Annual Report 2012

Centre for
Research-based
Innovation

SIMLab

Centre for Research-based Innovation

SINTEF

NTNU – Trondheim
Norwegian University of
Science and Technology

Objective

Within the field of structural impact SIMLab is concentrating on research areas that are of common interest to the 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 a 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*

Vision

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

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 21 PhD candidates where at least four are female.
2 To graduate 10 MSc students annually.
3 To attract 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 two international conferences between 2007 and 2014.

Industrial partners in 2012

HYDRO · Statoil · Forsvarsbygg (Norwegian Defence Estates Agency) · Audi · RENAULT · SSAB · Statens vegvesen · BMW · TOYOTA · BENTELER Automotive

Summary

SIMLab (Structural Impact Laboratory) – Centre for Research-based Innovation (CRI) – 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.

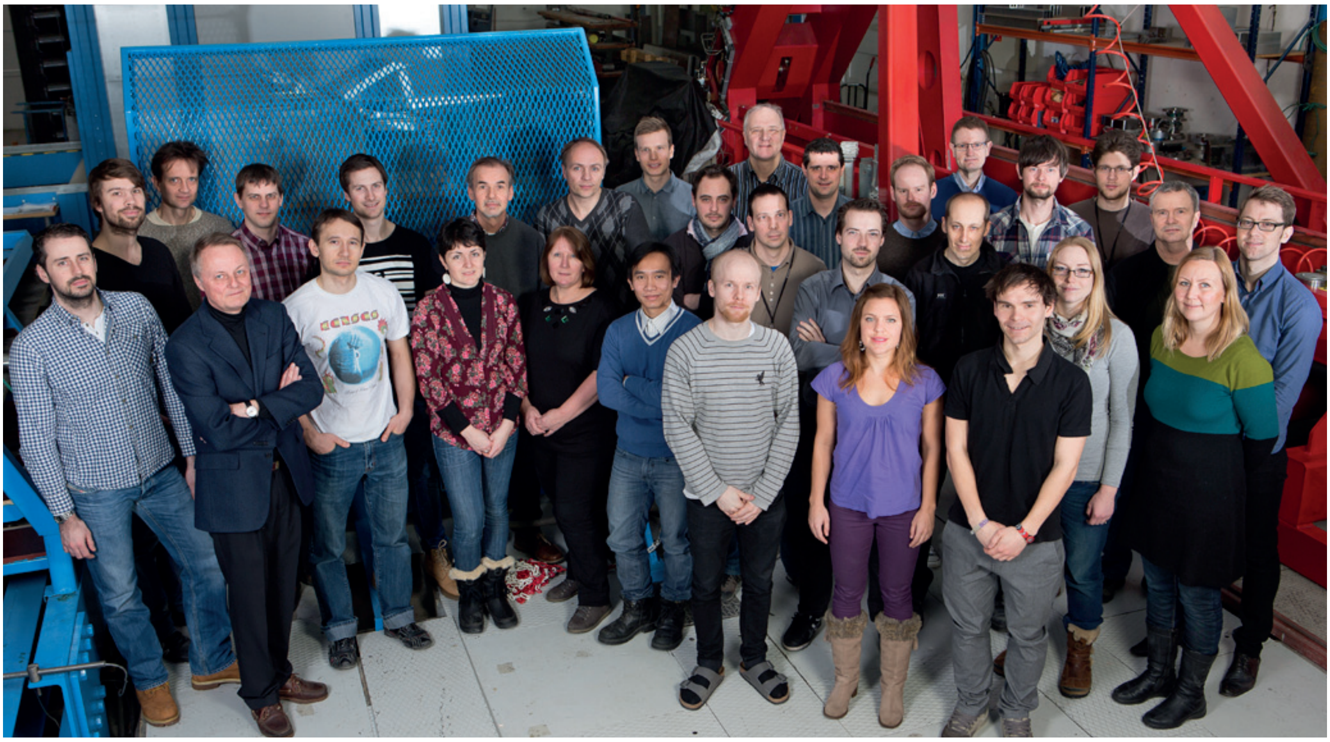
The industrial partners in the Centre in 2012 were Hydro, Audi AG, Renault, Toyota Motor Europe, BMW Group, Benteler Aluminium Systems, Statoil, SSAB, the Norwegian Public Roads Administration and the Norwegian Defence Estates Agency.

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 defined research areas for 2012 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 SIMLab on 23-24 May 2012 in order to give the partners hands on information about material testing and parameter identification of polymer materials. In addition two SIMLab Tool Box meetings have been organized; the first at SIMLab on 8–9 February 2012 and the second at BMW on 7-8 November in Munich.

A board meeting was held at the island of Sula off the coastline west of Trondheim on 18-21 June 2012. The partners concluded that the work carried out in the Centre was according to their expectations and that the transfer of technology from the research group in Trondheim to the partners through the SIMLab Tool Box was very satisfactory.



The research group. *Photo: Ole Morten Melgård.*

A Scientific Advisory Board meeting was arranged in Avize, France on 16–18 October. The Board was pleased with the high quality and productivity of the work carried out and stated that the publications from the group are among the strongest in the field of structural integrity, especially in the general area of impact and large plastic deformations. Furthermore advice was given with respect to the future of the Centre and the Board concluded that the unique competence on theoretical modelling and testing for impact related studies should be maintained.

In 2012, research work in the Centre resulted in 14 papers published in peer reviewed journals. In addition, 8 journal papers have been accepted, but not yet published. The research group has given 24 conference and seminar contributions and among them 6 invited lectures. Two reports have been published. One of them is based on the workshop held at SIMLab in December 2010 on modelling and behaviour of lightweight protective structures.

The research in the Centre is carried out through close cooperation between master's, PhD candidates, post docs and scientists. In 2012, 22 male and 4 female master's students, 12 male and 3 female PhD candidates have been connected to the Centre. Further, 1 female and 2 male post docs are employed at SIMLab. International students from Italy (2), France (3), and UK (1) have also stayed at the Centre during 2012. PhD candidates Egil Fagerholt, Gaute Gruben and Anne Serine Ognedal have defended their respective theses on the *"Field Measurements in Mechanical Testing Using Close-range Photogrammetry and Digital Image Analysis", "Ductile Fracture in Dual-Phase Steel. Theoretical, Experimental and Numerical Study" and "Large-Deformation Behaviour of Thermoplastics at Various Stress States-An Experimental and Numerical Study"*.

International cooperation and visibility are success parameters for a Centre. Thus the Centre has had cooperation with the following universities/research laboratories in 2012: 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; USA; Politecnico di Milano, Italy; European Commission, Joint Research Centre, Institute for the Protection and Security of the Citizen, Ispra, Italy; Karlsruhe Institute of Technology, Germany; and Impetus Afea Sweden. In addition the Centre has been involved in the Multidisciplinary University Research Initiative Project (MURI) titled *An Integrated Cellular Materials Approach to Force Protection* and sponsored by the U.S. Navy. The partners are the University of California Santa Barbara (UCSB) in cooperation with Harvard University, the University of Virginia, MIT, and the University of Cambridge, UK.

With respect to visibility the activities in the Centre have been presented in Norwegian newspapers and magazines as well as on Norwegian television and radio. 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 non-linear simulation tool for mechanical and multi-physics problems using graphics processing units (GPU).

Research areas

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

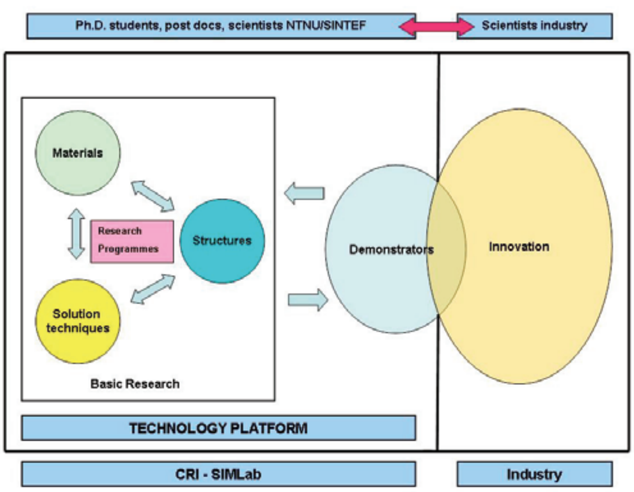
Materials: Development of improved quantitative constitutive models and failure criteria for large-scale analyses as well as identification methods.

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.

The research area "Structures" serves as a link between "Materials", "Solution techniques" and the "Demonstrators" activities, see figure below. The selection of demonstrators/benchmark tests for validation is carried out in close cooperation with the industrial partners. Included in the "Demonstrator" 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.



Research areas.

The basic research areas **Materials, Solution techniques** and **Structures** are linked by research programmes. The following research programmes have been running in 2012:

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.

Multi-scale Modelling of Metallic Materials (M^4): 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 riveted, bolted and bonded 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.

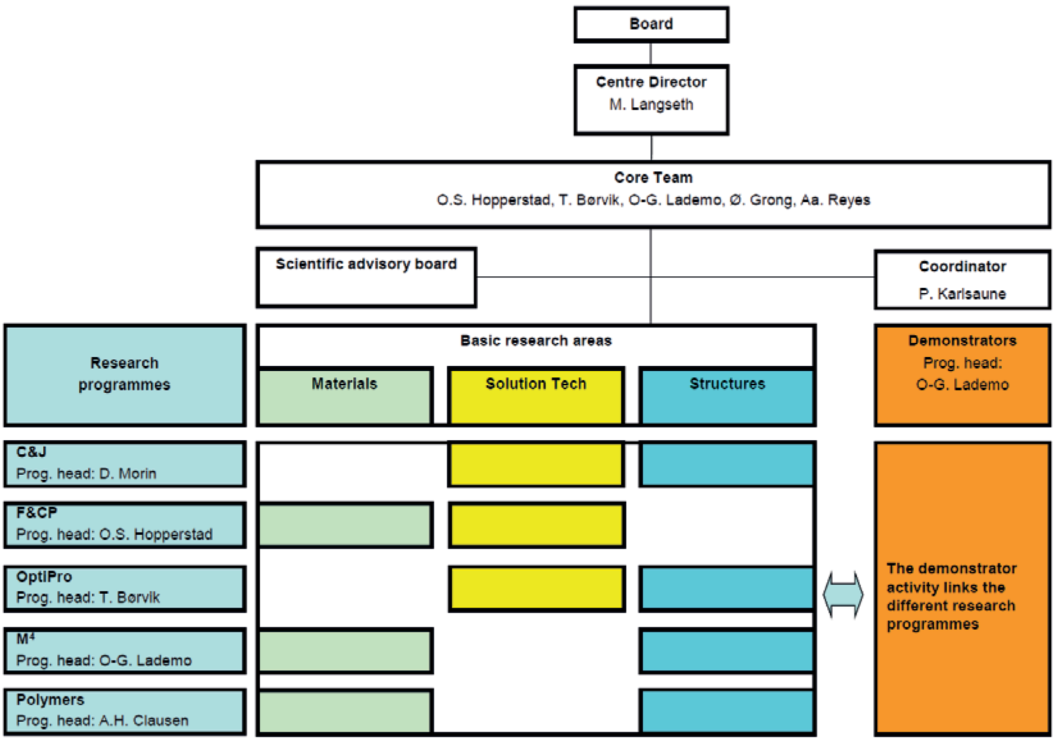
Research organization

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, a scientific advisory 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, BiW, Audi AG



Structure of the organization in 2012.

- Torstein Haarberg, Executive Vice President, SINTEF Materials and Chemistry
- Håvar Ilstad, Leader Pipeline Technology, Statoil
- Hans Erik Vatne, Head of Technology, Hydro
- Helge Langberg, Head of Research Department, Norwegian Defence Estates Agency
- Per Kr. Larsen, Professor Em., Department of Structural Engineering, NTNU
- Joachim Larsson, Manager, Knowledge Service Center/ Design, SSAB
- Jürgen Lescheticky, Head of Process Functional Design Layout Body, BMW Group
- Tsukatada Matsumoto, Senior Principal Engineer, Toyota Motor Europe
- Sigurd Olav Olsen, Special Advisor to the Director General, Norwegian Public Roads Administration
- Tore Tryland, Adjunct Professor/Dr. ing, Advanced Development, Benteler Aluminium Systems
- Eric Vaillant, Engineering Department Manager, Renault
- Astrid Vigtil, Head of Research Section, Faculty of Engineering Science and Technology, NTNU

Centre Director

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

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, PhD and 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

Core team and programme heads. From left: Odd Sture Hopperstad, Øystein Grong, Tore Børvik, Magnus Langseth, Odd-Geir Lademo, David Morin, Arild Holm Clausen, Peter Karlsaune. Aase Reyes was not present. Photo: Ole Morten Melgård

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 were held in each research programme when necessary with participation from all involved partners. In this context the Polymers programme organized a seminar at SIMLab on 23-24 May 2012 based on wishes from the partners. The main objective of this meeting was to give hands-on information to the partners on material testing and parameter identification of polymers. The partners involved took an active part in the testing in the laboratory as well as in the subsequent parameter identification. It was also decided to develop a polymers model library linked to the SIMLab Tool Box. In addition, two SIMLab Tool Box meetings have been held in 2012. The first one was held at SIMLab in Trondheim where the tool box concept was presented, i.e. the tool box hierarchy, the theory manual as well as the user manual. The partners were also given a training session in how to use the tool box as well as how the tool box can be linked to the software used by the different partners. The second seminar was held at BMW in Munich. Here the main objective was to get feedback from the partners who have started to use the Tool Box and to discuss further developments linked to needs raised by the partners. The verification and validation strategy presented was also discussed and the partners found this an important and necessary improvement of the Tool Box.

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

The project meetings were also supported by telephone meetings with our partners 1-3 times a year. In order to strengthen the spread of information within 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 on 8–9 February 2012 at SIMLab.

Board meeting at Sula

The Centre's Board meeting was held at the island Sula located on the coastline west of Trondheim 18-21 June 2012. Magnus Langseth presented the annual report which was followed by technical presentations by the programme heads focusing on new developments the last year. The partners presented future new challenges which were linked to a possible new CRI application. 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. It was pointed out that the existing SIMLab centre will form an excellent platform for a new CRI application with a strong focus on scientific computing.

A wind-up plan for the Centre was presented and a dedicated group of partners where chosen to run the process. Here Statoil, Benteler Aluminium Systems and Hydro volunteered to take part.

The Board also discussed the strong interest of GM and Honda to join the Centre. The Honda initiative came from their research centre in Ohio, USA whereas the GM initiative came from Detroit. After a discussion, the Board concluded not to involve new partners in the Centre at this rather late stage of the Centre period. However, the Centre administration was asked to see if other cooperative mechanisms could be established. In this context, Honda visited SIMLab in September 2012 and a plan for a PhD project on self-drilling screws was established which will start in autumn 2013 and end in summer 2017. During our meeting Honda was asked about their strong interest to work together with SIMLab and they came with the following statement: *"In our recent review of the body of published literature in this area we concluded that publications from NTNU/SIMLab were consistently of the highest technical quality and directly applicable to our future development needs. We were also advised by one of our expert consultants in the area of Crash CAE methods that SIMLab was one of the top 2 groups for aluminum structures crash CAE research capability in the world".*

Tool Box seminar on 7-8 November 2012 in Munich.

Board meeting at Sula. First row from left: Thomas Hambrecht (Audi AG), Odd Sture Hopperstad (SIMLab), Odd-Geir Lademo (SIMLab), Jürgen Lescheticky (BMW Group), Tore Tryland (Benteler Aluminium Systems), Karl Vincent Høiseth (NTNU), Per Kristian Larsen (NTNU), Magnus Langseth (SIMLab), Ernesto Mottola (Toyota Motor Europe), Helge Langberg (NDEA), Astrid Vigtil (NTNU), Arild Holm Clausen (SIMLab). Second row from left: Carl Henrik Ahlen (Statoil), Hans Erik Vatne (Hydro), Erik Levold (Statoil), Joachim Larsson (SSAB), Sven Samuelsen (The Research Council of Norway), Eric Vaillant (Renault). Third row from left: Tore Børvik (SIMLab), Svein Terje Strandlie (Benteler Aluminium Systems), Tsukatada Matsumoto (Toyota Motor Europe), David Morin (SIMLab).

International cooperation and state-of-the art research

International cooperation is one of the success criteria defined by the Research Council of Norway for a CRI centre. For SIMLab, this is taken care of by both international partners as well as strong interactions 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 co-operation has resulted in several joint research projects with common publications. Thus, the cooperation with top international research groups as well as the publications work carried out ensure that the Centre transfers state-of-the art technology to the partners and at the same time is able to define new and innovative research areas of importance to the partners.

Recruitment

Every year a recruitment campaign is carried out with respect to master's and PhD candidates. This year a seminar with contributions from our industrial partners as well as from Aker Solutions took place on 22 October 2012. The seminar was a success and five of our best male master's students are now employed as PhD candidates from autumn 2013. Three of the candidates will be linked to the Centre, whereas the two latter are linked to PhD projects with Aker Solutions and Honda respectively. No female candidates were qualified for the PhD programme.

Scientific Advisory Board meeting

The Scientific Advisory Board (SAB) meeting was organized in Avize, France on 16-18 October 2012. The SAB was this year given a broad mandate to evaluate the scientific relevance and quality of the work carried out as well as future research challenges coupled with new application initiatives from the SIMLab research group after 2014. Some of the conclusions and recommendations on these issues from the SAB report are as follows:

- *"The Board is pleased to be able to again note the high quality and productivity of the SIMLab group. The publications of the group are among the strongest in the field of structural integrity, especially in the general area of impact and large plastic deformations".*
- *"The SIMlab group have done an excellent job using DIC for measurements of local strains, but for many of the studies of damage which are envisioned, a 3D technique such as Tomography is essential. However, it is necessary to pay careful attention to the associated manpower needs because Tomography really demands a full-time researcher dedicated to the technique".*
- *"Structural Security is a growing area of public and industrial interest and SIMLab is ideally suited to focus on this research area after 2014. It is a broad topic embracing, for example, marine and ocean engineering, civil engineering, national defence, energy security and the protection of the national infrastructure".*
- *"The Board suggests that new application initiatives should also reflect safe transportation as a part of the structural security concept, where crash performance of vehicles as well as safe infrastructure along Norwegian roads are included. An involvement of the automotive industry will then ensure a transfer of technology between the existing Centre and the new initiatives".*
- *"A major objective of a new centre should be to develop methods and tools for industrial applications. The methods must be based on a solid theoretical foundation, which necessitates a detailed knowledge about the underlying mechanics. In material modelling, this may require several modelling scales, from the atomic scale to the macroscopic scale. Thus, a multi-scale modelling approach may be needed to capture and understand certain phenomena. However, the industrial applications still require a macroscopic modelling for reasons of efficiency, and for the methods to fit into the existing industrial computational mechanics environments".*
- *"If the group looks for renewable in areas related to inegrity og infrastructure, then it is necessary to increase activity on steel structures".*

Sula Rorbuer – Board meeting venue

Board meeting at the island Sula 18–21 June 2012

Sula lighthouse

Coffee break

Sula vs. Trondheim

Teambuilding at "Supen Pøbb" at Bogøyvær

Board meeting

The fisherman Jürgen Lescheticky

Eric Vaillant during his presentation about the future

Carl Henrik Ahlen, Thomas Hambrecht, Per Kristian Larsen and Arild H. Clausen. A good joke about fishing?

Sula

Sula

Scientific Board Meeting in Avize, France, 16–18 October 2012

SAB meeting members in Avize, France. From left: David Morin, Odd-Geir Lademo, Odd Sture Hopperstad, David Embury, John Hutchinson, Ahmed Benallal, Larsgunnar Nilsson, Norman Jones, Magnus Langseth, Tore Børvik, Francois Moussy, Arild Holm Clausen, Stefan Hiermaier (temporary replacing Klaus Thoma) and Serge Lefevre CEO Union Champagne.

Vineyards in Avize

SAB meeting venue

Champagne

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)

Programme head: 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. The research activities in 2012 have been within the following fields:

- Numerical aspects of fracture and crack propagation
- Fracture in cast materials – mechanisms and modelling
- Fracture in age-hardening aluminium alloys – mechanisms and modelling
- Optical measuring techniques
- Aluminium crash component in axial folding

In each of these research projects, save the last one, a PhD project has been defined, as described in the annual report for 2011. In 2012, two of our PhD candidates, Egil Fagerholt and Gaute Gruben, have received their PhD degrees, and their research work is briefly described below. The two remaining PhD candidates within F&CP, Marion Fourmeau and Octavian Knoll, are scheduled to receive their PhD degrees in 2013. A new PhD project will be started in August 2013. The topic will be micromechanical modelling of fracture in aluminium alloys.

Egil Fagerholt's thesis is entitled "Field measurements in mechanical testing using close-range photogrammetry and digital image analysis". Fagerholt has developed digital image correlation software for measuring displacement and strain fields on two- and three-dimensional surfaces, incorporating special features for analysis of crack propagation. The software is currently being integrated into the SIMLab Toolbox.

Gaute Gruben has investigated the fracture characteristics of cold-rolled, high-strength steel sheet, Figure 1. His thesis is entitled "Ductile fracture in dual-phase steel: Theoretical, experimental and numerical study". In this work, a phenomenological fracture criterion, denoted the ECL criterion, has been proposed and validated against experimental data. The ECL criterion is applicable to ductile metals, and has been implemented in the SIMLab Metal Model with some modifications.

Optimal Energy Absorption and Protection (OptiPro)

Programme head: Tore Børvik

The main objective of the OptiPro programme is to be able to design safer, more cost-effective and more lightweight protective structures. From a design perspective: explosion, impact, collisions and weapon actions are classified as accidental loads, and these events are becoming increasingly important for a number of civil and military engineering applications. To meet the challenges from such loads, product development is increasingly carried out in virtual environments by use of FEM in order to improve the design. The new designs also need to be checked, improved and validated through high-precision experimental tests.

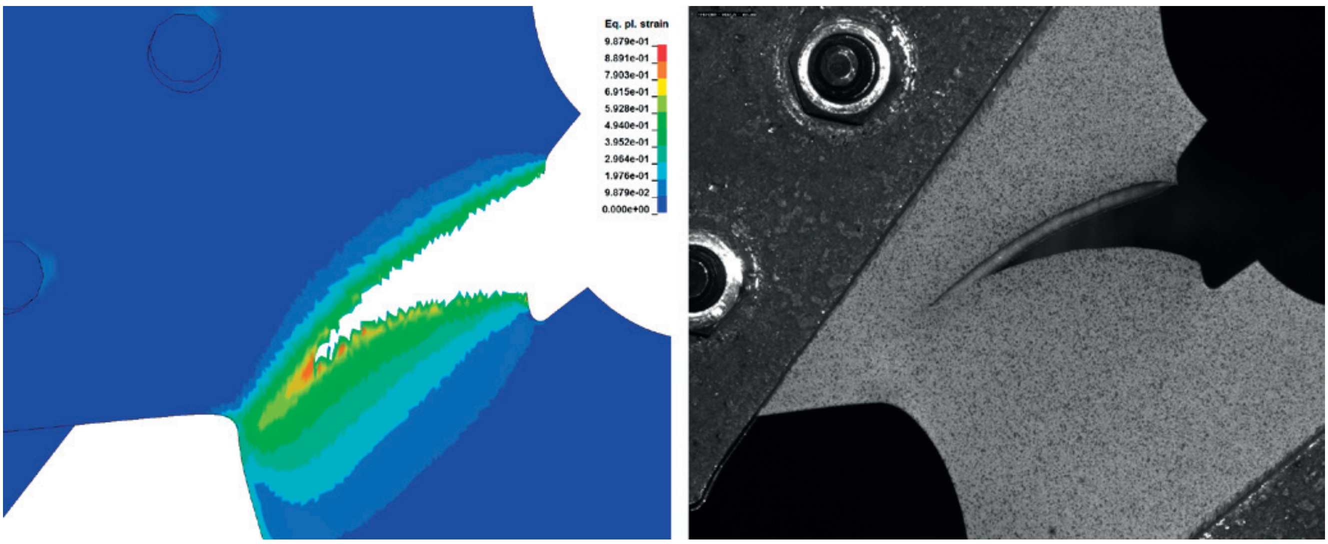


Figure 1 – Crack propagation in modified Arcan tests of cold-rolled, high-strength steel sheet: finite element analysis (left) and test (right).

The research activities in 2012 have mainly focused on the following fields:

- Strengthening techniques on steels for ballistic protection
- Lightweight protective structures
- Fragmentation during blast and impact
- Blast loading on structures
- Impact against pipelines

A PhD project has been defined within the three last research areas. The PhD project by Knut Gaarder Rakvåg on fragmentation during blast and impact loading is scheduled to finish in 2013, while the PhD project by Martin Kristoffersen on impact against pipelines will finish in 2014. These research projects are briefly described below. The PhD project by Vegard Aune on blast loading on structures was initiated in 2012. In addition, all research activities have been run in collaboration with a number of master's students.

The PhD project by Knut Gaarder Rakvåg investigates the effects of combined blast and fragment loading on protective structures. Since it is difficult to validate protective structures against such loads experimentally, our attention is turned towards numerical tools like the finite element method. Previous investigations of the perforation of high-strength steel plates struck by hardened steel projectiles have also found that under certain test conditions the projectile may fail upon impact, Figure 2. Numerical simulations without a proper failure description for the projectile material will then predict perforation of the target instead of fragmentation of the projectile, and thus underestimate the ballistic limit velocity of the target plate. All this may again cause very misleading results in computer-aided design of protective structures. The aim of this project is to carry out an experimental and numerical investigation of the fragmentation modes occurring in steels during blast and impact loading.

The PhD project by Martin Kristoffersen investigates how to design subsea pipelines in fishing areas 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 existing technology developed at SIMLab can be used to calculate the response of a pipeline subjected to impact loading conditions, Figure 3. Component tests are performed on pipes in the Kicking machine. These compo-

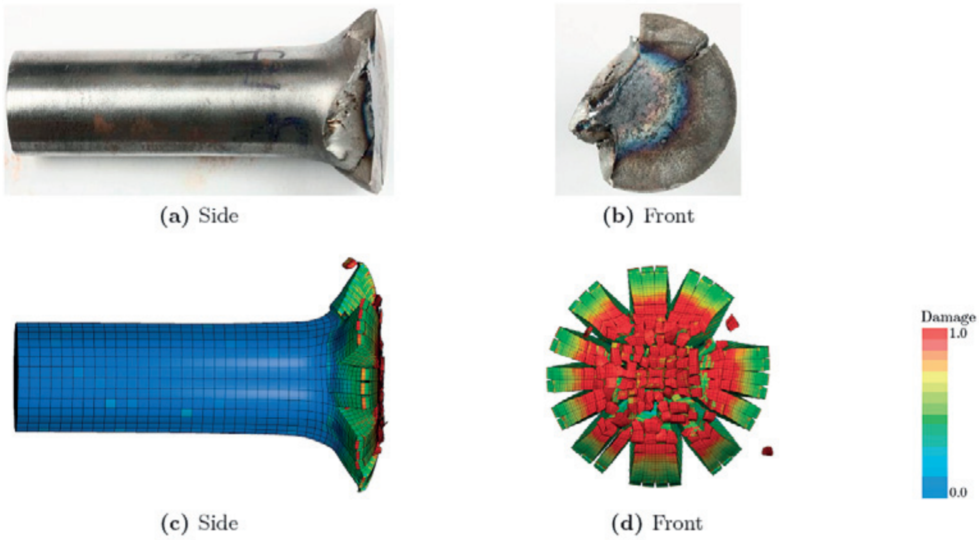


Figure 2 – Failure in hardened steel projectile (HRC40) after Taylor bar impact test at an impact velocity of 300 m/s. The numerical simulation is carried out deploying the node-splitting approach in the IMETUS AFEA Solver.

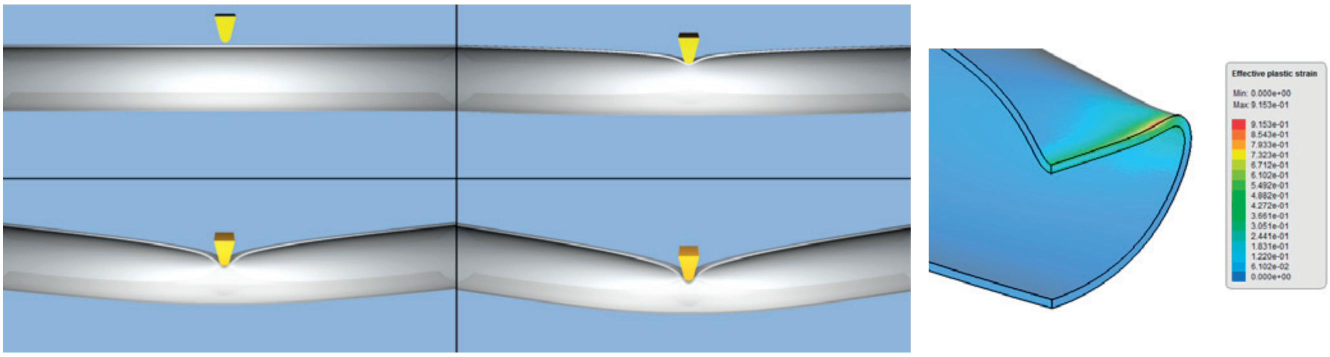


Figure 3 – Numerical simulation showing the global and local deformation and the effective plastic strain in a pipeline after an impact of v_0 = 3.24 m/s.

nent tests serve as a basis for validation of numerical models 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.

Polymers (Poly)

Programme head: 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 have also been some activity on fibre-reinforced polymers. The main attention has been paid to constitutive models representing the evolution of stress as function of the strain and strain rate, and some introductory work on temperature and viscoelasticity was recently started up. The long-term goal is to integrate some generic models for polymers in the SIMLab Toolbox, which at present covers metallic materials.

The research activities in 2012 have been within the following fields:

- Implementation and verification of models
- Damage and fracture of polymers
- Crashworthiness of glass-fibre reinforced polymers
- Coupling effects between plastic deformation and temperature

The first of these projects has mainly been run together with researchers from SINTEF. Different models describing the response of ductile thermoplastics have been explored, including the hyperelastic-viscoplastic model presented in earlier annual reports as well as a hypoelastic-viscoplastic model and a hypoviscoelastic-viscoplastic model. These models are going to be constituents in the SIMLab Toolbox.

The last three of the projects presented above are related to the research of PhD candidates. Anne Serine Ognedal defended her thesis "Large-deformation behaviour of thermoplastics at various stress states – an experimental and numerical study" in November 2012. Considering a PVC material with mineral particles, an important part of her work was to investigate the cavitation process experimentally and numerically. Figure 4 addresses the voids as detected in SEM and a unit-cell model applied for her numerical investigation. Ognedal found that this damage mechanism might be related to macroscopic features such as softening and increase of volume. Ognedal is continuing her research at SIMLab as a postdoctoral fellow.

The PhD project on glass-fibre reinforced polymers is carried out by Andreas Koukal at Audi in Ingolstadt. He is affiliated with the Technical University of Munich. A major contribution in his PhD work is the creation of a database comparing the response of polypropylene having 0%, 10% and 30% of glass fibres. This PhD project ends in 2013. However, a new PhD project on modelling of fibre-reinforced material is planned to start up at SIMLab in August 2013.

Starting as a PhD candidate in 2011, Marius Andersen is working on the viscoelastic response of ductile thermoplastics. He has also looked into thermal softening caused by adiabatic heating of the material, which occurs even at the rather low strain rate of 10^{-2} s^{-1}.

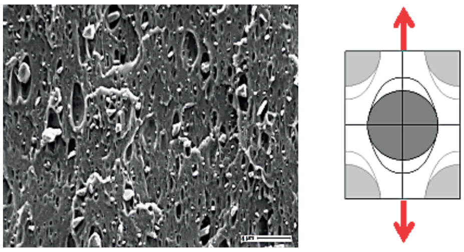


Figure 4 – SEM micrograph showing cavitation after deformation of a mineral-filled PVC (left), and cavitation around a spherical particle in a unit-cell model mirrored about symmetry axes (right).

Multiscale Modelling of Metallic Materials (M⁴)

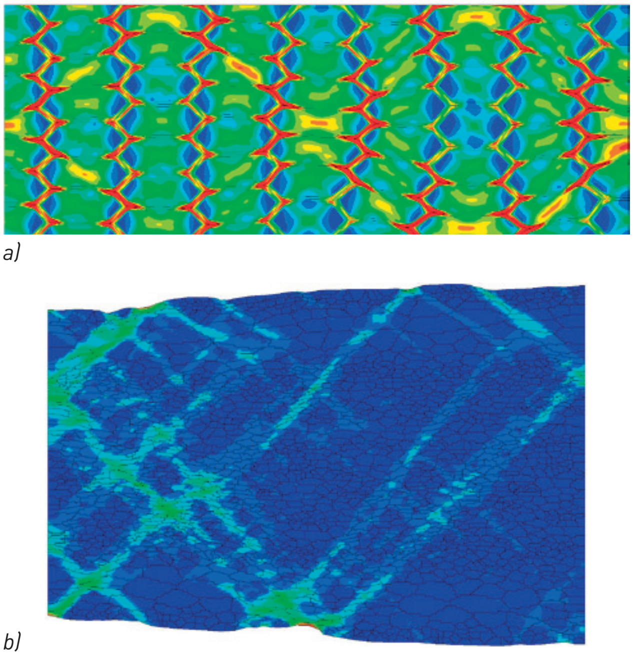
Programme head: Odd-Geir Lademo

The main objective of the M^4 programme is to develop a multiscale 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 lower (meso-/crystalscale) level, a framework for single- and polycrystal plasticity has been developed (including the SIMLab Crystal Plasticity Model). At microscale, a precipitation-based modelling procedure (NaMo) is used/developed that provides a description of strength and work hardening as function of the chemical composition of the alloy and its thermal history.

Various developments have been done for rolled and extruded aluminium alloys and high-strength steels. The research activities in 2012 have been within the following four fields and projects, each involving a PhD candidate:

- Fundamentals of multiscale 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 microscale properties on the macroscopic behaviour of the material. One activity has explored the use of multiscale tools to study the effect of the micro- and crystal structure on the ductility of aluminium alloys used in crash box application, see Figure 5. The second activity is designed to strengthen the hierarchical coupling between the Nanostructure Model (NaMo) and the crystal plasticity FEM (CP-FEM) approach and with the scientific purpose to study and understand strain localization in polycrystalline metals.



a)

b)

Figure 5 – Effect of grain property on material response for an idealized microstructure including PFZ (a); localization using a hierarchical coupling between NaMo and CP-FEM for a realistic microstructure (b); both in plane-strain tension.

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 2012, a broad experimental campaign has been carried out on the aluminium alloy AA6016. Beyond the experimental database, automated procedures for DIC-based strain measurements have been established.

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 2012 work has been carried out to improve the representation of alloys composed with a high Mg/Si ratio. A PhD student is still working to complete an extensive validation study of the concept for a set of generic welded components.

The last project aims to i) establish methods for testing metallic materials at wide ranges of temperature and strain rates; ii) to enhance the understanding of the underlying material mechanisms; and iii) to evaluate and further develop the model framework for these conditions. The work focuses on aluminium alloys, and is staffed by a PhD student. In 2012, emphasis has been given to the experimental procedures and execution of test series to establish an experimental database.

Connectors and Joints (C&J)

Programme head: 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 crash 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. For local studies (i.e. small scale analyses), a higher amount of detail can be built into the models as well as connectors allowing the use of more accurate and time consuming approaches.

In this research programme, behaviour and fracture of connections are handled from both experimental and numerical points of view. The experimental activities involve studies on the behaviour of single connectors as well as the assembly of connectors used in structural joints. These experiments are carried out for low and high strain rates to increase our understanding of the phenomena occurring during the large deformation behaviour of connectors. The numerical activities are divided into two modelling scales: macroscopic and mesoscopic. The macroscopic modelling is suitable for large scale analyses, but requires testing of single connector specimens for the calibration of the proposed models. In addition, since macroscopic modelling is a highly simplified way of representing joints, the quality of the prediction can then be of a moderate accuracy. On the other hand, mesoscopic models are based on accurate description of the joints with solid elements. This approach is relying only on material properties and process simulations but requires high computational times.

Over the past few years, the described methodology above has been applied to several joining techniques: self-piercing rivets, structural bonding and bolted connections. In Figure 6 the mesoscopic modelling approach is shown for bolted connections (PhD thesis of Henning Franplass). The model is used to describe the behaviour and failure of a threaded rod subjected to dynamic tensile loading. The proposed model is able to predict the global force displacement response as well as the failure mode observed during the test, i.e. thread stripping.

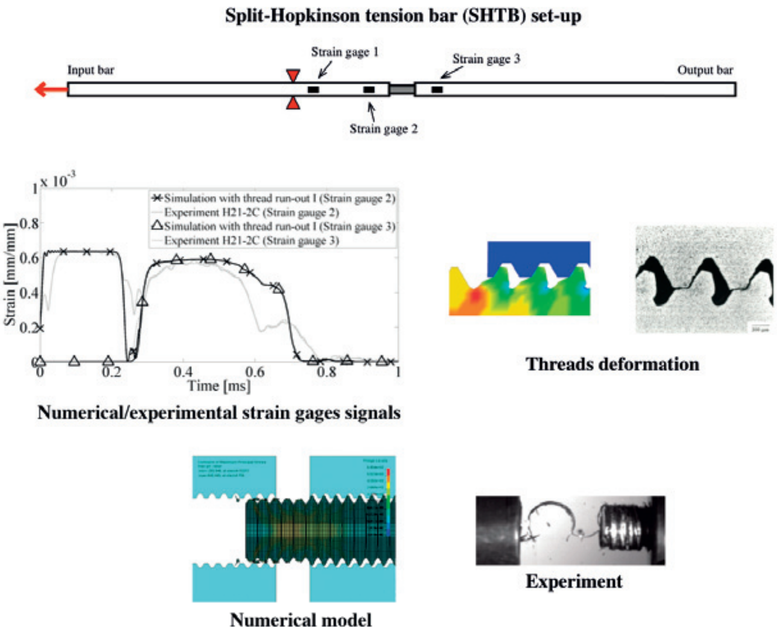


Figure 6 – Mesoscopic modelling of bolted connections under high rate loading.

Industrial Demonstrators (Demo)

Programme head: Odd-Geir Lademo

In brief, the main objective of this research programme is to facilitate industrial implementation of results produced within the Centre (e.g. experimental procedures and modelling concepts). In 2012, work has been done to develop software products and modelling guidelines. To support industrial pick-up, a two-day course/workshop has been arranged. In what follows, the SIMLab Tool Box is presented in some detail.

SIMLab Tool Box

As stated earlier, the overall objective of CRI SIMLab is to provide a technology platform for development of safe and cost-effective structures. Since 2010, a project has been run to structure the results produced in the centre in terms of interdependent software products. This is done to readily provide results for the industrial partners and thereby contribute to their short- and long-term innovation capability. As such, the SIMLab Tool Box represents the most important deliverable to the industrial consortium.

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 was defined as the resulting cluster of software products.

The above-mentioned components within the SIMLab Tool Box can be used as separate software-products or in combination with each other, as illustrated in Figure 7.

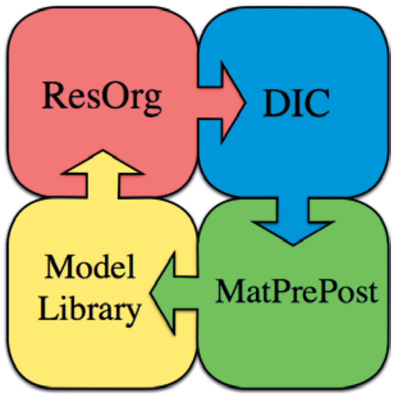
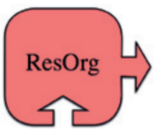


Figure 7 – SIMLab Tool Box software products.



ResOrg (Results organizer) is a software component that aims 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 (see Figure 8), but the underlying files can also be retrieved without this GUI through an accessible sub-directory structure.

Status and future developments of ResOrg

The 'ResOrg' concept was developed in the first year of the Centre and has since been used to systemize experimental planning, preparation and execution in the Centre. It has served the internal needs in the Centre, but the tool needs further focus before it can be distributed for broader external use among the industrial partners.

Discussions with the industrial partners of the Centre have also revealed the need for a database structure that gathers available experimental data (based on material and benchmark tests carried out in the Centre). Towards the end of the Centre this activity may recast the 'ResOrg' programme in a new and more versatile solution. In the wind-up of the Centre, work will also be defined to gather and/or produce potentially missing information (e.g. FE models for all specimens for supported FE solvers).

DIC (Digital Image Correlation) allows the determination of 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, Figure 9. 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 highly efficient computation times. The comprehensive GUI runs on Windows platforms.

Status and future developments of SIMLab DIC

The SIMLab DIC code has been industrially implemented with one of the industrial partners (Statoil). This work has been used to optimize the user-friendliness of the tool, and the software is now ready to be implemented among other partners. To support this process, the tool will be demonstrated in meetings/workshops with all the partners during 2013.

Further technological development is directed to develop the coupling to the 'Model Library'. During 2013, a coupling to the SIMLab Metal Model will be established that will allow to access local stress and plastic strain fields without the need for FE software.

MatPrePost is a tool for parameter identification and tailored pre- and post-processing. The outcome of the pre-processing utility include 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 (Figure 10) runs on Windows, Mac OS and Linux platforms.

Status and future developments of MatPrePost

The first official version, MatPrePost 1.0, which at present supports parameter identification for the SIMLab Metal Model (1.0), is now available for use among the partners of the Centre.

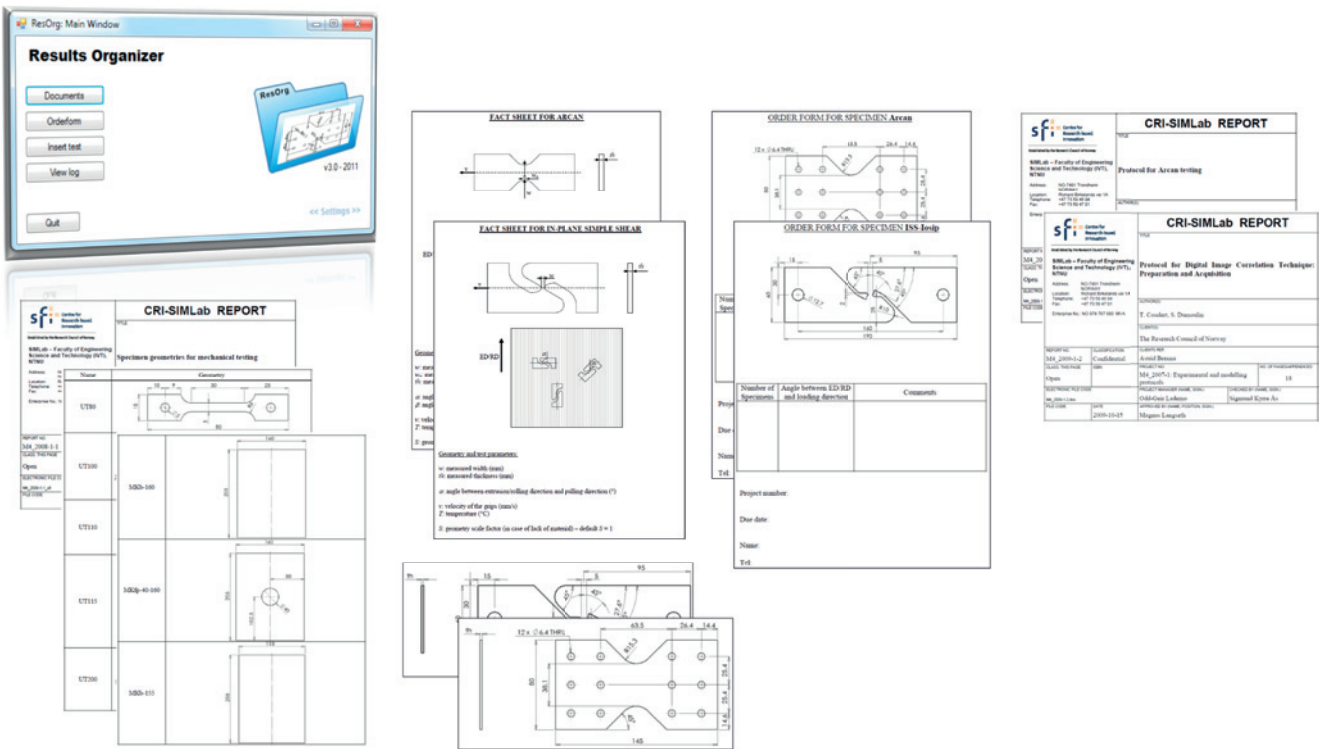


Figure 8 – ResOrg software.

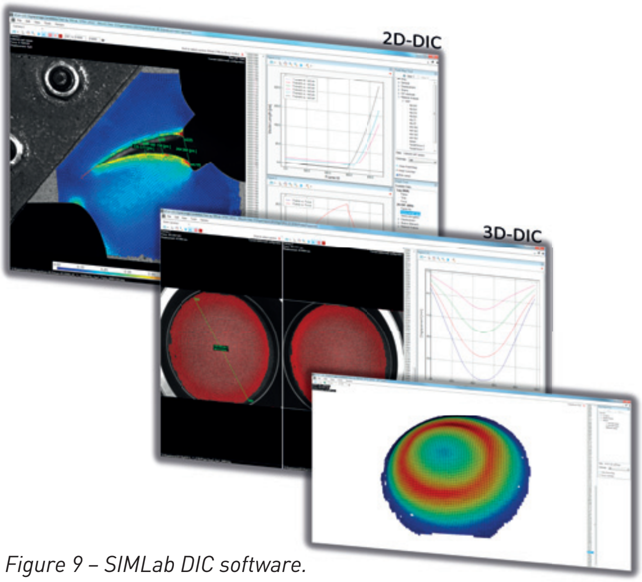
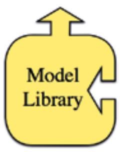


Figure 9 – SIMLab DIC software.

Further work will include measures to enable the identification of thermal sensitivity parameters of the SIMLab Metal Model, and develop customized post-processing features. The latter will enable users to visualize results from FE analyses in terms of e.g. stress/strain-related trajectories in relation to the yield surface, the forming limit diagram or the fracture locus. At a later stage functionality to support the use of the SIMLab Polymer Model needs to be built.



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, the SIMLab Crystal Plasticity Model, and the SIMLab Polymer Model. 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. The SIMLab Metal Model (1.0) is illustrated in Figure 11 and allows the user to include physical features thought to be of relevance for the innovation challenge at his/her hand. This structure further allows for a gradual shift in company-specific 'recommended practice': By modification of a few parameters in the input, the regular industrial approach (generally J2 plasticity) is replaced by more realistic representation of e.g. plastic anisotropy. The model is applicable to shell and brick elements and a set of special features are available to handle regularization techniques and fracture modelling. The Model Library can be linked to several FE codes, i.e. LS-DYNA, ABAQUS, PAMC-RASH and IMPETUS.

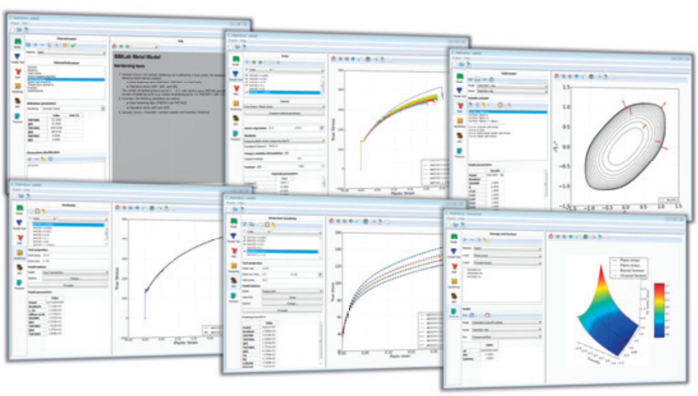


Figure 10 – MatPrePost GUI.

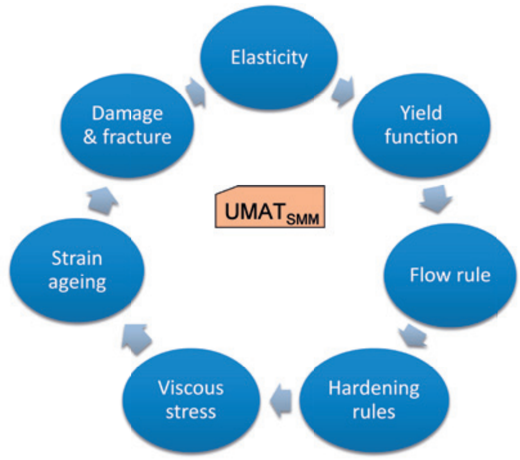


Figure 11 – SIMLab Metal Model structure.

Status and future developments of the Model Library

SIMLab Metal Model (1.0) has been made available for use among the partners of the Centre. In 2013, further work will be carried out to make it available for use with implicit FE solvers. A Verification and Validation (V&V) strategy has been developed that ultimately results in modelling guidelines for industrially relevant application areas of the model. Various studies on steel and aluminium alloys are to be undertaken.

The SIMLab Crystal Plasticity model also represents a rather mature modelling concept. However, a modelling strategy that relies upon this model is impeded by much higher computational costs and lowered robustness than previous models. Hence, further work is now undertaken to increase the efficiency and robustness of this model.

The SIMLab Polymer Model has matured during the last year. The polymer research programme will be strengthened by additional PhD students in 2013, which will speed up developments even further.

Listening to the elders

Arnfinn Jenssen

François Moussy

Svein Terje Strandlie

Eric Vaillant

To achieve excellence in research, you need cash and a workplace. You need world class researchers. You need discipline and creativity. You need drive and fierce criticism.

And then you need wisdom. Since time immemorial elders have gathered around the fire to deliberate, to weigh the pros and cons, to bring their experience to the issues at stake.

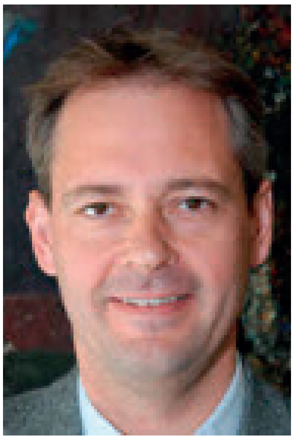
At SIMLab we feel privileged. We have some formidable elders to lean on. Arnfinn Jenssen used to head R&D at the Norwegian Defence Estates Agency. He was a partner of SIMLab and its predecessors for decades. Well into his 80s he is still one of Norway's most outspoken and knowledgeable authorities on the threats that surround us.

François Moussy is almost a generation younger, but decided to retire from his post at Renault. We hired him immediately. From his new position, he confronts us with irritating facts and unpleasant questions. He is an invaluable asset.

On the following pages, you'll meet our elders as well as present partners Renault, Benteler, Hydro and NDEA. We also present Dagfinn Buset's wisdom. He is assistant director at the Norwegian National Security Authority.

Structural impact comes in all shapes and sizes. As you'll hopefully understand from this section of the annual report, SIMLab won't run out of challenges for years to come.

Dagfinn Buset



Hans Erik Vatne

Helge Langberg

Text: Albert Collett
Photo: Ole Morten Melgård

Vigilant veteran

Many seniors just fold up and wither away. Others combine experience and wit to form some of the most knowledgeable advisers around. They shoot from the hip and they hit. At times it hurts more than we like to admit.

Arnfinn Jenssen used to head R&D at the Norwegian Defence Estates Agency, NDEA*, a SIMLab partner. In his 83rd year, he is still one of Norway's most outspoken authorities on the threats that surround us and on our often failing ability to take action against them.

WHY?

- Why on earth was the LNG plant at Risavika near Stavanger built where an explosion risks killing more than a thousand people in the nearby ferry terminal? (The distance is 250 metres. US standards say 16 kilometres.)
- Why do we put frames in the windows of high-risk buildings when we know danger is dramatically decreased if we don't?
- Why isn't the security expert called in at the same time as the architect?

IMPERTINENT QUESTIONS

Impertinent questions, indeed; questions that need to be put and answered. Yet we don't always fancy them. More often than we like to think, people who put these kinds of questions are silenced. They get sacked, "promoted" or discredited. Arnfinn Jenssen doesn't risk any of these consequences, so he can speak freely. Therefore it should be included in this story that he was speaking freely also before retirement – without being silenced.

THANK HEAVENS

Thank heavens; most terrorists don't have Arnfinn Jenssen's combination of expertise and trust. It's not everyone who is able to leave Israel and arrive in the US without passing security controls.

As it is, Mr Jenssen is happiest of all that Norway's July 22nd terrorist was a relative amateur. Mr Breivik could have produced a much larger explosion at the heart of the government headquarters with explosives from his pockets had he been more skilful.

RESEARCH NEEDED

Arnfinn Jenssen, on the other hand, has more in his pockets. Here's another of his examples:

A few years ago, the Dutch authorities asked five consultants to establish a risk zone around a certain site. The zone was to be established on the basis of common information about risk ingredients at the site and common standards for protection. The recommended risk zone varied from 50 to 700 metres in diameter. It turned out that the five consultants used different computer models and also interpreted the common standards differently.

There is no particular reason to expect that Norwegian consultants would have responded differently. This is but one in a million examples to show the massive need for research on how to protect ourselves from explosions, floods, storms, sabotage and the like.

HIGHLY APPRECIATED

So, why does a man who retired more than a decade ago figure in SIMLab's annual report? One reason could have been that the NDEA has been one of the main contributors to SIMLab and its predecessors for many, many years; on Arnfinn Jenssen's decision and due to his firm belief that the area needs research.

At this stage, the reason for his appearance is that SIMLab finds his expertise still relevant, a view shared by many. Just a few months ago he gave his views at "The Security Days", a conference hosted by another department at NTNU. Mr Jenssen was invited to join a panel with some of Norway's foremost capacities.

"SIMLAB IS NEEDED"

Luckily, Norway is equipped with more vigilant veterans. Former Prime Minister Kåre Willoch is one of them. He headed a commission appointed by the government in 1999 to evaluate the vulnerability of Norwegian civil society. Their conclusion: one ministry and one body should have the overall responsibility for security. One body should be responsible for research. Arnfinn Jenssen agrees:

"Norway needs a laboratory that can make students understand the response of structures and materials subjected to unintentional external loads from numerous sources including 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. Unfortunately the Dutch example is highly relevant. There are lot of people working in this field who are unable to evaluate a risk analysis and thus calculate the consequence of a defined threat or accident. With the possible exception of the Petroleum Safety Authority we seriously lack competence. So we need SIMLab, as well as biologists and actuaries to analyse risk."

WHEN TIME HAS COME

Ours is a complicated world. Still there are some simple truths around. One of them is the fact that the more you know, the better you can prepare for the unexpected. This is fundamentally true also for the reason put by the author Helge Iberg in one of Arnfinn Jenssen's favourite quotes: **"When time has come, it's always too late."**

** NDEA is responsible for 13 000 buildings and installations with a total area of 4.3 million square metres. The 1 400 strong staff produces revenues of more than USD 1 billion. In addition to the responsibility for all defence installations, NDEA gives advice to the civilian authorities with a potential need for protection, including government offices.*

The blessing of the unruly

If you want to do well, you need someone to confront you with irritating facts and unpleasant questions. That's why SIMLab hired François Moussy after he had been a client for many years.

Irritating fact, example 1: You may be the best researcher in the world. But if no one is able to make use of your findings, they're worth absolutely nothing. Zero. In François Moussy's words:

"SIMLab's numerical simulations are developed in the LS-DYNA code. Renault uses PAM-CRASH. Someone has to translate; otherwise the results are useless to Renault. The translation is not academic research, but someone has to do it. This is painful, but it's a fact: if you forget the last step of the study necessary for the industrial application, you lose everything."

DYNAMIC

Of course, Moussy wouldn't be working for SIMLab if he didn't think that Professor Langseth and his team actually walked that extra mile. Better than that: Moussy is quite in line with Audi's key research executives who said the following in last year's annual report:

"The people at SIMLab aren't just a group of top rank scientists. They're extremely dynamic. A project we've done there recently ended up in the Audi Validation Programme. This had nothing to do with where we started. SIMLab happily changed focus and defined new topics on the way. That's the outstanding point."

AGAIN AND AGAIN

Irritating fact, example 2: Renault has to be able to apply test results in-house. If that's not possible, the results are no longer useful. This means that SIMLab has to downgrade their methods so that they can be used by their partners. Their findings are accurate and correct but the formulation is too complex for Renault to use. Of course, academic people don't like to downgrade their work, but it has to be done.

Moussy knows that SIMLab will do this, but it is part of his new engagement to point out these aspects of reality again and again so the researchers don't find themselves isolated in an ivory tower one day.

AT THE CROSSROADS

François Moussy started his career at Institut de Recherche de la Sidérurgie, the French Iron and Steel Research Institute, working for 15 years with iron and steel before moving on to work for Renault for 20 years. He has always found himself at the crossroads between industry and research and always working with materials. With time, aluminium and, to a lesser extent, magnesium was included on his list.

He first met SIMLab director Magnus Langseth at a summer school 20 years ago. Before long, through common contacts in Hydro and elsewhere, closer contact was established. This led to cooperation.

RARE COMBINATION

The long-time Renault employee is very enthusiastic about SIMLab's core characteristics:

"In one and the same place you have the qualitative understanding of the physics of materials behaviour, with close links to Hydro and others; you have the complex equations for the quantitative modelling of mechanical behaviour, with the studies of stresses, strains and fracture; and finally, you have the numerical simulations to solve these complex equations for industrial applications. If one of these three components is missing, you cannot work correctly. Still, it is very seldom to find them all in one place. Several of the experimental facilities at SIMLab are unique; the Kicking machine is one of them. There's nothing like it anywhere else. It also has to be said that the risk of focusing only on academic research is always present. Luckily, this is not the case at SIMLab."

REGULAR PRESENTATIONS

In order to get his points through to SIMLab's researchers, François Moussy is invited to give regular presentations to them and repeat his precise questions and irritating facts again and again.

This way, in his new position, he is able to help both his former employer and his present one: "I know what Renault needs and I know the time-frame they have set to obtain the desired results," he adds.

He is also crystal clear about the benefits for Renault:

"Not only do they have the results of the PhDs, but they gain much more information in addition to that. Some of this information is the result of the contribution from all the other CRI partners. An example is the access to a whole library of mechanical properties for different materials. The quality of the data is undisputable, which is fundamental. In many cases, one doesn't know if the available data are correct. Here we do, and if you read your way through this library, you can make endless numbers of industrial calculations. This represents immense value to SIMLab's partners."

"DON'T FORGET STEEL"

Irritating fact, example 3:
"I have to keep repeating the importance of not only focusing on aluminium, it's important to study steel as well. Most cars, even the lighter ones, are still made of 60-65 % iron-based materials. Therefore I'm happy to observe that SIMLab has decided to increase their research activities in that area," says François Moussy.

It seems that the man with the irritating facts and unpleasant questions carries some weight with his new employer. That's probably good news for everyone.

Coming up: the natural car

Three major challenges that constantly face the car industry are: lighter, stiffer and safer. The hunt for new materials follows naturally. Don't rule out that SIMLab will be testing the crashworthiness of bio-materials in the years to come.

It's not a joke. The department manager for analysis and material behaviour at Renault, Eric Vaillant and his colleagues are already working on bio-materials for use in dashboards and the like. It will make them lighter and more sustainable. It's full circle of course. For decades, we've seen imitations of wooden dashboards. Now the real stuff may be on its way back to the industry.

This is not to say that bio-materials will become a major part of future cars. Rather, it is an indication that the industry is looking for specific materials in specific areas for specific needs. Along with this comes the challenge of assembling different materials and see how they interact.

RENAULT GOES GREEN

That being said, bio-materials make perfect sense. Renault was the first car manufacturer to introduce a mass production programme of full electric vehicles with the Fluence ZE, Kangoo ZE, Twizy and Zoe models. The French producer collaborates closely with Japanese Nissan and considers it is a market leader in reducing CO_2 emissions. Bringing bio-materials back to the production line is a natural part of the quest to reduce the mass of a vehicle. Composites are another and possibly much more important example of materials waiting to be introduced. It seems that SIMLab will not run out of challenges for a long time.

LONG-LASTING

Eric Vaillant inherited the SIMLab connection from his former employee François Moussy and stresses the importance of long-lasting relationships.

"My own contact started in 2005 and I have worked closely with Professors Langseth and Hopperstad in Trondheim. Creating effective human contact is a good basis for obtaining satisfactory results. This is part of my strategy, as it facilitates the fast exchange of results and a very interactive contact," he says.

Vaillant is especially impressed by SIMLab's high level of technological know-how and efficient approach to marketing. He is positive to having external research partners and has similar cooperation with the Technical University in Darmstadt on fatigue behaviour.

SHARING WITH COMPETITORS

This kind of networking brings results. As do the large international networks Renault is linked to via SIMLab. One of these networks is the scientific advisory board, with members from world-leading universities; another is the cooperation with Toyota, Audi, BMW and other market leaders in automotive safety.

"There's no denying that it's complicated to share projects and results with our fiercest competitors, but this is also one of the major strengths of the CRI scheme. We are several partners with the same need and we are in frequent contact organized by SIMLab. This exchange between partners brings robust results and teaches us a lot. If we see extensive synergy between our findings and those of our competitors, we have an indication that our strategy is right. If the differences are significant, we are forced to consider if we are on the right track," Vaillant observes.

CHALLENGES

Renault's department manager for analysis and material behaviour sees three major areas for future collaboration with SIMLab. One is the quest for lightweight structure parts. Another is the continuation of an on-going process, namely to substitute real tests by simulations. The third major area is to further develop the contact with SIMLab's extensive network, including the best labs and companies in material engineering anywhere in the world. Renault has the clear ambition to meet the other car manufacturers in the development of new projects and thereby make use of this network efficiently.

TV ON THE GO

These challenges are in line with the trends Eric Vaillant envisions for the car industry:

"Especially in Europe the all-important objective is to reduce CO_2 emissions. We will also be looking at ways to replace expensive raw materials with alternatives and not the least: we want to provide the customer with the sustainable and connected car."

Renault is well on the way and considers itself in the lead in the field of electric vehicles. For example, the new Clio combines GPS, internet and other services for the good of the customer and the environment, a connected vehicle that provides a continuum between home, car and the office.

SIMLab may well be one of the world leaders in its field. That's hardly a boring position to be in. Having world leaders as our partners makes it all the more exciting.


VW TIGUAN
16863
ATTENTION


BENTELER
Automotive

Totally devoted

In a global enterprise with 29 000 employees of which 22 000 are dedicated to the automotive industry, competition is omnipresent. Competition from within is part of it. That's one of the reasons why Benteler's people at Raufoss appreciate SIMLab as a platform with state-of-the-art competence and technologies.

"SIMLab is world-leading in crash management. At Benteler Raufoss we want to position ourselves as technological leaders. We are constantly benchmarked against other parts of the company. Critical questions are routine. In this context SIMLab's expertise and the contact with the other partners is invaluable." Says Svein Terje Strandlie, general manager at Benteler Aluminium Systems Norway and region manager in the Nordic countries.

THE WHOLE CAR

Two facts are the key to describe Benteler Automotive: the company is totally devoted to car parts and it looks at all parts of the car, with integrated lightweight design as the main focus. The ground-breaking Fisker Karma plug-in hybrid with its aluminium space frame, wheels and body is a good example.

Benteler is family-owned and based in Austria. Development and production is world-wide. The logo is visible at 170 locations in 38 countries, including Norway, Sweden, Denmark, the UK, Germany, France, the USA and China ready to serve the car industry.

Up to 25% of all front bumpers on new European cars are made by Benteler. Every week of the year 100 000 bumpers leave the plant at Raufoss alone.

50 MILLION CARS

Hydro's sale of their automotive division was a win-win situation for SIMLab. Not only did Hydro decide to continue their partnership. This meant that Norway's aluminium corporation had found sufficient value in SIMLab's research to make it interesting for other business areas. At the same time, the buyers in question, Benteler, joined in as well. SIMLab got a new partner that is devoted to cars.

"The link between the market and research that is typical of CRIs like SIMLab is particularly interesting. Also, it is somewhat unique to have such close cooperation with some of our most important clients. We recently attended a joint meeting of all SIMLab partners at BMW in Munich. This would have been unthinkable without an instrument like the CRI," confirms Strandlie.

THE VISION

Benteler Automotive shares a vision with several of the other partners, that of being able to avoid needing full-scale tests.

"Of course, no date is set yet, but one thing is certain: Such a vision would be impossible without the close cooperation we have on the material side," says Strandlie.

The cooperation is lubricated by SIMLab's extensive academic network both within NTNU and internationally and by a burning enthusiasm combined with considerable capacity for smooth operations.

Benteler also profits from the steady production of new expertise in the sense that one of their latest researchers was recruited from SIMLab.

WHAT NEXT?

It is no accident that Svein Terje Strandlie is member of SIMLab's strategy group. The on-going programme runs out at the end of 2014. After that, SIMLab has to design a new programme that is not just a continuation of the present one if they want to keep their CRI status. This is a tricky issue for the Research Council of Norway, for SIMLab and other CRIs and for the partners.

"We understand the challenge facing the Research Council. At the same time we think Professor Langseth and his colleagues have a track record that is definitely worthy of continued interest. The CRI has established a team of specialists within different areas of expertise that work together to solve multi-disciplinary challenges. Both researchers and students from around the world have shown interest in this working mode in addition to the already remarkable results achieved. We and the other partners are serious players with long-lasting ties that we want maintain and develop further. That's why we definitely want to take part in the discussions on what will hopefully be SIMLab 2.0," Svein Terje Strandlie concludes.

Preparing for next time

In the wake of July 22nd 2011, Norway is still struggling. The terrorist is convicted; the commission of inquiry has delivered its report. Still, formidable questions linger: What will it be like next time? How do we prepare?

In the spring of 2011, SIMLab's scientific advisory board gave their advice about where to direct attention for the next CRI programme. Their advice was to focus on anti-terror work. In the following months, SIMLab held meetings with all the central bodies; the Norwegian Police Security Service, the Directorate for Civil Protection and Emergency Planning and the Norwegian National Security Authority.

The Norwegian Defence Estate Agency (NDEA) has been a SIMLab partner for many years. They decided to follow the advisory board's advice by sponsoring a new professorship in anti-terror measures.

Then terror struck. It goes without saying that anti-terror automatically gained momentum. So did the importance of the cooperation between SIMLab and NDEA. All the more so since the government has decided to establish a new, central anti-terror unit under NDEA's command.

IN A CENTRAL PLACE

Where does this leave the Norwegian National Security Authority (NSM)? In a central place. NSM is not old. It was born after the new security act was passed in 2001 and is both a directorate and a function. NSM is one leg of the three-legged creature that constitutes Norway's secret service; the secret police and military intelligence are the other two. The secret police are mainly concerned with the participants on the scene, evaluating and reacting towards threats. Military intelligence focuses on issues abroad. NSM's main responsibility is to protect targets, whether in the shape of information or objects. In other words, its task is to protect assets of the highest importance to society. This in turn aims to reduce threats and avoid unwanted incidents of espionage, sabotage and terrorism. NSM is a unit with a high level of competence that works with preventive security on the human, technological and organizational levels. It covers both civil and military sectors, reporting to the ministries of defence and justice.

IMPORTANT CONTACT

NSM is not a SIMLab partner. So why include them in our annual report? It is because part of SIMLab's activities in the year behind us followed up the 2011 decision of the scientific advisory board to focus more on terror. Developing our contact with NSM belongs to this picture. NSM collaborates closely with SIMLab partner NDEA and has a crucial coordinating position in helping society understand the situation: How do we address it? What are the right steps?

NSM is constantly looking for good research proposals as well as giving assignments.

"We really need highly competent scientific bodies to do security research," confirms NSM assistant director Dagfinn Buset.

CONSEQUENCES OF JULY 22ND

July 22nd obviously influenced the work of NSM. Mr Buset puts it like this:

"The attack showed with crystal clarity that incidents might occur without any warning whatsoever. From the first minute, before the police and rescue services arrived, a lot of functions and offices were left isolated. For us, the paramount issue in such a situation is to have basic security in place, to have permanent measures which resist or reduce damage by the use of barriers, buildings and constructions, to detect and react as swiftly as possible. In that particular situation, NSM gave advice to government offices and others about how to secure protected and encrypted information. We focused on object security before July 22nd and will continue to do so."

In the aftermath, it has been a major task for NSM to make sure that the affected government offices were re-established in suitable,secure surroundings.

COORDINATORS

The role of NSM is not to give exact specifications on the thickness of walls and the like. Rather, they are a coordinating body, making sure that the right pieces of advice arrive at the right place at the right time.

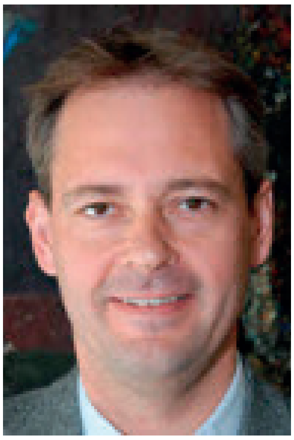
"The gap between threats and security measures is increasing. This is worrying," observes Dagfinn Buset: "Therefore we need to make society understand the importance of improving security across sectors. We also need to direct attention towards vulnerable spots. "

WHAT IF . . . ?

NSM's job is to prepare for the worst. As part of that, they naturally ask "what if?" after a major incident. For example: what if the government's high-rise office block, with the prime minister's office on top, had been constructed according to today's standards and regulations? Would it have collapsed like the Twin Towers? Dagfinn Buset's answer is, if not crystal clear, definitely noteworthy:

"I don't have the qualifications to give you an exact answer. However, I've registered one trait: In earlier days, buildings were constructed taking into account that one wasn't quite sure how much they needed to take. Now, the aim seems to be a building that is exactly as safe as it needs to be. As a consequence, the spare resistance capacity that used to be there is not there any longer. The consequence could be more vulnerable constructions. But again, this is something where I think; I'm not qualified to give you an exact answer."

Bird's-eye view of the sea



Last year's annual report contained a story about the close cooperation between SIMLab, its long-time partner Hydro and the car industry. This year a few words about Hydro's marine vision are in place.

Newly appointed Head of Technology, Senior Vice President Hans Erik Vatne explains:
"Let's take a bird's-eye view at it. Norway is world leading in aluminium. At the same time we are world leading in marine sectors like oil, gas, shipbuilding and fish farming. Our vision is to combine the sectors. Aluminium is low on corrosion, maintenance and weight. In the north, weight is critical when icing occurs. In the far north another quality may become increasingly important: aluminium gets stronger the colder it is. Steel, on the contrary, turns brittle."

CONSERVATIVE STANDARDS

Approaching these challenges, Vatne sees an obvious need for SIMLab's expertise:

"The activities in The North Sea are ruled by conservative standards. SIMLab can help us show the usefulness of new materials that aren't contained in today's standards. SIMLab's simulation skills and material database provide the required competence to ease the introduction of very promising new product areas. An exciting part of this is SIMLab's contribution to the automotive industry. This industry leads the use of simulation tools to cut time in bringing forward new models. We think other industries such as oil and gas have something to learn in this respect and SIMLab can help us do this. In this way we will reap even greater benefits from SIMLab's expertise. It should certainly thrill the Research Council of Norway to see the gains from the money invested when the oil and gas industry realizes the usefulness of this research."

SHOULD TAKE ADVANTAGE

"An additional point is the potential benefit for the people working on design and construction in the oil and gas sector. Today this environment is very much concentrated around steel. Many students have hardly any knowledge about the use of aluminium in large constructions. SIMLab's educational environment, on the other hand, has a lot to offer master's and PhD students in this field. This is an important function. If we don't teach our students, industry is left without the possibility to take advantage of our national resources and potential," Hans Erik Vatne points out.

WORLD'S LEADING PROVIDER

Vatne's statement comes at a truly exciting moment in the company's history. Hydro and the Nordic conglomerate Orkla have agreed to combine their respective profiles, building systems and tubing businesses, creating the world's leading aluminium solutions provider. The new company, to be named Sapa, will be a 50/50 joint venture. As this annual report goes to print, the completion of the transaction is still pending.

Concentrating efforts

Last October, the Norwegian government decided to establish a competence centre focusing on the protection and security of governmental properties, buildings and sites. The task was given to the Norwegian Defence Estates Agency (NDEA).

NDEA is a long-time partner of SIMLab. In last year's annual report we interviewed Helge Langberg. At the time he headed R&D at NDEA, now he is the head of the new competence centre. The centre includes the former R&D activities but is four times as large and growing. This is partly due to the reorganization of already existing NDEA activities, and partly because of expansion following new tasks and challenges.

CLEAR RECOGNITION

The government's decision on where to place the competence centre is clear recognition of NDEA's capacities in this field and signals the government's conviction that one, central unit will be more beneficial than spreading the expertise amongst several units in different governmental organizations. The new centre widens the scope of activities under Mr Langberg's command substantially. Earlier his R&D work was focused on protecting buildings, camps and properties of the armed forces. It was only when there was spare capacity that he and his colleagues helped other governmental or public authorities. This was also the case for two other NDEA departments that are now included in the competence centre.

As of October 15th last year, the exception became the rule. All buildings, properties and sites belonging to the government are included in the domain of the centre.

VERY MUCH IN DEMAND

The centre is not a result of the July 22nd terrorist attack: "The idea was already on our minds and plans in the making. However, there is no doubt that July 22nd speeded things up," Helge Langberg confirms.

The new competence centre operates somewhat differently from most other governmental offices in the sense that all work is ordered and paid for through consultation contracts. There is no basic funding on the side. This doesn't worry Helge Langberg one bit: "The challenge is rather to be able to meet the demand. So far we have more assignments than we are able to deliver. That's also why we are still growing," he states.

NEEDS SIMLab

Assignments include project planning, recommendations, R&D, risk calculation, protection methods and so on. Some of the fundamental research will be carried out at SIMLab in Trondheim, but NDEA will also perform research and carry out small- and full-scale tests in their own right.

"As far as I can see now, we will carry on our cooperation with SIMLab much in the same way as before. The need for this cooperation certainly hasn't become less with the new centre," Helge Langberg says.

SIMLab test facilities

The laboratory at SIMLab/Department of Structural Engineering is equipped with a number of special-purpose test facilities. Some of these facilities 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.

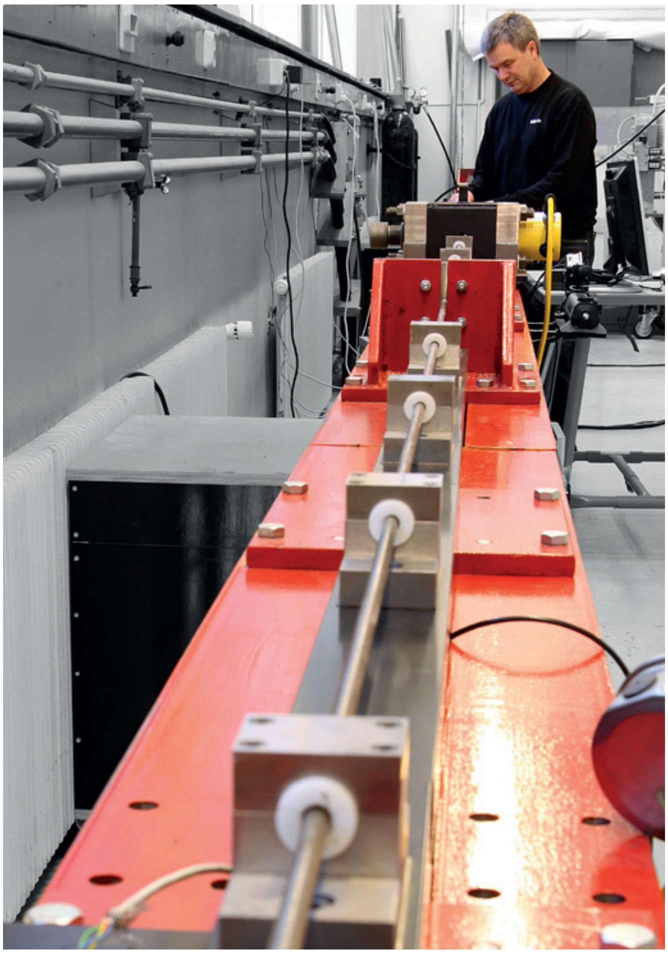
Material testing at elevated rates of strain

Split-Hopkinson Tension Bar (SHTB)

The split-Hopkinson tension bar, see Figure 12, 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.

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.



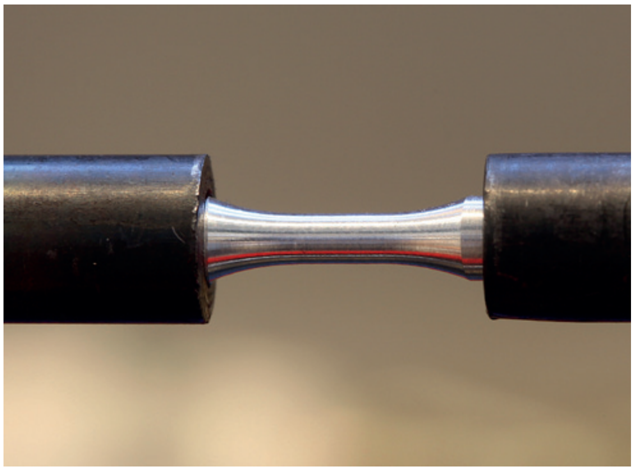


Figure 12 – Split-Hopkinson tension bar. Photo: Melinda Gaal

Split-Hopkinson pressure bar (SHPB)

The new split-Hopkinson pressure bar at SIMLab, Figure 13, 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 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.

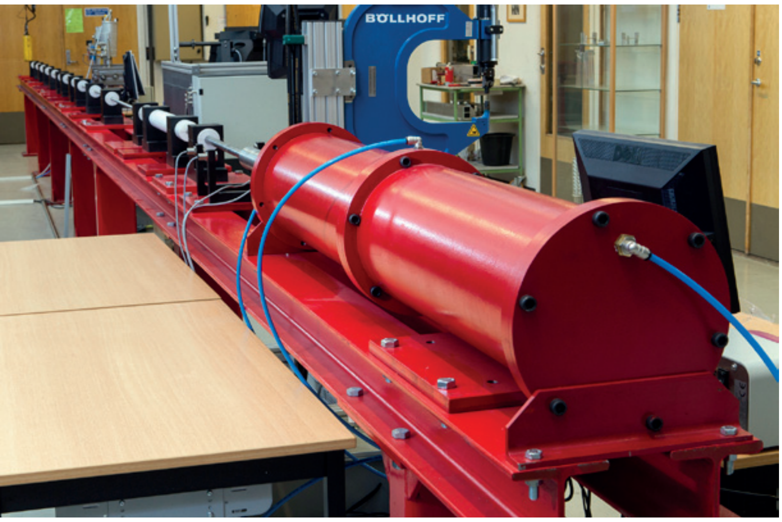


Figure 13 – Split-Hopkinson pressure bar.
Photo: Ole Morten Melgård

Hydro-pneumatic machine (HPM)

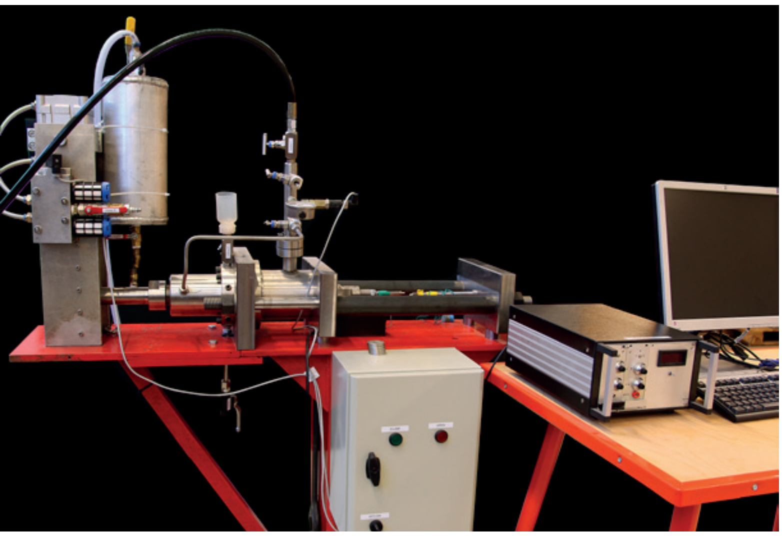


Figure 14 – Hydro-pneumatic machine. Photo: Melinda Gaal

The hydro-pneumatic machine (HPM), see Figure 14, 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 12, 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 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 15, 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 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.

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.* Accepted for publication in Strain, 2013.

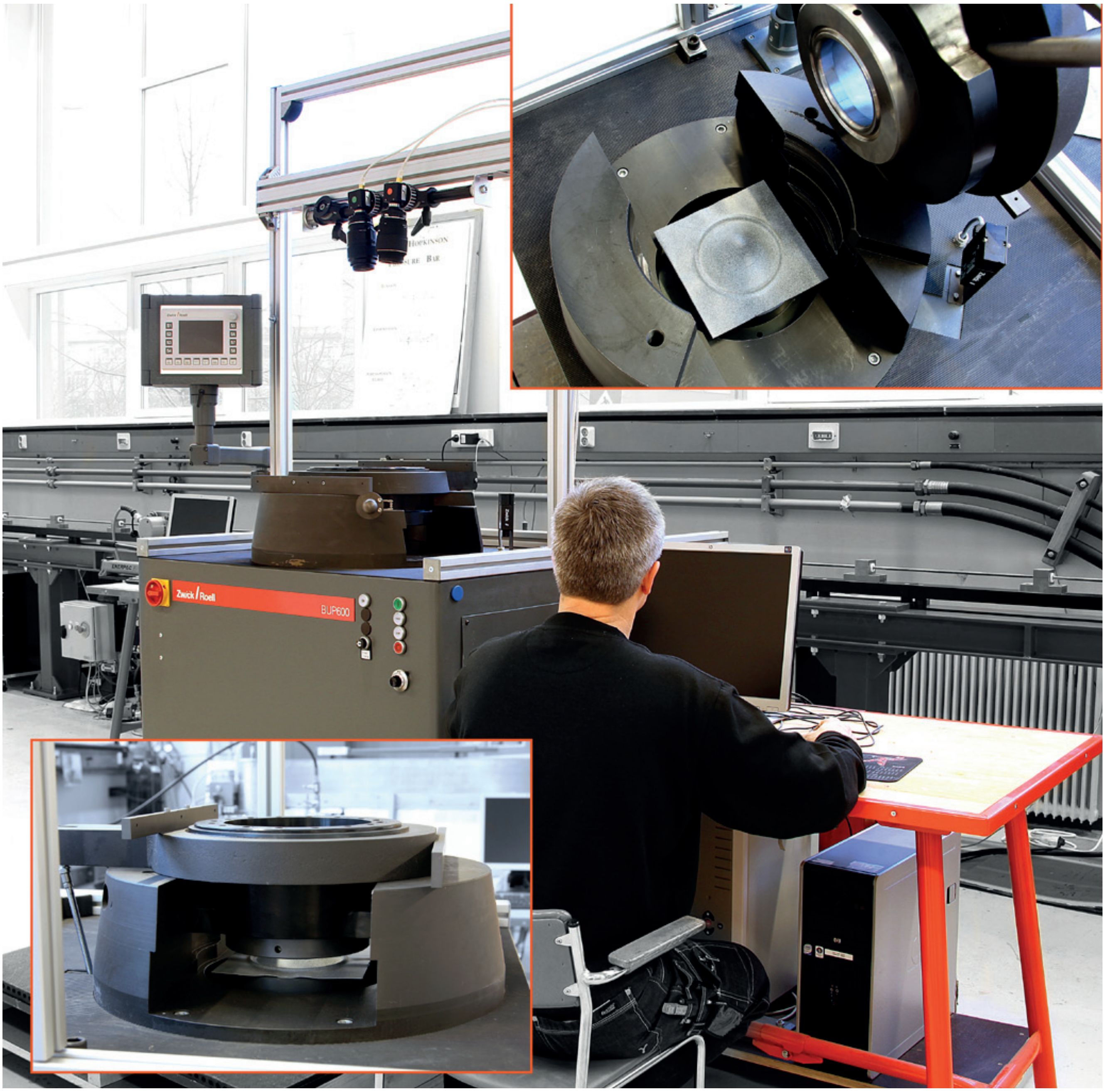


Figure 15 – BUP 600 machine. Photo: Melinda Gaal.

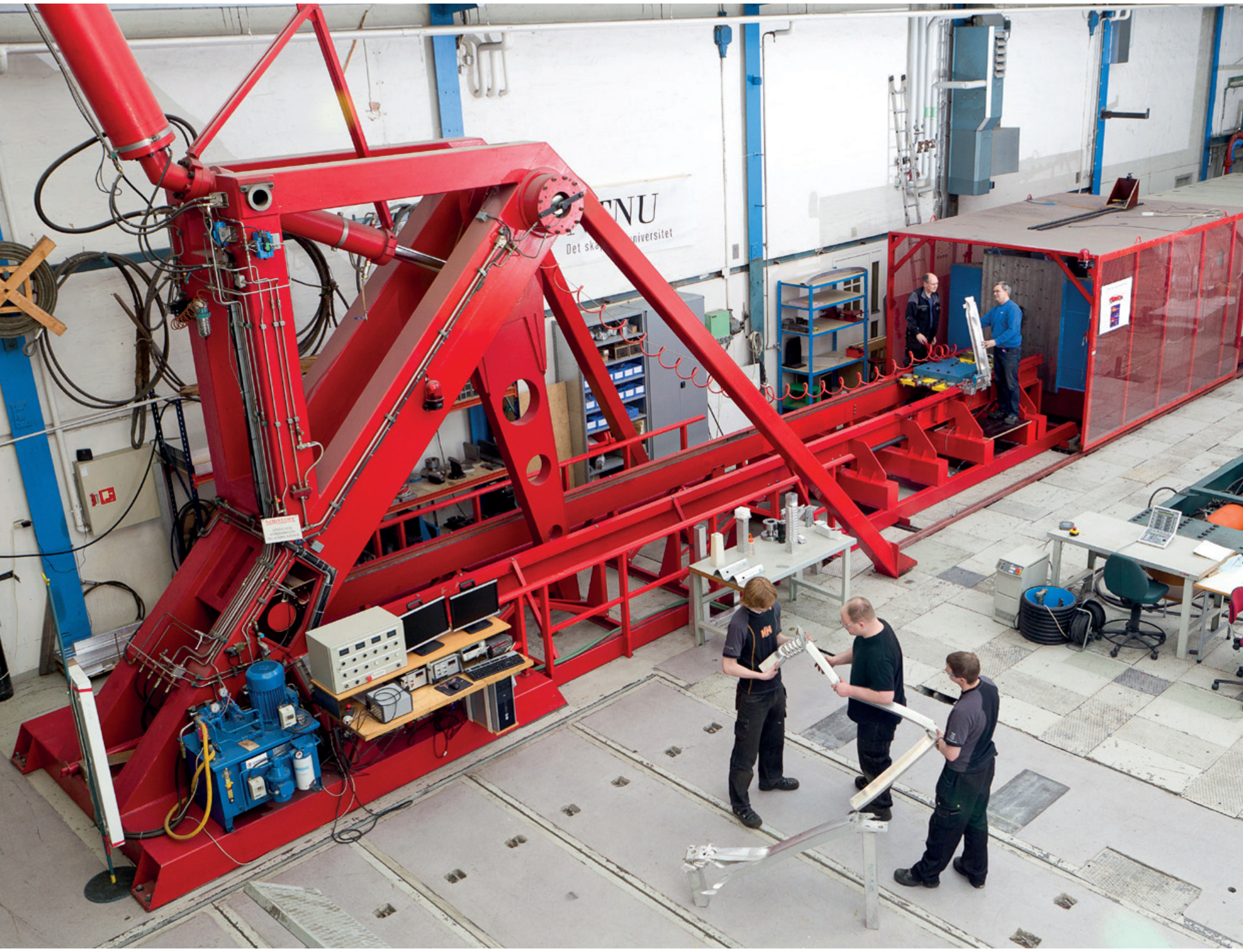


Figure 16 – Pendulum accelerator. Photo: Ole Morten Melgård

Pendulum accelerator (Kicking machine)

The pendulum accelerator is a device for impact testing of components and structures, Figure 16. 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.

Figure 17 – Pneumatic accelerator. Photo: Melinda Gaal

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.

Pneumatic accelerator

In this test rig, see Figure 17, 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.

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.

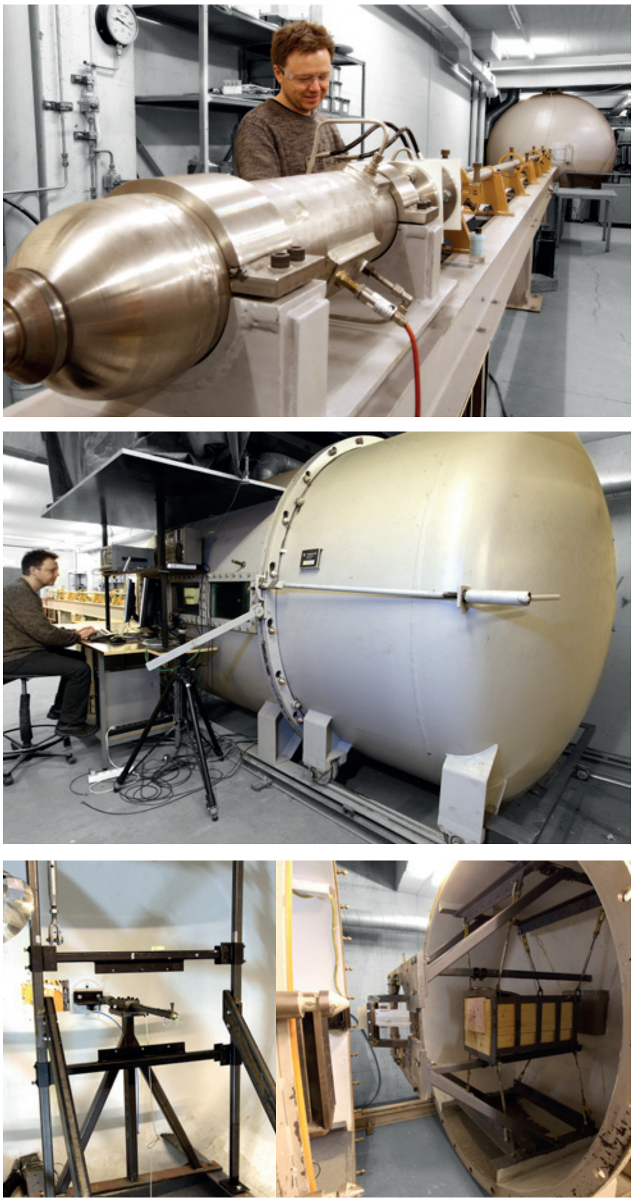


Figure 18 – Compressed gas-gun facility. Photo: Melinda Gaal

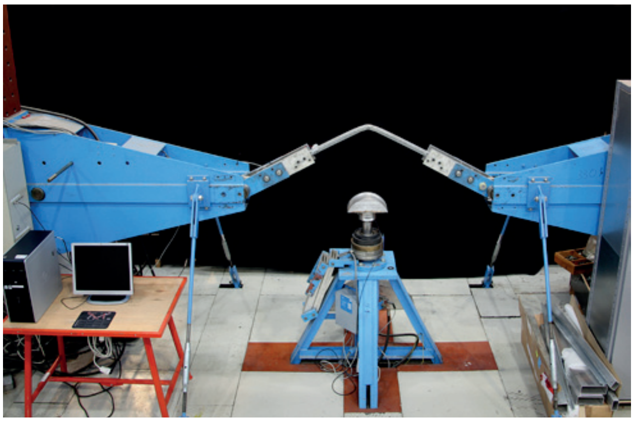
Compressed Gas Gun

A picture of the compressed gas gun is shown in Figure 18. 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 m^3 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 250g 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 may 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.



Stretch-bending rig

The stretch-bending rig, see Figure 19, 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 servohydraulic 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. It can be operated in force as well as displacement control, and a broad variety of loading sequences may thus 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. and Langseth M.: *Stretch bending rig. Experimental set-up*. Report R-9-96 (Revised 1999). Department of Structural Engineering, NTNU.

Droptower impact system

In this machine, see Figure 20, impact testing of materials and small components can be carried out at low and high temperatures. The projectile's mass 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

Figure 20 – Droptower impact system. Photo: Ole Morten Melgård

Joining machine

Self-piercing riveting machine

In this machine, see Figure 21, self-piercing riveting can be carried out of sheets under industrial conditions. The machine has been purchased from Böllhoff in Germany.

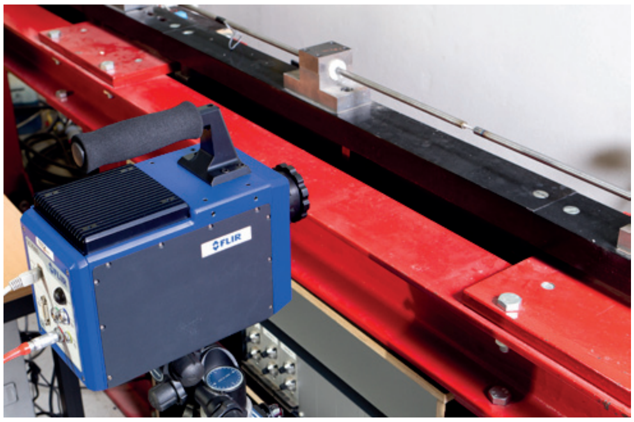
FOR MORE INFORMATION:
(http://www.boellhoff.com/en/de/assembly_systems/riveting/rivset.php)

Cameras

Infrared camera

The infrared camera (FLIR SC7500) shown in Figure 22 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.

FOR MORE INFORMATION:
www.flir.com



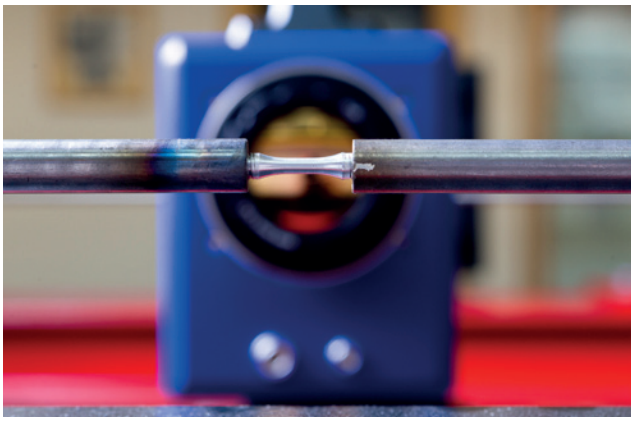


Figure 22 – Infrared camera. Photo: Ole Morten Melgård

Figure 21 – Self-piercing riveting machine. Photo: Melinda Gaal

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. The latter two cameras were purchased in 2012.

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.

Concurrent research projects

Utilizing the high level of competence that has been developed at the Centre, a selection of research projects that have been run in 2012 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 PV industry long-term access to world leading technological and scientific expertise.

KMB COMPACT (2009-2013): This project is based on collaboration with the research group 'Polymers and composites' at SINTEF Materials and Chemistry, and other industries than those that are involved in the Centre. There is close analogy to the activities at the Centre as this project will develop design tools for composite structures on advanced continuous fibre polymer composites. One PhD candidate is supervised by personnel from the Centre.

European Commission-funded projects

The issue of EU applications with involvement from the partners has been discussed by the Board, but so far there is no enthusiasm for such an initiative among the majority of the industrial partners. Based on experience from previous EU projects, the international partners say that the CRI-concept is a much better model in order to obtain generic technical focus where theory and applications are strongly linked. Thus the strategy in 2012 has been, as previous years, not to take any initiative for such an application, but rather try to be involved in applications where the initiative is coming from an institution outside the consortium.

With this in mind, NTNU has been involved in an EUROSTARS proposal on the development of a new non-linear simulation tool for mechanical and multi-physics problems with unsurpassed accuracy, user-friendliness and industrial robustness adapted near-100 % to computing on graphics processing units (GPU), which is a new hardware technology for high computational speed. The partners behind the application were Impetus Afea Norway (coordinator), Impetus Afea Sweden, NVIDIA Corporation, Centro Ricerche Fiat and NTNU. The application was approved and the duration of the project is 3 years starting on 1 April 2012. The role of NTNU is to carry out validation of the proposed software.

New equipment

High-speed cameras: Two Phantom V1610 high-speed cameras have been purchased. At a speed of 16 000 FPS the resolution is 1280x800 pixels, whereas at a speed of 1 000 000 FPS the resolution is 128x16 pixels.

Cameras for DIC developments: Two Prosilica GC2450 cameras have been purchased to support future developments of the DIC technique at SIMLab. The cameras have a maximum speed of 15 FPS.

Visibility

Workshops and seminars

Professors Per Kristian Larsen and Arne Aalberg at SIMLab were involved in organizing the Nordic Steel Construction Conference held in Oslo on 5-7 September 2012. Professor Larsen was the chair of the technical committee, whereas Professor Arne Aalberg at SIMLab was a member of the organizing committee. The 83 presentations at the conference covered important issues for modern steel construction; building structures, bridges, high strength and stainless steel, connections, fire engineering and composites structures.

Invited and guest lectures

Professor Arild Holm Clausen gave a lecture at a seminar organized by the professional trade union Tekna, 5-6 June 2012, in Oslo. The title was: *Fra en faglærers ståsted: Ha'kke tid, ha'kke råd,* focusing on challenges related to teaching and research.

Professor Arild Holm Clausen gave a guest lecture at the University of São Paulo, Group of Solid Mechanics and Structural Impact (GMSIE) on 21 November 2012, in São Paulo, Brazil. The lecture was titled *Void Growth in a Mineral-Filled PVC - an Experimental and Numerical Study.*

Professor Magnus Langseth was invited to give a presentation of SIMLab at the Research Council of Norway's industry and commerce seminar *Næringslivsdagen* on 24 April 2012. The presentation was titled *Forskning som redder liv*, presenting SIMLab's research and potential for innovation.

Professor Magnus Langseth gave a lecture at a seminar organized by the professional trade union Tekna on 5-6 June 2012, in Oslo. The lecture title was *Forskning ved bruk av laboratorier,* presenting SIMLab's use of laboratories in research.

Post doc David Morin held a presentation at the University of Valenciennes, Engineering school-ENSIAME, on 19 October 2012 in Valenciennes, France. The title was *Modelling of connections in the automotive industry.*

Post doc David Morin gave a lecture at the University of Valenciennes, Science institute - ISTV, on 19 October 2012 in Valenciennes, France. The lecture was titled *Modélisation des assemblages dans l'industrie automobile.*

Magazines/Newspapers/TV/Conferences

An article describing SIMLab's activity and the cooperation with Audi AG was printed in the magazine **aktuelt@møller.no no. 1 2012**, a trade magazine for the Norwegian Audi dealer MøllerGruppen AS.

An article discussing security issues was published in the Research Council of Norway's magazine **Bladet Forskning no. 1 2012**. The article was written by Professor Magnus Langseth.

Head of Research at Benteler Aluminium Systems, Anders Artelius, highlighted the importance of their collaboration with SIMLab at a conference in Sandefjord on 8-9 September 2012.

Adresseavisen 10 May 1012 A picture of Professor Tore Børvik was used in a job advertisement for the Norwegian Defence Estates Agency. Børvik is quoted: "Graduated? Never."

Fædrelandsvennen 24 February 2012
SIMLab is involved in a EUROSTARS application that was approved. This was covered both by the local newspaper *Fædrelandsvennen* in the city of Kristiansand and the local TV station *NRK Sørlandet*. This was on 24 and 25 February respectively.

SIMLab's activity was presented in the magazine **Innsikt no. 1 2012**. *Innsikt* is a magazine for employees at the Norwegian Defence Estates Agency.

Dagens Næringsliv 1 June 2012
PhD Anne Serine Ognedal wrote a feature article about SIMLab's development of computer models and the cooperation with the car industry. The article was published in *Dagens Næringsliv*, Norway's leading business newspaper on 1 June 2012.

A delegation from SIMLab's partner Hydro, led by their CEO Svein Richard Brandtzæg, visited SIMLab on 18 April. The visit was covered by the TV news on the Norwegian Broadcasting Corporation (NRK) and in an article in Teknisk Ukeblad no. 16 2012, a weekly technical journal.

B. Holmedal, Aa. Reyes, O.S. Hopperstad and T. Furu

T. Auestad and T. Wisth

Testing in the Kicking machine

M. Langseth, S.R. Brandtzæg, T. Børvik and S. R. Skjærvold

B. Holmedal, S.R. Brandtzæg, H.E. Vatne

A. Skille (NRK), S.R. Brandtzæg, M. Langseth

Photo: Ole Morten Melgård.

Committees

- Professor Magnus Langseth was elected as a member of the Board of DYMAT - European association for the promotion of research into the dynamic behavior of materials and its applications.

- Professor Magnus Langseth, NTNU is a member of an International Scientific Committee at the University of Valenciennes, France, evaluating the research carried out at the Centre for Sustainable Transports and Mobility.

Visits

- The 11th Alunord seminar visited SIMLab on 25 September. The group of 60 people consisted of teachers and students from the Nordic and Baltic countries. The seminar focused on the use of aluminum.

- A delegation from the Australian oil company Apache and GE Oil & Gas was given a tour at SIMLab on 23 November.

National cooperation

The Centre has ongoing cooperation with Professor Ørjan Fyllingen at the Bergen University College. Graduated as PhD from SIMLab in 2008, he has specialized in how parameter variations can be taken into account in numerical simulations to predict robust behaviour of structures subjected to impact. Ørjan Fyllingen is a co-supervisor for one of the PhD candidates (Espen Myklebust) at SIMLab.

International cooperation

Visiting scientists/professors

The following researchers visited SIMLab in 2012:

- Professor Georges Cailletaud Ecole des Mines de Paris, France. January-May 2012
- François Moussy, France. 21-24 May 2012 and 26-30 November 2012
- Professor Thomas Pardoen, Louvain School of Engineering, Belgium. 26-27 January 2012
- Professor Laurent Tabourot, University of Savoie, Annecy, France. 11-12 June 2012
- Professor Ahmed Benallal, LMT-Cachan, France. 26-30 November 2012

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 2012:

- *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). Impetus Afea (Dr Lars Olovsson), Sweden. Politecnico di Milano (Assoc Professor Andrea Manes) and European Commission, Joint Research Centre (JRC), Institute for the Protection and Security of the Citizen, Ispra (Dr Folco Casadei), Italy. Harvard University (Professor John Hutchinson) and University of Virginia (Professor Hayden Wadley), USA. University of Liverpool (Dr Graham Schleyer), UK. Technical University of Madrid (Dr Francisco Gálvez Díaz-Rubio), Spain. Dr. Warren and Dr. Forrestal, USA.

- *Research visits abroad by our PhD candidates and SIMLab staff*
  – Two of our PhD candidates, Martin Kristoffersen and Knut Garder Rakvåg spent three months at JRC Ispra, Italy, in the spring of 2012.

  – Professor Hopperstad stayed at ENS Cachan, France from 23 May to 1 June 2012.

  – Professor Aase Gavina Reyes started her sabbatical year at University of Florida, USA in August 2012.

  – Professor Arild Holm Clausen visited the Group of Solid Mechanics and Structural Impact (GMSIE) at University of São Paulo, Brazil from 22 November to 1 December 2012.

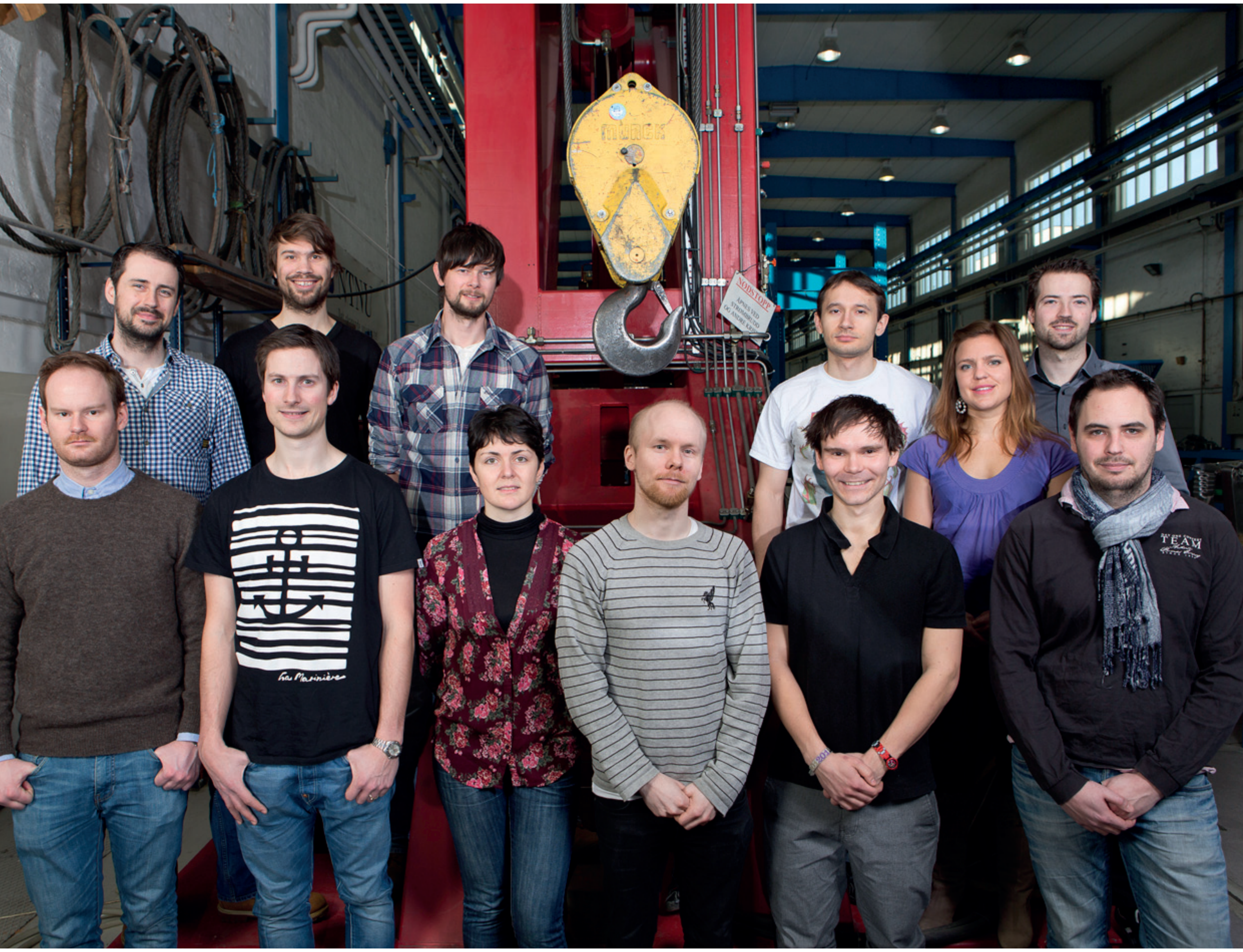
Guest lectures at SIMLab

The following guest lectures were given at SIMLab in 2012:

- Professor Ahmed Benallal, LMT-Cachan, France: *Instabilities and localization in coupled problems.*
- Professor Georges Cailletaud, Ecole des Mines de Paris, France. The following guest lectures were given during his stay at SIMLab:
  - Multiscale modelling of the contact between rough surfaces.
  - From thermodynamics to the general elasto-plastic formulation of material models.
  - Multiscale modeling of transformation induced plasticity.
- PhD student Liza Lecarme, Louvain School of Engineering, Belgium: *Influence of viscoplastic effects on damage and fracture of titanium alloy Ti-6Al-4V.*
- Francois Moussy, France. The following guest lectures where given during Moussy's two visits at SIMLab:
  - Lightening of cars: Realism of the last developments issued from the car industry versus proposals issued from material suppliers and from some academic institutions.
  - How to reduce weight of a car body.

- Professor Thomas Pardoen, Louvain School of Engineering, Belgium: *Ductility of thin nanocrystalline metallic films revealed by on chip nanomechanical testing*.
- PhD student Ryan Holloman, University of Virginia, USA: *Compressive response of an aluminum square tube structure.*
- Professor Laurent Tabourot, University of Savoie, France: *Compartmentalized model for the mechanical behaviour of metallic materials.*
- PhD candidate Nicholas Underwood, University of Liverpool, UK: *Progressive collapse.*
- Duane Detwiler, Manager, Vehicle Structure Research at Honda R&D Americas, Ohio, USA: *Computer Aided Engineering at Honda.*

Students



PhD candidates and post docs. First row from left: Knut Rakvåg, Vegard Aune, Marion Fourmeau, Marius Andersen, Martin Kristoffersen, David Morin.
Second row from left: Octavian Knoll, Espen Myklebust, Egil Fagerholt, Mikhail Khadyko, Anne Serine Ognedal, Vincent Vilamosa.
Photo: Ole Morten Melgård.

PhD candidates

The following PhD candidates have been connected to the Centre in 2012:

Name	Start	Planned exam	Programme	From	Male/Female
Henning Fransplass*	Spring 2005	Autumn 2013	C&J	Norway	Male
Egil Fagerholt*	Winter 2008	Spring 2012	F&CP	Norway	Male
Gaute Gruben*	Summer 2008	Autumn 2012	F&CP	Norway	Male
Anne S. Ognedal*	Autumn 2008	Autumn 2012	Polymers	Norway	Female
Octavian Knoll*	Summer 2009	Autumn 2013	F&CP	Germany	Male
Marion Fourmeau**	Autumn 2009	Autumn 2013	F&CP	France	Female
Knut Rakvåg**	Summer 2009	Summer 2013	OptiPro	Norway	Male
Dmitry Vysochinskiy**	Spring 2010	Autumn 2014	M^4	Russia	Male
Mikhail Khadyko**	Autumn 2010	Autumn 2014	M^4	Russia	Male
Martin Kristoffersen*	Autumn 2010	Autumn 2014	OptiPro	Norway	Male
Espen Myklebust**	Autumn 2009	Spring 2014	M^4	Norway	Male
Marius Andersen*	Autumn 2011	Autumn 2015	Polymers	Norway	Male
Vincent Vilamosa*	Autumn 2011	Autumn 2014	M^4	France	Male
A.B. Alisibramulisi**	Autumn 2007	Autumn 2013	M^4	Malaysia	Female
Vegard Aune**	Autumn 2012	Autumn 2016	OptiPro	Norway	Male

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

New PhD candidate in 2012
Vegard Aune started as PhD candidate in August 2012. Aune is a former master's student at SIMLab.

Related PhD candidates in 2012
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.

Equal opportunity
In 2012, 3 of the 15 PhD candidates were females, i.e. 20%.

Post docs

The following post docs were linked to the Centre in 2012:

Name	Start	End	Programme	From	Male/Female
David Morin	Autumn 2010	Autumn 2014	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 2012:

- Master's student Luca D'Angelo from University of Naples, Italy, visited SIMLab for 5 months. He was associated with the Connectors and Joints programme.
- Master's student Joumana Benabou from University of Valenciennes, France, stayed at SIMLab for 5 months and was associated with the Connectors and Joints programme.
- PhD candidate Andrea Gilioli from Politecnico di Milano, Italy , stayed at SIMLab for 1,5 months and was associated with the OptiPro programme.
- PhD candidate Nicholas Underwood from the University of Liverpool, UK, visited SIMLab for 2 weeks in the autumn of 2012. He was associated with the OptiPro programme.
- Master's student Robin Vacher from the University of Annecy, France, stayed at the Centre for 3 months and was associated with the Fracture and Crack Propagation programme.
- Phd candidate Mathieu Vautrot from the University of Savoie, France, stayed at the Centre for 3 months and was associated with the Fracture and Crack Propagation programme.

Master's student

The following master's students were associated with the Centre in 2012:

STUDENT	TOPIC
V. Aune and M.S. Hovdelien*	*Impact Against Offshore Pipelines*
H. Bergsager and E.H. Bårgard*	*Buried Penstock in Steep Terrain*
A. Bratlie and C.B. Hillestad*	*Impact on Duplex Steel Pipes with Precipitated Sigma-phase*
J.Ø. Gjernes and E.R. Klokk*	*Simulation of fracture and crack propagation using X-FEM*
M.K. Grindstad and A. Ostad*	*Behaviour of End Plate Joints in Hollow Sections*
S. Gundstad and O. Neset*	*Structural Frame for Tidal Stream Turbine*
E.F. Haare	*Penetration of Pile Shoes in Rock*
N.K. Haga and L.J. Reiersølmoen*	*Design of steel fasteners for use in concrete*
T. Hegni	*Validation of material model for polypropylen (HDPE)*
J.K. Holmen and J. Johnsen*	*Effects of Heat Treatment on the Ballistic Properties of AA6070 Aluminium Plates*
T. Karlsen and A.B. Kjølseth*	*Fragmentation of Metallic Materials During Impact*
V. Martinsen	*Micromechanical Modelling of Strain Localization and Fracture in Aluminium*
V. Schønberg and C.D. Øien*	*Simulations of impact using the modified Gurson model*
K. Sælen	*Validation of material model for polypropylene (PP)*
K. Vange	*Validation of material model for polypropylene (PP)*
T. Østen	*Validation of Material Model for Polyvinyl Chloride (PVC)*

* Joint thesis

PhD disputations

EGIL FAGERHOLT defended his thesis on 30 March. The topic of his thesis was *Field Measurements in Mechanical Testing Using Close-Range Photogrammetry and Digital Image Analysis.* 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 Pierre Vacher from the University of Annecy, France and Professor François Hild from ENS Cachan/CNRS/UPMC/PRES UniverSud Paris, France, while Adjunct Professor Arve Grønsund Hanssen from NTNU acted as administrator.

PhD disputation for Egil Fagerholt - supervisor and committee. From the left: Odd Sture Hopperstad, Tore Børvik, Pierre Vacher, François Hild, Egil Fagerholt and Arve Grønsund Hanssen.

GAUTE GRUBEN defended his thesis on 4 October. The topic of his thesis was *Ductile Fracture in Dual-Phase Steel. Theoretical, Experimental and Numerical Study.* His supervisors were Professor Tore Børvik and Professor Odd Sture Hopperstad, both from Department of Structural Engineering, NTNU. The evaluation committee had four members; Professor Em. Norman Jones from the University of Liverpool, UK, Professor Larsgunnar Nilsson from the University of Linköping, Sweden, Professor Ørjan Fyllingen from Bergen University College, Norway, while Professor Magnus Langseth from NTNU was administrator.

PhD disputation for Gaute Gruben – supervisors and committee. From the left: Odd Sture Hopperstad, Norman Jones, Ørjan Fyllingen, Gaute Gruben, Larsgunnar Nilsson, Magnus Langseth and Tore Børvik

ANNE SERINE OGNEDAL defended her thesis on 15 November. The topic of her thesis was *Large-Deformation Behaviour of Thermiplastics at Various Stress Rates – An Experimental and Numerical Study.* Her supervisors were Professor Arild Holm Clausen and Professor Odd Sture Hopperstad, both from Department of Structural Engineering, NTNU. The evaluation committee had four members; Professor Nadia Bahlouli from the University of Strasbourg, France, Professor Franck Lauro from the University of Valenciennes, France and Dr Frode Grytten from SINTEF, Norway, while Professor Tore Børvik from NTNU was administrator.

Dr. Anne Serine Ognedal with the committee and supervisors. From left: Tore Børvik, Nadia Bahlouli, Arild Holm Clausen, Anne Serine Ognedal, Frode Grytten, Odd Sture Hopperstad and Franck Lauro.

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 2012 are shown below.

SIMLab: Funding 2012 (All figures in 1000 NOK)

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	1016	312			870		100						400	1328	2698	0.49
C & J	I																
F&CP	F	2222	1313		200		500				85	200		600	3535	5120	0.69
F&CP	I																
M^4	F	1158	212	1100								100		2400	2470	4970	0.50
M^4	I																
OptiPro	F	1552	912		1780							200			2464	4444	0.55
OptiPro	I																
Poly	F	1186	1573				200		700	200		200			2759	4059	0.68
Poly	I																
Demo	F																
Demo	I		212		80	80	80	80	80	80	80	80	280	80	212	1212	0.17
Equipment		1577			27	30	30	30	30	30	30	10	30	50	1577	1874	
Adm		1220	1000		113	140	190	290	190	190	455	10	190	570	2220	4558	
Total		9931	5534	1100	2200	1120	1000	500	1000	500	650	800	500	4100	16565	28935	

F = Fundamental research
I = Industrial research

RCN = Research Council of Norway
NDEA = Norwegian Defence Estates Agency

NPRA = Norwegian Public Roads Administration

SIMLab: Cost 2012 (All figures in 1000 NOK)

Research Programmes	Host (NTNU)	SINTEF	NDEA	NPRA	AUDI	BMW	Renault	Toyota	Statoil	SSAB	Benteler	Hydro	Total
C & J	928	700		870								200	2698
F&CP	2570	1850	200		500								5120
M^4	1070	1400								100		2400	4970
OptiPro	2844	400	1000							200			4444
Poly	2559	1000					500						4059
Demo	212	800									200		1212
Equipment	1874												1874
Adm	3238	1320											4558
Total	15295	7470	1200	870	500	0	500	0	0	300	200	2600	28935

Publications

The following lists journal publications and conference contributions generated from the Centre in 2012:

Journal publications

1. Dumoulin S., Engler O., Hopperstad O.S., Lademo O-G.: *Description of plastic anisotropy in AA6063-T6 using the crystal plasticity finite element method.* Modelling and Simulation in Materials Science and Engineering 20 (2012) 055008 (20pp).
2. Fagerholt E., Østby E., Børvik T., Hopperstad O.S.: *Investigation of fracture in small-scale SENT tests of a welded X80 pipeline steel using digital image correlation with node splitting.* Engineering Fracture Mechanics 96 (2012) 276-293.
3. Fyllingen Ø., Langmoen E.C., Langseth M., Hopperstad O.S.: *Transition from progressive buckling to global bending of square aluminium tubes.* International Journal of Impact Engineering DOI:10.1016/j.ijimpeng.2011.02.010 (2012).
4. Grong Ø.: *Recent Advances in Solid-State Joining of Aluminium.* Welding Journal Vol. 91 (2012) 26-33.
5. Gruben G., Hopperstad O.S., Børvik T.: *Evaluation of uncoupled ductile fracture criteria for the dual-phase steel Docol 600DL.* International Journal of Mechanical Sciences 62 (2012) 133-146.
6. Hoang N-H., Hanssen A.G., Langseth M., Porcaro R.: *Structural behaviour of aluminium self-piercing riveted joints: An experimental and numerical investigation.* International Journal of Solids and Structures 49 (2012) 3211-3223.
7. Kang J., Mishra R.K., Wilkinson D.S., Hopperstad O.S.: *Effect of Mg content on Portevin-Le Chatelier band strain in Al-Mg sheet alloys.* Philosophical Magazine Letters DOI:10.1080/09500839.2012.714082 (2012).
8. Lademo O-G., Engler O., Benallal A., Hopperstad O.S.: *Effect of strain rate and dynamic strain ageing on work-hardening for aluminium alloy AA5182-O.* International Journal of Materials Research (formerly: Zeitschrift fuer Metallkunde) DOI: 10.3139/146.110741 (2012).
9. Manes A., Porcaro R., Ilstad H., Levold E., Langseth M., Børvik T.: *The behaviour of an offshore steel pipeline material subjected to bending and stretching.* Ships and Offshore Structures 7:4 (2012), 371-387.
10. Ognedal A.S., Clausen A.H., Polanco-Loria M., Benallal A., Raka B., Hopperstad O.S.: *Experimental and numerical study on the behaviour of PVC and HDPE in biaxial tension.* Mechanics of Materials 54 (2012), 18–31.
11. Othman R.: *Cut-off Frequencies Induced by the Length of Strain Gauges Measuring Impact Events.* Strain 48 (2012), 16-20.
12. Vautrot M., Balland P., Hopperstad O.S., Tabourot L., Raujol-Veille J., Toussaint F.: *Characterization of High Carbon Steel C68 at Elevated Temperatures and Different Strain Rates.* Technische Mechanik 32 (2012), 577 – 586.
13. Vysochinskiy D., Coudert T., Reyes A., Lademo O-G.: *Determination of forming limit strains using Marciniak-Kuczynski tests and automated digital image formulation procedures.* Key Engineering Materials 504-506 (2012), 17–22.
14. Westermann I., Hopperstad O.S., Marthinsen K., Holmedal B.: *Effect of alloying elements on stage-III work-hardening behaviour of Al-Zn-Mg(-Cu) alloys.* International Journal of Materials Research (formerly: Zeitschrift fuer Metallkunde) 103 (2012), 603-608.

Invited lectures

1. Clausen A.H.: *Fra en faglærers ståsted: Ha'kke tid, ha'kke råd.* Teknaseminar: Ludorium et laboratorium - Fra sandkasse til vitenskap. 5-6 June 2012, Oslo.
2. Clausen A.H.: *Void Growth in a Mineral-Filled PVC – an Experimental and Numerical Study.* Guest lecture at the University of São Paulo, Group of Solid Mechanics and Structural Impact (GMSIE), 21 November 2012, São Paulo, Brazil.
3. Langseth M.: *Forskning som redder liv.* Presentation at Forskningsrådets Næringslivsdag, 24 April 2012, Oslo.
4. Langseth M.: *Forskning ved bruk av laboratorier.* Teknaseminar: Ludorium et laboratorium - Fra sandkasse til vitenskap. 5-6 June 2012, Oslo.
5. Morin D.: *Modelling of connections in the automotive industry.* Presentation at the University of Valenciennes, ENSIAME, 19 October 2012, Valenciennes, France.
6. Morin D.: *Modélisation des assemblages dans l'industrie automobile.* Presentation at University of Valenciennes, ISTV, 19 October 2012, Valenciennes, France.

Conference contributions

1. Børvik T., Benallal A., Hopperstad O.S.: *Modelling of plugging failure in structural impact.* 23rd International Congress of Theoretical and Applied Mechanics (IUTAM), 19-24 August 2012, Beijing, China.
2. Fourmeau M., Børvik T., Benallal A., Hopperstad O.S.: *Anisotropic failure of aluminium alloy AA7075-T651.* 8th European Solid Mechanics Conference, 9-13 July 2012, Graz, Austria.
3. Forrestal M., Børvik T., Warren T., Chen W.: *Perforation of 6082-T651 aluminum plates with 7.62mm APM2 bullets at*

normal and oblique impacts. SEM XII International Congress & Exposition on Experimental and Applied Mechanics - Measurement Challenges for New Structures and Materials, 11-14 June 2012, Costa Mesa, CA, USA.

4. Fyllingen Ø., Berstad T., Langseth M., Hopperstad O.S., Tarigopula V., Schill M., Bernhardsson A.: *On stretch-bending of a high-strength steel component taking into account the forming history.* Nordic LS-DYNA Users Forum, 11 October 2012, Gothenburg, Sweden.
5. Gruben G., Hopperstad O.S., Børvik T.: *Effects of constitutive model and fracture criteria on ductile crack propagation in dual-phase steel.* 8th European Solid Mechanics Conference, 9-13 July 2012 Graz, Austria.
6. Hopperstad O.S., Børvik T., Formeau M., Pedersen K.O., Benallal A.: *Anisotropic fracture of quasi-brittle aluminium alloys.* 23rd International Congress of Theoretical and Applied Mechanics (IUTAM), 19-24 August 2012 Beijing, China.
7. Knoll O., Hopperstad O.S., Langseth M., Schweizerhof K.: *An investigation on failure probabilities in thin-walled aluminium die-castings subjected to quasi-static loading.* 6th European Congress on Computational Methods in Applied Science and Engineering (ECCOMAS 2012), 10-14 September 2012, Vienna, Austria.
8. Kristoffersen M., Børvik T., Langseth M., Ilstad H., Levold E., Hopperstad O.S.: *Impact against offshore pipelines.* 23rd International Congress of Theoretical and Applied Mechanics (IUTAM), 19-24 August 2012 Beijing, China.
9. Morin D., Hopperstad O.S., Lademo O-G., Langseth M.: *Multiscale modelling of aluminium for crash analyses.* International Symposium on Mechanics of Solids and Structures, 17-19 September 2012, Aberdeen, UK.
10. Ognedal A.S. , Seelig T., Helbig M., Hempel P., Berstad T., Hopperstad O.S., Clausen A.H.: *Experimental and micromechanical study of void growth in a mineral filled PVC.* DYFP 2012., 15th International Conference on Deformation, Yield and Fracture of Polymers, 1-5 April 2012, Kerkrade, the Netherlands.
11. Ognedal A.S., Seelig T., Hopperstad O.S., Clausen A.H.: V*oid growth in a Mineral-filled PVC – Experimental and Numerical Study.* 8th European Solid Mechanics Conference, 9-13 July 2012, Graz, Austria.
12. Rakvåg K.G., Børvik T., Hopperstad O.S., Westermann I.: *Experimental and numerical study on fragmentation of steel projectiles.* 10th International DYMAT Conference, 2-7 September 2012, Freiburg, Germany.
13. Tryland T. and Berstad T.: *A simple shear test to evaluate material ductility based on specimens cut from thin-walled sections.* 11th LS-DYNA Forum, 9-10 October 2012, Ulm, Germany
14. Vilamosa V., Clausen A.H., Hopperstad O.S., Børvik T., Skjervold S.: *Measurement of local strain and heat propagation during high-temperature testing in a split-Hopkinson tension bar system.* 10th International DYMAT Conference, 2-7 September 2012, Freiburg, Germany.
15. Vysochinskiy D., Coudert T., Reyes A., Lademo O-G.: *Determination of forming limit strains using Marciniak-Kuczynski tests and automated digital image formulation procedures.* The 15th ESAFORM conference, 14-16 March 2012, Erlangen, Germany.
16. Westerman I., Hopperstad O.S., Myhr, O.R., Marthinsen K., Holmedal B.: *Modeling of Work-Hardening in an Age-hardenable AA7108 Aluminum Alloy.* Proceedings of the 13th International Conference on Aluminium Alloys (ICAA13), 3-7 June 2012, Pittsburg, PA, USA.
17. Aalberg A., Birkeland I.: *Classification boundaries for stiffness of beam-column joints and column bases.* Proceedings of Nordic Steel Conference, 5-7 September 2012, Oslo, Norway.
18. Aalberg A., Torp Karlsen F.: *Bolted RHS end-plate joints in axial tension.* Proceedings of Nordic Steel Conference, 5-7 September 2012, Oslo, Norway.

Reports

1. Fyllingen Ø., Berstad T., Langseth M., Hopperstad O.S., Tarigopula V.: *On stretch-bending of a high-strength steel component taking the forming history into account.* SIMLab Report OptiPro2012-4. SIMLab, Department of Structural Engineering, Norwegian University of Science and Technology, Trondheim, Norway (2012).
2. Krauthammer T., Langseth M., Børvik T.: *Workshop on Modelling and behaviour of lightweight protective structures.* Workshop report. SIMLab, Department of Structural Engineering, Norwegian University of Science and Technology, Trondheim, Norway (2012).

Did you see us on Norwegian television during Easter?

Annual Report for SIMLab Centre for Research-based Innovation 2012

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