Annual Report 2010

sfi Centre for Research-based Innovation

Established by the Research Council of Norway

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 its industrial partners and hence create a link between Norwegian industry and some of the major actors in the global market, i.e. the automotive industry. However, in order to meet the requirement for innovation and value creation in an international market, Norwegian industry has to adopt new and original knowledge in product development. Here, an 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 20 PhD candidates where at least 5 are female.
2 To graduate 10 MSc students annually.
3 To attract 5 international 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.

Industrial partners in 2010

HYDRO Statoil Forsvarsbygg Audi RENAULT SSAB Statens vegvesen

Summary

SIMLab (Structural Impact Laboratory) – Centre for Research-based Innovation – is hosted by Department of Structural Engineering, Norwegian University of Science and Technology (NTNU) in co-operation with Department of Materials Technology, 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 industry, improved highway safety as well as protective structures for international peacekeeping operations.

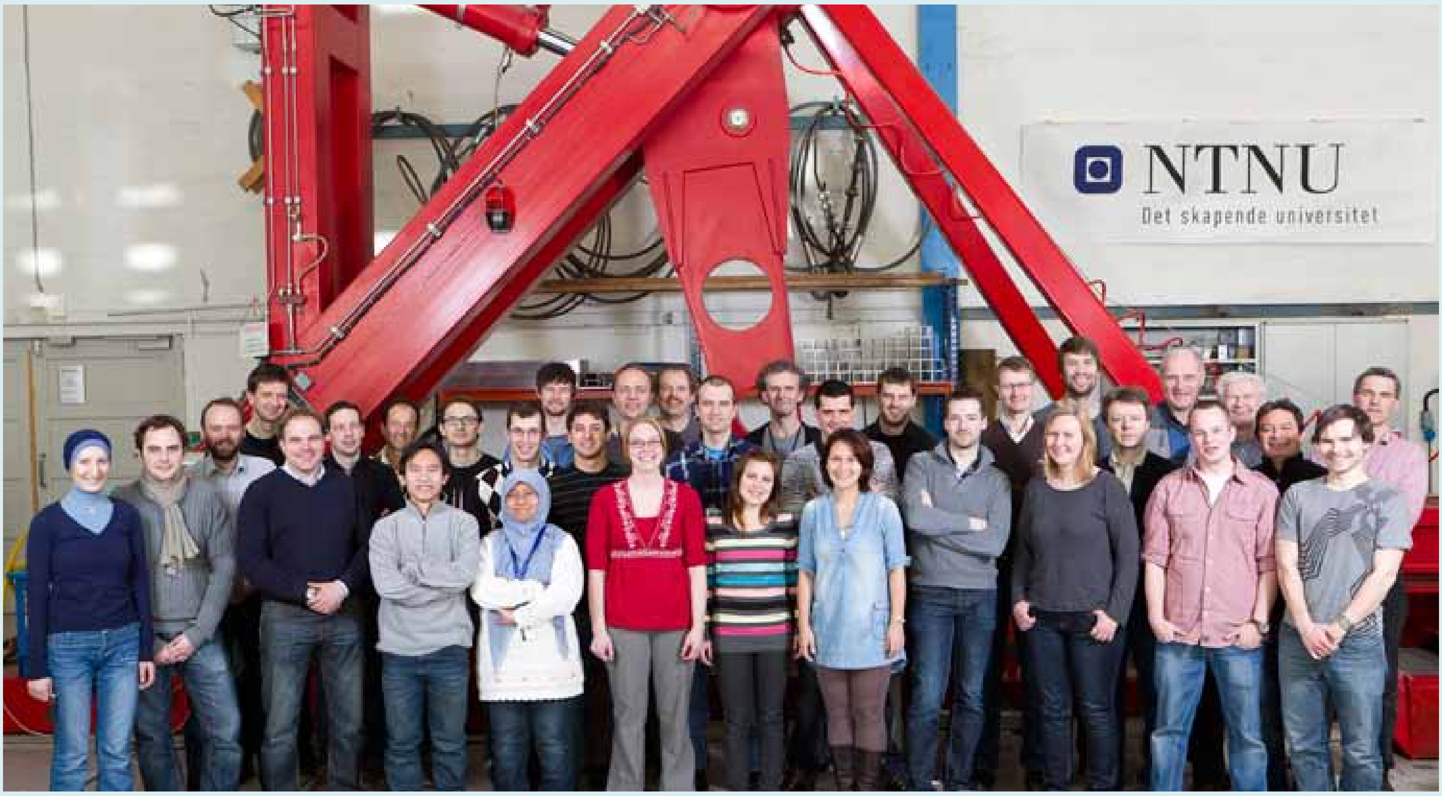
The industrial partners in the Centre in 2010 have been Hydro Aluminium, Audi AG, Renault, Statoil, SSAB Swedish Steel, the Norwegian Public Roads Administration and the Norwegian Defence Estates Agency. Furthermore, BMW and Toyota are new partners from January 2011.

The overall management structure of the Centre consists of a board comprising members from the consortium participants. A Centre 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 provide scientific and strategic advice based on a defined mandate.

The defined research areas for 2010 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 contribution from PhD candidates, post docs and scientists from the partners.

Workshops are organized in order to strengthen the idea generation in the Centre. The OptiPro programme arranged an international workshop in December 2010 at NTNU with invited experts from Norway, Italy, Germany, England, France, USA, South Africa, China and Singapore. The topic of the workshop was the behaviour and modelling of lightweight protective structures and valuable conclusions were drawn with respect to future collaboration and research needs within this area. Furthermore, a workshop on bake hardening of high-strength steels was held in Paris in June 2010. This was organized by SIMLab in cooperation with LMT-Cachan in France. The workshop was related to the M^4 research programme with participants from Norway, Sweden, France and Canada.

The midterm evaluation by the Research Council of Norway was carried out in October 2010 and the Centre received excellent marks. The committee concluded



The research group. Photo: Ole Morten Melgård.

that *"SIMLab is characterized by excellent research conducted under dynamic leadership by a group of students and senior scientists that seem to cooperate well both internally and with user partners, from which they receive strong support. The evaluation team encourages the Centre to continue its work along the lines presented in the written report and during the presentation"*. Furthermore, the committee recommended *"that the Centre vigorously continue its efforts to ensure continuation after 2014"*.

In 2010 the research work in the Centre has resulted in 26 papers published in peer reviewed journals. In addition, the research group has given 20 conference contributions and among them one keynote lecture. Furthermore, it is worth mentioning that four of the research team members have been guest editors in a special issue of the *International Journal of Impact Engineering*. The special issue was based on contributions at the conference on Impact Loading of Lightweight Structures hosted by SIMLab in 2008.

The research in the Centre is carried out by strong cooperation between master's, PhD candidates, post docs and scientists. In 2010, 20 male master's students, 12 male and 4 female PhD candidates have been connected to the Centre. Further, 1 female and 1 male post doc are employed at SIMLab. One international student from Spain has stayed at the Centre during the autumn semester. PhD candidate Virgile Delhaye defended his thesis on the *"Behaviour and modelling of polymers for crash applications"* in December with excellent result.

International cooperation and visibility are success parameters for a Centre. Thus the Centre has had cooperation with the following universities/research laboratories in 2010: Ecole Normale Supérieure de Cachan/Laboratoire de Mécanique et Technologie (ENS/LMT), France; University of Savoie, France; Ecole Centrale de Nantes, France; Technical University of Madrid, Spain; University of São Paulo, Brazil; MIT, USA; University of Linköping, Sweden, Politecnico di Milano, Italy; Karlsruhe Institute of Technology, Germany. In addition the Centre is 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, University of Virginia, MIT and University of Cambridge, UK. A one day seminar was held at SIMLab in August to discuss future cooperation.

With respect to visibility the activities in the Centre have been presented in international and national magazines. In this context Discovery Channel did some filming at the SIMLab laboratory in October. The shot will be a part of the programme Mega World Norway which will be shown spring 2011.

Several concurrent research projects have been run in parallel with the Centre activities. Furthermore, the Centre has been involved in one application for a research project with European funding (Eurostars).

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.

This research area 'Structures' is serving as a link between 'Materials', 'Solution techniques' and the "Demonstrators" activity, see figure below. The selection of demonstrators is carried out in close cooperation with 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.

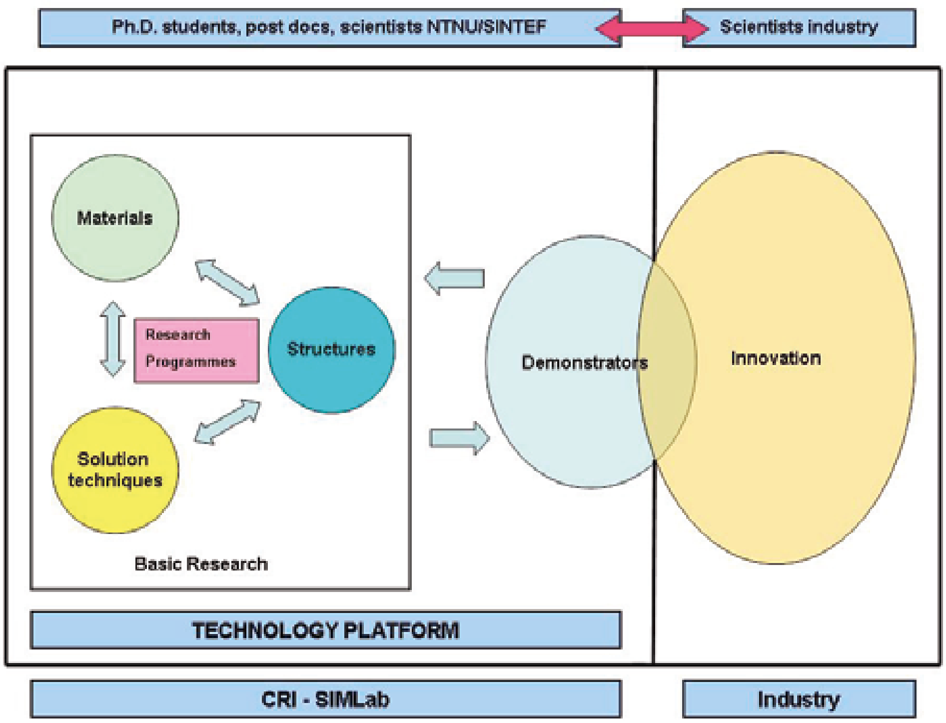
The Centre is dealing with aluminium extrusions and plates, aluminium castings, high-strength steels and polymers.

The basic research areas **Materials, Solution techniques** and **Structures** are linked by **Research programmes**. The number of research programmes and the content in each programme (research projects) can vary dependent on the interest of the partners. The following research programmes have been running in 2010:

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

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

- **Polymers (Poly):** Development of validated models for polymers subjected to quasi-static and impact loading conditions. An important prerequisite is to establish a set of test methods for material characterization and to generate a database for validation tests. The programme for the time being is limited to thermoplastics.
- **Multi-scale Modelling of Metallic Materials (M⁴):** Phenomenological constitutive models of metals are available in commercial FE codes, but they do not provide any information about the physical mechanisms responsible for the observed material response. Thus, in this programme the material response is described on the basis of the elementary mechanisms governing the macroscopically observed phenomena. This approach is required for the design of optimized process chains, for the development of next-generation phenomenological models, and for reducing material characterization costs.
- **Connectors and Joints (C&J):** Information about the behaviour and modelling of self piercing rivet 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 as well as the behaviour of joints using dissimilar materials.



Research areas

Research organization

Structure of 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. Within each research programme, research projects are defined with a project leader. Furthermore, an advisory scientific board of international experts provides scientific and strategic advice.

The Board

- Karl Vincent Høiseth, Professor/Head of Department, Department of Structural Engineering, NTNU (Chairman)
- Thomas Hambrecht, Head of Functional Design, MLB, Audi AG
- Torstein Haarberg, Executive Vice President, SINTEF Materials and Chemistry
- Håvar Ilstad, Principle Researcher, StatoilHydro
- Helge Jansen, Senior Vice President, Hydro Aluminium
- Helge Langberg, Head of Research and Development Department, Norwegian Defence Estates Agency
- Per Kr Larsen, Professor Em., Department of Structural Engineering, NTNU
- Joachim Larsson, Manager Structural Technology, SSAB
- Eric Vaillant, Department Manager Analysis & Materials Behavior, Renault
- Sigurd Olav Olsen, Special Advisor to the Director General, Norwegian Public Roads Administration
- Ingvald Strømmen, Professor/Dean, Faculty of Engineering Science and Technology, NTNU

Centre Director

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

Core Team and programme heads

- Tore Børvik*, Dr. ing., Norwegian Defence Estates Agency
- Arild Holm Clausen, Professor,

Department of Structural Engineering, NTNU
- Øystein Grong, Professor, Department of Materials Technology, NTNU
- Arve Grønsund Hanssen*, Dr. ing., Impetus Afea AS
- 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

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

Scientific Advisory Board

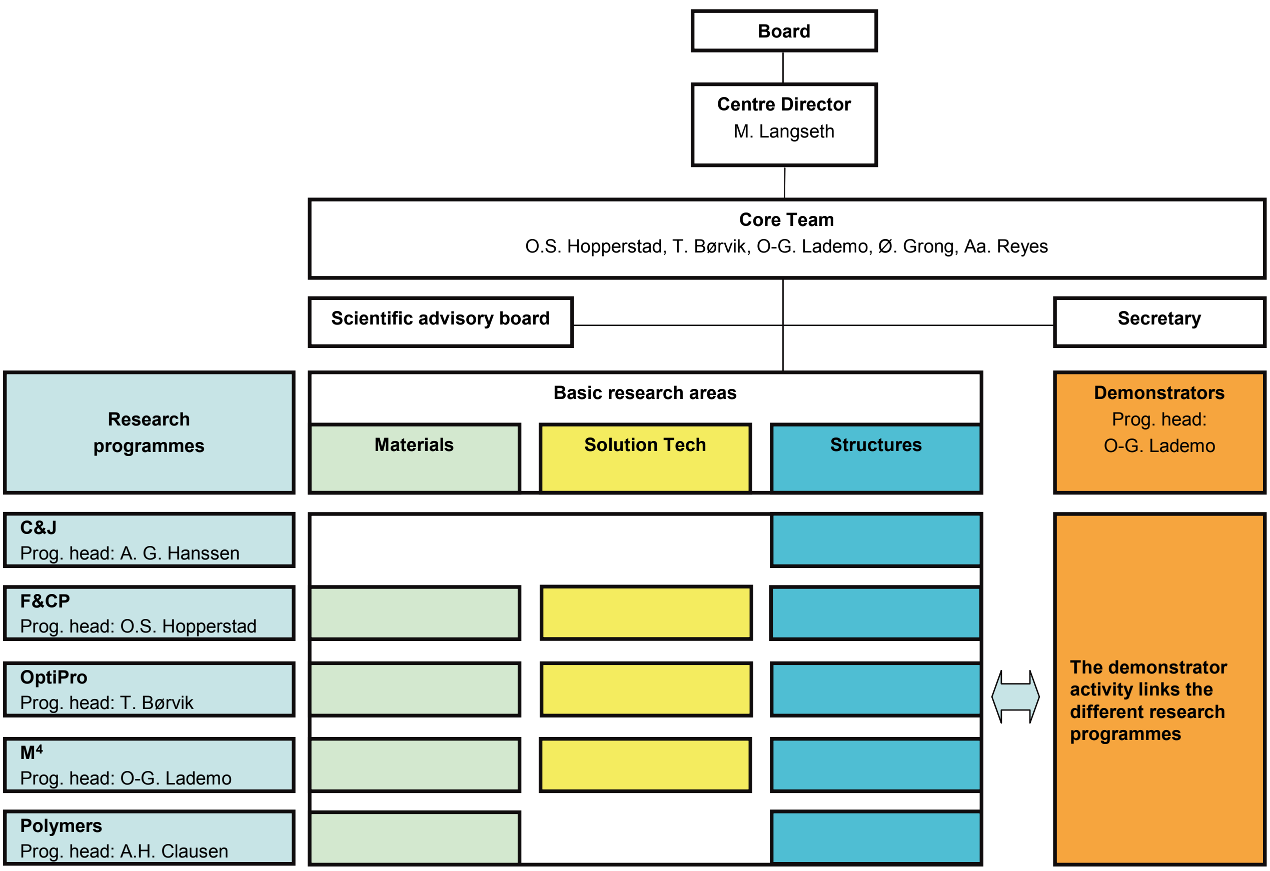
- Professor Ahmed Benallal, LMT-Cachan, France
- Professor Em. David Embury, MacMaster University, Canada
- Professor John Hutchinson, Harvard University, USA
- Professor Em. Norman Jones, University of Liverpool, UK
- Professor Larsgunnar Nilsson, University of Linköping, Sweden
- Professor Klaus Thoma,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

Partners

- Host institution
  - NTNU
- Research partner
  - SINTEF Materials and Chemistry
- Industrial partners
  - Audi AG
  - Hydro Aluminium
  - Renault
  - SSAB Swedish Steel
  - Statoil
  - 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 the



Structure of organization in 2010.

modelling activities carried out, 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 and interaction between partners

The annual work plans for each programme were defined with contribution from each partner. Scientists from NTNU and SINTEF, 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, Audi and Renault are mainly taken care of by PhD candidates working half time at the Centre and half the time at the respective industrial partner. Furthermore, NDEA has a scientist who is permanently working at the Centre with good contact with the NDEA research and development group in Oslo. However, the cooperation and spread of information within the main research group (NTNU and SINTEF) and between the industrial partners have been carried out using programme and project meetings as well as seminars.

Once a week the centre director had a meeting with the programme heads and the core team members. These meetings were used to coordinate the activities in the research programmes and to ensure that the progress and cost plan as well as the deliverables were in accordance with the defined annual work-plans. In addition, specific project meetings were held within each research programme when necessary with participation from all involved partners. These project meetings were supported by telephone meetings with our international 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).

From left: Odd-Geir Lademo, Øystein Grong, Tore Børvik, Aase Reyes, Magnus Langseth, Arve Grønsund Hanssen , Arild H. Clausen and Odd Sture Hopperstad.

Photo: Ole Morten Melgård.

Research programmes and demonstrators

Research in the Centre is based on annual work plan. Thus each research programme and the demonstrator activity are composed of several research projects. The following gives an introduction to each research programme and some highlights from the activities carried out.

Fracture and Crack Propagation (F&CP)

Programme head: O.S. Hopperstad

Introduction
In numerical simulations of quasi-static and dynamic ductile fracture, e.g. in analysis of forming processes, crashworthiness and structural impact, many complex and interacting phenomena generally occur: large deformations, contact, elastoplasticity, viscous and thermal effects, damage, localization, fracture, length-scale effects and crack propagation. The solution of such problems requires advanced numerical techniques.

Today the finite element method is used in most cases, and problems involving ductile fracture and crack propagation are typically solved using uncoupled or coupled damage mechanics and element erosion at a critical value of damage. This approach is deemed to depend on mesh size and mesh orientation, and various regularization techniques (e.g. the non-local approach, gradient theories and viscous regularization) have been proposed to enhance mesh convergence. Two examples of alternative strategies are node splitting coupled with adaptive meshing and extended finite element methods (XFEM). There is a need to evaluate established methods against other possible approaches for the modelling of ductile fracture and crack propagation, and to make these novel procedures available for industrial use.

In the F&CP programme, mathematical models and numerical algorithms for damage, fracture and crack propagation in ductile materials are developed and validated against laboratory tests. The materials considered are rolled, extruded and cast aluminium alloys and high-strength steels. In 2010, projects have been running within the following research areas:

- 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

Within each of these research areas, a PhD project has been defined. The main results of the research within the PhD projects of Gaute Gruben, Marion Fourmeau, Octavian Knoll and Egil Fagerholt are briefly described below.

Numerical aspects of fracture and crack propagation (PhD candidate Gaute Gruben)
The fracture characteristics of a cold-rolled, high-strength steel sheet (Docol 600DL) have been established under quasi-static loading conditions using several different test set-ups. In all the tests, the sheet material was initially in plane stress states. Optical field measurements with digital image correlation were used to determine the strain fields to fracture, to calibrate the material model for the sheet material, and to validate the finite element models of the tests. Based on the field measurements, a novel method for experimental determination of the stress triaxiality and the Lode parameter has been developed within the project. These parameters were also obtained from the finite element (FE) simulations. As an example, Figure 1 compares the strain field obtained with DIC and FE simulations in some of the tests. Comparisons showed that the two methods gave approximately the same average values of the stress triaxiality and the Lode parameter up to fracture. The sheet material displayed only moderate variation in ductility as a function of the stress triaxiality and the Lode parameter within the investigated range of these parameters. The most critical through-thickness position in the specimens was found to be in the centre, where the strains and the stress triaxiality are highest. A novel modification of the Mohr-Coulomb fracture criterion has been proposed and calibrated to the fracture properties of the cold-rolled, dual-phase steel sheet. This fracture criterion was shown to

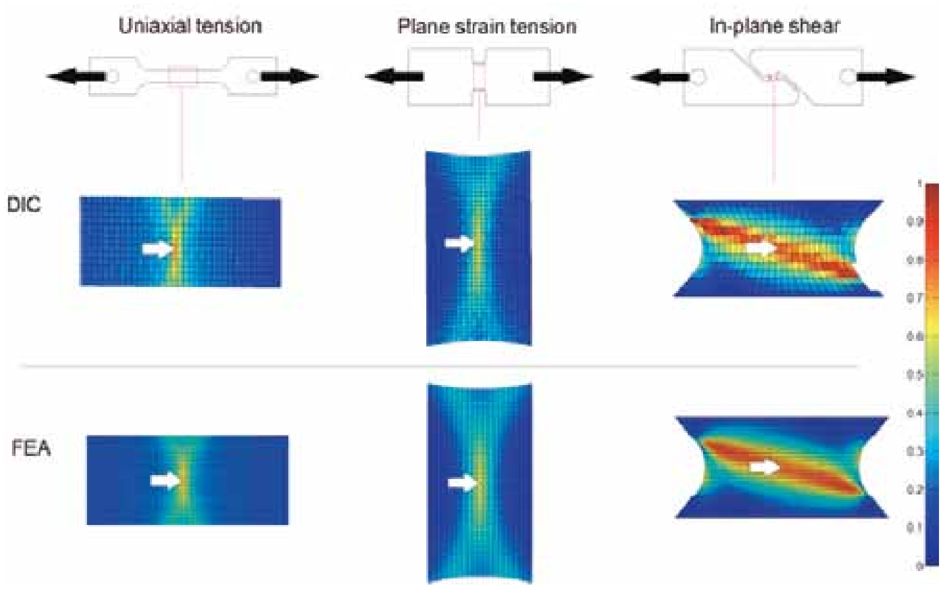


Figure 1 – Strain magnitude fields for uniaxial tension, plane-strain tension and shear tests from DIC recordings and FE analyses.

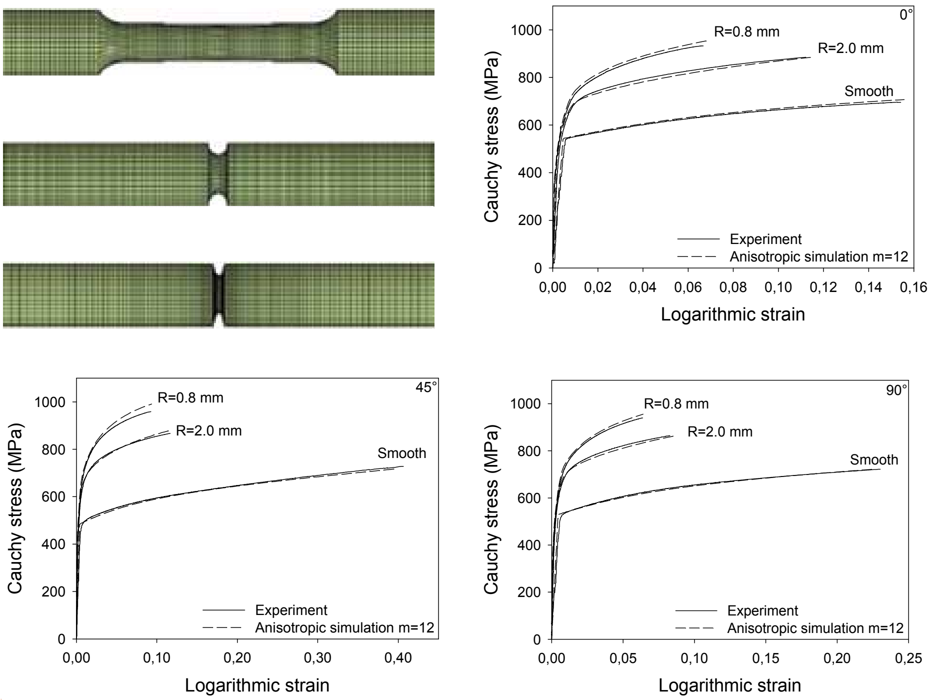


Figure 2 – Comparisons of experimental and predicted stress-strain curves with the anisotropic model of tensile tests on smooth and notched specimens (top left) in different material directions relative to the rolling direction 0° (top right), 45° (bottom left) and 90° (bottom right).

give good predictions of the fracture strain in the different material tests.

Fracture in age-hardening aluminium alloys – mechanisms and modelling (PhD candidate Marion Fourmeau)

The influence of plastic anisotropy on the mechanical behaviour of a cold-rolled aluminium plate under quasi-static loading conditions has been studied experimentally and numerically within this project. Material tests in different directions with respect to the rolling direction of the plate were carried out on various specimen shapes providing a wide range of stress states. The Yld2004-18p anisotropic yield function was identified through uniaxial tensile tests, shear tests and upsetting tests. This yield function was found to provide an adequate description of the significant anisotropic behaviour of a high-strength AA7075-T651 plate. Numerical simulations of all the material tests were then performed with an elastoplastic material model using both the anisotropic and an isotropic version of the yield function. The numerical predictions of the mechanical response for notched tensile tests obtained with the isotropic version of the material model clearly over-estimated the experimental results. Similar results have been reported in the literature on other materials using isotropic constitutive relations. This over-estimation was significantly reduced when using the anisotropic version of the material model, indicating that plastic anisotropy is important for an accurate prediction of the notch-strengthening effect – and thus for damage evolution and fracture. It was also established that the exponent of the yield function Yld2004-18p has strong influence on the results for the notched tensile tests.

When the exponent of the yield surface was assigned a sufficiently high value, an almost perfect fit between the numerical predictions and experimental results was obtained, as shown in Figure 2.

Fracture in cast materials – mechanisms and modelling (PhD candidate Octavian Knoll)

A detailed material characterization was carried out for an Aluminium High Pressure Die Casting (HPDC) alloy. Quasi-static tensile tests with specimens cut from a generic HPDC component were performed to analyse the scatter of the mechanical properties. Based on this material characterization, a global and local scatter was observed. Especially the local scatter demonstrated a stochastic character with respect to the ductility of HPDC alloys. Based on these conclusions, a rather simple constitutive model with a stochastic approach to model fracture was established. The elastic-plastic material behaviour is described by a constitutive model consisting of a high exponent, isotropic yield criterion, the associated flow law and an isotropic hardening rule. The phenomenological ductile fracture criterion by Cockcroft-Latham is used. It is assumed that the fracture parameter follows a modified weakest link Weibull distribution. The constitutive model was implemented in the Finite Element (FE) solver LS-DYNA as a user routine. Figure 3 compares the numerical prediction with experimental results from two distinctive parts of the HPDC component. The dominant stochastic nature can be observed. Additionally, the probability of fracture of

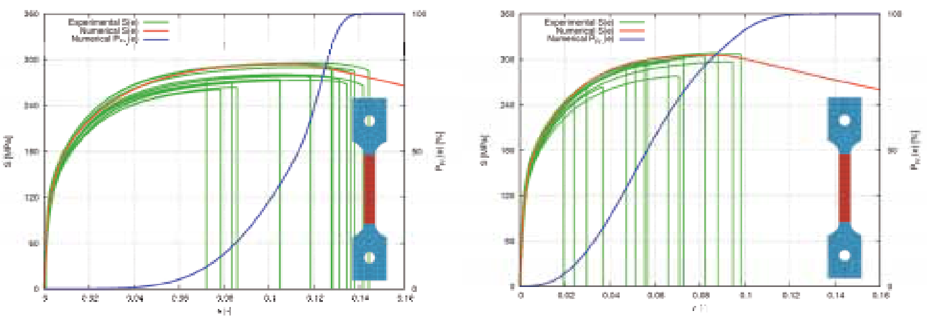


Figure 3 – Experimental and numerical engineering stress vs. engineering strain data and numerical calculated probability of fracture vs. engineering strain data. Left graph: Results from a ductile part of the generic HPDC component. Right graph: Results from a brittle part of the generic HPDC component.

the test specimens based on the numerical simulation is plotted. It can be seen how the scattering behaviour can be evaluated by using a stochastic approach.

Optical measuring techniques (PhD candidate Egil Fagerholt)

An automatic crack detection and handling algorithm has been developed for the two-dimensional Digital Image Correlation (2D-DIC) method in this project. The adopted 2D-DIC method is based on the two-dimensional finite element formulation. The algorithm is based on analysing grey-scale correlation residuals from the DIC process to evaluate possible cracks in the target specimen. In the algorithm, actions are taken to handle the detected cracks. Based on user-defined criteria, the elements in the mesh are refined (split) and eroded to avoid the crack region during analysis of an image series. The DIC algorithm has been tested both on images recorded from mechanical experiments and on artificially generated images. Artificial image series have been generated with known displacement fields and crack propagations using bi-cubic interpolation of nodal displacements from finite element simulations. The robustness of the crack detection and the handling in the DIC algorithm has been evaluated based on these data sets. Figure 4 illustrates the effective strain maps obtained by the developed algorithms for a notched Arcan specimen with crack propagation.

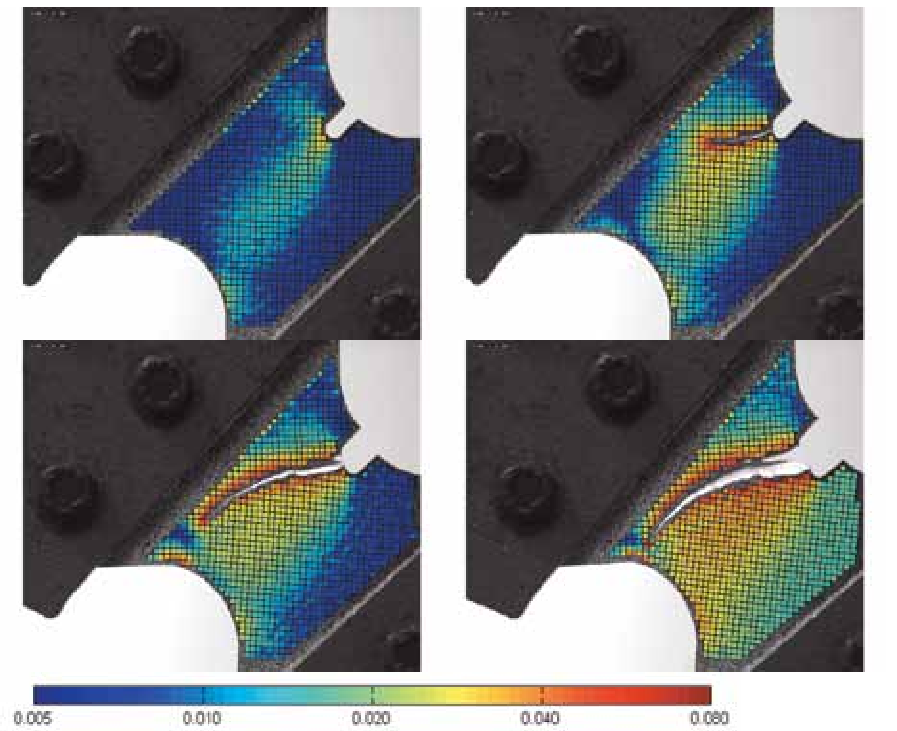


Figure 4 – Results from the analysis of a notched Arcan specimen. The calculated effective strain maps from the DIC analysis is plotted on top of the recorded images, using a logarithmically scaled colour map. The DIC mesh is automatically adapted by element erosion as the crack propagates through the specimen.

Optimal Energy Absorption and Protection (OptiPro)

Programme head: T. Børvik

Introduction

From a design perspective explosion, impact, collisions and weapon actions may be classified as accidental loads. These events are becoming increasingly important for a number of civil, military and industrial engineering applications and for the safety of people. Since it is both difficult and expensive to validate and optimize protective structures against accidental loads experimentally, the product development is increasingly carried out in virtual environments by use of the finite element method (FEM) to have safe and more cost-effective design. These new designs also need to be validated through high-precision experimental tests involving advanced instrumentation.

The main objective with the OptiPro research programme is to be able to design safer, more cost effective and more lightweight protective structures for a variety of engineering applications using advanced computational tools. In 2010, the main focus has been on the following research activities; 1) Strengthening techniques, 2) Blast loading using FEM, 3) Lightweight protective structures, 4) Impact loading of high-strength steel components and 5) Impact against pipelines. In the following, only a few selected research activities are highlighted. It should be noted that several sub-projects are carried out within each main research activity, and that there has been a close collaboration between the OptiPro programme and the F&CP programme in 2010.

Blast loading using FEM

The effect of blast loading on various structures has become more and more important for modern society. Since it is both difficult and expensive to validate protective structures against blast loading experimentally, we have to turn our attention towards numerical tools like the finite element method. In 2010, the structural response of a stainless steel plate subjected to the combined blast and sand impact loading from a buried charge has been investigated. This was done using a fully coupled approach in which a discrete particle method was used to determine the load due to the high explosive detonation products, the air shock and the sand, and a finite element method predicted the plate deflection. The discrete particle method is based on rigid, spherical particles that transfer forces between each other during collisions, see Figure 5. This method, which is based on a Lagrangian formulation, has several advantages over coupled Lagrangian-Eulerian approaches as both advection errors and severe contact problems are avoided. The method has been validated against experimental tests where spherical 150 g C-4 charges were detonated at various stand-off distances from a square, edge clamped 3.4 mm thick AL-6XN stainless steel plates, Figure 6. The experiments were carried out for a bare charge, a charge enclosed in dry sand and a charge enclosed in fully saturated wet sand. The particle-based method was found able to describe the physical interactions between the explosive reaction products and soil particles leading to a realistic prediction of the sand ejecta speed and momentum, Figure 7. This work has been carried out in collaboration with Impetus Afea and the MURI-project "An Integrated Cellular Materials Approach to Force Protection" sponsored by the U.S. Navy. Good quantitative agreement between the experimental and predicted deformation response of the plates was also obtained.

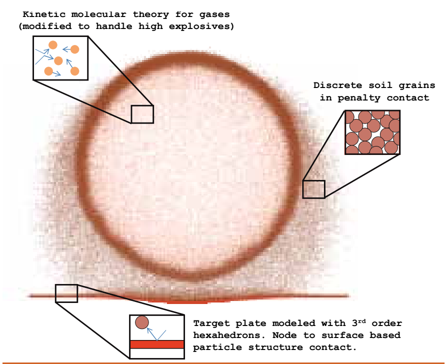
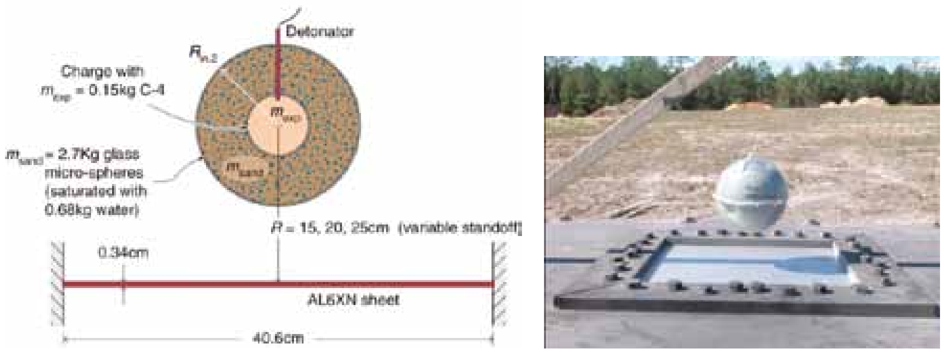


Figure 5 - Modelling principle of the discrete particle method.

Lightweight protective structures

During impact and perforation of high-strength materials, the projectile and/or the target may fragment upon impact. When this happens, the projectile looses all its penetrating ability and the target looses all its energy absorbing capacity instantaneously. If this is not properly taken into account in computer-aided design of protective structures, severe error prediction of the capacity of the protection may be the result. Thus, it is very important to study fragmentation during the projectile impact of protective structures.



a) b)

Figure 6 - (a) Sketch of the experimental set-up where a sphere of C-4 is detonated above a square AL-6XN stainless steel plate. The charge may be bare, surrounded by dry sand or surrounded by fully saturated wet sand, (b) Picture of a typical set-up at the test site just before detonation.

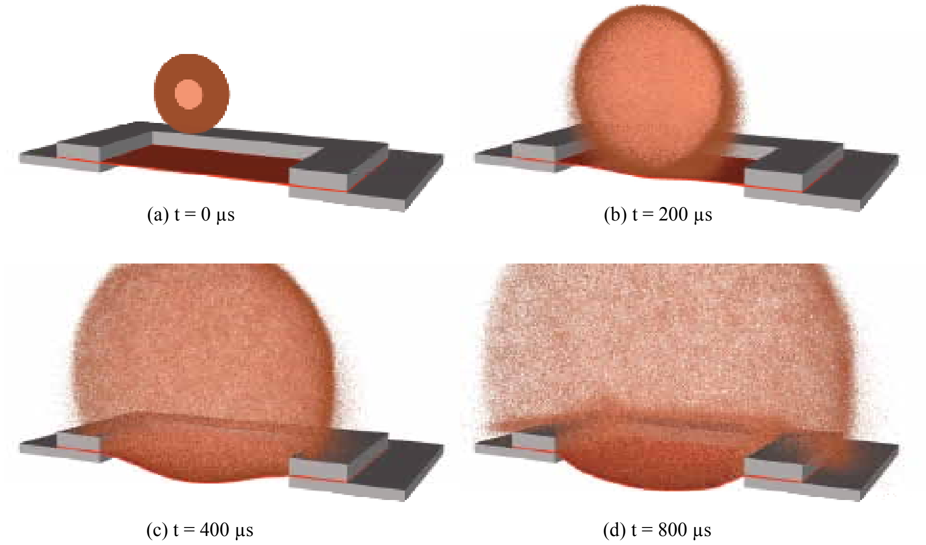


Figure 7 - Sequence of plots showing the deformation of the AL-6XN plate after impact of C-4 and saturated wet sand at stand-off distance of 150 mm.

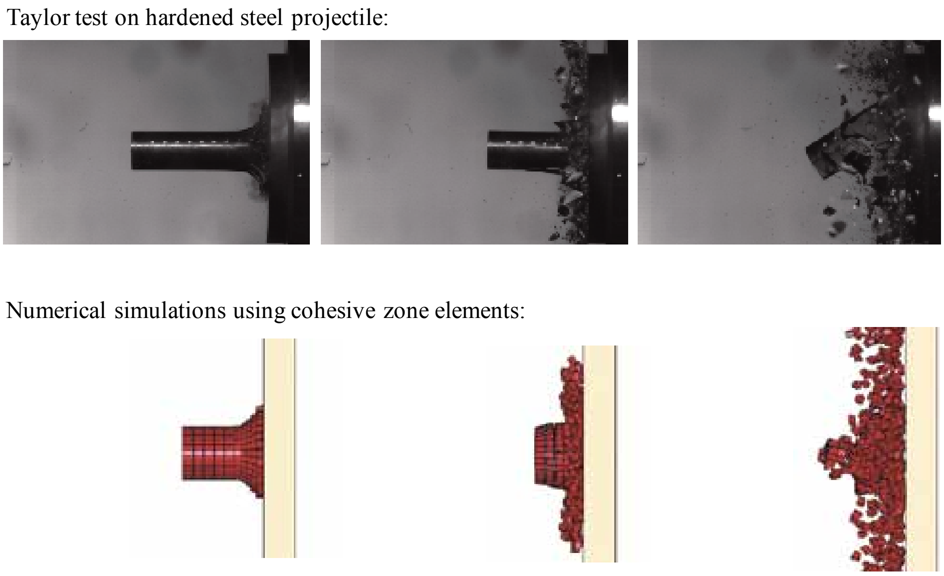


Figure 8 - Comparison between an experimental test and a numerical simulation of a Taylor tests using a steel projectile hardened to HRC 53.

In this study, fragmentation of projectiles during impact has been studied both experimentally and numerically using so-called Taylor tests. In the component tests, projectiles with various degrees of hardness (e.g. unhardened, hardened to HRC 40 and hardened to HRC 53) were fired into a rigid wall. During impact, the behaviour of the projectile was photographed by a high-speed camera system, and the deformation (mushrooming) and fragmentation as a function of impact velocity and initial hardness were studied. Quasi-static and dynamic fracture mechanics tests using notched specimens in 3-point bending and instrumented Charpy tests were carried out to determine the fracture toughness of the various projectile materials. The data were used to calibrate the Tvergaard-Hutchinson cohesive zone model for use with solid elements available in LS-DYNA. It was however found difficult to use the fracture mechanics tests to have a reliable calibration of the cohesive zone model. 3D numerical simulations using predefined cohesive zones in the projectiles were finally carried out and the results were compared with the experimental findings. A comparison between an experimental test and a numerical simulation of a Taylor tests using a steel projectile hardened to HRC 53 is shown in Figure 8. This work will continue in 2011 using alternative numerical techniques and additional experimental data.

Impact against pipelines

During the last few years, discussions with the Norwegian offshore industry have focused on fundamental research on the behaviour, modelling and design of subsea production systems subjected to impact loads from dropped objects and fishing gear. The discussions have been motivated by the lack of knowledge related to the interaction between the water, the impactor and the structure, and how this will influence the structural response. Thus, a fundamental research programme is needed to explore these issues in more detail to have future oil production which is safe, reliable and environmentally friendly. The increased interest in exploring new oil fields in the Barents Sea has put additional focus on these issues.

Det Norske Veritas (DNV) has worked out guidelines on how to design sub-sea pipelines in rich fishing areas that could be subjected to interference by trawl gear. One topic of special interest for the offshore industry is pipelines first subjected to impact loading before being dragged along the seabed. Such loading scenarios may introduce both large global deformations and local strains in the pipe. After impact, the pipe is straightened due to rebound and the axial forces present. The material in the highly deformed zone will experience a complex stress and strain history, which subsequently can cause leakage or full failure. Other accidental loads related to marine activities, such as anchor impacts, may also have to be taken into consideration in the design of sub-sea pipelines.

In order to study these topics, full scale testing is not straightforward and a simplified approach is chosen as a first step in the present activity. In 2010, impact loads against offshore pipelines were studied using experiments and numerical analyses. The experiments consisted of two tests; first impact before stretching, see Figure 9. Scaled pipes were first impacted in the pendulum accelerator at SIMLab before stretching the dented pipes at Statoil's laboratory in Trondheim. Fracture occurred in all pipes during the stretch phase. Material test specimens were taken from the actual pipe wall and tested both quasi-statically and dynamically. A material model, including a constitutive relation and a fracture criterion, was calibrated for use in numerical analyses. Strain hardening and strain rate sensitivity were accounted for in the constitutive relation, and only isotropic hardening was assumed. Notched test specimens were tested to capture the effect of stress triaxiality on the fracture strain. The pipes were modelled using Abaqus/ Explicit and the experiments were recreated numerically. Both shell and volume element models were used in the simulations. The global response in the experiments and the numerical simulations agreed very well, see Figure 10. However, the numerical simulations were not able to predict the fracture accurately, see Figure 11. A mesh sensitivity study revealed that a large number of elements were required to accurately describe the plastic strains in the critical area. A study of the stress situation in the critical element indicated

a) Impact tests b) Stretch tests

Figure 9 - Experimental set-up for the component tests.

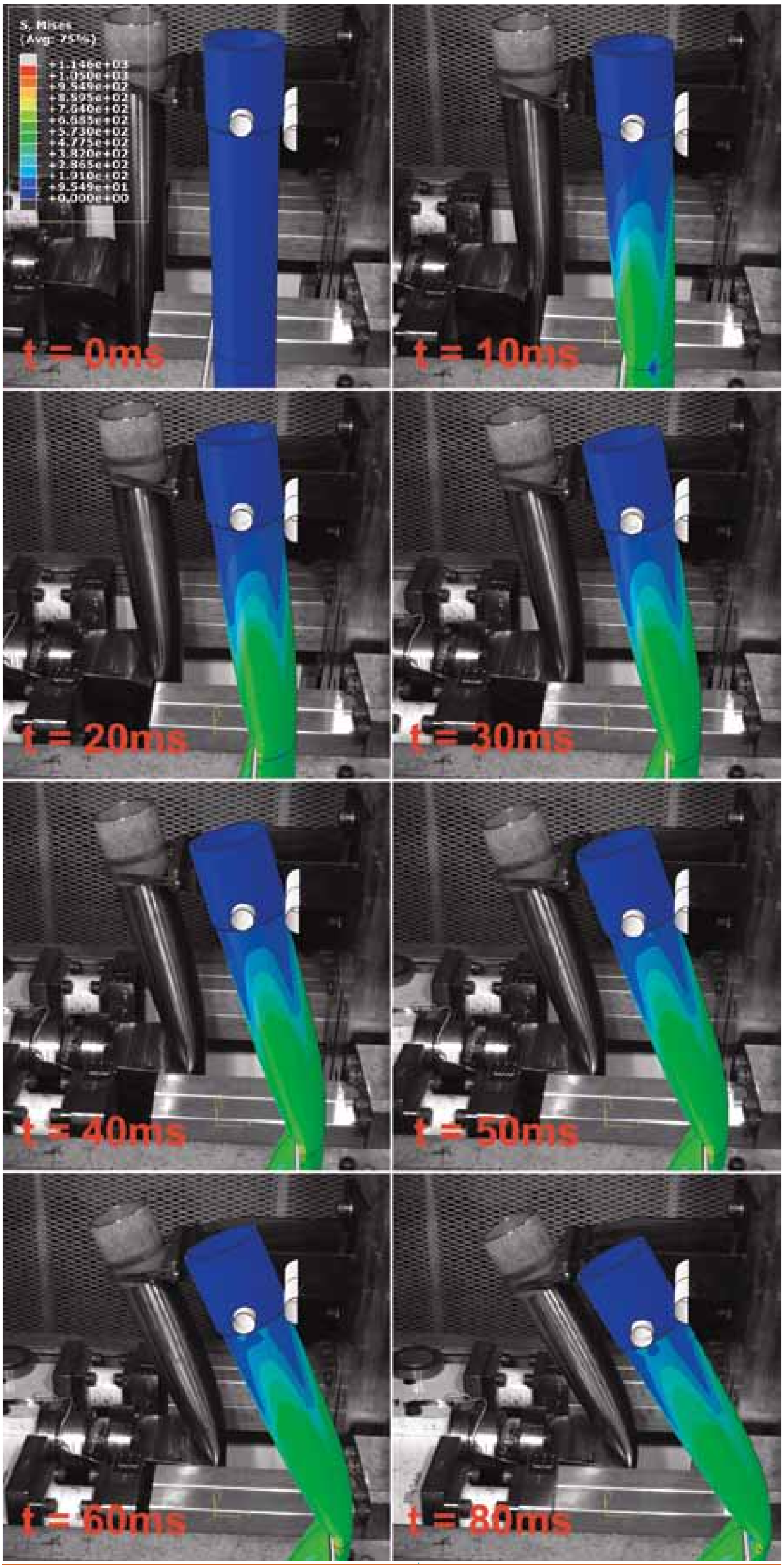


Figure 10 - Comparison between analysis and experiment results for the impact on a pipe.

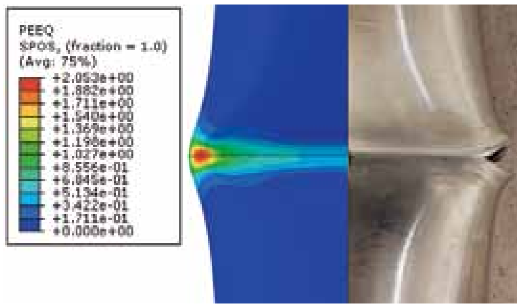


Figure 11 - Contour plot of the equivalent plastic strain shown together with the deformed pipe (including fracture) from the experiment.

that isotropic hardening may underestimate the strains and that the cyclic hardening properties of the material should be further investigated. This will be done in 2011.

Polymers (Poly)

Programme head:

A.H. Clausen

Introduction

Polymers are promising for use in several applications. In particular, such materials are light, they may be very ductile, and therefore have excellent energy absorption characteristics. The experience in using polymers in impact protection systems, however, is limited, and there are several challenges which call for research. One of the most obvious is the lack of robust material models in commercial finite element codes. Some of the features commonly observed for polymers are pressure sensitivity, which means that the material properties are different in tension and compression, and strong dependence on temperature and strain-rate. In general, the behaviour of polymers is fundamentally different from the typical response of metals.

The main objective of this programme is to develop validated material models for polymers subjected to impact. An important prerequisite and sub-goal is to establish a set of test methods for material characterization, and generate a database with results from different component tests. The programme is for the time being limited to thermoplastics, and constitutive modelling has been in focus so far, i.e. failure has not been considered.

The Polymers programme can, broadly speaking, be regarded as three activities running in parallel: (i) Material tests, (ii) Constitutive model, and (iii) Component tests. Three PhD candidates were affiliated to the programme in 2010. Virgile Delhaye worked with two PP materials delivered by Renault as a part of their contribution in kind. He defended his thesis in December 2010, and is now employed as a researcher at SINTEF. He will continue his involvement in the Polymers programme. Anne Serine Ognedal looks at strains and damage in thermoplastics subjected to large deformations, and seeks to explain how the mechanism of void formation within the material affects the response. Finally, Audi has engaged Andreas Koukal as a PhD student. Formally connected to the Technical University of Munich, he has a weaker affiliation with SIMLab. He works on fibre-reinforced thermoplastics.

Material tests

Thermoplastics have a fundamentally different type of behaviour from that observed for other materials, such as metals, and this calls for some special precautions during material testing. Thus a conventional experimental set-up involving an extensometer cannot be employed because of the propagating neck and cold-drawing phenomenon. Also, many thermoplastics change their volume during plastic deformation, and it is therefore necessary to measure transverse strains in addition to the longitudinal strains in order to determine the true stress. These challenges are handled by an optical measurement technique based on digital image correlation (DIC).

The change of volume is likely to be closely related to the growth of voids and cavities in the material. Virgile Delhaye paid some attention to this in his thesis. A typical mechanism, also known from the literature, is that voids are formed around particles in the material. Such particles may be made of rubber or talc. Figure 12 shows a micrograph of the fractured surface of a tension

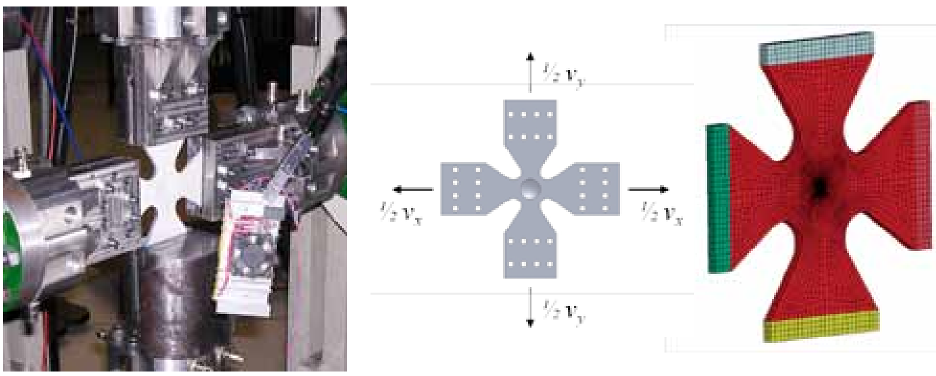
Figure 12 - Micrograph of fracture surface of a polyvinylchloride material after a tension tests. The calcium particles are initiators for void formation.

test specimen made of polyvinylchloride. Clearly, voids seem to be created close to the particles inherent in the material. Anne Serine Ognedal will continue this kind of investigation in her PhD project.

Constitutive model

A first version of the constitutive model for thermoplastics was published in 2010. It is a hyperelastic viscoplastic model that captures the typical features of the behaviour for such materials. It was implemented in LS-DYNA for brick elements, and the user-defined material routine has also been transferred to PAMCRASH. Virgile Delhaye implemented a shell version of the model.

A drawback with the model, however, is that it predicts some increase of volumetric plastic strains also in compression, while experiments indicate a decrease. One possible way to solve this problem is to change the so-called flow rule in the model,



(a) (b) (c)

Figure 13 - (a) The test setup of biaxial test, (b) Sketch of how the deformation was applied, and (c) LS-DYNA finite element mesh.

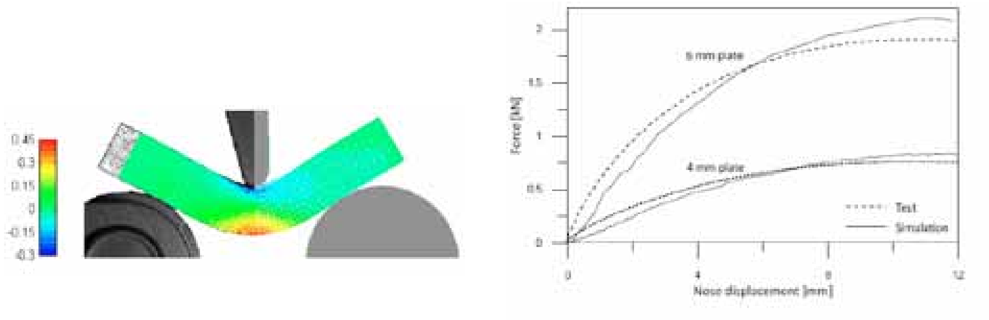
which determines the evolution of plastic deformation. As a part of his thesis, Virgile Delhaye introduced a different formulation for the flow rule, recognizing the existence of voids, see Figure 12, more explicitly as a damage parameter. This alternative model captures the change of volume more accurately, but it involves two more coefficients.

On the other hand, there is reason to believe that the Raghava yield criterion and flow potential of the original model works well in problems dominated by tension. Anne Serine Ognedal is paying considerably attention to this issue in her research. Applying a test machine located at LMT-Cachan in France, see Figure 13a, she has performed biaxial tests on two thermoplastic materials. The loading ratio varied between the tests, and Figure 13b illustrates a situation with identical velocities in the x- and y-directions. Figure 13c presents a finite element mesh of the test sample, which was employed in the subsequent numerical evaluation of the model.

Component tests

Precision tests on components subjected to relevant loading and deformation modes are an important pre-requisite for evaluation of a constitutive model. In general, an independent check of the capabilities of the model is obtained by using one set of tests, typically tension and compression tests, for calibration of the coefficients in the model, and separate component tests for the validation purpose. Of course, these components have to be made of the same material as was investigated in the material tests. These experimental benchmark tests should be well-defined with respect to factors such as geometry, boundary conditions and the application of load.

Two MSc students doing their final thesis for their master's degree contributed significantly in 2010. One of them, Martin Thuve Hovden, was awarded the prize for the best master's thesis among the civil engineering students in 2010 for his research work. He applied a three-point bending set-up for his validation tests, see Figure 14, and found good agreement between experimental test results and numerical predictions. The other student used SIMLab's BUP machine in his validation tests.



(a) (b)

Figure 14 - Bending test of a small beam made of polyethylene. (a) Comparison of strains found from experimental test (left-hand part of figure) and numerical simulation (right-hand part of figure). (b) Comparison of force-displacement curves found from experimental test and numerical simulation.

Multi-scale Modelling of Metallic Materials (M^4)

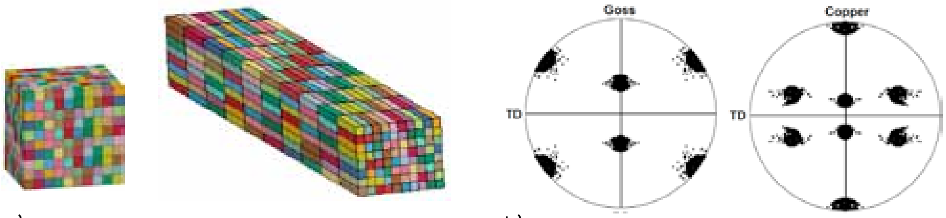
Programme head: O-G. Lademo

Introduction

Automotive manufacturers are in the need of suppliers who can develop cost-efficient, optimized solutions and products with high customer value in a sustainable manner. In the long run the winning suppliers will be those who can realize an integrated perspective for their alloy, process and product development. The integrated perspective requires, quite generally, quantitative models, where as many quantitative links as possible must be established, so that the needs with respect to a product's cost and performance can be addressed along the value chain. Further, quantitative links and tools are required at all levels to reduce development time and costs (e.g. reduced engineering costs, reduced tooling/trimming, reduced number of prototypes, optimized performance/weight ratio).

During recent years accurate phenomenological constitutive models of metals have been developed and made available in commercial FE codes. These models represent the macroscopically observed behaviour (e.g. work hardening, anisotropy, process effects) on the basis of continuum mechanics. However, they do not provide any information about the physical mechanisms responsible for the observed material response. Hence, the models do not contribute to enhance the understanding of micro-mechanisms of plastic deformation and offer limited action upstream in the material processing chain. Another complementary approach consists of looking at the metal, or polycrystal, from a physical point of view. In this approach 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 characterisation costs. The physical models are often computationally expensive and cannot replace the phenomenological models. Instead an optimized use of the models at various scales must be found.

In the M^4 research programme, modelling frameworks at continuum and meso-/crystal level have been established. Within these frameworks, lower-scale model approaches are used to represent micro- and nano-structural features of the materials. Some of the results achieved in 2010 are highlighted below. These are divided between fundamental strategic development and application oriented projects.



a) b)

Figure 15 - Methodology for studying grain shape and texture effects in aluminium sheet material; a) RVEs and b) example of two studied textures.

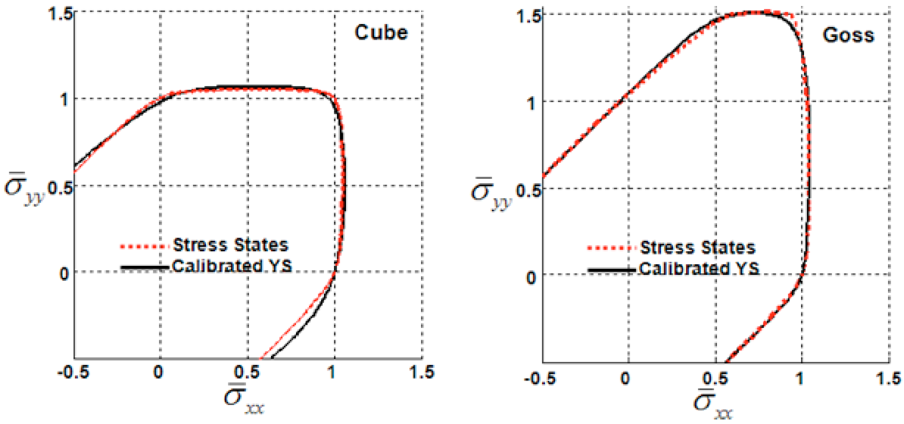
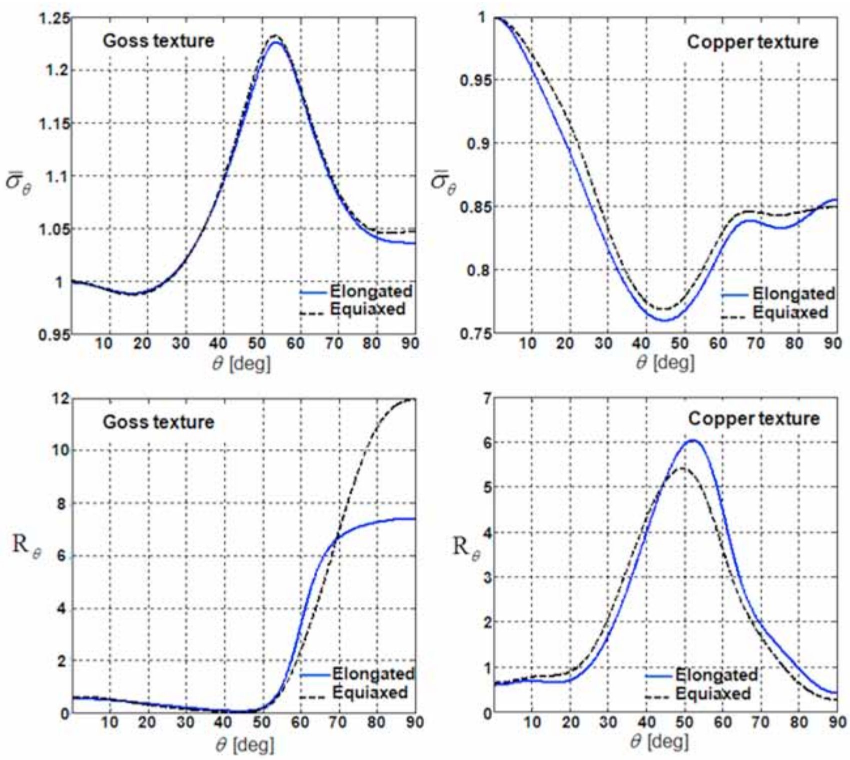


Figure 16 - Yield locus defined by the analytical yield surface Yld2004-18p (solid black line) and CP-FEM (dashed red line) for cube (left) and Goss textures (right).



a) b)

Figure 17 - Flow stress ratio $\bar{\sigma}_\theta$ and strain ratio R_θ related to Yld2004-18p yield surfaces calibrated from CP-FEM simulations for a) Goss and b) copper textures in the case of elongated (solid blue line) and equi-axed grains (dashed black line).

Fundamentals of multiscale modelling

In recent years, a framework for single- and polycrystal plasticity has been developed and implemented into the finite element code LS-DYNA (i.e. an FE-based crystal plasticity approach, here denoted CP-FEM). In 2010, a mechanism study on the influence of crystallographic texture and grain shape on the yield surface of aluminium sheet material at small strains was undertaken. Representative volume elements (RVE) of different microstructures, having either equi-axed or elongated grains, with different textures were modelled, Figure 15. Yield surfaces were built using each RVE, i.e. each combination of grain shape/texture. The yield surfaces were then fitted using the phenomenological yield criterion Yld2004-18p of Barlat and co-workers. Two different grain shapes, i.e. equi-axed and elongated, and five different typical textures which develop in aluminium alloys (copper, brass, S, Cube and Goss) were investigated.

Small effects of grain shape were found at small strains compared with the marked influence of crystallographic texture. These effects depend on the texture at hand. The yield surfaces for Goss, cube and copper textures were more affected by grain shape than those for S and brass textures.

The ability of Yld2004-18p to fit the anisotropic shape of the yield surfaces also depends on the texture at hand: good fit was obtained for copper, brass and S textures while some limitations were observed for Goss and cube textures, see Figure 16.

Finally, Yld2004-18p was used to investigate the effect of the grain shape on the directional variation of the stress and strain ratios predicted from the calibrated yield surfaces for copper and Goss textures. It was found that the small deviations in stress states induced by the effect of the shape of the grains mainly affect the strain ratios, see Figure 17. However, it was difficult to confirm if these effects were really associated with the grain shape rather than the calibration process.

Application oriented activities

Three projects have been concerned with

strain-rate dependent properties of aluminium alloys:

1. Several activities have been run related to the modelling of Dynamic Strain Ageing (DSA), the associated negative strain-rate sensitivity and the Portevin-Le Châtelier (PLC). An example of the negative strain-rate sensitivity response of alloy AA5182 is given in Figure 18. This response is challenging to model and various new model concepts are to be explored in 2011.

2. A study has explored the use of the model proposed in 2009 (for positive strain-rate dependence) in cold-drawing analyses. A user-defined material model has been implemented in a MARC environment, and is currently used in an industrial context to understand causes for strain localization and fracture in such mechanical operations. This activity in 2011 will result in an industrial demonstrator for this model concept.

3. An extensive experimental programme has investigated the mechanical properties of the 6060 alloy at high strain-rates and high temperature. The objective of this work is to evaluate the constitutive models used in numerical simulation of extrusion.

The 'through-process' modelling approach for the analysis of the properties of welded structures is still under evaluation through the PhD study of A.B. Alisibramulisi. In parallel, models for 7xxx alloys are being investigated based on data from the PhD study of Ida Westermann.

In the project related to bake-hardening in advanced high-strength steels, a workshop was arranged in Paris to debate the physical understanding and models for this phenomenon. A simple model concept which (so far) relies upon isotropic work- and bake-hardening is numerically implemented in the 'SIMLab Metal Model' (see separate section about the SIMLab Model Library in the Industrial Demonstrators). Three-point bending tests were further performed in order to evaluate the applicability of the model concept through numerical simulations. The FE model of the test set-up and experimental and preliminary model results are presented in Figure 19. Based on these results we conclude that a more complex model that relies upon kinematic hardening is required to capture the bake-hardening effect.

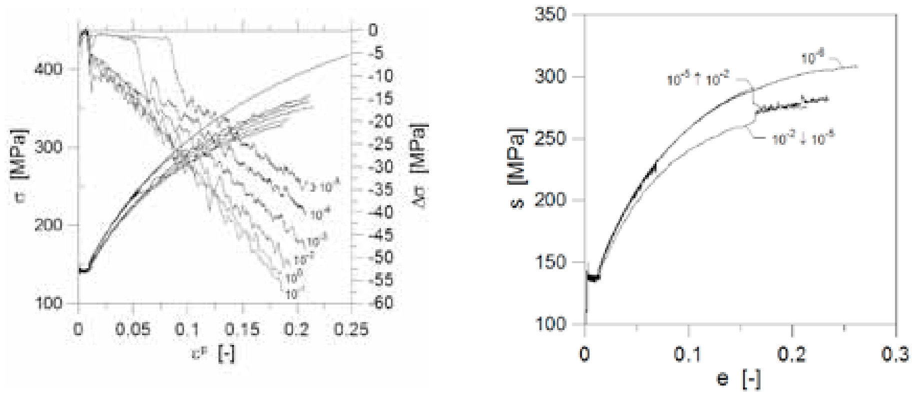


Figure 18 - Negative strain-rate sensitivity of AA5182, experimental data for steady-state strain-rate tests (left) and strain-rate jump tests (right).

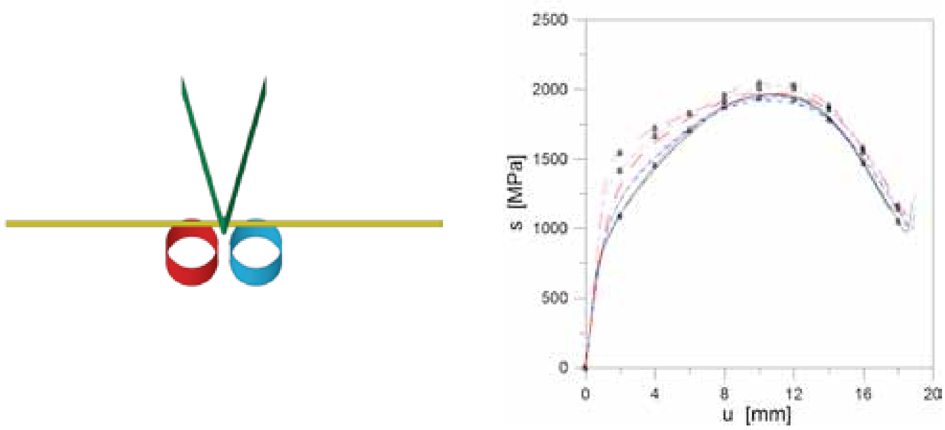


Figure 19 - Three-point bending tests for evaluation of model for bake-hardening effect: FE model of test set-up (left) and experimental and model results (right).

Connectors and Joints (C&J)

Programme head:

A. G. Hanssen

Introduction

Modelling of structural assemblies requires proper modelling of connections, such as rivets, welds and bolts. 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 has to be used. However, the models should tend to represent the large deformation behaviour and connector failure with a fair degree of accuracy. For single components, a higher amount of detail can be built into the models and connectors as well.

In this programme, experimental methods are used to characterize the behaviour of connectors subjected to static and dynamic loading conditions. The experimental activity involves both studies of the behaviour of single connectors as well as the assembly of connectors into structural joints. In parallel, numerical studies are carried out to gain increased understanding of the phenomena occurring during the large deformation behaviour of connectors.

Activities in 2010 include investigation of the self-piercing riveting (SPR) process when replacing the steel rivet by aluminium rivets. Moreover, complete joint assemblies with aluminium rivets have been made and physically tested to serve as basis for validation of a large-scale SPR point connector model developed previously at SIMLab. In addition, investigations have been done into the local induction heating of aluminium plates prior to setting the rivet. The intention is to soften the aluminium sheets prior to the riveting process and thus increase the possibility of creating a successful joint. Furthermore, a feasibility study was done on detailed component modelling of rivet assemblies, which was fully based on detailed brick models for all parts. With increased computational power, such models will be industrially feasible and increase the accuracy of the CAE process. Finally, there is ongoing activity on the modelling of safety barriers in road restraint systems, where the aim is to gain improved understanding of how threaded steel fasteners behave under combined loadings of tension and shear at elevated rates of strain. In the following we give a short resume of a selected set of activities.

Self-piercing rivets of aluminium
(PhD candidate Nguyen-Hieu Hoang)
In this activity the candidate investigates the feasibility of using a high-strength aluminium self-piercing rivet for riveting two aluminium sheets. This is especially relevant to the automotive industry from a recycling perspective. The challenge in replacing the traditional steel rivet with an aluminium rivet is that fracture of the aluminium rivet becomes imminent, Figure 20. This is caused by reduced ductility of the high-strength aluminium alloys used for making the rivets. This means that the whole SPR process has to be optimized in order to successfully create acceptable rivet connections. This project has focussed on developing a suitable material model with an appropriate failure criterion, so that the process can be numerically optimized in a robust way.

Assemblies of aluminium SPR rivets into structural joints
(PhD candidate Nguyen-Hieu Hoang)
Here the candidate has connected aluminium extrusions by using aluminium rivets and subjected the connection to large deformations, Figure 21. The purpose is to validate an SPR connector model developed at SIMLab for large scale analysis based on shell elements.

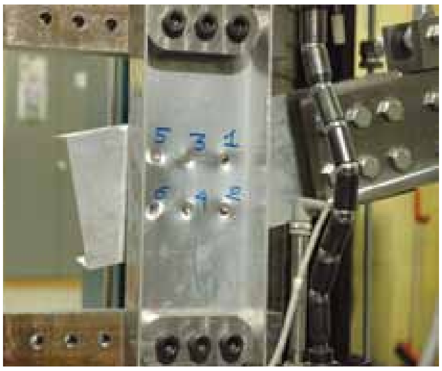


Figure 21 – Behaviour of assemblies using aluminium rivets.

Modelling of self-piercing rives for detailed component analysis
The SPR point connector model developed for large scale crash analysis will have limitations when used for detailed component analysis. However, in order to do research on the basis for future industrial approaches for modelling of such connectors, a feasibility study was done on a double hat section assembled by self-piercing rivets in a completely volume element based model, see Figure 22. Selective mass scaling was used to increase the time step in the rivet regions where the nodal distance is small. The study showed that such a simulation is feasible with manageable computational costs, but this requires that the modeller has control of the whole CAE process, from material identification, modelling of the SPR process and import of this data to the final component assembly. The advantage will be a higher overall computational accuracy, especially in predicting material failure arising from the rivet region.

Modelling of road-restraint systems – Safety Barriers
(PhD candidate Henning Fransplass)
The PhD candidate is studying the modelling of connectors for road-restraint systems. Road median and road side safety barriers are one of the most efficient measures to reduce the risk of head-on or run-off-road traffic accidents. Many types of road restraint systems are available. However, in this project we focus on safety barriers made of steel which deforms during a vehicle impact.

The safety barrier is made of w-beam rails and sigma posts. The rails are fastened to the sigma post by a bolt and a hex-nut. In a situation where an errant vehicle hits the safety barrier, the bolt is designed to fail and thereby releasing the w-beam from the sigma post. During the last two years, the focus in the project has been on the tensile behaviour of threaded steel fasteners at elevated rates of strain and an experimental and numerical study has been conducted. Two different failure modes occurred in these tests; bolt fracture in the cross-section area, and fracture when the external threads were stripped off, see Figure 23. It was observed that the grip length (the stressed length) and the strain rate had an influence on the tensile strength, ductility and failure mode. In 2010, a design model to predict the maximum load and mode of failure at elevated rates of strain has been

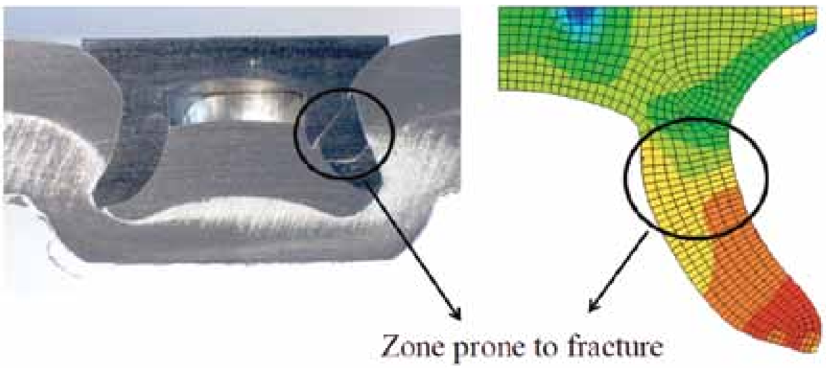


Figure 20 – Failure in aluminium rivets.

proposed. A feasibility experimental study on threaded steel fasteners subjected to combined tension and shear loads at elevated rates of strain has been carried out and will continue in 2011.

Industrial Demonstrators (Demo)

Programme head: O-G. Lademo

Background

The research areas defined in the Centre address the fundamental and generic aspects of the behaviour and modelling of an impact loaded structure, i.e. material models and response characteristics of generic components and joints, with emphasis on numerical solution techniques. In real structures a wide range of loading modes, materials and types of connectors has to be considered. Furthermore, each component might have been subjected to a thermo-mechanical process in the form of shaping and ageing, the effect of which must be captured in the numerical model. The applicability and feasibility of the various models can only be assessed when tested on full-scale industrial systems, here denoted demonstrators. The main objectives of this research area are: 1) to establish a link between the basic research and real structures for validation and possible refinements of the developed technology and 2) to facilitate industrial implementation of the developed modelling concepts.

SIMLab Material Model library and MatPrePost

Some principal outcomes of the research in the Centre are numerical implementations of constitutive models and failure criteria. The annual report for 2009 presents the developed model library, consisting of models for metals, polymers, solid geomaterials, crushable foams and castings along with tailored development on the associated solution techniques.

Interest is expressed by several of the consortium partners to make use of the

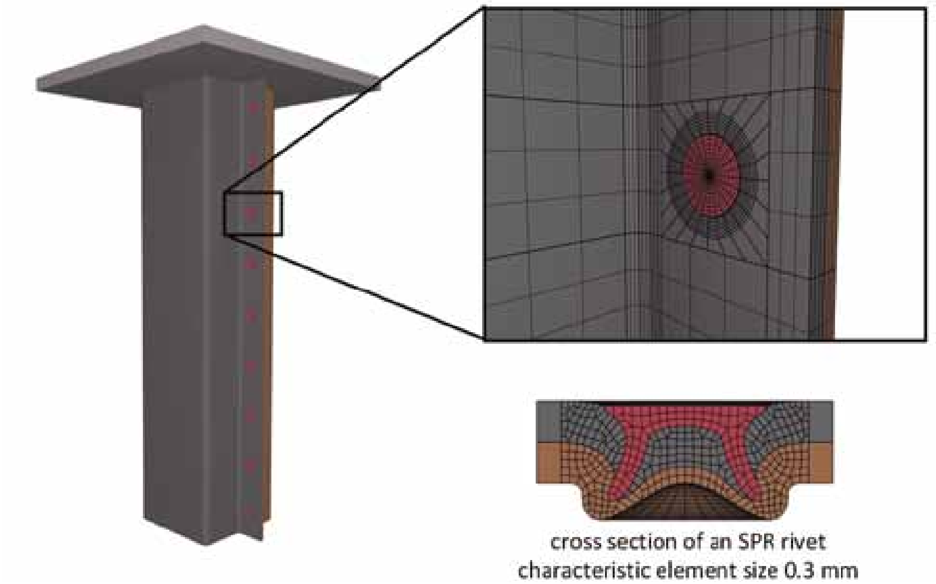


Figure 22 - Detailed modelling of rivet assemblies in component analysis.

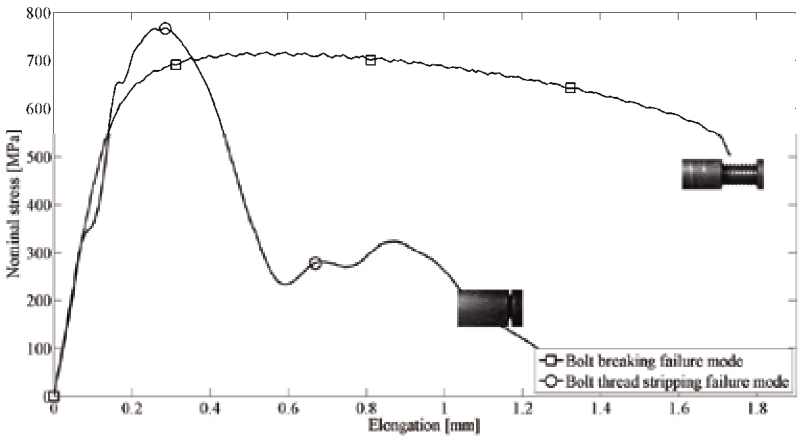


Figure 23 - Threaded assembly tests with different nominal strain-rates, but the same length of thread engagement.

material models in various industrial contexts and in various FE programmes. A project was initiated in 2010 to maximize the industrial benefit of the research-based models, for minimized efforts for both SIMLab personnel and the industrial partners. In other words, the overall aim of the activity is to bring the SIMLab models to a higher (or the highest) 'technology readiness' level.

In 2010 focus has been paid to the various, and so far co-existing, metal plasticity models within the SIMLab model library (WTM/STM-2D, GSTM, MJC, HAZ-2D). It was decided to restructure and combine these models into a single, highly versatile model thus being applicable to a broad range of mechanical problems. In order to do this a rewrite of current source codes was called for. In parallel, a re-structuring of parameter identification and visualization procedures was initiated.

Solution strategy and product interdependencies:
A value chain for non-linear numerical analyses was chosen, as illustrated in Figure 24. Four principal steps are distinguished, as seen along the timeline axis (abscissa).

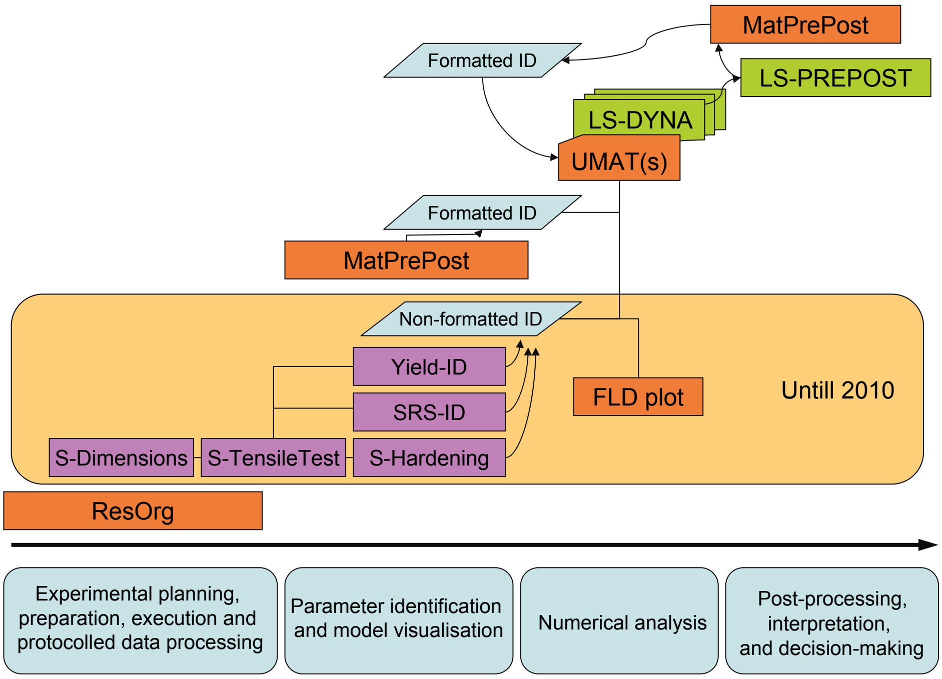


Figure 24 - Value chain and associated numerical toolbox.

In short these are: 1) Experimental testing, 2) Parameter identification, 3) Numerical analysis and 4) Post processing. The desired outcome of the chain is processed results that allow for proper engineering decisions. It is important to optimize the individual elements of the chain, e.g. appropriate experimental tests must be defined, proper identification procedures must be available, accurate model representation of physical response and supportive post-processing must be facilitated. The optimization of the chain, as a whole, must also be ensured, in the sense that the 'pre-fabric results' are fed efficiently along the chain.

As illustrated in Figure 24, three inter-dependent products will be developed:

ResOrg:
'Result Organizer' that supports experimental planning, execution and processing. This tool is, in principal, built since the initiation of SIMLab in 2007.

MatPrePost:
Tool for parameter identification and tailored pre- and post-processing. MatPrePost is developed based on different in-house programs and spreadsheets (as indicated by the box 'Untill 2010' in Figure 24), and tailored for efficient industrial application. The outcome of the pre-processing utility are for instance visualizations of the model concept, predicted Forming Limit Diagrams (FLDs) and fracture locus plots, and formatted input for the user-defined material model. This tool will at the end support output to several FE codes.

UMAT(s):
User-defined material model able to represent the physical phenomena of the engineering material in question. As stated earlier, we choose to define customized material models for the individual materials classes. The focus in 2010 has been on the metal plasticity model, which should be valid for rolled and extruded metals and alloys. The FE-code LS-DYNA is used as development platform, but the UMAT (as well as MatPrePost) will be adapted also for use with other FE-codes.

Status:
A 'beta-version' of 'MatPrePost' is established and released for internal use and evaluation. The preliminary appearance of the tool is illustrated in Figure 25 by some selected interface windows. A modular source code for the metal model has been written which so far includes a limited number of options. This work will be continued in 2011.

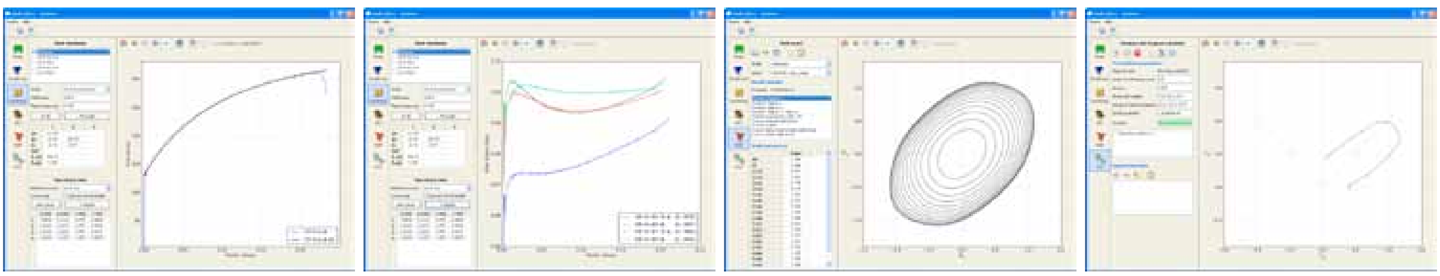


Figure 25 – Examples of the user interface of 'MatPrePost'.

SIMLab test facilities

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

Material testing at elevated rates of strain

Split-Hopkinson tension bar (SHTB)

The split-Hopkinson tension bar, see Figure 26, is a device for material testing at strain rates in the range between 200 and 1500 s^{-1}. It consists of two steel bars with diameter 10 mm. They are denoted input and output bars, having lengths 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 prestressed by means of a jack attached at the bar's end. By releasing the lock, an elastic stress wave is released, propagating towards the sample with a velocity of 5100 m/s. Applying one-dimensional stress wave theory, the response of the specimen, i.e. stress, strain and strain rate, is determined from records of strain gauges glued to each bar. High-speed camera instrumentation is also feasible. Moreover, an induction heater fascilitates tests also 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 sheet 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. Submitted for possible publication.

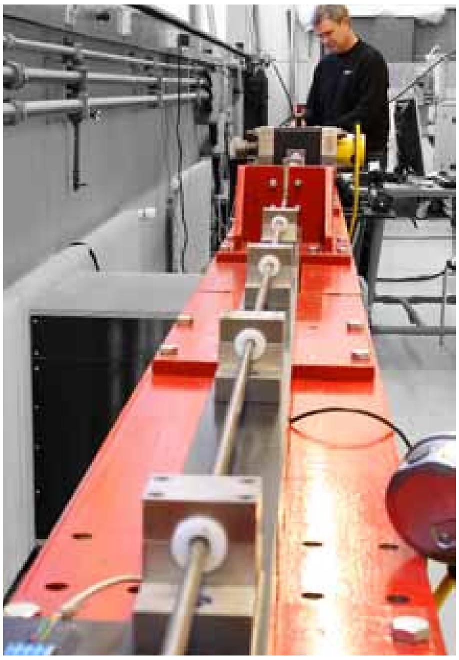


Figure 26 – Split-Hopkinson tension bar.

Photo: Melinda Gaal.

Hydro-pneumatic machine (HPM)

The hydro-pneumatic machine (HPM), shown in Figure 27, is a device for tensile material testing and is operating in the strain-rate range between 1-200s^{-1}. The diameter of the shafts is in the range 8–12 mm. The facility is operated by gas and water and has 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 a 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 the 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 which behave elastically during testing. The specimen elongation is measured by means of a displacement transducer.

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 temperatures.

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.

Sheet metal testing machine (BUP 600)

This fully PC-controlled multi-purpose hydraulic sheet metal forming machine, see Figure 28, is designed for formability testing of sheet metals in accordance with the most common standards and procedures. Its main advantages are an easy and rapid inter-changeability of the test tools, availability of tools for all well-known test standards and procedures, low cylinder-piston frictions delivering accurate measurement acquisitions and excellent reproducibility, and numerous modular possibilities of extensions. These features make this machine an excellent mean for performing advanced research in studying forming processes and for validation of numerical models as well as for educational training of master's and PhD candidates. 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. 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. Although the intention of the machine is to test sheet metals, it can also be applied with samples made of thermoplastics.

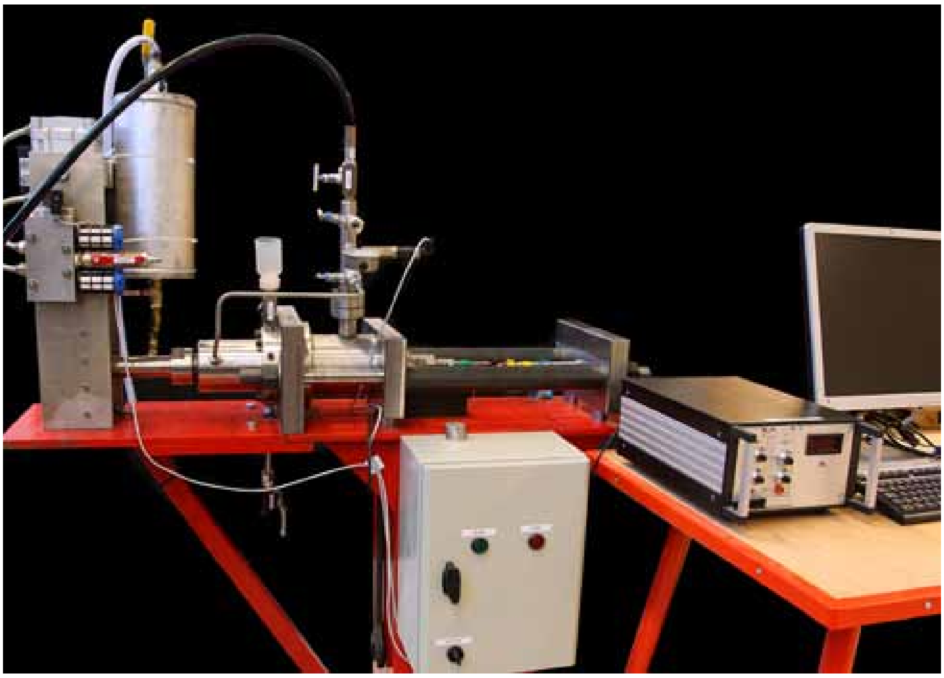


Figure 27 – Hydro-pneumatic machine.
Photo: Melinda Gaal.

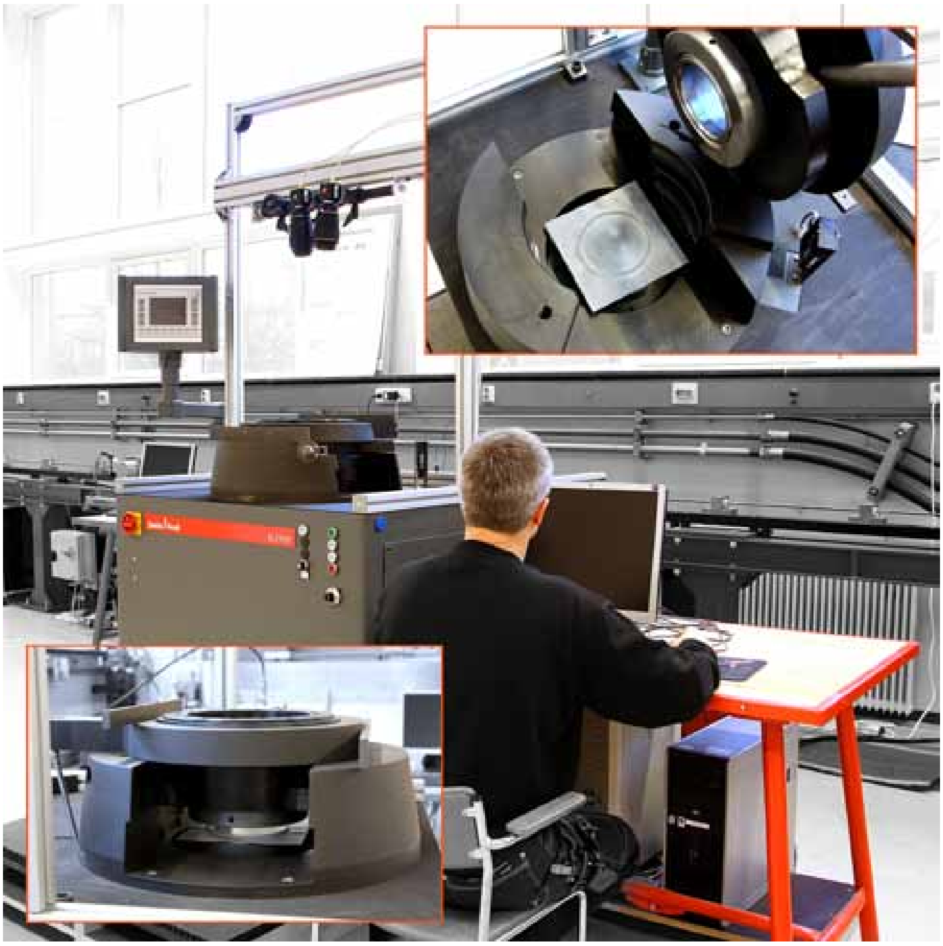


Figure 28 – BUP 600 machine. *Photo: Melinda Gaal.*

The machine has been equipped with a pair of high resolution black and white Prosilica cameras GC2450, with a resolution of 2448x2050 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 KO, Hopperstad OS: *Identification and validation of constitutive model and fracture criterion for AlMgSi alloy with application to sheet forming,* Materials & Design 2009; 30: 3005-3019.

Component and structural testing

Pendulum accelerator ("Kicking machine")
The pendulum accelerator is a device for impact testing of components and structures, see Figure 29. Basically, the test rig accelerates a trolley on rails towards a test specimen fixed to a reaction wall. The accelerating system consists of an arm that rotates around a set of bearings. The arm itself is connected to a hydraulic/

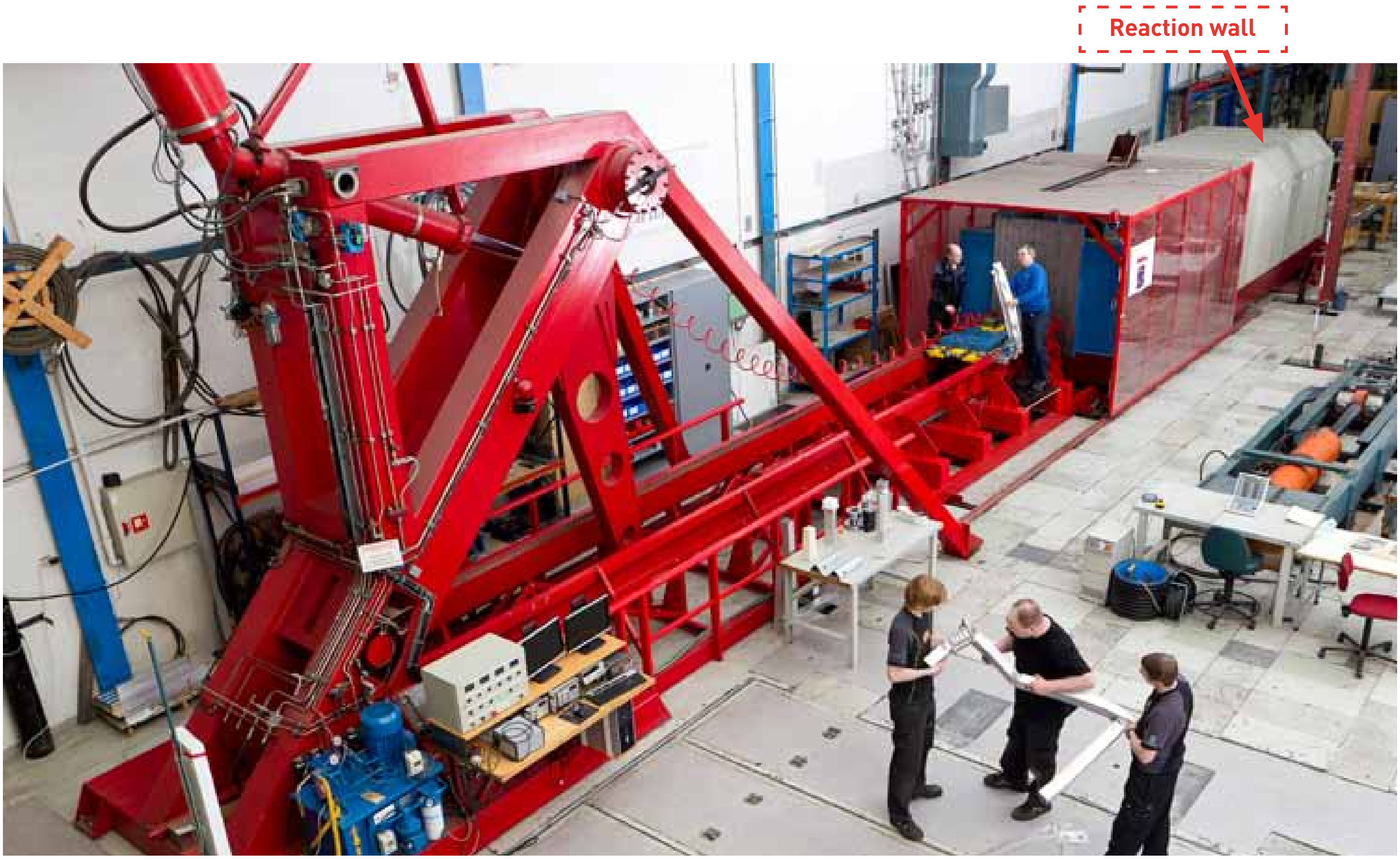


Figure 29 – Pendulum accelerator. *Photo: Ole Morten Melgård.*

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 400 and 1500 kg, giving a maximum velocity between 50m/s and 26m/s which is measured with a photocell system. In case the specimen does not have sufficient energy absorption capability 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 with two simultaneous working highspeed cameras.

FOR MORE INFORMATION:
Hanssen A.G., Auestad T., Tryland T. and 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 30, a projectile with a mass of 50 kg can be accelerated up to velocity of 25m/s. The rig consists of an accelerator tube (with an internal diameter of 160mm) 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. After integrating the force signal twice, 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. and Larsen P.K.: *Dropped Objects´ Plugging Capacity of Steel Plates:* An Experimental Investigation. International Journal of Impact Engineering 9 (1990) 289–316.

Compressed gas gun

A compressed gas gun for ballistic impact studies is also available at SIMLab. A schematic drawing of the facility is shown in Figure 31. 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 250 g projectile/sabot

Figure 30 – Pneumatic accelerator. *Photo: Melinda Gaal.*

Figure 31 – Schematic drawing of the gas-gun facility. *Photo: Melinda Gaal.*

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 OS, Malo KA. *Ballistic penetration of steel plates.* International Journal of Impact Engineering 1999;22:855-886.

Børvik T, Hopperstad OS, Langseth M, Malo KA. 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 32, 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 a complete instrumenttion 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.

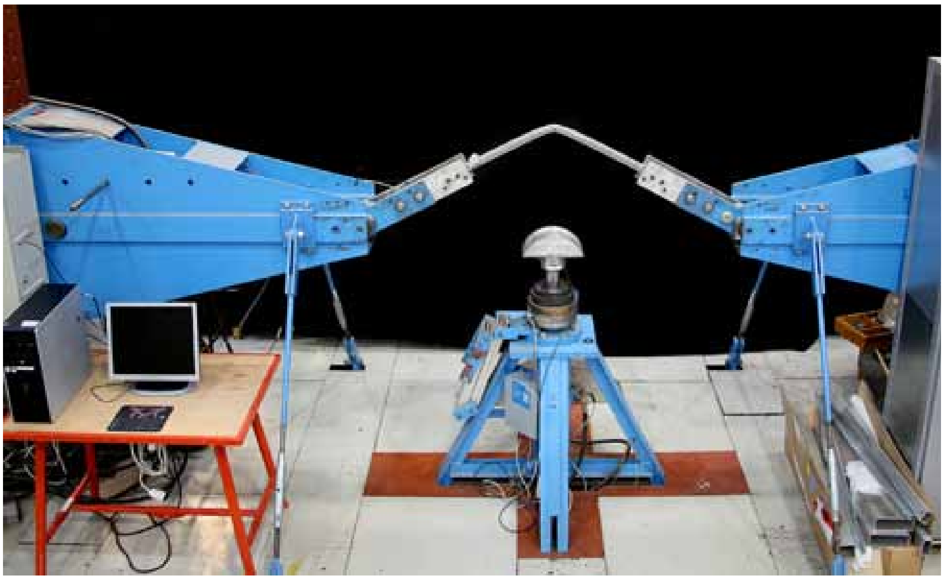


Figure 32 – Stretch-bending rig. *Photo: Melinda Gaal.*

Figure 33 – Self-piercing riveting machine. *Photo: Melinda Gaal.*

The rig has been employed in tests where the bending operation of car bumpers is studied. It has also been used to simulate pipelaying and in formability tests exploring the onset and propagation of fracture.

FOR MORE INFORMATION:
Clausen A.H., Hopperstad O.S. and Langseth M.: *Strech bending rig. Experimental set-up.* Report R-9-96 (Revised 1999). Department of Structural Engineering, NTNU.

Joining machine

Self-piercing riveting machine
In this machine, see Figure 33, self-piercing riveting can be carried out of sheets under industrial conditions. The machine has been purchased from Böllhoff in Germany.

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

Midway Evaluation of the Centre

The fourteen Centres for Research-Based Innovation (CRI) supported by the Research Council of Norway were evaluated by one-day site visits in October 2010, approximately 3.5 years after they were started and about midway in the planned eight-year programme. The evaluation had two main purposes:

- To form the basis for a decision by the Research Council of Norway about whether to continue financing of each individual centre for the final three years of the eight-year term.

- To give comment and advice to the centres about their activities and how it should be improved.

Each Centre was evaluated by a team of four experts. Two of them were experts that had the competence to evaluate the Centre from a scientific point of view. Two further "generalists" had experience from similar programmes for university-industry research collaboration. The "generalists" evaluated the management, organization and funding of the Centre, and also its interactions with user partners, in terms of mutual mobility of researchers, transfer of results and stimulation of innovations.

SIMLab was evaluated on 27 October 2010, and the conclusions and recommendations from the panel were as:

SIMLab is characterized by excellent research conducted under dynamic leadership by a group of students and senior scientists that seem to cooperate well both internally and with user partners, from which they receive strong support. The evaluation team encourages the Centre to continue its work along the lines presented in the written report and during the presentation. We recommend:

- that the transfer of results for application in partner industries be enhanced by arranging courses specifically designed for individual partners

- that the Centre vigorously continue its efforts to ensure continuation after 2014

- that strong efforts be pursued to engage more women as senior researchers and students in SIMLab activities

- that the Centre pay some attention to the fact that the present rather informal way of management is effective, but highly dependent on personal contacts

Based on the evaluation report the Research Council of Norway has approved a prolongation of SIMLab from 2012 to 2014 without requiring any improvements.

Concurrent research projects

The following selection of research projects have been run in 2010 utilizing the competence developed at the Centre:

- Crash systems in trucks (2009-2011): SIMLab together with Kongsberg Automotive and SINTEF Raufoss Manufacturing is involved in a user defined research project (BIP project) funded by the Research Council of Norway. The activity at SIMLab is related to a PhD candidate (Espen Myklebust) who is working on robust design related to material variations.

- Duplex pipe fittings with sigma phase precipitation (2010): SIMLab in cooperation with SINTEF has been involved in a project for Statoil to evaluate the impact resistant of duplex pipe fittings with sigma phase precipitates. Both materia tests at elevated rates of strain and impact tests in the SIMLab's pendulum accelerator have been carried out.

- FME BIGCCS (2009-2016): In the research task CO2 Pipeline Integrity, the main objective is to develop a coupled fluid-structure model to enable safe and cost-effective design and operation of CO2 pipelines. Further, requirements to avoid running ductile fracture in pipelines pressurized with CO2 and CO2 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.

- SECURE: SIMLab is involved in the research platform SECURE through post doc Heidi Moe Føre from SINTEF Fisheries and aquaculture (2010-2013). SECURE consists of 9 research partners, and involves technological and biological research within escape of fish from aquaculture. SIMLab contributes in modelling of fish farms and studies of material properties.

- BIP NextGenSi: SINTEF, NTNU and TU Bergakademie Freiberg together with 3 PV-related companies are involved in this BIP project for the period 2009-2013. The main objective of the project is to develop technologies for next generation production line equipment for ultra-thin silicon wafers. A modelling activity is working on assessing and understanding the effects of selected parameters on wafer life in the production chain.

- 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 advanced continuous fibre polymer composites. One PhD candidate is supervised by personnel from the Centre.

Furthermore, the associated SINTEF team has been involved in the following new project initiatives:

- COPAT: Hydro Aluminium Precision Tubing (HAPT) has taken initiative to an innovation project related to cost efficient and competitive manufacturing processes for production of leak-free tubes. This project will be strongly linked to the research at SIMLab, and allow the involved scientists in the Centre to be actively engaged in a required industrial innovation. In addition to direct process innovations, this also enables efficient implementation of such methods in HAPT.

- FAST-Tunn: A main objective of this project initiative is to develop more efficient cutter rings for Tunnel Boring Machines (TBM) used in hard rock formations. Numerical models will be developed to understand the rock/cutter interaction.

European Commission – funded applications

An EU application with involvement from the partners has been discussed by the Board, but so far there is no enthusiasm for such an initiative from the majority of the industrial partners. The experience the international partners have from previous EU projects is 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 2010 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 outside the consortium.

With this in mind, NTNU has been involved in a 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 coordinator of the proposal was Impetus Afea AS, Norway. The proposal was positively evaluated by an independent evaluation panel and was ranked above the quality threshold with respect to the technology and innovation criteria as well as the market and competitiveness criteria. However, funding was not raised and thus the application was not approved.

New equipment

- A new reaction wall for the Pendulum accelerator has been designed and installed in autumn 2010, see Figure 29. The new reaction wall has a total weight of 150 000 kg and is floating on the laboratory floor by using special purpose designed shock absorbers. This will limit the transfer of dynamic forces to the laboratory floor and thus the rest of the building.

Workshop on Lightweight Protective Structures at SIMLab.

Workshops and seminars

- The Centre organised a two-day international workshop 2-3 December 2010 on the behaviour, modelling and analyses of lightweight protective structures at SIMLab. The workshop gathered totally 33 scientists and PhD candidates from Norway, USA, UK, France, Italy, Germany, Singapore, South Africa, Sweden and China. During the workshop the state-of-the-art was presented and discussed as well as future needs for research within this area. A workshop report will be worked out which will summarize all presentations, discussions and conclusions.

- In collaboration with Professor Ahmed Benallal at LMT-Cachan, a workshop on bake hardening and related problems (e.g. static and dynamic ageing phenomena, Lüders banding and the Portevin-Le Chatelier effect) was arranged in Cachan, France. The workshop had 13 participants from France, Canada, Sweden and Norway, representing academia, research institutions and steel industry. In the workshop, the industrial perspectives and the state-of-the-art in experiments and modelling of static and dynamic ageing phenomena were presented and discussed. The majority of the presentations given at the workshop are gathered in the workshop proceedings.

Workshop on Bake Hardening at LMT Cachan, France.

MURI seminar at SIMLab.

Seminar at SIMLab recognizing the retirement of Professor Per Kristian Larsen.

- As a part of the cooperation between SIMLab and the MURI project (Multi-disciplinary University Research Initiative Project titled An Integrated Cellular Materials Approach to Force Protection and sponsored by the U.S. Navy) a one day seminar was held 24 August 2010. Discussions were undertaken on how the particle-based method used in the OptiPro programme to simulate blast loading coupled with fragments as well as the Centre aluminium research can be coupled with the landmine activity and protection of vehicles in the MURI project.

- In order to recognize the 70th birthday of Professor Per Kristian Larsen and thus also his retirement from chair of steel structures at the Department of Structural Engineering, NTNU, a seminar was held in June 2010. Invited speakers were his former PhD students as well as other people from Norwegian industry and the Research Council of Norway, with whom he has cooperated during his 40 years at NTNU.

Visibility

Journals

- Elsevier has appointed Adjunct Professor Tore Børvik as an Associate Editor of the International Journal of Impact Enginee-ring.

- Elsevier has appointed Professor Odd Sture Hopperstad as an Associate Editor of the European Journal of Mechanics A/Solids.

Evaluation committees

- Professor Magnus Langseth, NTNU has been a member of an International Scientific Committee which has evaluated the new Centre at the University of Valenciennes, France, on Research for Sustainable Transportation.
- Professor Odd Sture Hopperstad, NTNU has been a member a committee which has evaluated the SYMME Laboratory at the University of Savoie, France.

Keynote lectures

- Professor Magnus Langseth, NTNU gave a keynote lectures at the Design and Analysis of Protective Structures conference (DAPS2010) in Singapore 10-12 May 2010.

Guest lectures

- Professor Arild Holm Clausen, NTNU gave a guest lecture at the Karlsruhe Institute of Technology, 30 November 2010 on the topic *"Constitutive Model for Thermoplastics – Calibration and Validation"*.

Magazines/Newspapers

- An article about the filming by Discovery Channel at SIMLab in October was presented in the local newspaper Adresseavisen on 16 October 2010.
- The magazine Gemini presented an article in the February issue about the Centre activities on the use of aluminium in the automotive industry, i.e. *"Cars have put on quite a lot of weight over the last*


NTNU på Discovery Channel

Adresseavisen 16 October 2010

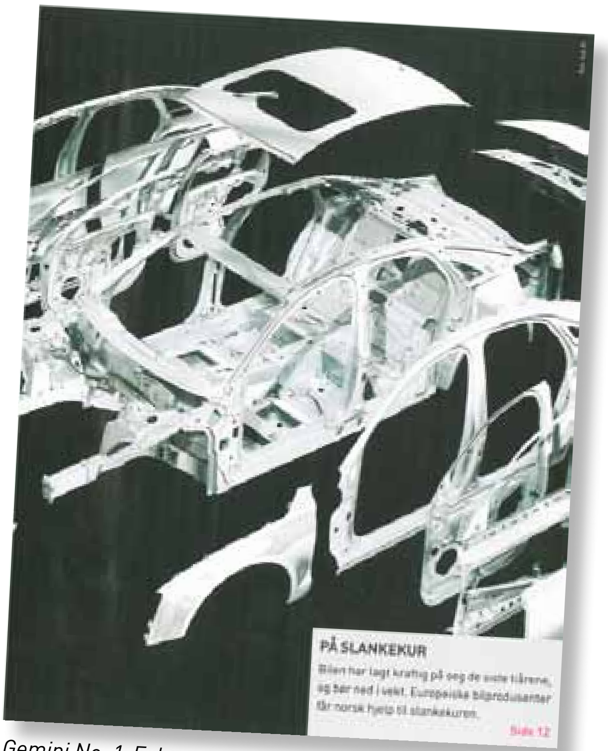

Trøndersk trøkk

Audi magazine 01/2010


NTNU skal slanke Audi

Audi vil lage lettere biler for å få ned drivstofforbruk og utslipp av klimagasser. Forskere i Trondheim deltar i dette arbeidet.

Bil&trafikk – Adresseavisen 27 May 2010


PÅ SLANKEKUR

Bilen har lagt kraftig på seg de siste tiårene, og bør ned i vekt. Europeiske bilprodusenter får norsk hjelp til slankekuren.

Side 12

Gemini No. 1-February 2010


Tilstand av kontrollert panikk

Universitetsavisa 25 November 2010

Gemini Spring 2010

decades, and need to lose weight. European carmakers are getting Norwegian help with their diets. Heavy cars damage the environment more than light-weight cars, and Audi is slimming down their models with help from Trondheim". In addition the spring issue of the same magazine presented a photo of a crushed aluminium profile based on a test in the SIMLab laboratory.
- SIMLab was presented in the Adresse-avisen magazine "BIL & trafikk" 27 May with a focus on the research at the Centre on lightweight design and modelling.
- SIMLab was also presented in the Norwegian Audi magazine 01/2010 published by the Norwegian Audi dealer Harald A. Møller AS.
- PhD student Anne Serine Ognedal was interviewed by the university newspaper "Universitetsavisa" about what it is like to be a PhD candidate at SIMLab.

National cooperation

The Centre has a running cooperation with Assoc 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 a robust behaviour of a structures subjected to impact. Ørjan Fyllingen is a co-supervisor for one of the PhD candidates at SIMLab.

International cooperation

Visiting scientists/professors
- Professor Ramzi Othman from Ecole Centrale de Nantes, France, stayed at the Centre for two months working on the design of a new Split Hopkinson Pressure Bar.
- Dr Jidong Kang from McMaster University, Canada, stayed at the Centre for one month working with dynamic strain aging of aluminium alloys.
- Professor Alan Leacock from the University of Ulster, UK, stayed at the Centre for one month working on forming of aluminium.

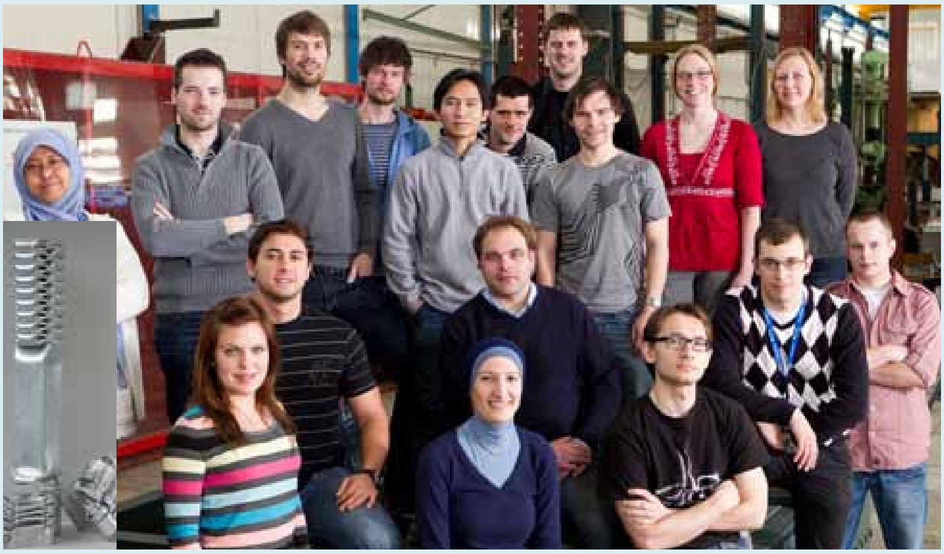
Research cooperation with organizations
The Centre has strong international cooperation due to three international partners, i.e. Audi, Renault and SSAB Swedish Steel. Furthermore, the following organizations are taking active part in the Centre projects in 2010:

- *Cotutelle agreements for PhD students:* LMT-Cachan (Professor Ahmed Benallal) and Ecole Centrale de Nantes (Professor Ramzi Othman), France; Karlsruhe Institute of Technology (Professor Karl Schweizerhof), Germany.
- *Other organizations involved in Centre activities:*
  - University of Sao Paulo (Professor Marcilio Alves), Brazil. University of Savoie (Professor Lauent Tabourot), France. Impetus Afea (Dr Lars Olovsson), Sweden. Politecnico di Milano (Assoc Professor Andrea Manes), Italy. University of Linköping (Professor Larsgunnar Nilsson), Sweden. Harvard University (Professor John Hutchinson), MIT (Professor Tomasz Wierzbicki) and University of Virginia (Professor Hayden Wadley), USA. Technical University of Madrid (Dr. Francisco Gálvez Díaz-Rubio), Spain.

Guest lectures
The following guest lectures have been given at SIMLab in 2010:

- Professor Em. David Embury, McMaster University, Hamilton, Canada gave during his three-day stay at the Centre the following lectures:
  - *Basic Mechanisms of Fracture and Design for Fracture Resistance*
  - *Routes to the Production of Ultra-fine scale Materials*
- Dr Jidong Kang, McMaster University, Hamilton, Canada: *Dynamic Strain Aging and Shear Banding in Strip Cast Automotive Aluminium AA5xxx Sheets*.
- Professor Ramzi Othman, Ecole Centrale de Nantes, France: *Wave separation in Kolsky-Hopkinson bar*.
- Professor Karl Schweizerhof, Karlsruhe Institute of Technology, Germany: *On the Static Interaction of Fluid and Gas Loaded Multi-Chamber Systems in Large Deformation Finite Element Analysis*.
- Professor Thomas Seelig, Karlsruhe Institute of Technology, Germany: *Macroscopic and microscopic modelling of thermoplastic polymers*.
- PhD candidate Borja Erice, Polytechnic University of Madrid: *JCX model - A new plasticity and failure model for ballistic application.*

Students



PhD students, post docs and visiting students from Brazil, Denmark, France, Germany, Malaysia, Netherlands, Norway, Russia, Syria and Vietnam. Photo: Ole Morten Melgård.

PhD candidates

The following PhD candidates have been linked to the Centre in 2010:

NAME	START	PLANNED EXAM	PROGRAMME	CITIZENSHIP	MALE/FEMALE
Ida Westermann*	Autumn 2007	Spring 2011	M^4	Denmark	Female
Henning Fransplass*	Spring 2005	Autumn 2011	C&J	Norway	Male
Virgile Delhaye*	Summer 2007	Autumn 2010	Polymers	France	Male
Egil Fagerholt*	Winter 2008	Spring 2011	F&CP	Norway	Male
Nguyen-Hieu Hoang*	Autumn 2007	Spring 2011	C&J	Vietnam	Male
Gaute Gruben*	Summer 2008	Summer 2012	F&CP	Norway	Male
Anne S. Ognedal*	Autumn 2008	Autumn 2012	Polymers	Norway	Female
Octavian Knoll*	Summer 2009	Summer 2012	F&CP	Germany	Male
Marion Formeau**	Autumn 2009	Autumn 2012	F&CP	France	Female
Knut Rakvåg**	Summer 2009	Summer 2013	OptiPro	Norway	Male
Dmitry Vysochinskiy**	Spring 2010	Spring 2014	M^4	Russia	Male
Mikhail Khadyko**	Autumn 2010	Autumn 2014	M^4	Russia	Male
Martin Kristoffersen*	Autumn 2010	Autumn 2014	OptiPro	Norway	Male
A.B. Alisibramulisi**	Autumn 2007	Autumn 2011	M^4	Malaysia	Female

*= Salary and operational cost from the Centre,
**= Operational cost from the Centre only – salary from other sources

New PhD candidates in 2010

- Martin Kristoffersen and Mikhail Khadyko were recruited through a campaign towards our own master's students spring 2010.
- PhD candidate Dmitry Vysochinskiy was recruited from Reinertsen Engineering in Trondheim where he worked as a structural engineer.

Related PhD candidates in 2010

- Espen Myklebust is employed as a PhD candidate at the Department of Structural Engineering and linked to a BIP project on robust design of crash systems in trucks. The coordinator of the project is Kongsberg Automotive. Espen Myklebust is affiliated with the SIMLab group and utilizes the available infrastructure.
- Andreas Koukal is a PhD candidate at the Technische Universität München. He was recruited by Audi to work on behaviour and modelling of polymers and is thus linked to the Centre through Audi.

Equal opportunity

At present 4 of the 16 PhD candidates are females.

Post docs

The following post docs are linked to the Centre in 2010:

NAME	START	END	PROGRAMME	FROM	MALE/FEMALE
David Morin	Autumn 2010	Autumn 2012	C&J	France	Male
Afaf Saai	Autumn 2009	Autumn 2011	M^4	Syria	Female

Visiting PhD candidates

- PhD candidate Borja Erice from Department of Material Science, Polytechnic University of Madrid stayed at the Centre for three months and was linked to the OptiPro programme on penetration.

PhD disputation

Virgile Delhaye defended his thesis 16 December 2010 with an excellent statement by the committee. The topic of his thesis was *"Behaviour and modelling of polymers for crash applications"* while the public lecture was on *"Design of fish farming net cages"*. The thesis was covered by a Cotutelle agreement between NTNU and Ecole Centrale de Nantes, France, and the candidate thus got a degree from both institutions. The advisors were Professors Arild Holm Clausen and Odd Sture Hopperstad from NTNU and Professors Ramzi Othman and Arnaud Poitou from Ecole Centrale de Nantes, France. In addition it is worth mentioning that Mr François Moussy from Renault has given the candidate excellent support and encouragement during the thesis work.

The evaluation committee had three members, i.e. Professor Franck Lauro from the University of Valenciennes, France and Professor David Barton from the University of Leeds, UK, while Professor Magnus Langseth from NTNU was the administrator.

PhD disputation for Virgile Delhaye – advisors and committee. From the left: Odd Sture Hopperstad, François Moussy, Arild Holm Clausen, Virgile Delhaye, Magnus Langseth, David Barton, Franck Lauro and Ramzi Othman.

Master's students

The following master's students were linked to the Centre in 2010:

STUDENT	TOPIC
M.B. Austnes and O. Bjøklid**	Impact on Duplex stainless steel pipes with and without precipitated sigma phase
H. Torseth	Optimization of steel for protective structures
M. Haugen	Tests and Numerical Simulations of Polymer Components
M.T. Hovden*	Tests and Numerical Simulations of Polymer Components
E. Høyland and M. Kristoffersen**	Fragmentation of metallic materials during impact
C. Kaurin and M.O. Varslot**	Blast loading on square steel plates: A comparative study on numerical methods
M. Khadyko	Numerical modelling of the effects of crystallographic texture and grain structure on the macroscopic behaviour of metals
H.L. Nossen	Behaviour of aluminium at elevated strain rates and temperatures
Ø. Nørstebø and Ø. Torgersrud**	Ductility of aluminium alloy 6016
G. Olsen	Design of an aluminium test cart
S. Oven	Design of lightweight protective structures
A. Rybakken	Evaluation of Material Models for Thermoplastics
K. Slåttedalen and A. Ørmen**	Impact against offshore pipelines
S.J. Tveito	Driving of hollow steel piles with rock shoes into rock
Ø. Vagnildhaug	Pipelines response to trawl pull-over

* Martin Thuve Hovden was awarded the prize for the best master's thesis of 2010 in the MSc study programme of Civil Engineering, comprising more than 150 students, for his work on "Tests and Numerical Simulations of Polymer Components".

** Joint thesis

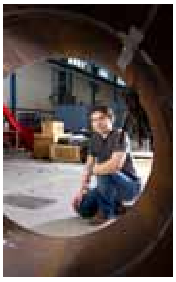
Last year 16 young professionals from 7 countries were busily working on their PhDs at SIMLab.



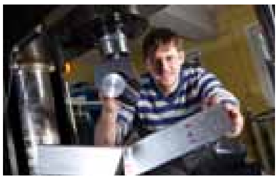


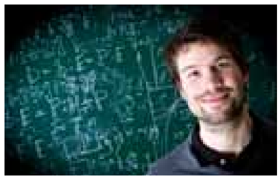










Have a look at the following pages and get a glimpse of 16 fascinating histories, personalities and programmes.

Text: Albert Collett

Photo: Ole Morten Melgård

Martial and other arts

Since primary school Anizahyati Alisibramulisi has loved drawing. In secondary school she took up martial arts as well. Beware! Malaysian martial arts are no joke.

Some people actually claim that martial arts legend Bruce Lee died after losing to a master of Silat Gayung. Enough said? Possibly not. Anizahyati is all smiles and looks very innocent. Maybe further warning is in place. Joking aside, we don't really think so.

Structural behaviour

It's not for everyone to understand the complexity of PhD programmes. Anizahyati had that in mind when she put down ten sentences to describe the content of her thesis at SIMLab. Sentence one explains that the aim is to improve the modelling of the structural behaviour of welded aluminium structures, with emphasis on the effect of heat affected zones, since these cause the main problem in welded aluminium structures. To an amateur that's partly understandable, but only partly; "what exactly does she mean by structural behaviour?"

Anizahyati explains: "A structure refers to a system of connected parts used to support a load, whereas the behaviour of the structure to withstand that load is called structural behaviour."

Aunt Gerda

Anizahyati also helps with the last sentence. This is aimed at aunt Gerda: "What I am doing is all about getting to know my best friend Ms Aluminium – what are her strengths and weaknesses when heated. Then Mr Computer will try to show what she has gone through on the screen. If it is correct, Mr Computer can be her new "aluminium forecast" like the weather forecast."

Our conclusion? Thank heavens for aunt Gerda. Anizahyati's conclusion? She looks forward to return home with her newly acquired expertise, not only in aluminium but also in personal relations.

Friendly professors

"The professors here are so friendly. They treat us like colleagues. I will also bring back the way we work with industry and the time we have for research. In my university we have to teach at least 20 hours a week. The equivalent here is six hours. When I return home I will tell my university that we need more time for research. Finally, I will contact the car industry in Malaysia to check on the possibilities to continue industry-related research."

Plastic fantastic

"I love plastic! It's a fantastic material with endless possibilities," says Anne Serine Ognedal. She feels extremely privileged to be able to pursue her curiosity at SIMLab.

Before being recruited to her programme, Anne Serine worked on Laerdal Medical's most advanced manikin. The anatomical model gives correct responses to all kinds of impulses, pupils expanding with increased adrenalin and all. Price tag: the equivalent of a small car. Just as well Anne Serine left Laerdal. If not, who knows; she might have been developing a new model, replacing us all at the workplace.

Wanted to know

"At Laerdal Medical I experienced how you can modify the structures of plastic to get the properties you want. You can make geometries of plastic like no other material. I also discovered that no one knows the exact properties of the materials. I always wanted to know more, so when I got the chance to become a PhD candidate here at SIMLab, I decided to take the opportunity," she says.

Small pores

The title of Anne Serine's programme is "Damage and fracture of polymers". This means that her work deals with exposing pieces of plastic to large deformations. If you ever tried to deform a piece of plastic yourself, you might have seen that it turns white. Anne Serine's PhD work basically starts where the plastic turns white and ends where it breaks. She tries to find out how much polymer materials can take before they turn white and after that how the white evolves and causes fracture.

What we perceive as white when we look at it, really is lots and lots of micrometre-sized pores. They are formed as the material is deformed. The pores look white (when we don't look at them in a microscope) because light is scattered when it hits them.

All this has to be expressed in mathematical terms so a computer can understand and compute the whole process.

Incredible

If Anne Serine succeeds in her research, computers will be able to predict how a bumper deforms when a car hits a pedestrian. This can be used to try out different designs on the computer in search of a bumper that doesn't hurt the pedestrian.

Useful? Definitely. Fun? Anne Serine puts it like this: "People don't know how great it is to do a PhD. Little me working with world-class scientists. When I entered the programme, the professors asked: "What would you like to do?" Incredible."

Leaving Kaliningrad

What do you do when your ambitions reach further than a degree from your local university can get you? You break up. Meet **Dmitry Vysochinskiy.**

The Russian exclave of Kaliningrad is surrounded by the EU; Poland to the south, Lithuania to the north and east, and the Baltic Sea to the west. Until 1945, Kaliningrad was Königsberg, capital of East Prussia, home of Immanuel Kant. More about him later.

Technical guy

Meet Dmitry Vysochinskiy first: "I was a technical guy right from the start, good in maths and natural sciences. After obtaining my bachelor's degree I decided I didn't want to spend my life as a construction engineer in Kaliningrad, so I found a master's programme at Chalmers University in Gothenburg. After that I landed a job as a pipeline engineer with Reinertsen Engineering here in Trondheim," Dmitry recounts. After two years in industry, he filed an application at SIMLab. It's still early days, but the topic of his programme is clear: the forming of metal sheets. The experiments will be carried out with an aluminium alloy; exactly which one is yet to be decided.

Stretching limits

Like many of his colleagues, Dmitry will subject his material to large plastic deformations and examine what happens when the material fails in different ways. He is particularly interested in stretching. When a material is stretched, a number of phenomena may occur.

The sheet can simply tear if the metal is not ductile enough. Then there's the plastic instability. If you stretch, you want to do it uniformly but you may experience local instability. Plastic deformation concentrates at one place; the metal sheet becomes thinner and eventually fractures there.

Shear instability may be regarded as a special type of fracture and is yet another phenomenon to be studied.

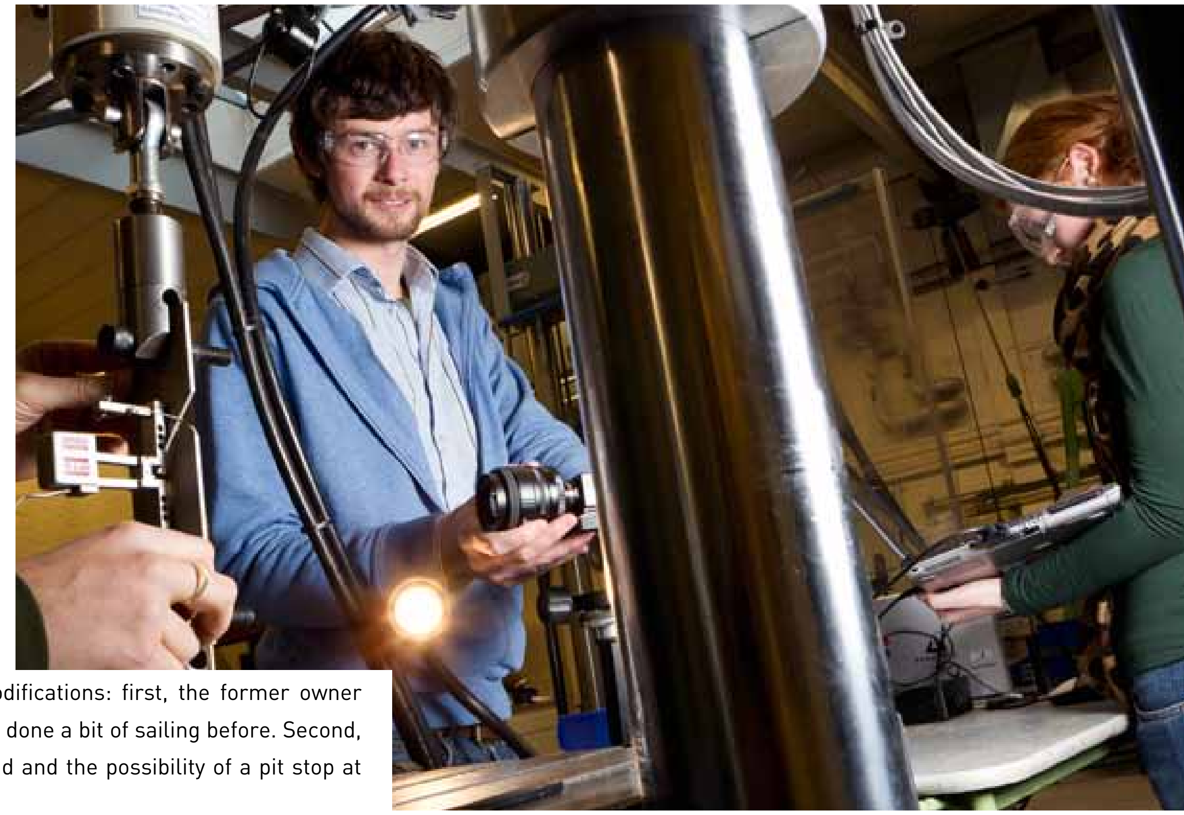
Idealist

"The main question is how the material properties influence the forming limits. We can determine the material properties. We can also determine forming limits for some simple cases of forming by experiments. The challenge is to combine these two and predict the forming limits for more complicated cases of forming," Dmitry says.

He confesses to be a bit of an idealist. That harmonizes well with fellow citizen Kant and his doctrine on transcendental idealism, which maintains that the human experience of things is similar to the way they appear to us. It remains to be seen whether Dmitry's thesis will be in accordance with this.

Setting off for Spitsbergen

Listen to this: **Egil Fagerholt** had never set foot in a sailboat. The first thing he did after buying one in 2008 was to head for Spitsbergen. That's six days and nights of sailing due north in Arctic waters.



Two comforting modifications: first, the former owner came along. He had done a bit of sailing before. Second, there is sight of land and the possibility of a pit stop at Bjørnøya half way.

It ended well, with a little help. As they closed in on Spitsbergen, fog closed down visibility. The VHF had broken down so they never got the message that a massive ice floe was heading their way. Neither did they know that several other boats were caught in the ice nor the fact that the Norwegian Coast Guard was searching to stop them in time. Luckily, the fog lifted just before they reached the ice. Right in front of them was the Coast Guard, blocking the way to give a clear message.

And now, science

So, there's a daring scientist for you. Maybe that's why he's not afraid to enter new territory. Where others study fracture and crack propagation through testing and calibrating with numeric simulations, Egil has chosen the camera as his tool, taking advantage of the extreme developments in technology. 10 000 high resolution exposures a second is way beyond an Instamatic. Typically several hundred digital images are recorded in a single experiment.

Develops software

"The camera generates massive amounts of field info directly from the test. The method can be compared to numerical simulations but my approach moves in from the other side, so to say. Where others use commercial software, I develop it. The challenge is to measure samples with crack propagation. The main task in this PhD work is developing software algorithms to analyse such image series. That part of the work is also the biggest kick for me," Egil confesses. He truly enjoys being able to concentrate on a project for a long time and has already accepted a position as Post Doc.

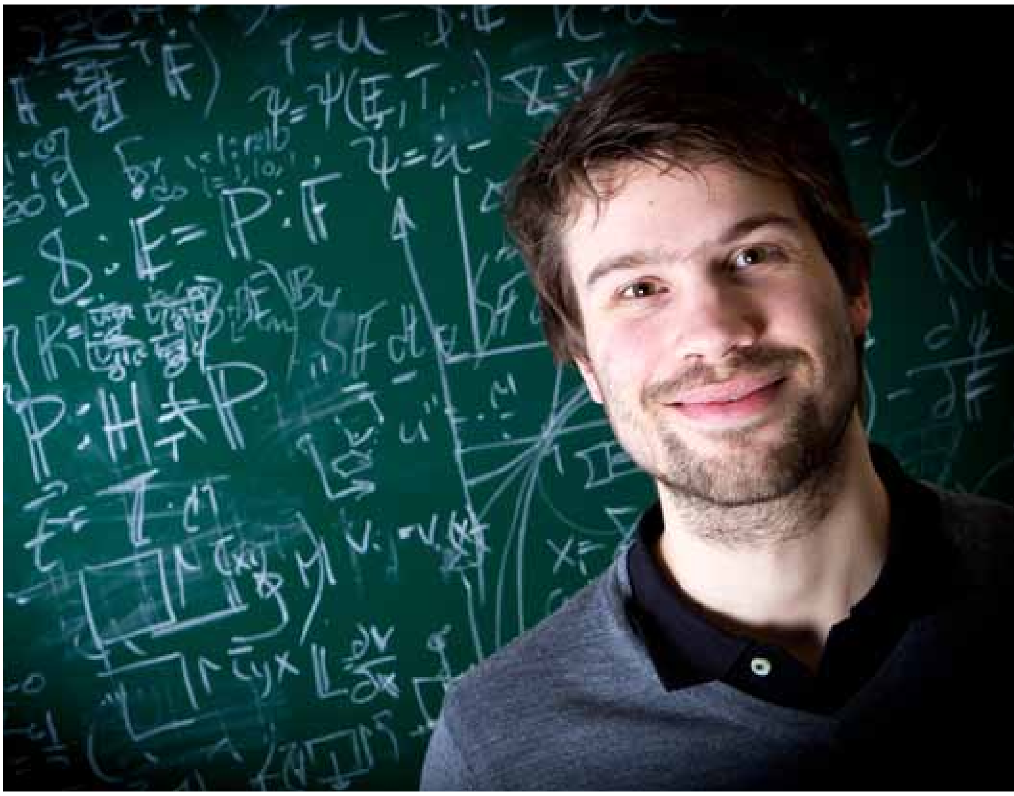
Ready for release

After defending his thesis later this year, Egil hopes to develop his software further towards a user-friendly application. Only time will tell if it can be turned into a commercial product.

"In principle it should be interesting for experiments with any material – steel, aluminium or plastic," predicts Egil.

Searching for the soul

We all know it. Judging merely by looks is foolish. In the long run inner qualities count more.
Not only when it comes to people.
The same goes for materials.



The question is how you find the soul of steel and how you describe it .
Espen Myklebust is doing just that.

"When you look at a material, it looks homogeneous. However, if you subject it to an increasing load, something will happen. At a certain point the material will weaken in one place or other. What inner qualities make this happen? If you look at the material in a microscope, you will see variations. These variations are not taken into explicit consideration when the strengths and weaknesses of the material are modelled. That's what I intend to do something about. My aim is more realistic models," he says.

Double benefit

Espen's method is to describe the variations, to disclose the soul of the material as it were, and then to make models and perform analyses. In the verification process he will see if the same things happen in experiments as in the models and if the model could be applied to more metals. There are double benefits:

"First, the models will help us find good designs for existing materials because we will have a greater understanding of how the structures of the material influence its mechanical behaviour. More correct models may also diminish the need for safety factors.

Second, the models will help us design new and better materials. For instance, we can better decide the right size of material building blocks.

The exciting part is the principles and methods: can we do this? Can we actually make these models? If the variations from the computations match the variations from the lab I have succeeded," Espen sums up enthusiastically.

Planes and bicycles

His interest for engineering is easily explained. His father works for Volvo Aero Norway, producing plane parts. Espen developed an early interest in bicycles and soon became the popular bicycle mechanic for all his mother's friends. Before long he made money from his expertise, working part time in the local sports shop all through secondary school.

His decision to start studies at NTNU came as a logical consequence: "I went to an education fair to look for a good place to become an engineer. NTNU's folder had a fancy sketch of a bicycle on the front page. That did it!"

The steel tormentor

As far as we know, steel doesn't feel pain. Just as well.

Gaute Gruben is putting it through all kinds of strain.

Imagine being pulled by your head and heels till you actually split in two. Just the thought of it is torture. Gaute Gruben may be a tough guy, but he wouldn't dream of such an experiment. Give him steel, though, and he's ready for anything. As it is, no one suffers from his work, with the possible exception of his girlfriend. Gaute admits being a bit of a workaholic.

Norwegian wood

He started out as a carpenter in his home town of Mo i Rana in northern Norway. Then he developed his interest to become a civil engineer. At the end of his fourth year at NTNU, Centre Director Magnus Langseth from SIMLab suddenly turned up in class. He had been given five minutes. That was enough. Gaute's interest was caught. He sent an email and received an invitation to visit. Before long he was taking his master's degree at SIMLab.

Swedish steel

SSAB supplies Gaute with the two millimetre steel plates he needs for his experiments. The Swedish steel producer is one of SIMLab's partners. In return they get advanced knowledge about the qualities of their products.

What Gaute does, is to take specimens of different shapes and pull them till they break in the middle. He then simulates the experiments with numerical models from which he collects data that determine the fracture characteristics of the material. This data is then used to calibrate different types of fracture criteria.

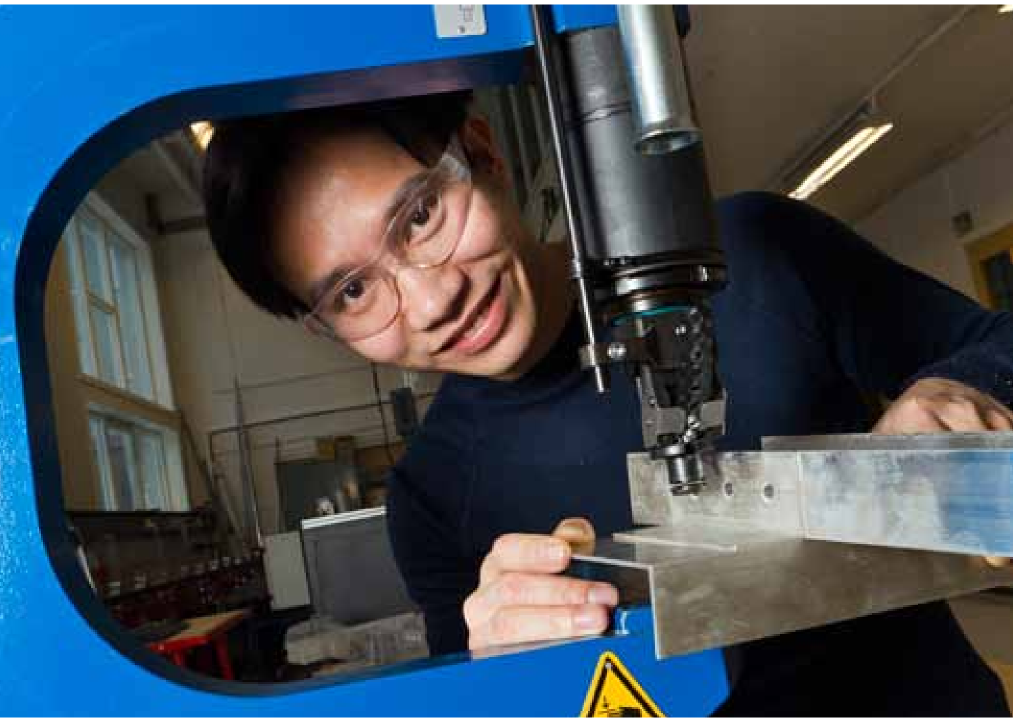
"We need different types of tests; first we need tests for calibrating the criteria, and second we need tests for validating the criteria. Afterwards we can foresee when the fracture occurs," Gaute says.

Danish girlfriend

Moving from Norwegian wood to Swedish steel it's only natural that Gaute has a Danish girlfriend. But that is a total deviation, of course. Let's get back on track.

In the last part of his PhD project, the plan is to test different numerical techniques for simulating crack propagation. The element erosion technique will be compared with the node splitting technique and the extended finite element method. The simulations will be compared with experimental data.

"The car industry is interested in this. Some phenomena linked to fracture have not been thoroughly explored. At the end of my PhD programme I hope I have made a contribution to better understanding."



The wizard of Vinh

Every American child knows the wizard of Oz. It remains to be seen whether Nguyen-Hieu Hoang will be named the wizard of Vinh and be as well known in Vietnam.

Don't rule it out. If Hieu succeeds in his efforts to introduce aluminium self-piercing rivets in the car industry, he may have done the environment a great service. Hieu rightly sees his little tubular rivets as magic wands. They may be smaller than the one in Oz, but they surely have the potential to work wonders. And they are plentiful.

Adding heat

Until now self-piercing rivets are made of steel. There may be over a thousand rivets in a modern aluminium car body. Thus, it is a costly and difficult process to remove the steel rivets when recycling the car body. It would be much cheaper and easier with aluminium rivets. The aluminium alternative would also reduce the car's weight.

Therefore BMW, Audi and Renault are following Hoang's experiments with interest. "Riveting with aluminium rivets is a challenging task, since the strength of aluminium alloys is much weaker than that of steel. The aluminium rivet can be severely deformed when compressed into the aluminium plates, and hence no connection is formed. Heating the aluminium plates to be joined before riveting might be used to facilitate the process, but we still aren't where we want to be," he admits.

Different alloys

Hieu's experiments also show that the aluminium rivet may fracture when riveting aluminium plates. Through further experimental and numerical work he hopes to find out what 'potion' (i.e. a right relation between the strength of the rivet material and the plate materials to be joined) will provide good mechanical behaviour. His work includes self-piercing rivets and plates in different aluminium alloys. He is not trying to modify the geometry of the rivet. That will be left for future research.

All these elements are of extreme importance since the "strength" of a car depends not only on the behaviour of the car components but also the strength of the joints.

To learn English

People have all kinds of reasons for coming to Norway. Hieu already knew French from home in Vietnam and improved it further when he took his master's degree in Rennes. "Therefore I was looking for a place to take my PhD where I could improve my English," he explains. He is happy about the choice: "The scenery is beautiful and people are open."

Hieu claims to be a patient person, but everyone has their limits. "I hope I gain sufficient control over my magic wands before I become crazy. If I succeed, I can call myself a wizard. That's when I will have deserved the PhD," he smiles.

How to bake a bumper

If you want to bake the perfect loaf of bread, finding the right balance between time and temperature is crucial. The same goes for bumpers, of course. Ask Ida Westermann.

She fell in love with aluminium at the age of eighteen. Raised in the Danish village of Bredebro, she was invited to spend two weeks at the nearby plant of Norwegian aluminium firm Hydro. That started it all.

Not in the family

"My mother is a midwife and my father a veterinarian. There was nothing in the family to suggest I should become interested in physics. But I did. I discovered it in high school and readily accepted the invitation from Hydro when it came," she says.

After two weeks learning about extruding and plastic forming, she was also invited to visit NTNU in Trondheim as well as the Hydro plants in Sunndalsøra and Raufoss. By then she was hooked: her future was in metal. If all goes well she will have earned her PhD by June.

A bumper in the oven

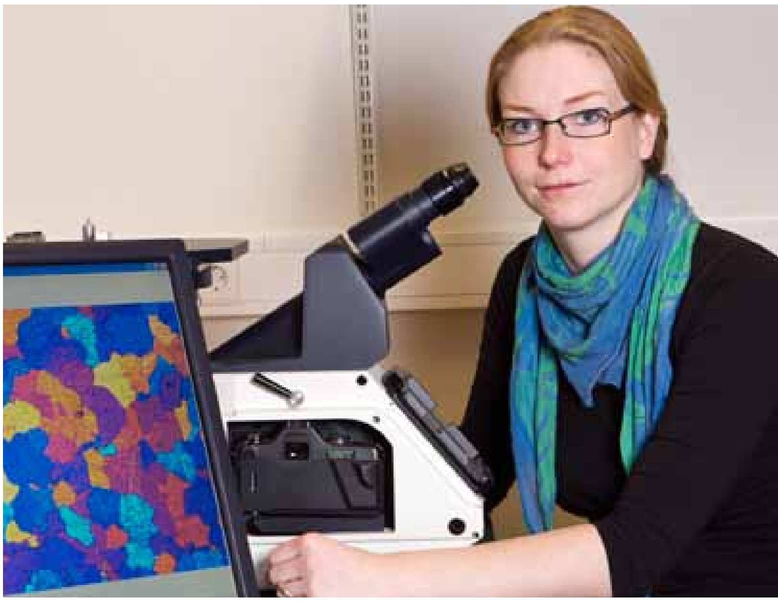
When Ida puts a bumper in the oven, artificial ageing is the correct scientific term for the baking process. Small nanoscale particles can be created to increase the strength of a component. The mechanical response is greatly dependent on the microstructure, i.e. what the interior of the metal looks like on a nano-/micro-scale level.

"Strength will increase with time up to a certain level. After that it sinks. The same is valid for temperature. To be able to control this process, it is important to know what happens inside the material. In my PhD project I am trying to find a mathematical relationship between microstructure and strength of aluminium based on experimental investigations," Ida says.

Shooting electrons

A possible aim for finding the right balance is to reduce weight. Another is to find the strength. If the metal is very strong, it may become crunchy. Reducing the strength a bit increases bendability and ductility. These are properties that are needed in bumpers for maximum reduction of injury to people.

To study what happens, Ida cuts tiny disks, 3 millimetres in diameter, one tenth of a millimetre and downwards thick, and etches a whole in the middle. Then she puts them in the transmission electron microscope. The area nearest the hole is very, very thin.



"I shoot electrons through the thin area and study the effect. I can see a picture of how the particles are distributed and the size of them," she says.

Full of praise

Ida is full of praise for SIMLab: "The atmosphere is great. Our professors are competent and strong personalities. It's their achievement that we have such good relations with industry."

After finishing her degree, Ida hopes to continue her research as part of Trondheim's academic environment.

Damage done

40 years have passed since Neil Young wrote his classic tale about the needle and the damage done. As it happens, needles have no monopoly on harm. Ask Knut Gaarder Rakvåg.

"What I study in particular, is the synergetic effect that occurs in explosions. Existing design methods for protective structures treat the shock waves and fragments separately. This has limited value as long as experimental evidence shows a synergetic effect. Design codes to protect should take this into account," he says.

This is all about security. Military, industrial and government structures could all be exposed to an explosion; vehicles as well, both military and civilian ones.

No-fly material

Concrete has traditionally been the chosen material in this field. A lot is known about its properties in stationary constructions. However, flying concrete walls from the USA or Norway to Afghanistan is impractical, to say the least. The need for mobile and lightweight protective structures is steadily increasing, both because of international operations and for temporary assignments like protecting an embassy for a limited period of increased threat. That's where Knut's curiosity comes in handy.

What's inside?

As a child Knut liked everything to be speedy and noisy. Although he was not particularly interested in explosions, he has always wanted to know what things looked like inside. The interest wasn't exactly hampered by his father being a car mechanic. He watched, asked and got answers. At school his interest for mathematics and physics was born. Before long he knew he wanted to be an engineer. Precisely in what field was more uncertain for a long time, until a desire was born when travelling in and out of the fjords on the western coast of Norway; why couldn't they build bridges across all of them? With age and knowledge, interest shifted towards computational mechanics, exploring the limits of what is possible. That's where destruction comes in.

Tests in the UK

Knut collaborates closely with the Norwegian Defence Estates Agency carrying out his experiments. He also has access to a rig in the UK where he can test how steel and aluminium plates react to shock waves, specifically how the shape of holes in plates influence crack propagation.

Trouble on the seabed

Martin Kristoffersen has a fascinating photo on his computer screen. It shows fish investigating a pipeline hit by an anchor. Unfortunately, Martin doesn't know what the fish found out.

Which means that he will have to do the job himself; how much can a pipeline take, when does it break, what kind of damage follows different kinds of impact, how does the damage develop, at what level must production come to a halt, when is the pipeline beyond repair?

"When the pipeline is finally released, it recoils back towards its initial position. After such a complex history of local deformation from the impact and global deformation from the anchor hook, we need accurate models in order to describe the behaviour accurately," Martin explains.

Costly cut-off

His photo is from a real case. In November 2007, a ship's anchor hooked onto a pipeline from the Kvitebjørn field in the North Sea and dragged it out of position. Luckily the anchor chain broke before the pipeline. After inspection, production was restarted. However, in 2008 a gas leak was discovered and production was shut down for half a year until it could be repaired. In the end, the area of the impact had to be cut away and replaced by a new pipe. It was the first time in history that such an advanced operation was carried out by remote control at such depths. It was an expensive repair.

Maths and football

Martin's engineering studies started at home in Narvik in Norway's north, where he took his bachelor's degree. After that he turned to maths and moved to Tromsø, even further north, before ending up at NTNU to take his master's degree.

"I love learning, so when the head of SIMLab, Professor Magnus Langseth asked if I was interested in aiming at a PhD, that was perfect for me," he confesses.

A lot of his childhood friends from Narvik also study in Trondheim and in their spare time they play football. Martin is a skilled player, doing some good work on the field for Kvik in the third division.

Industry interest

Hopefully he isn't as destructive on the football field as in the lab: "We have a test rig in which we crash a wagon into the pipeline to ensure our models are accurate. After that we put the pipe in Statoil's stretch machine here in Trondheim to study the crack propagation. The ambition is to find good models for estimating the residual strength of the pipeline. Statoil is very interested in what we are doing," he says.

Mass Effect

In his free time, **Mikhail Khadyko** is often found deeply involved in a DOS-game from the 90s or in Mass Effect 2. In his PhD programme, mass effects of quite another nature are in focus.

Mass effect one: if you take a cube of metal and press it flat, the sheet will probably end up more or less like a square.

Mass effect two: If you make a cube out of just one grain of metal and press, the sheet will become elongated.

"We call the former behaviour isotropic and the latter anisotropic," Mikhail explains. In other words, the properties of a piece of metal differ from the properties of each grain.

Quests

The differing types of behaviour are the platform for Mikhail's quests.

Theme of quest one: How do the mechanical properties of metals depend on the properties of the grains and their orientations?

Theme of quest two: If we have a metal sheet where the grains on the surface are oriented one way and on the inside in another way, will it be different from a sheet where all grains are oriented randomly?

Sci-fi

If you find the quests odd, Mikhail might have the appropriate explanation:

"I'm the typical nerd," he says. Computer games is one indication, sci-fi novels another. Neal Stephenson, Peter Watts and Alastair Reynolds are all on his favourite list of authors.

The inclination towards engineering may be traced to his mother, who was educated as a construction engineer back home in Arkhangelsk in the north of Russia.

"I always thought that engineers are able people. They are needed in society and will always find work," Mikhail says.

His fluent Norwegian has another explanation: "I came here in 2004 through a student quota programme. I wanted to see the world. When I had learned Norwegian and finished my bachelor's degree, I decided I was better than that. After obtaining my master's, I thought the same: I'm better than that. So here I am!"

Why

So, who would want to know how the properties of metal vary with the orientation of the grains? Hydro Aluminium for one. Or Mikhail himself. If you can change the orientation of the grains through heat, pressure or extrusion, perhaps you can obtain just the properties you need for a vehicle designed for outer space, ready for the great challenges of Mass Effect 2?

Oboe

The first aluminium oboe* may not have been built yet, but who knows what will happen when **Marion Fourmeau** finishes her PhD on high-strength alloys.

Both Marion's parents are music teachers, so her musical tendencies should come as no surprise. As a child she played the piano, but now it is the oboe and she is a member of a brass band.

Fragile boundaries

Since brass is not studied much at SIMLab, Marion has chosen another metal: "My research project concerns the fracture of high-strength aluminium alloys. These alloys are particularly tough thanks to hardening precipitates inside the aluminium grain," she explains.

However, there are hidden problems. The grain boundaries are very weak and make the alloy brittle. What Marion is trying to study is the way the alloy will fracture depending on the kind of loading it is submitted to: compression, traction or something else.

Two laboratories

She will also look at the characteristics stemming from the fact that this alloy mainly is obtained in plates by successive rolling operations, making the grains flat and elongated in the rolling direction. As a consequence, the mechanical properties are not the same in all directions. Turn the plate 90 degrees and you get another material, so to say. This multiplies the number of tests necessary to get a complete model of the behaviour of the alloy.

Marion divides her time between the two universities cooperating on the project; NTNU in Trondheim and LMT in Cachan, France. This gives her access to two laboratories and expands the number of tools.

Scandinavia calling

Marion had her mind set on Scandinavia for the last part of her studies. Maybe the love of hiking is involved. Her parents took her to the Alps from the age of six and she still loves a good walk in spectacular scenery.

"I knew that nature is beautiful in Scandinavia. Trondheim came up because of NTNU's cooperation with LMT. I did the first year of my master's internship in Trondheim and SIMLab challenged me to apply for a PhD. I accepted right away simply because I wanted to come back," Marion confesses.

** On second thoughts, building an aluminium oboe may not be so easy. It would represent a contradiction in terms. The word oboe is Italian, but the origin is a phonetic approximation to the French haut bois, literally: high wood, referring to its pitch. So perhaps that muffles that idea.*

How Renault lost their man

Virgile Delhaye worked with Renault all the way through his PhD programme. Now they've lost him to a girl from Trondheim. Love conquers all.

"There's a very good chance I will stay in Trondheim for a long time. It's easier for me to work as a scientist here than it is for my girlfriend to get a job as a psychologist in France," Virgile says. So he's landed a job with SINTEF continuing his research on ductile thermoplastics for crash applications.

Investing time and money in the development of highly skilled staff always carries a risk. Renault knows that as well as anyone and they are prepared to run the risk. Sometimes you win, sometimes you lose.

Protecting pedestrians

Not everything is lost, though. Virgile's findings are there for the picking and they are right at the heart of Renault and any other carmaker's needs: the ever on-going search for better bumpers. In more scientific terms, they deal with the characterization and modelling of ductile materials for crash applications. Virgile has looked at two particle-reinforced thermoplastics. One is rubber-modified; the other mineral-filled.

Such reinforcement is common in the car industry. The particles naturally change the behaviour of the materials. Virgile has investigated how. He has subjected them to varying degrees of tension, compression and shear at quasi-static and dynamic strain rates. All the tests have been instrumented by the help of a digital image correlation technique to acquire the strain field.

To make a four-year story very short, finding good models for the mineral-filled material proved more difficult than for the rubber-modified version. Still, his thesis is a solid contribution towards reducing financial and personal bumper-related costs.

Additional challenge

Virgile came to NTNU via Renault's long-time cooperation with SIMLab. All through the programme he divided his time between Trondheim and Renault's Research and Development Center in Versailles, spending six months at a time in each place.

Cooperating that closely with an external partner has given extra spice to his work. Renault's approach has of course been industrial. They will always want specific answers. The challenge has been to combine the need for an academic thesis and please Renault at the same time. All indicators point towards success: Virgile was awarded his PhD, SIMLab's cooperation with Renault goes on.

With a passion for cars

You could say that Andreas Koukal is your classical western European male, playing soccer since childhood, skiing and snowboarding in the Alps, getting his first motorcycle at 16, his first car at 18.

"You could also say that working on my car was a passion right from the start," he admits. Just as well. Like most 18-years-olds, he didn't have the money for a brand new vehicle, so the passion may have grown out of necessity.

Working with Audi

Andreas' home town Landsberg in Bavaria is not only close to the Alps. It is also close to the Technical University in Munich and to Audi's headquarters in Ingolstadt.

During his master's, Andreas had a professor who cooperated with Audi. Through this cooperation Andreas got a supervisor at Audi who was working with SIMLab. This partly explains how he ended up where he is now, with a PhD programme on crash and fracture behaviour of polymers in pedestrian protection.

Half way through his programme he is also very closely involved with SIMLab's programme partner Audi, having only spent one month in Trondheim so far.

"I spend four out of five weekdays at Audi and hope to continue working for them after finishing my PhD," he confesses.

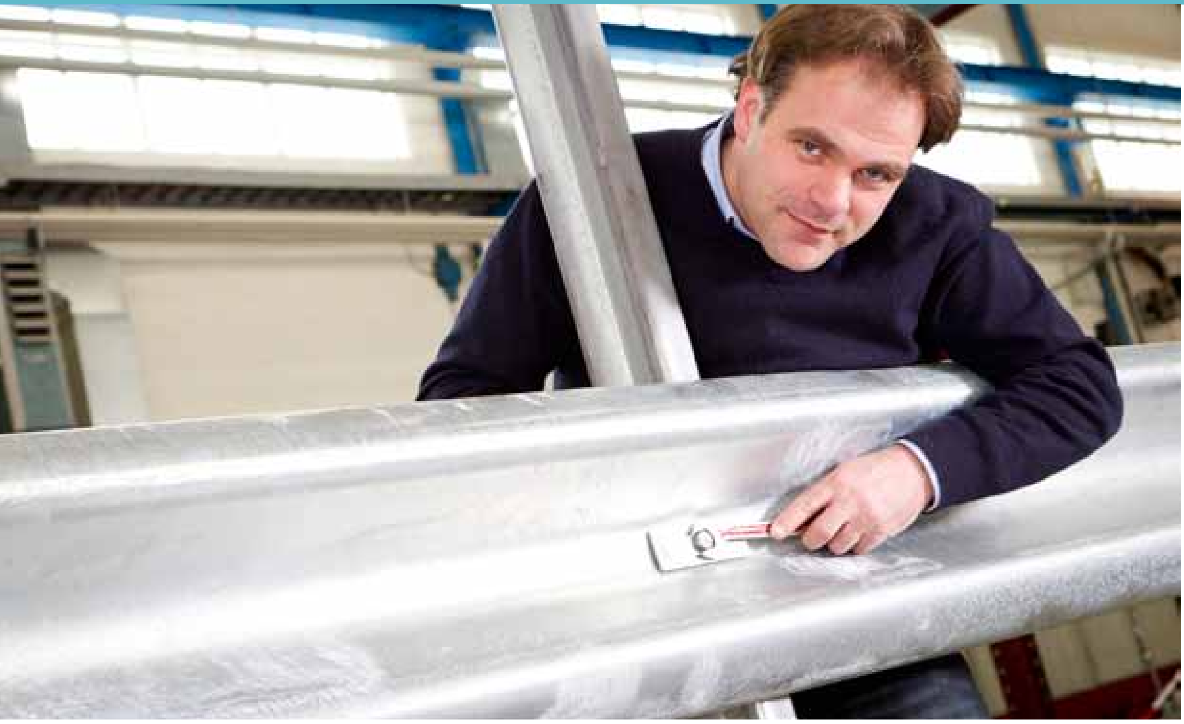
Pedestrian protection

Did you think that your bumper is there to protect yourself and your car? Well, Andreas looks at it from quite the opposite angle. That means he is concerned with protecting pedestrians. To achieve this, the car industry carries out physical tests and computer simulations whenever they develop a new model. The tests involve impacts on the bumper, subjecting it to large deformations and possibly fracture. The bumper and most of the other pedestrian protection relevant components are typically made of polymers.

"The object of the project I'm working on is to improve the knowledge and understanding of crash and fracture mechanics of polymers," explains Andreas.

Reinforced polymers

Andreas' particular field of interest is glassfibre reinforced polymers, which behave differently from the unreinforced polymers. The latter can be treated almost as isotropic, the former not. His ambition is to implement an anisotropic material model for the fibre reinforced polymers. On his way there he is setting up mathematical models taking the manufacturing influences into account. This includes fibre orientation. The results are correlated and verified with experimental data and finally integrated in component and vehicle simulations. His ambition: better pedestrian protection.



Rivets and bolts since 1660

Few people can trace their professional roots 350 years back. Henning Fransplass can. He is a master of the same trade as the one introduced to his hamlet more than ten generations ago.

It all started around 1660 when a man called Franz came from Holland or Germany to the Norwegian highlands. His expertise was wanted. The hamlet of Lesja attracted foreign craftspeople when iron ore was found. This particular iron ore was rich in chrome and was perfectly suited for making the rivets used in shipbuilding. Franz knew how. He came and he settled. His place was named after him - Fransplass.

Like a hammock

Henning Fransplass works in the same field, almost. Instead of iron rivets, he's making steel bolts. The topic of his PhD is the bolts used in road safety barriers.

The aim is to understand better how bolted connections behave in a safety barriers when hit by a vehicle. An optimal barrier should work like a hammock; gently containing and redirecting the vehicle back onto the road without bouncing it over to the oncoming lane.

No small challenge, by the look of it. Henning puts it like this: "The challenge is to control the large kinetic energy difference. Between a small car and a bus it is about 1 to 18. The aim is to maintain the functionality of the barrier throughout the whole scale of impacts. To achieve this, the bolt has to break at exactly the right moment to obtain the hammock effect."

Saves time and money

In the SIMLab laboratories Henning is carrying out experiments with scaled bolts. This is a huge time- and cost-saving process as it reduces the need for full-scale experiments to a fraction.

Henning then develops life-like animations by using commercial software. The information from the animations is used to improve accident analysis. This enables him to study design and limitations of safety barriers.

Against death penalty

Henning's aim is the same as that of the Norwegian Public Roads Administration (NPRA), where he is employed: "The road transport system should be designed in such a way that roads, vehicles and road users interact to ensure safety. Human errors shouldn't carry the death penalty."

NPRA is a SIMLab partner. When Henning's thesis is ready, they will have more specific recommendations for the properties of bolts than today. Many lives may be saved and injuries reduced.

Lighter and more reliable

Casting aluminium allows thin-walled components with complex geometries, but a die-cast is more brittle than sheets and less homogeneous than extruded aluminium. So, what can we do? Well, Audi, SIMLab and collaborating university KIT in Karlsruhe have put Octavian Knoll on the job.

Audi needs die-castings for rocker rails and pillars in their cars. They want the components to be as light as possible and at the same time as reliable as possible in a crash situation. This is where Octavian comes in:

Filling a mould

"The challenge in the design and virtual crash analysis of such components is that the mechanical properties depend on the process chain," he explains. Let me give an example:

"When you pour liquid aluminium into a mould of a large component, fronts are built where the metal comes into contact with air during the filling time. When these fronts meet, you get a part of the component with different mechanical properties and a potential breaking point."

The cooling process also influences the properties. As a result the deformation behaviour can vary significantly within a component. This complicates the crash simulation.

Keep it simple

To deal with this, Octavian is performing detailed material characterization, component testing and numerical simulations.

"I divide my time between the institutions. Here at SIMLab I enjoy the benefit of the support from the entire group and their experience in material modelling – especially in aluminium alloys. They help me to interpret test and simulation results as well as to establish a new method in material modelling of aluminium die castings. Audi wants to keep it simple. Too much detail makes the model too complicated, so what I'm looking for is a model that works on an everyday level – for example in the field of full-scale car crash simulations. In other words, the goal of my PhD is to develop a simulation methodology that allows reduced weight and increased reliability in the components," he says.

Started in construction

Octavian's first steps as an engineer were in the construction business. Both his parents are architects. When Octavian was a child, they had the huge ongoing project of building their own house.

"I soon discovered that I lacked their creativity but I did enjoy the more mechanical aspects like screwdrivers and hammers," he recalls. He also has a tendency to get totally absorbed in what he's doing. Combine that with a certain lack of ability to say no and you have a very busy person.

"Of course, those are not entirely positive qualities. Hopefully they are compensated by my dedication and loyalty," says Octavian.

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 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 2010 are shown below.

SIMLab: Funding 2010 (All figures in 1000 NOK)

		STATE AID			INDUSTRY									
Research Programme	Type of research	RCN Grant	Host (NTNU)	SINTEF	NDEA	NPRA	AUDI	Renault	Statoil	SSAB	Hydro Aluminium	Total State Aid	Total Funding	State aid/total funding
C&J	F	1853	312			1020					300	2165	3485	0.62
C&J	I													
F&CP	F	2103	1173		200		500			50	300	3276	4326	0.76
F&CP	I													
M^4	F	1033	1613	1100						250	2600	3746	6596	0.57
M^4	I													
OptiPro	F	1343	312		1579				70	130		1655	3434	0.48
OptiPro	I													
Poly	F	1568	912					1000	150		50	2480	3680	0.67
Poly	I													
Demo	F										350		350	
Demo	I	250	212				300				51	462	813	0.57
Equipment		1030								180	50	1030	1260	
Adm		1478	1000		421	100	200		430	190	399	2478	4218	
Total		**10658**	**5534**	**1100**	**2200**	**1120**	**1000**	**1000**	**650**	**800**	**4100**	**17292**	**28162**	

F = Fundamental research
I = Industrial research

RCN = Research Council of Norway
NDEA = Norwegian Defence Estates Agency
NPRA = Norwegian Public Roads Administration

SIMLab: Cost 2010 (All figures in 1000 NOK)

Research Programmes	Host (NTNU)	SINTEF	NDEA	NPRA	AUDI	Renault	Statoil	SSAB	Hydro Aluminium	Total
C&J	2115	500		870						3485
F&CP	2326	1300	200		500					4326
M^4	2446	1350						200	2600	6596
OptiPro	1684	650	1000					100		3434
Poly	2430	750				500				3680
Demo	263	900								1163
Equipment	1260									1260
Adm	2343	1875								4218
Total	**14867**	**7325**	**1200**	**870**	**500**	**500**		**300**	**2600**	**28162**

Publications

The following lists journal publications and conference contributions generated within the Centre in 2010.

Journal publications

1. Benallal A., Berstad T., Børvik T., Hopperstad O.S.: *Uniqueness, loss of ellipticity and localization for the time-discretized, rate-dependent boundary-value problem with softening.* International Journal for Numerical Methods in Engineering 84 (2010) 864–882.
2. Børvik T., Forrestal M.J., Warren T.L.: *Perforation of 5083-H116 aluminum armor plates with ogive-nose rods and 7.62mm APM2 bullets.* Experimental Mechanics 50 (2010) 969-978.
3. Børvik T., Hopperstad O.S., Pedersen K.O.: *Quasi-brittle fracture during structural impact of AA7075-T651 aluminium plates.* International Journal of Impact Engineering 37 (2010) 537–551.
4. Børvik T., Lange H., Marken L.A., Langseth M., Hopperstad O.S., Aursand M., Rørvik G.: *Pipe fittings in duplex stainless steel with deviation in quality caused by sigma phase precipitation.* Materials Science and Engineering A 527 (2010) 6945-6955.
5. Delhaye V., Clausen A.H., Moussy F., Hopperstad O.S., Othman R.: *Mechanical response and microstructure investigation of a mineral and rubber modified polypropylene.* Polymer Testing 29 (2010) 793-802.
6. Dumoulin S., Louche H., Hopperstad O.S., Børvik T.: *Heat sources, energy storage and dissipation in high strength steels: Experiments and modelling.* European Journal of Mechanics - A/Solids 29 (2010) 461–474.
7. Dørum C., Lademo O.-G., Myhr O.R., Berstad T., Hopperstad O.S.: *Finite element analysis of plastic failure in heat-affected zone of welded aluminium connections.* Computers & Structures 88 (2010) 519–528.
8. Fagerholt E., Grytten F., Gihleengen B.E., Børvik T., Langseth M.: *Continuous out-of-plane deformation measurements of AA5083-H116 subjected to low-velocity impact loading.* International Journal of Mechanical Sciences 52 (2010) 689-705.
9. Fagerholt E., Dørum C., Børvik T., Laukli H.I., Hopperstad O.S.: *Experimental and numerical investigation of fracture in a cast aluminium alloy.* International Journal of Solids and Structures 47 (2010) 3352-3365.
10. Forrestal M.J., Børvik T., Warren TL.: *Perforation of 7075-T651 aluminum armor plates with 7.62mm APM2 bullets.* Experimental Mechanics 50 (2010) 1245-1251.
11. Fyllingen Ø., Hopperstad O.S., Hanssen A.G., Langseth M.: *Modelling of tubes subjected to axial crushing.* Thin-Walled Structures 48 (2010) 134-142.
12. Fyllingen Ø., Hopperstad O.S., Tarigopula V.: *On material batch variation of the dual phase steel DP800.* International Journal of Material Forming 3 (2010) 199 – 202.
13. Hanssen A.G., Olovsson L., Porcaro R., Langseth M.: *A large-scale finite element point-connector model for self-piercing rivet connections.* European Journal of Mechanics A/Solids 29 (2010) 484-495.
14. Hoang N-H., Porcaro R., Langseth M., Hanssen A.G.: *Self-piercing riveting connections using aluminium rivets.* International Journal of Solids and Structures 47 (2010) 427-439.
15. Lademo O.-G, Engler O., Aegerter J., Berstad T., Benallal A., Hopperstad O.S.: *Strain-Rate Sensitivity of Aluminium Alloys AA1200 and AA3103.* Journal of Engineering Materials and Technology 132 (2010) p. 041007 (8 pp.).
16. Lilleby A., Grong Ø., Hemmer H.: *Cold pressure welding of severely plastically deformed aluminium by divergent extrusion.* Materials Science and Engineering A 527 (2010) 1351-1360.
17. Lönn D., Fyllingen Ø., Nilsson L.: *An approach to robust optimization of impact problems using random samples and meta modelling.* International Journal of Impact Engineering 37 (2010) 723–734.
18. Moe H., Fredheim A., Hopperstad O.S.: *Structural analysis of aquaculture net cages in current.* Journal Journal of Fluids and Structures 26 (2010) 503–516.
19. Moura R.T., Clausen A.H., Fagerholt E., Alves M., Langseth M.: *Impact on HDPE and PVC plates – Experimental tests and numerical simulations.* International Journal of Impact Engineering 37 (2010) 580-598.
20. Myhr O.R., Grong Ø., Pedersen K.O.: *A combined precipitation, yield strength and work hardening model for Al-Mg-Si alloys.* Metallurgical and Materials Transactions A 41 (2010) 2276-2289.
21. Olovsson L., Hanssen A.G., Børvik T., Langseth M.: *A particle-based approach to close-range blast loads.* European Journal of Mechanics – A/Solids 29 (2010) 1-6.
22. Polanco-Loria M., Clausen A.H., Berstad T. and Hopperstad O.S.: *Constitutive model for thermoplastics with structural applications.* International Journal of Impact Engineering 37 (2010) 1207-1219.
23. Rønning L., Hopperstad O.S., Larsen P.K.: *Numerical study of the effects of constitutive models on plastic buckling of plate elements.* European Journal of Mechanics A/Solids 29 (2010) 508–522.
24. Rønning L., Aalberg A. and Larsen P. K.: *An experimental study of ultimate compressive strength of transversely stiffened aluminium panels.* Thin-walled structures 48 (2010); 357-372.
25. Snilsberg K.E., Westermann I., Holmedal B., Hopperstad O.S., Langsrud Y., Marthinsen K: *Anisotropy of bending properties in industrial heat-treatable extruded aluminium alloys.* Materials Science Forum 638–642 (2010) 487–492.
26. Westermann I., Hopperstad O.S., Marthinsen K., Holmedal B.: *Work-hardening behaviour of a heat-treatable AA7108 aluminium alloy deformed to intermediate strains by compression.* Journal of Materials Science 45 (2010) 5323–5331.

Special issues

1. Impact Loading of Lightweight Structures. Special Issue - International Journal of Impact Engineering. Volume 37, Issue 6, June 2010. Guest editors: Børvik T., Clausen A.H., Hopperstad O.S., M. Langseth.

Keynote lectures

1. Langseth M.: *Aluminium as a Structural Material Used in Lightweight Protection: Behaviour, Modelling and Validation.* Keynote lecture at DAPS2010 (Design and Analyses of Protective Structures) Conference, 10-12 May 2010, Singapore.

Oral presentations at conferences

1. Børvik T., Hopperstad O.S., Langseth M.: *High-strength aluminium plates struck by ogival-nose projectiles.* Proceedings of the Third International Conference on Design and Analysis of Protective Structures (DAPS2010), 10-12 May 2010, Singapore.
2. Clausen A.H., Hovden M.T., Polanco-Loria M., Berstad T., Hopperstad O.S.: *A Constitutive Model for Thermoplastics with some Applications.* IMPLAST (International Symposium on Plasticity and Impact Mechanics), 12-14 October, Providence, RI, USA.
3. Clausen A.H., Hovden M.T., Polanco-Loria M., Berstad T., Hopperstad O.S.: *Constitutive model for thermoplastics – Calibration and validation.* 19th DYMAT Technical Meeting, 1-3 December 2010, Strasbourg, France.
4. Delhaye V., Clausen A.H., Moussy F., Othman R., Hopperstad O.S: *Behaviour and modelling of a polypropylene applied in automotive industry for crash applications.* SFIP, 9-10 June, Douai, France.
5. Delhaye V., Clausen A.H., Moussy F., Othman R., Hopperstad O.S.: *Caractérisation et modélisation d'un polypropylène appliqué au crash dans l'industrie automobile.* MATERIAUX 2010, 18-22 October, Nantes, France.
6. Fourmeau M., Børvik T., Benallal A., Hopperstad O.S.: *On the fracture locus of AA7075-T651.* 14th International Conference on Experimental Mechanics (ICEM14), 4-9 July 2010, Poitiers, France.
7. Fyllingen Ø., Hopperstad O.S., Tarigopula V.: *On material batch variation of the dual phase steel dp800.* ESAFORM 2010, 7-9 April 2010, Brescia.
8. Fyllingen Ø., Langseth M., Hopperstad O.S.: *Experimental study on the buckling mode of aluminium extrusions,* IMPLAST, 12-14 October 2010, Rhode Island.
9. Hoang N-H., Porcaro R., Langseth M., Hanssen A.G.: *Behaviour and modelling of aluminium self-piercing riveted connections.* INALCO2010 international Conference, 23-25 June 2010, Netherlands.
10. Hoang N-H., Porcaro R., Langseth M., Hanssen A.G.: *Aluminium self piercing riveted connections: Effect of pre-straining and natural aging on the mechanical behaviour.* Oral presentation at ICAA12 (International Conference on Aluminium Alloys) international Conference, 5-9 September 2010, Japan.
11. Holmedal B., Hopperstad O.S., Berstad T.: *Modeling Transients Related to Strain-path Changes.* Proceedings of the 12th International Conference on Aluminium Alloys, 5-9 September, 2010, Yokohama, Japan.
12. Hopperstad O.S., Pedersen K.O., Børvik T.: *Experimental and Numerical Study on the Fracture Behaviour of the Aluminium Alloy AA7075-T651.* Proceedings of the 12th International Conference on Aluminium Alloys, 5-9 September, 2010, Yokohama, Japan.
13. Kane A., Østby E., Lademo O-G., Berstad T., Hopperstad O.S.: *Effects of the yield criterion on predicted fracture responses of pipelines subjected to large plastic deformation with and without internal pressure.* 29th International Conference on Ocean, Offshore and Arctic Engineering (OMAE 2010), 6-11 June 2010, Shanghai, China.
14. Moura R.T., Mazzariol L.M., Clausen A.H., Langseth M., Alves M.: *Axial Loading of Cylinders Made of Nylon with Nano-particles.* IMPLAST (International Symposium on Plasticity and Impact Mechanics), 12-14 October, Providence, RI, USA.
15. Polanco-Loria M., Clausen A.H.: *An inverse modelling methodology for parameters identification of thermoplastic materials.* 23rd Nordic Seminar on Computational Mechanics, 21-22 October 2010, Stockholm, Sweden.
16. Westermann I., Snilsberg K.E., Holmedal B., Hopperstad O.S., Marthinsen K.: *Bendability and Fracture Behaviour of Heat-Treatable Extruded Aluminium Alloys.* Proceedings of the 12th International Conference on Aluminium Alloys, 5-9 September, 2010, Yokohama, Japan.

Poster presentations at conferences

1. Børvik T., Dey S., Olovsson L., Langseth M.: *Normal and oblique impact of APM2 bullets on AA6082-T4 aluminium plates.* 11th Hypervelocity Impact Symposium, 11-15 April 2010, Freiburg, Germany.
2. Delhaye V., Clausen A.H., Hopperstad O.S., Othman R., Nesa D.: *Behaviour and modelling of two polypropylenes applied in automotive industry.* 19th DYMAT Technical Meeting, 1-3 December 2010, Strasbourg, France.
3. Ognedal A.S., Clausen A.H., Hopperstad O.S., Polanco-Loria M., Benallal A., Raka B.: *Biaxial loading of PEHD and PVC.* 19th DYMAT Technical Meeting, 1-3 December 2010, Strasbourg, France.

Annual Report for SIMLab Centre for Research-based Innovation 2010

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