61 (2013) 674–699.

Invited lectures

1. Hopperstad O.S.: *Challenges in the modelling of the behaviour of aluminium alloys for structural applications*. Royal Institute of Technology, KTH, 18 March 2013, Stockholm, Sweden.
2. Hopperstad O.S.: *Challenges in the modelling of the behaviour of aluminium alloys for structural applications*. Viggo Tvergaard Symposium: New Horizons in Materials Mechanics, 5-7 June 2013, Lyngby, Denmark.
3. Langseth M.: *Design of Aluminium components for structural and engineering applications: Basic principles.* Aluminium symposium, 22 January 2013, Qatar.
4. Langseth M.: *Forskning som redder liv*. NSMs sikkerhetskonferanse, 19-20 March 2013, Oslo, Norway.
5. Langseth M.: *Design av aluminiumskonstruksjoner; basic principles*. Aluminium til havs, 17 April 2013, Oslo, Norway.

Conference contributions

1. Børvik T., Olovsson L., Dey S.: *Penetration of bullets into granular targets*. Proceedings of 27th International Symposium on Ballistics, 22-26 April 2013, Freiburg, Germany.
2. Dey S., Børvik T., Rakvåg K.G.: *On the credibility of computer-aided design for protective structures*. Proceedings of the 15th International Symposium on Interaction of the Effects of Munitions with Structures, ISIEMS2013, 17-20 September 2013, Potsdam, Germany.
3. Khadyko M., Dumoulin S., Myhr O.R., Hopperstad O.S.: *A combined precipitation and crystal plasticity model for AlMgSi alloys*. Proceedings of the 13th International Conference on Computational Plasticity, Complas XII, 3-5 September 2013, Barcelona, Spain.
4. Kristoffersen M., Børvik T., Langseth M., Hopperstad O.S., Ilstad H., Levold E.: *Damage and failure in an X65 steel pipeline caused by trawl gear impact*. Proceedings of the ASME 32nd International Conference on Ocean, Offshore and Artic Engineering (OMAE2013), 9-14 June 2013, Nantes, France.
5. Kristoffersen M., Casadei, F., Børvik T., Langseth M., Solomos G., Hopperstad O.S.: *Numerical simulations of submerged and pressurised X65 steel pipes*. Proceedings of 12th International Conference on Computational Plasticity, COMPLASXII, 3-5 September 2013, Barcelona, Spain.
6. Morin D., Hopperstad O.S., Lademo O-G., Langseth M.: *Modelling of Aluminium Components for crash loadings*. 9th European LS-DYNA Conference, 3-4 June 2013, Manchester, UK.
7. Zhang K., Holmedal B., Dumoulin S., Hopperstad O.S.: *An explicit integration scheme for hypo-elastic viscoplastic crystal plasticity*. The first Asian Conference on Aluminum Alloys, 13-17 October 2013, Beijing, China.

Notes

MAIN ACHIEVEMENT

Release of SIMLab Tool Box version 2.0

ENCOURAGING COMMENTS

"SIMLab's modelling toolbox helps us optimize processes to avoid damage and reduce material loss

Torstein Haarberg, Executive Vice President
SINTEF Materials and Chemistry

"SIMLab is one of the most effective groups I've seen. They really stand out

Professor John Hutchinson, Harvard University

Annual Report for SIMLab Centre for Research-based Innovation 2013

CONTACT – RESPONSE

Professor Magnus Langseth
Dr. ing., Centre Director
Phone: +47 73 59 47 82, +47 930 37 002
Email: magnus.langseth@ntnu.no

Peter Karlsaune, Coordinator
Phone: +47 73 59 46 72, +47 450 02 177
Email: peter.karlsaune@ntnu.no

Postal address:
SIMLab, Department of Structural Engineering,
NTNU, NO-7491 Trondheim, Norway

Office location:
NTNU, Richard Birkelands vei 1a, Trondheim, Norway

Skipnes Kommunikasjon Nordic ecolabel - printed matter Lisence no. 241 731

www.ntnu.edu/simlab

www.sintef.no