Annual Report 2007

SIMLab

Centre for Research-based Innovation

sfi Centre for Research-based Innovation
Established by the Research Council of Norway

NTNU

SINTEF

Vision

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

Objective

Within the field of structural impact SIMLab will concentrate on research areas that are of common interest to the user partners and hence create a link between Norwegian industry and some of the major actors on a global market, e.g. the automotive industry. However, in order to meet the requirement for innovation and value creation in an international market, the 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 the user partners, a multidisciplinary approach is needed where researchers from the partners and academia contribute. This is only achievable through a centre activity with long term objectives and funding. Thus, the main objective with the centre is

To provide a ***technology platform*** *for development of safe and cost effective structures*

Industrial partners

Audi, BMW, Renault, Hydro, Statens vegvesen, Forsvarsbygg

Summary

The Norwegian Research Council has defined SIMLab (Structural Impact Laboratory) as a Centre for Research-based Innovation for the period 2007-2014. The Centre is hosted by Department of Structural Engineering, NTNU in cooperation with Department of Materials Technology, NTNU, and SINTEF Materials and Chemistry.

The main objective with 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 research areas *Materials, Solution techniques, Structures* and *Demonstrators*. The ability of light-weight structures to withstand loads from collisions and explosions is a key issue in the Centre. Examples of applications are safety in the automotive industry, improved highway safety as well as protective structures for international peacekeeping operations. The technology developed is also relevant for other segments of Norwegian industry, i.e. for safety assessments in the offshore oil and gas industry.

The user partners in the Centre in 2007 have been Hydro Aluminium Structures, Hydro Aluminium Metals, Hydro Aluminium Products, BMW Group, AUDI AG, Renault, the Norwegian Public Roads Administration and the Norwegian Defence Estates Agency. In addition the Centre cooperates with Raufoss Technology and Industrial Management (RTIM) in order to facilitate innovation in small and medium sized companies. From January 2008 Plastal, SSAB Swedish Steel and StatoilHydro joined the Centre as new partners. From the same date, Hydro Aluminium replaced Hydro Aluminium Structures, Hydro Aluminium Metals and Hydro Aluminium Products in the consortium.

The defined research areas are linked with research programmes with focus on *Fracture and Crack Propagation, Connectors and Joints, Polymers, Multi-scale Modelling of Metallic Materials* and *Optimal Energy Absorption and Protection*. For each research programme annual work plans are defined with contribution from PhD students, post docs and scientists from the partners. At present four male and two female PhD students and two male post docs are connected to the Centre. The contribution from the industrial and public partners is related to their contribution in kind. In order to strengthen the cooperation and interaction between the partners seminars and telephone meetings have been held. The latter has been very important due to travel restrictions at the automotive partners.

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

The research in the Centre has in 2007 resulted in 15 papers published in peer review international journals. Furthermore, 13 conference papers have been published in addition to a large number of scientific reports.

International cooperation and visibility are success parameters for a Centre. Thus SIMLab has established cooperation with Ecole Normale Supérieure de Cachan/ Laboratoire de Mécanique et Technologie (ENS/LMT) and European Commission - DG JRC, Institute for Protection and Security of the Citizen, Ispra, Italy with respect to research and exchange of personnel. Two of the professors in the Centre stayed at these institutions, while a professor from LMT-Cachan has had a shorter stay in the Centre in 2007. Furthermore, Professor M. Langseth has been appointed by Elsevier as an Editor-in-Chief of the International Journal of Impact Engineering, while Professor O.S. Hopperstad is an Assoc Editor and Adjunct Professor T. Børvik is a member of the Editorial Board of the same journal.

Goals

The main quantitative goals of the Centre are as follows:

- **Industrial:** 1) To implement the developed technology by mutual exchange of personnel between the Centre and the user partners. 2) To arrange annual courses for the user partners. 3) To facilitate employment of M.Sc. and Ph.D. candidates at the user partners.
- **Academic:** 1) To graduate 10 Ph.D. students where at least three are female students. 2) To graduate 10 M.Sc. students annually. 3) To attract 5 foreign professors/scientists over the centre period. 4) To publish on average 8 papers in international journals with peer review annually in addition to conference papers. 5) To arrange two international conferences, the first one in 2008 when SIMLab shall organise the international conference "Impact Loading of Lightweight Structures".

Research areas

The technology platform is developed through advances in the following 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 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 will serve as a link between 'Materials', 'Solution techniques' and 'Demonstrators'.
- **Demonstrators:** Selection of demonstrators in close cooperation with user partners. The interaction between the activities denoted 'Basic Research' and 'Demonstrators' is crucial with respect to validation and possible refinement of the technology developed in the Centre.

The Centre is dealing with aluminium extrusions and plates, aluminium and magnesium 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 five programmes were defined:

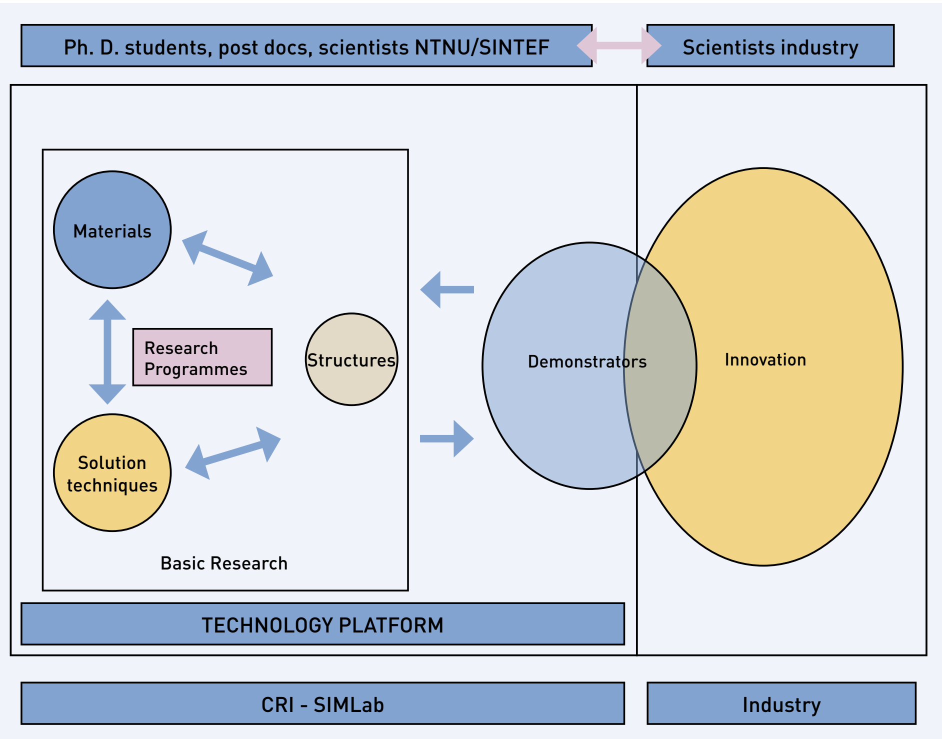
- **Fracture and Crack Propagation (F&CP):** Validated models for fracture and crack propagation in ductile materials including rolled and extruded aluminium alloys, high-strength steels, cast aluminium and magnesium and polymers will be developed. Formulations for shell structures and solid bodies will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

- **Connectors and Joints (C&J):** Information about the behaviour and modelling of self piercing rivet connections subjected to static and dynamic loading conditions will be 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.

- **Polymers (Poly):** Validated models for polymers subjected to impact loading conditions will be developed. An important prerequisite is to establish a set of test methods for material characterization and generate an impact test database. The programme is for the time being limited to thermoplastics.

- **Multi-scale Modelling of Metallic Materials (M^4):** Phenomenological constitutive models of metals are available in commercial FE codes, but they do not provide any information about the physical mechanisms responsible for the observed material response. Thus, in this programme the material response is described on the basis of the elementary mechanisms governing the macroscopically observed phenomena. This approach is required for the design of optimised process chains, for the development of next-generation phenomenological models, and for reducing material characterisation costs.

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



Research areas

Research organisation

Structure of organisation

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 is providing scientific and strategic advice.

Board

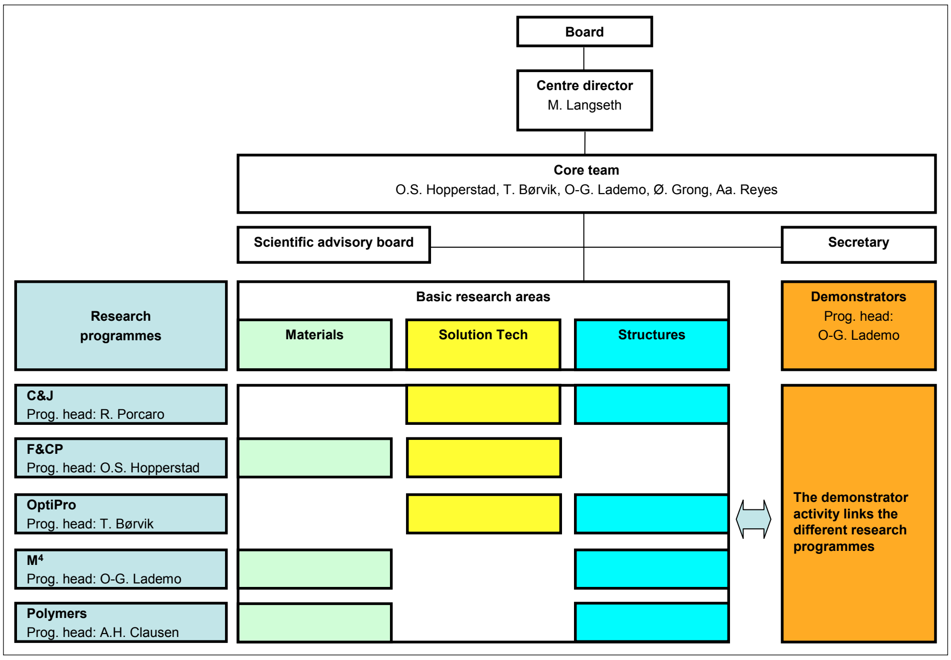
- Jens Christlein, Head of Department for Side and Pedestrian Protection, Audi AG
- Hariaokto Hooputra, Senior Engineer for Passive Safety Simulation, BMW Group
- Torstein Haarberg, Executive Vice President, Sintef Materials and Chemistry
- Helge Langberg, Head of Research Department, Norwegian Defence Estates Agency
- Per Kr Larsen, Professor, Department of Structural Engineering, NTNU
- Åge Larsstuen, Managing Director, Hydro Aluminium Structures
- Francois Moussy, Head of Materials Engineering Department, Renault
- Sigurd Olav Olsen, Director of Vehicle Section, Norwegian Public Roads Administration
- Svein Remseth, Chairman, Department of Structural Engineering, NTNU
- Ingvald Strømmen, Dean, Faculty of Engineering Science and Technology, NTNU

Centre director

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

Core team, programme heads and secretary

- 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
- Odd Sture Hopperstad, Professor, Department of Structural Engineering, NTNU
- Odd-Geir Lademo*, Dr. ing., Sintef Materials and Chemistry
- Raffaele Porcaro, PhD, Sintef Materials and Chemistry
- Aase Reyes, Assoc. Professor, Department of Structural Engineering, NTNU
- Toril Wahlberg, Secretary
  *Adjunct Professor at Department of Structural Engineering (20% position)



Structure of organisation

Scientific advisory board

- Professor Ahmed Benallal, LMT-Cachan, France
- Professor David Embury, MacMaster University, Canada
- Professor John Hutchinson, Harvard University, USA
- Professor 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 (SINTEF)
- Public partners
  - The Norwegian Public Roads Administration (NPRA)
  - The Norwegian Defence Estates Agency (NDEA)
- Industrial partners
  - Hydro Aluminium Structures
  - Hydro Aluminium Products RDB
  - Hydro Aluminium Metals RTD
  - BMW Group
  - Renault
  - Audi AG

Cooperation and interaction between partners

The annual work plans for each programme were defined with contribution from each partner. Scientists from NTNU and SINTEF and PhD students and post docs have been the main contributors, while each industrial and public partner has participated based on their defined contribution in kind. The contribution in kind for NPRA and Renault were taken care of by PhD students sitting half the time in the Centre and half the time at the respective industrial partner. Furthermore, NDEA has a scientist who is permanently sitting in the Centre with good contact with the NDEA research and development group in Oslo. However, in order to strengthen the cooperation within the main research group (NTNU and SINTEF) and between the partners the following actions have been taken:

From left: Toril M. Wahlberg, Øystein Grong, Raffaele Porcaro, Arild H. Clausen, Tore Børvik, Magnus Langseth, Odd Sture Hopperstad, Aase Reyes, Odd-Geir Lademo

Cooperation within the research group: A two day seminar was held in Selbu in February in order to merge the research groups behind the application. The seminar had participants from the Department of Structural Engineering and the Department of Materials Technology, NTNU, and Sintef Materials and Chemistry. During the seminar all defined work-plans for 2007 were discussed as well as the role of each scientist/professor.

Workshop in June 2007: In June a one day seminar was held in Trondheim with the Norwegian industrial and public partners. All obtained results so far were discussed and evaluated. The automotive industry was invited, but declined to attend due to travel restrictions.

Telephone and project meetings: In order to strengthen the involvement of the international partners as well as the interaction between all partners, each research programme has in 2007 organised 1-3 telephone meetings where the progress and obtained results have been discussed. Before the meetings, a power-point presentation has been sent out as a basis for the discussion. These meetings have been a success and will continue in 2008.

Seminar January 2008: In connection with the Board meeting in Munchen at BMW in January 2008, a one day seminar was held where all partners were present. The seminar gave no room for comprehensive scientific discussions, but was rather a forum where the work carried out in 2007 was presented and feedback from the partners was given. Such meetings where all partners are present will in the future be held once a year.

National cooperation

The main user partners in the centre are large Norwegian and international companies, as well as governmental bodies with extensive in-house research. However, in order to facilitate innovation in small and medium sized companies in Norway, the Centre is cooperating with Raufoss Technology and Industrial Management (RTIM). RTIM was designated as a Norwegian Centre of Expertise (NCE) from 2007, with the objective to promote the development of Norwegian industry working in an international market. RTIM is presently serving approximately 100 companies where 50 of them are SMEs (Small and Medium Sized Enterprises) and international companies in the Raufoss region employing approximately 4500 persons. RTIM is not a partner in the Centre, but one scientist from RTIM has spent approximately two months in the centre in 2007. Further, a high degree of participation of SINTEF scientists ensures that the open technology becomes readily available to the Norwegian industry through contract research.

New partners from 2008

One of the success criteria for a Centre is to attract new partners and to increase the funding from the existing partners. The Centre administration has been quite active the last year and SSAB Swedish Steel, StatoilHydro and Plastal became partners from January 2008. In addition Hydro Aluminium has replaced Hydro Aluminiuim Structures, Hydro Aluminium Metals and Hydro Aluminium Products from January 2008.

Research programmes and Demonstrators – results

The research in the Centre is based on annual work-plans. Each research programme and the Demonstrator activity is composed of several research projects. A background for the different programmes, the objective and scope as well as the most important obtained results in 2007 is given below.

Fracture and Crack Propagation (F&CP)

Programme head: O. S. Hopperstad

Background

In numerical simulation of quasi-static and dynamic ductile fracture, e.g. in analysis of forming processes, crashworthiness or structural impact, many complex and interacting phenomena generally occur: large deformations, contact, elastic-plasticity, viscous and thermal effects, damage, localization, fracture, length-scale effects, and crack propagation. Solving such problems requires advanced numerical techniques. Today the finite element method is used in most cases, and 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. There is a need to evaluate established methods against other possible approaches to ductile fracture and crack propagation, and to make these novel procedures available for industrial use.

There are essentially two ways to describe fracture and crack propagation: The discontinuous approach and the continuous-discontinuous approach. The discontinuous approach includes fracture mechanics based techniques as cohesive zone elements and extended finite element methods (X-FEM) in which a strong discontinuity is embedded in the element displacement field. These techniques give no information about onset of fracture, and additional hypotheses have to be made in this respect. In the continuous-discontinuous approach damage mechanics (coupled or uncoupled) is used to model ductile fracture evolution and to predict the onset of fracture (with necessary regularization schemes), while crack propagation is modelled by use of crack direction indicators, adaptivity and remeshing, and node splitting (or element erosion). It is the current belief that the latter approach is preferable for problems involving large deformations and large strains. However, both approaches will be investigated within the frame of the program. There are also alternatives to the finite element method, and important candidates are element-free Galerkin (EFG) methods and smooth particle hydrodynamics (SPH) methods. These alternatives will be investigated for applications in structural impact, as penetration and perforation problems, where the deformations and strains are very large.

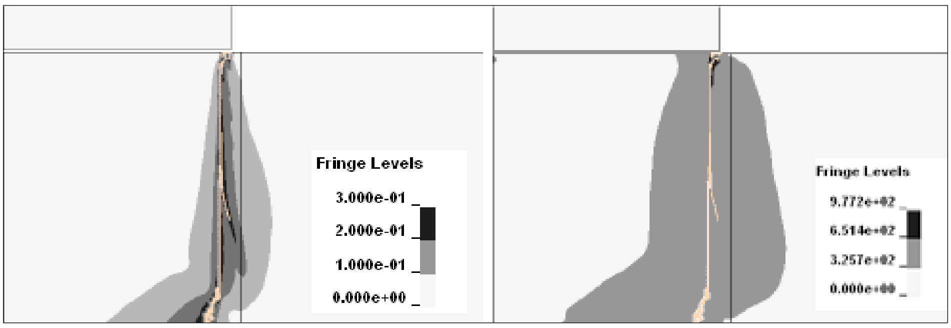


Figure 1 - Simulations of adiabatic shear banding in Weldox 460E steel plates: damage field (left) and temperature field (right).

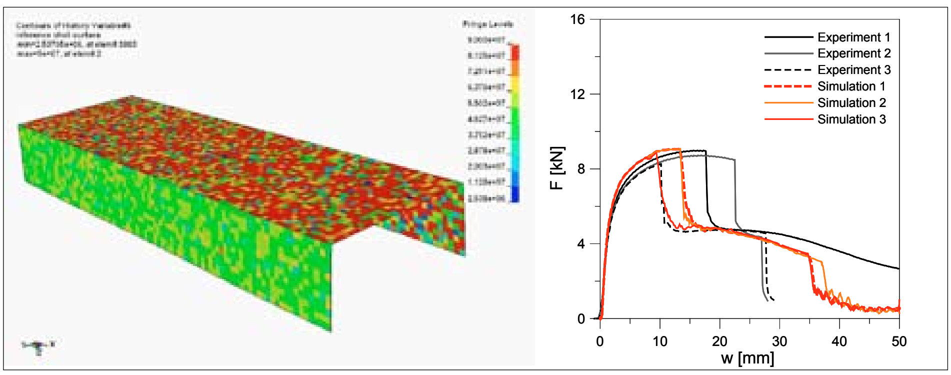


Figure 2 - U-shaped aluminium casting with Weibull distributed fracture parameter (left) and force-displacement curves from three parallel experiments and simulations of three-point bending (right).

Objective and scope

The main objective of the F&CP programme is to develop validated models for fracture and crack propagation in ductile materials including rolled and extruded aluminium alloys, high-strength steels, cast aluminium and magnesium and polymers. Formulations for shell structures and solid bodies will be established and implemented in LS-DYNA for verification and validation. Accuracy, robustness and efficiency are considered to be the major success criteria for the F&CP models. The programme is limited to ductile materials, i.e. it is assumed that fracture and crack propagation occurs after gross plastic deformations. However, theories for fracture in brittle and semi-ductile materials will be investigated for possible use for cast aluminium and magnesium.

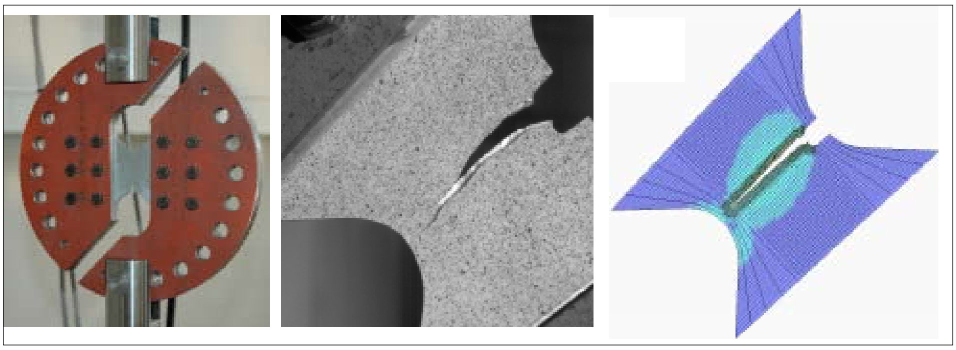


Figure 3 - Arcan test set-up in the laboratory (left) and crack propagation in test (middle) and simulation (right) for 45° load angle. Damage-driven adaptivity is used in the simulation.

Projects
Three research projects were defined in 2007:

F&CP-2007–1: State-of-the-art
A state-of-the-art report on fracture and crack propagation has been completed. The report covers damage mechanics, coupled and uncoupled theories, micro-mechanical modelling, length-scale effects (process zone), strain localization, regularization techniques, crack direction indicators, adaptivity and re-meshing, transfer and consistent recovery of state variables, element erosion and node splitting and cohesive zone elements. In addition, two new activities have been initiated during the year. First, anisotropic damage models are currently being implemented in LS-DYNA. These models are based on continuum damage mechanics and include (I) unilateral condition and isotropic damage variable, (II) anisotropic damage variable, and (III) unilateral condition and anisotropic damage variable. Second, the influence of damage coupling and non-local regularization on mesh dependence in adiabatic shear banding is studied. Simulations of adiabatic shear banding is shown in Figure 1.

F&CP-2007–2: F&CP in shell structures
In this project, a procedure for simulation of fracture and crack propagation has been developed based on damage-driven fission adaptivity and element erosion. The method works for 2D structures and shell structures. It has been evaluated against existing results in the literature. The results are promising. Procedures for simulation of fracture and crack propagation based on damage-driven adaptivity and node-splitting (and cohesive elements) have been evaluated. It was found that robust implementation of node-splitting schemes is a major task that will be pursued in the continuation of the project.

A new approach for numerical modelling of fracture for thin-walled aluminium castings has been developed. Experimental observations have shown that measured ductility increases as the specimen size is reduced. This "size-effect" can effectively be modelled by combining a ductile fracture criterion with probabilistic methods using the Weibull distribution. By performing several parallels of uniaxial tensile tests experimentally, fracture data can be identified for each of these tests in order to calibrate the required parameters for the Weibull distribution. The behaviour of the cast material can then be investigated numerically with stochastic FE-simulations in LS-DYNA. Preliminary simulations show promising results, Figure 2.

F&CP-2007–3: Characterization of F&CP for sheets
This project aimed at establishing experiments for characterization of fracture and crack-propagation under quasi-static and dynamic loading. For dynamic loading it was decided to use the instrumented Charpy test for pre-notched specimens, while for quasi-static loading an Arcan test set-up has been built, Figure 3. A high speed video camera is used to monitor the fracture propagation. The selected materials are DP800, AA7108-T6, AlSi9-TF and AlSi9-T6. Initial tests have been carried out to ensure that the test set-ups behave as intended, while the complete test-programme will be carried out and reported in 2008.

Connectors and Joints (C&J)

Programme head: R. Porcaro

Background
For 2007 the Connectors and Joints programme has focused on self-piercing rivets (SPR). After 2007 the programme will be extended to take into account alternative joining techniques. Self-pierce riveting is a method for joining two or more pieces of material, Figure 4. The process can be highly automated and is well suited for industrial purposes. It is attractive since the method can join different types of materials, such as an aluminium sheet to a piece of plastic. SIMLab initiated an activity on self-piercing rivets in 2000 and gained considerable experience from research on connections consisting of two aluminium sheets. Parameter studies have been done to study the influence of sheet thickness and material on the connector behaviour. Experimental facilities, Figure 5, have been developed which allow for systematic studies of the riveting process (Figure 5a) and the final connector strength and ductility (Figure 5b). The static connector capacity can be studied for a variety of loading conditions. We have also recently done experiments at the Ecole Normale Supérieure de Cachan/Laboratoire de Mécanique et Technologie (ENS/LMT), Paris, on the dynamic (impact) behaviour of SPR connections.

Numerical models have been established of the riveting process and validated against tests. The numerical results from the process simulation (geometry and material) can be mapped to a 3D model to study the influence of the process on the mechanical capacity, Figure 6. Finally, we have suggested robust design formulas regarding strength and ductility of SPR connections for shear and pull-out loading conditions.

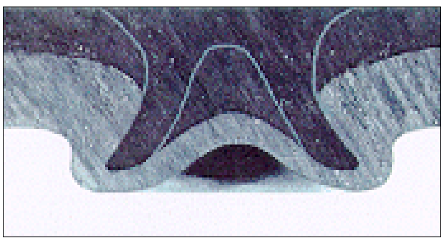


Figure 4 - Cross-section of a typical riveted connection.

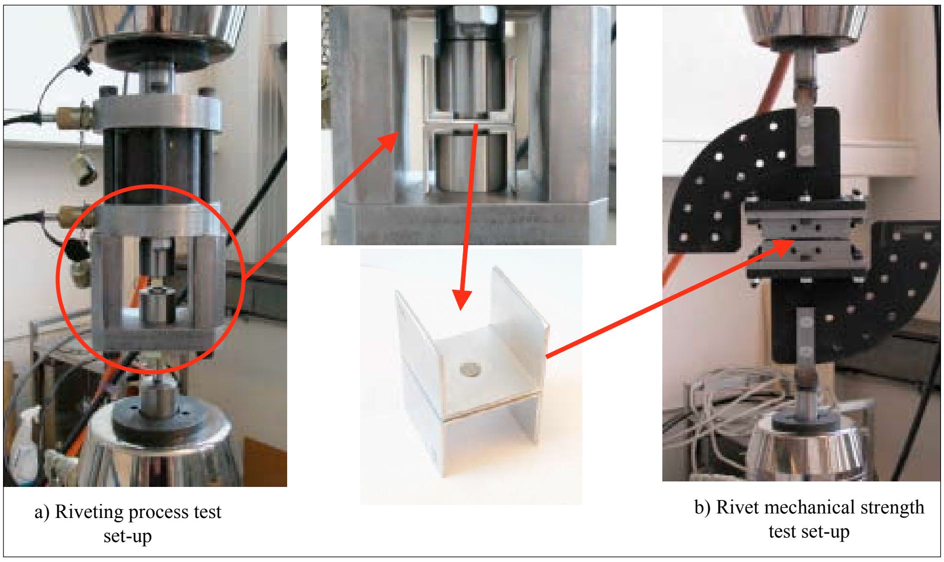


Figure 5 - Experimental facilities.

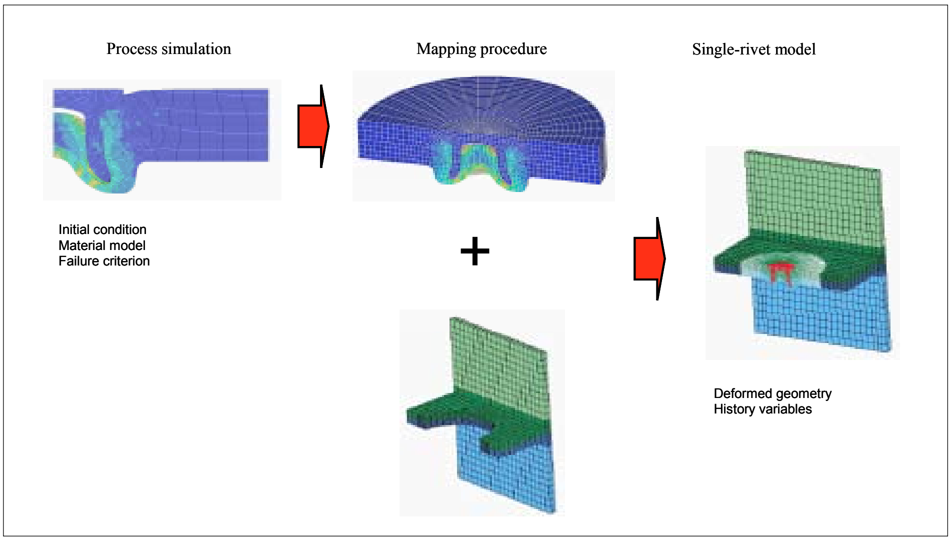


Figure 6 - Numerical simulations.

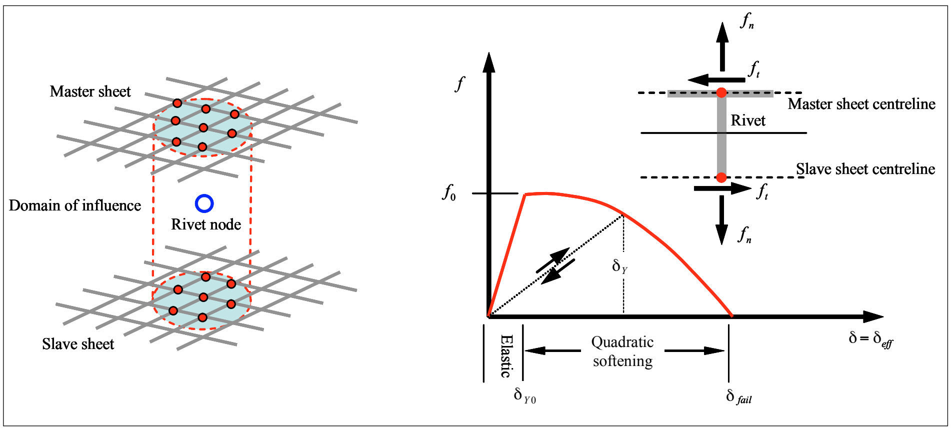


Figure 7 - SPR point-connector model.

Objective and scope

The objective of the programme in 2007 was to develop a new robust SPR connector model that can be used in large-scale shell-based numerical simulations of crash events. Such a model will include the accumulated knowledge concerning strength and failure behaviour of connections consisting of two aluminium sheets joined by a SPR. In order to broaden the validity of such a model, an extensive experimental programme has been defined for novel material combinations of the joint. Furthermore, the programme includes also an activity on the possible experimental techniques for dynamic testing of SPR connections as well as a pilot study on the fatigue life behaviour of such connections and its influence on the subsequent impact behaviour.

Projects

Six research projects were defined in 2007:

C&J-2007-1: Literature study

A literature survey was carried out with regards to the riveting process, the mechanical behaviour of SPR joints, existing shell-based numerical models for crash simulations and laboratory facilities for testing of point connectors. The collection of articles, provided by this literature survey, is currently used in the subsequent projects.

C&J-2007-2: SPR point-connector model

The objective of this project was to develop and implement a robust and user-friendly point-connector model in LS-DYNA (Figure 7), which allows the description of the capacity and failure behaviour of aluminium-to-aluminium sheets. A keyword input deck for LS-DYNA has been established and implemented. Subroutines were created for reading the keyword input deck and initialising the SPR parameters with LS-DYNA. A local description of the deformation and failure of the SPR connection, Figure 7, to be used in LS-DYNA was then implemented. The local model controls the load and ductility for various load conditions as a function of rivet geometry and the property of the connected sheets. Furthermore, a mesh sensitivity study was performed. The model has shown acceptable mesh sensitivity for all loading conditions. We are currently working on the validation of the model using the existing experimental database.

C&J-2007-3: Experimental database
The objective was to test SPR connections for novel material combinations. This project has focused on testing of a simple specimen geometry with only one self-piercing rivet under combined shear and pull-out quasi-static loading. A new test rig was developed for the new specimen geometry. The materials and the combinations of interest have been chosen in collaboration with the partners involved. All the materials have been collected and the specimens have been assembled. Material tests have been performed in order to characterize the material of the connected plates. The tests will start as soon as the specimens are riveted by Böllhoff.

C&J-2007-4: Dynamic testing
This project has evaluated relevant experimental techniques and assessed their potential for point connectors subjected to dynamic loading conditions. The possibility to perform dynamic tests using a Split-Hopkinson pressure bar was evaluated based on the tests recently performed at the Laboratoire de Mécanique et Technologie, Cachan. Accurate 3D numerical models of the experimental tests were used to analyze the experimental results. The experimental results and the numerical simulations have shown no rate effect on the behaviour of the connections. However, this study has revealed that the experimental results regarding the dynamic capacity of SPR connections were difficult to interpret. In order to overcome these problems, a new experimental test set-up was developed to perform dynamic testing of self-piercing riveting connections using the Split Hopkinson tension bar that is available at SIMLab. Numerical simulations of the new system have been carried out in order to better design the new test set-up.

C&J-2007-5: Self-piercing riveting optimization
During the last years, SIMLab has gained considerable experience in the modelling of the SPR process. Numerical models have been established and validated against experimental tests. The objective of this activity is to develop a methodology based on our numerical models for optimization of the riveting process. In the second half of 2007, PhD student Nguyen-Hieu Hoang was recruited to the project, and he will focus on the optimization of a SPR connection by using an aluminium rivet. A detailed plan of his PhD work will be defined within the first half of 2008.

C&J-2007-6: Fatigue of SPR
This is an initial study to investigate the state of the art and future research possibilities on fatigue of SPR joints. A literature search was carried out and showed that there is a limited number of available publications on this topic, and that there is no study on the effect of fatigue on the crashworthiness of SPR joints. Based on the study conducted, it is very likely that cyclic loading will affect the impact behaviour of SPR joints. The presence of oxide as well as roughening of interfaces will alter the friction properties between the rivet and sheet material. Incipient cracks, cyclic softening, and plastic deformation will cause free-play and degrade the static strength, as well as influencing the dynamic response of the global structure. Suggestions for possible studies on the crashworthiness of fatigued SPR specimens were proposed.

Polymers (Poly)

Programme head: A. H. Clausen

Background
Among the different classes of materials, i.e. metals, concrete, wood, polymers etc., few materials face the same world-wide increase in demand and use as polymers do. There are two main reasons for the current growth:

(1) Production of artificial polymers (in contrast to rubber and other natural polymers) has been possible for some decades only, and it takes time for a rather new class of material to be accepted as an alternative to the materials traditionally used. Now, it is time for polymers to challenge the existing design solutions.
(2) Polymers have attractive properties: Cheap, easy to form, low density, large ductility etc.

Polymers are promising for use in several applications, and such materials may have excellent energy absorption characteristics. The experience in using polymers in protective 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, which are essential tools in today's engineering design. Material models for polymers should be capable to handle large temperature and strain-rate effects, deformation-induced anisotropy, viscosity, and other features commonly observed for polymers.

Modelling of polymer behaviour at impact situations is a rather new activity at SIMLab. Therefore, the first year of the project was used to establish an in-house state-of-the-art competence where we as far as possible utilized our prior knowledge in behaviour of metallic materials. The research projects within the Polymer programme in 2007, see below, reflected this starting position.

The main strategy for the polymer research is similar as for our activities within constitutive modelling of metals during the last 15 years. Material tests in our laboratory provide insight in which observed phenomena the model should be able to represent. This is most likely to be an iterative process where the model is gradually improved. In addition to material tests required for calibration of the coefficients involved in a model, well-defined experimental component tests will serve as bench-mark cases for numerical validation of the model.

Objective and scope
The main objective of this programme is to develop validated 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 an impact test database. The programme is for the time being limited to thermoplastics.

Materials
At the current stage of research, quite generic thermoplastics will be chosen: Plates made of PEHD and PVC, and three PP materials delivered by Renault as a part of their contribution in kind. They are deliberately chosen to facilitate easy machining of

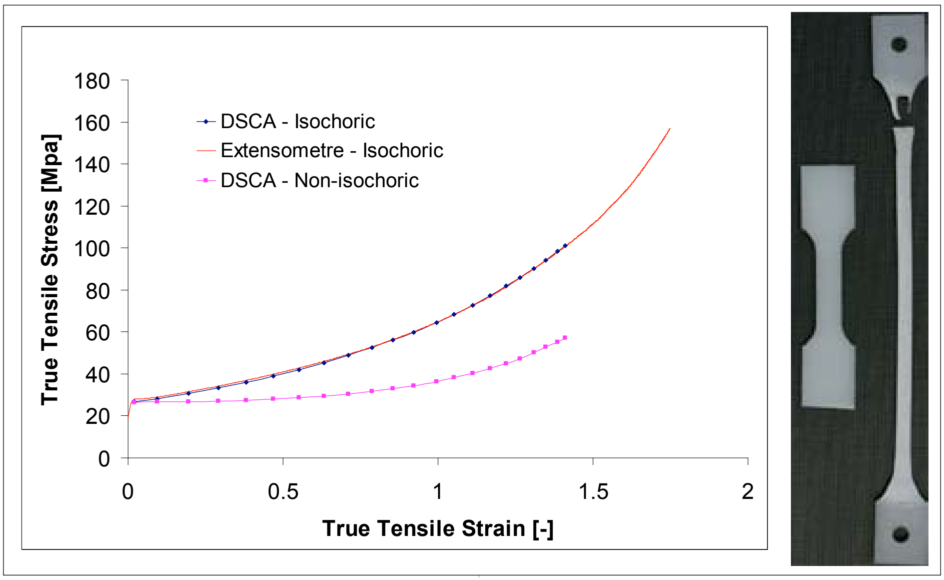


Figure 8 - Unlike metals, polymers do not preserve their volume during plastic deformation, i.e. they behave non-isochoric. This complicates the determination of true stress and strain during a tensile test. In additional to the longitudinal elongation, the lateral deformation of the test coupon has to be monitored. Full-field optical measurements by means of a camera and the digital image correlation (DIC) technique can reveal the transversal strains and subsequently the dilatation (volume increase). The figure shows stress-strain curves as determined with the metal plasticity approach ("isochoric"), and a more correct curve based on DIC measurements ("Non-isochoric").

material test coupons as well as specimens for the validation tests.

Projects

Four research projects were defined in 2007:

Poly-2007–1: State-of-the-art

As over previous experience with polymers was quite limited, an extensive literature review was required at an early stage. This review, resulting in a state-of-the-art report, focused primarily on mechanical properties and the mechanisms causing observed behaviour.

Poly-2007–2: Test techniques

This project was concerned with experimental procedures for material testing of ductile thermoplastics. Also here, the literature was consulted to explore practise elsewhere. Polymers are in general reported to behave non-isochoric in tension, i.e. the volume increases with deformation. One of the main challenges is therefore to determine the true stress-strain behaviour in tension. Use of an optical measurement technique has therefore been explored, Figure 8. Another task reported in the literature is that polymers behave different in tension and compression, calling for tests in both modes when material models are to be calibrated.

Poly-2007–3: Model implementation

A slightly modified version of a model originally proposed by Professor Boyce at MIT has been implemented in LS-DYNA. After checking the capabilities of this model, it was in general found to work quite well. Some adjustments, however, were relevant, e.g. introduce a yield criterion taking care of the pressure sensitivity. We plan to follow two paths during the further work in 2008; (1) improve the Boyce model; and (2) implement a new viscoelastic-viscoplastic model, more directly based on the framework applied in existing models for metals plasticity.

Poly-2007–4: Validation of model

A set of benchmark tests was selected to check the capability of the implemented models. However, no bench-mark tests were carried out in 2007.

In addition to these four defined research projects, PhD student Virgile Delhaye is connected to the Polymer programme.

Multi-scale Modelling of Metallic Materials (M⁴)

Programme head: O-G. Lademo

Background

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 the ones who can realize an integrated perspective of 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 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, optimised performance/weight ratio,.....).

During the later years rather 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. They do, however, not provide any information about the physical mechanisms responsible for the observed material response. Hence, the models do not contribute in enhancing the understanding of micro-mechanisms of plastic deformation and offers limited action upstream in the material processing chain. Another complementary approach consists in 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 optimised process chains, for the development of next-generation phenomenological models, and for reducing material characterisation costs. The physical models are often computationally expensive and can not replace the phenomenological models. Instead an optimised use of the models at various scales must be searched.

Objective and scope

We shall develop quantitative tools for analysis, design and optimisation that improve the ability and efficiency of the industry to develop and improve aluminium alloys, processes and products for automotive applications. The model development must rely upon high-precision experiments at various scales. Qualitative judgments shall be investigated on the basis of quantitative models through implementation in state-of-the-art FE-tools and numerical simulations.

Projects

In 2007, five projects were initiated. Projects 1 to 3 are generic projects run to establish and streamline the fundament for various integrated experimental-numerical research activities within the research programme. The deliverables are to great extent in-house tools structuring the developed knowledge. Projects 4 and 5 are application-oriented projects that are connected to projects run by the industrial participants as a contribution in kind to the Centre.

M⁴-2007-1: Experimental and modelling protocols

Extensive hand-in-hand experiments and numerical analyses are essential, for the M⁴ research programme, in particular, and for the Centre activities in general. Model development, parameter identification and related validation work must rely upon series of experiments that needs quality assurance and repeated documentation. On the basis of experimental protocols, a virtual laboratory or database is to be established with catalogued optimised numerical models of the various experimental techniques. Furthermore, a comprehensive database gathering experimental and numerical data, including all experimental specimen geometries used within the Centre shall be built.

In 2007, emphasis was put on the definition and acquisition of new experimental facilities: A multi-purpose hydraulic sheet metal forming machine and a set of high resolution cameras. A typical application using these facilities is the establishment of forming limit diagrams, Figure 9. Protocols for tensile and shear testing have also been defined and written. Specific protocols for the newly purchased tools will be defined upon delivery in 2008 together with a database containing the experimental and numerical protocols.

M⁴-2007-2: Work hardening and strengthening mechanisms

Modelling work hardening and strengthening mechanisms accounting for microstructure and microstructure evolution in aluminium alloys is of great interest with respect to describing and understanding the effects of specific features such as dynamic strain aging (DSA) and metallurgical aspects (solutes, precipitates ...) on the material behaviour. During the recent years the focus has been on modelling microstructure evolution and corresponding work hardening in 5xxx (AlMg) alloys, Figure 10. In SIMLab the 6xxx and 7xxx precipitation hardening alloys are of interest as well, bringing in two additional aspects: (i) The influence of mixed solutes in solid solution; and (ii) precipitation hardening.

A paper summarizing earlier activities on precipitation and corresponding mechanical properties of a cast 6xxx alloy is in progress. A paper on how to handle strain-rate and temperature variations properly in the mechanical threshold strength model was finalized early in 2007 and published in Acta Materiala.

Existing continuum plasticity models for strain path dependency have been explored, and an alternative mathematical formulation has been proposed that will be implemented in LS-DYNA in 2008.This model is designed to capture the predictions by a crystal plasticity model published in the International Journal of Plasticity.

PhD student Ida Westermann is recruited in the project and will be central in performing the requested fundamental experimental investigations. The research needs and methodology of the project are now well defined, partly based on the experience gained in M⁴-2007-5. Materials have been selected and are ordered.

M⁴-2007-3: Hierarchical modelling

In need-driven, or top-down, multiscale modelling there are several approaches for including physics-related features, Figure 11. One approach consists in explicit coupling of physically-based models with the component scale. Another approach is to use averaging techniques in order to decrease CPU-costs. Finally, a hierarchical approach can be used, where phenomenological models are identified based on lower scale physically-based models,

A framework for single- and poly-crystal plasticity has been defined and implemented both as a stand-alone code and into the commercial finite element code LS-DYNA. Different models describing the crystal behaviour have been implemented and validated. Some bulk metal forming processes, i.e. simple compression and rolling, have

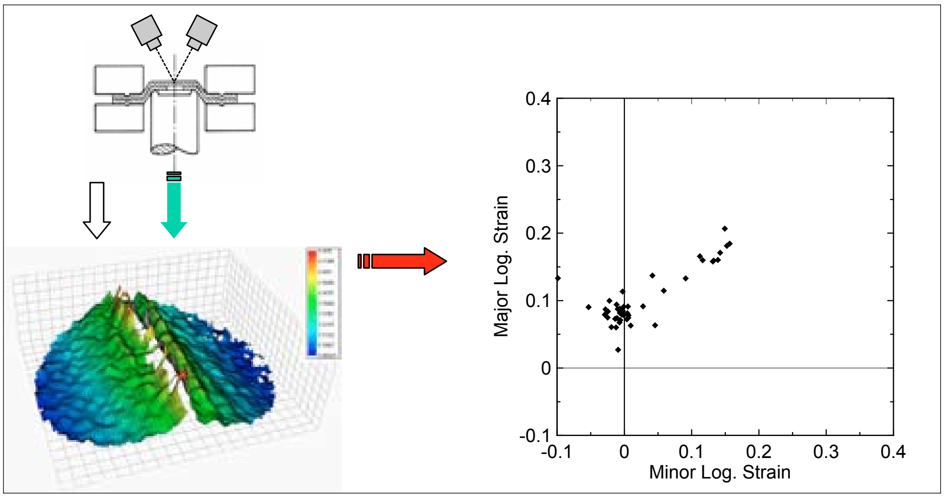


Figure 9 - Typical use of BUP600 (Marciniak-Kuczynski formability test set-up) and strain field measurements to determine the forming limit diagram for a material.

been successfully modelled as validation cases. Further work on sheet metal forming, i.e. deep-drawing, is ongoing.

Work has been performed on calculating yield surfaces from measured textures. Firstly an algorithm has been developed for properly picking an adequate number of grain orientations from EBSD maps, e.g. scans by scanning electron microscopy at various positions through the plate thickness. Based on the MTM-KUL Taylor model implementation, Fortran 77 programs have been written that can calculate selected sections and parts of the yield surface by the Taylor model with the measured textures as input. First attempts have also been made on running the Los Alamos version of the visco-plastic self-consistent model by Tomé and Lebensohn.

Fitting of yield surfaces for three-dimensional brick elements requires a distribution of stress paths in the 5-dimensional stress space (incompressible materials). Algorithms for even distributions do not exist. Therefore, an approximate algorithm has been developed and implemented in order to fit the recent Barlat yield locus to Taylor model predictions. This is described in a paper submitted to the International Journal of Plasticity.

M^4-2007-4: Formability of rolled aluminium alloys

A series of papers based on past research in the field have now (mostly) been accepted, but required extensive effort in the reviewing process. The publications document the predictive power of modelling procedures and are thus important for documentation and dissemination of 'state-of-the-art' in the field at the initiation of SIMLab. The publications document experimental-numerical investigations on the formability of extruded 6xxx and 7xxx alloys, covering the influence of various 'formability limiting phenomena' and various methods and technologies for identification of governing model parameters.

The activity has also made progress on the formability of rolled alloys – according to the work plan. A manuscript on the formability of the rolled aluminium alloy AA6016 has been prepared. In this work, uniaxial tension tests, shear tests and polycrystalline yield surface calculations are used to identify the material constants of a constitutive equation and failure criterion. Plane strain tension tests, plane strain bending tests, bulge tests, square-cup drawing tests (Figure 12), and Nakazima and Marciniak-Kuczynski (M-K) formability tests have been performed to assess the validity of the modelling approach. A metallurgical investigation has been performed to strengthen the scientific basis of the modelling procedure.

Strain-rate sensitivity effects for rolled 5xxx aluminium alloys and related models have been addressed through an experimental programme previously performed in the VIRFORM project. With respect to modelling, efforts have been put into numerical studies on the influence of DSA and the related Portevin-Le Châtelier (PLC) effect and preparation of journal publications on the topic. Integrated experimental-numerical investigations will be undertaken in 2008.

M^4 -2007-5: Capacity and ductility of welded structures

The current project is run in tight interaction with activities of Hydro Automotive Structures. The present summary presents highlights achieved within the combined activity.

A new model for work hardening has been proposed that relies upon the chemical composition of the alloy and the thermo-mechanical process chain. The model enables the prediction of the strength and work hardening within the HAZs of a welded aluminium structure on the basis of a welding simulation through the FE code WELDSIM. The proposed model has been

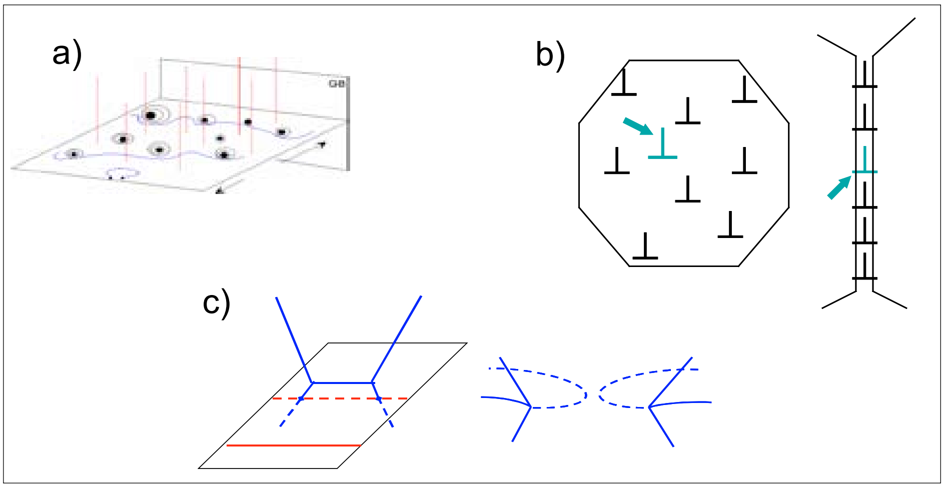


Figure 10 - Modelling of work hardening and strengthening mechanisms such as a) effects of geometrical obstacles, b) storage of dislocations, c) dynamic recovery.

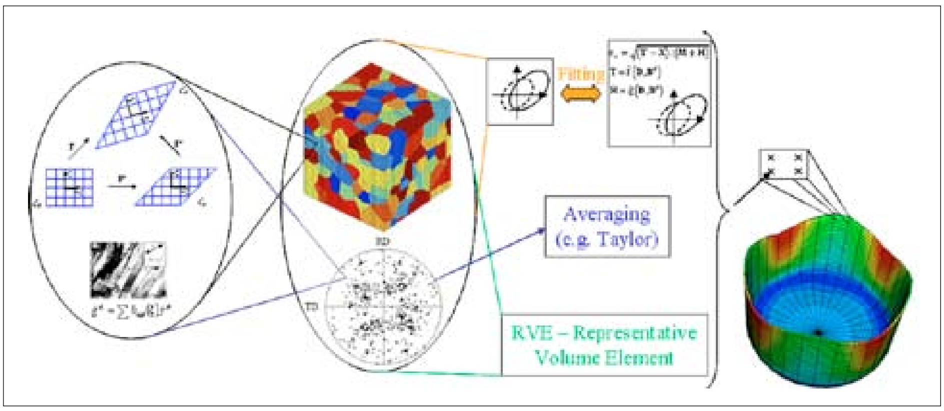


Figure 11 - Multiscale approaches.

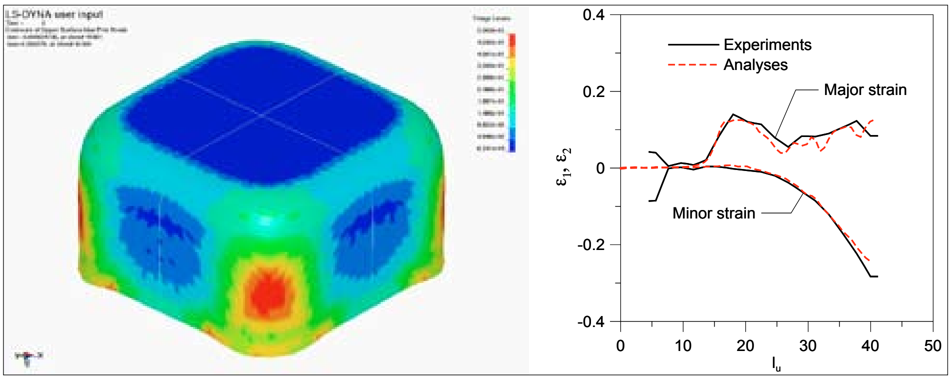


Figure 12 - Example of results from validation analysis of a square-cup drawing test. Analysis model and experimental and predicted principal strain profiles.

implemented in the FE code LS-DYNA and used for subsequent mechanical analysis of welded components/structures.

An experimental programme on the structural performance of generic automotive components made out of 6xxx and 7xxx alloys has been executed in project Demo-2007-2. For the 6xxx alloys, welding simulations have been performed on the basis of a modified 'Namo' precipitation model. Refined precipitation models applicable to 7xxx alloys are currently being explored on the basis of past PhD works. The PhD project of Ida Westermann (see M^4-2007-2) will build further knowledge to support this activity into 2008. Shell-based analyses with LS-DYNA have been undertaken to address the predictive power of the modelling methodology and to establish a comparison with phenomenological modelling strategies. The results will be documented by an article intended for publication in the Welding Journal.

A second PhD student (A.B. Alisibramulisi) has been recruited to the programme. She will focus on the performance of welded structures and further validation of the developed modelling approaches.

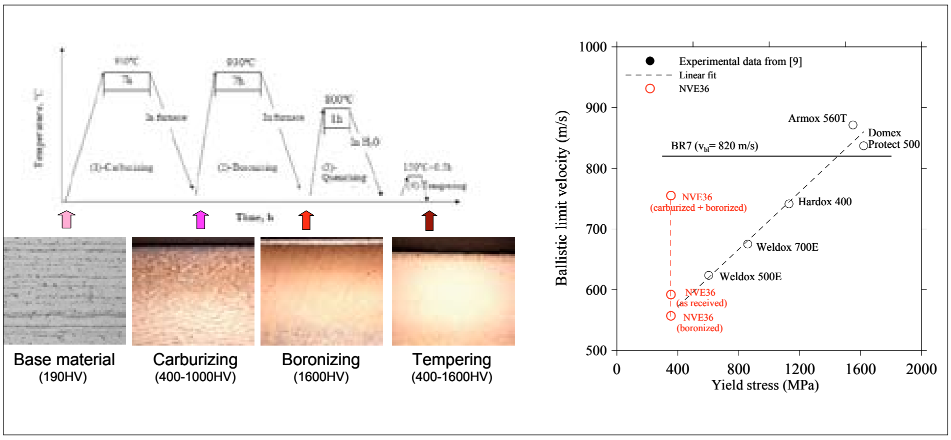


Figure 13 - Surface strengthening procedure used on a low-cost/low-strength steel plate (left) and the increase in ballistic limit velocity after surface strengthening versus other steels when impacted by 7.62 mm Ball (soft core) projectiles (right). As seen, a 30% increase in ballistic perforation resistance is gained by the surface strengthening techniques. It is believed that this promising effect can be further increased by a proper and optimized surface strengthening.

Optimal Energy Absorption and Protection (OptiPro)

Programme head: T. Børvik

Background:

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 and military engineering applications and for the safety of the citizen in general. Since it is both difficult and expensive to validate and optimise protective structures against accidental loads experimentally, the product development is increasingly carried out in virtual environments by use of the finite element method in order to have a safe and cost effective design. Finally, these new designs need to be validated through high-precision experimental tests involving advanced instrumentation.

Objective and scope

The main objective with the OptiPro research programme is to be able to design safer, more cost effective and lightweight protective structures for both civilian and military applications using advanced computational tools.

Projects

The research in 2007 has been carried out through six projects, and some main activities from each project so far will be briefly presented in the following. It should be noticed that all these activities will continue in 2008.

OptiPro-2007-1: State-of-the-art

The state-of-the-art has been and will be a continuous activity where the goal is to be up-to-date on the literature related to accidental loads. In 2007, the work has been closely related to the state-of-the-art activity within the F&CP programme, where a report based on this work has been completed.

OptiPro-2007-2: Strengthening techniques

In this project, the goal has been to reveal the effect of using different surface strengthening techniques on various steels to see if it is possible to increase their ballistic perforation resistance. Techniques such as boronizing, carburizing, carburizing followed by boronizing, plasma spraying and high velocity spraying (HVOF) have been tested and evaluated. Based on this work, two reports were published in 2007. In the first report the potential of the technique was demonstrated by increasing the ballistic limit with 30% when a low-cost/low-strength NVE36 steel plate was first carburized before it was boronized, Figure 13. In the second report, the applied strengthening technique was tried optimised. However, the increase in ballistic limit after optimisation was nearly negligible. This indicates that we were close to the optimal conditions in the first report. The next steps are to use these techniques on layered plates and on steels with higher initial strengths. This work is in progress and will be continued in 2008. In addition, a journal paper on adiabatic shear banding during penetration of steels was completed and published in 2007.

OptiPro-2007-3: Blast loading using FEM

The idea with this activity was to investigate different FEM techniques used to simulate the behaviour of structures exposed to blast loading. While most ballistic impact scenarios are regarded as complex material problems, where full-scale component tests rather easily can be accomplished, blast loads are regarded as structural problems. Since it is difficult, expensive and often impossible to validate and optimise protective structures or vital infrastructure against blast loads using full-scale experimental tests, we had to turn our attention towards advanced numerical tools like the finite element method (FEM). Two journal papers on the behaviour of unprotected/protected containers during blast loads have been published. In addition, a report on close-range blast loading of aluminium foam panels using the arbitrary Lagrangian-Eulerian (ALE) technique in LS-DYNA has been completed. This report was also presented at the IUTAM symposium in Paris in 2007. Now, simulations using three different FEM techniques (with increasing level of complexity and expected accuracy) to describe the blast response of an unprotected container are carried out (first purely Lagrangian, then Eulerian + Lagrangian, and finally fully coupled Eulerian-Lagrangian). The aim is to generate a reference basis which can be used for engineering design of blast loaded structures. This work is in progress, and the results will be presented in a journal paper. Figure 14 shows a comparison between a full-scale blast test of an unprotected 20ft ISO container and a corresponding LS-DYNA simulation using a fully coupled Eulerian-Lagrangian approach. As seen, both the qualitative and quantitative agreement is good. However, it has been shown that full-scale blast tests on flexible structures are difficult to control and that more tests are required in order to validate FEM based blast simulations.

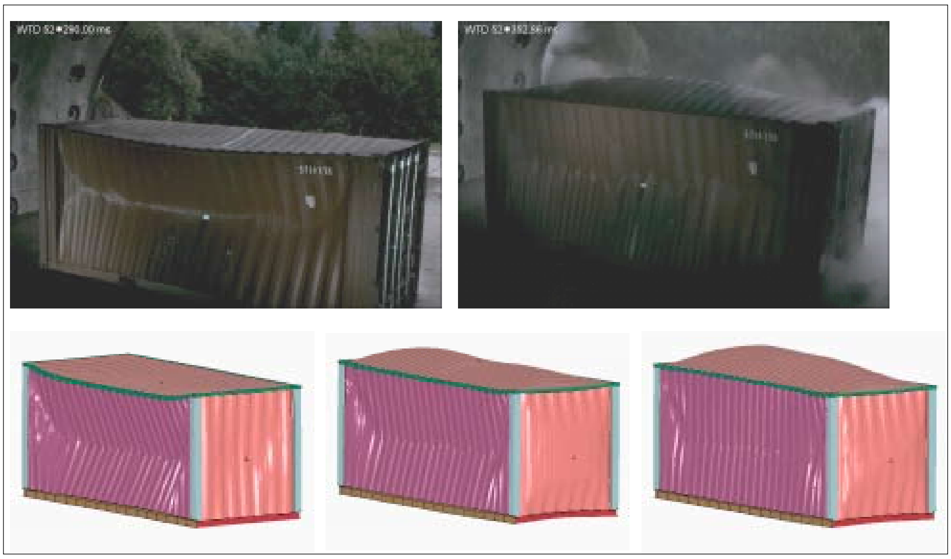


Figure 14 - Deformed shapes of a 20ft ISO container during blast loading. The numerical plots are based on a LS-DYNA simulation using a fully coupled Eulerian-Lagrangian approach.

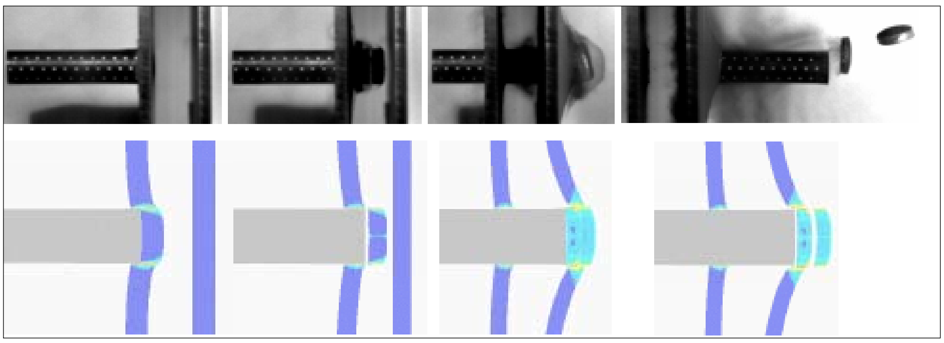


Figure 15 - Experimental test versus LS-DYNA simulation of the perforation process of a 2x6 mm thick double-layered steel plate spaced with 24 mm of air impacted by a blunt projectile at an impact velocity of 250 m/s.

OptiPro-2007-4: Light-weight protective structures

This project contained several activities, and they will continue in the years to come. The overall goal is to determine the effect of using new and alternative designs, such as laminated, layered, spaced, hybrid or aluminium based materials, for ballistic and blast load protection purposes. We will also try to propose guidelines for optimization of such structures, and to establish new and improved numerical methods for impact, penetration, perforation and crashworthiness. In 2007, the effect of laminating several thinner plates instead of using a monolithic plate with the same weight has been investigated both for steel and aluminium. It has been proven that the overall ballistic protection level increases considerably if the plates are double-layered. However, it remains to see if this also yields for small-arms ammunition threats at high impact velocities and if the stacking and number of plates are of importance. A numerical study is further in progress where the goal is to try to optimise the design of layered plates using FEM. This activity will continue in 2008. Furthermore, an analytical method called cavity-expansion-theory has been validated against experimental tests and FEM simulations on the perforation resistance of aluminium plates with different thicknesses. This work will continue on various steel plates impacted by small-arms ammunition. For the latter problem, numerical models able to describe the material behaviour during impact have been established. Work has also been carried out on the anisotropic response of thin aluminium plates under quasi-static or dynamic loading. Finally, a state-of-the-art report on the behaviour of composite panels for ballistic protection has been completed. Such materials are of vital importance in the design of lightweight protective structures, especially since the cost of such materials has dropped considerably in later years. Tests and simulations are shown in Figure 15.

OptiPro-2007-5: Impact loading of high-strength steel components
A post doc was working on this project preparing journal articles on material behavior and modelling of dual-phase high-strength steels.

OptiPro-2007-6: Modelling of road restraint systems
This activity is a PhD-project for Henning Fransplass, and serves as the contribution in kind from NPRA. The aim of the project is an improved understanding of bolted connections used on flexible road restraint systems, with emphasis on the investigation of the plastic deformation, fracture and crack propagation of such connections during impact. These connections experience high loads in the impact region of the guardrail, and as a result, the head of the bolt may be pulled through a slotted hole in the w-beam. This behaviour can have a significant effect on the performance of the guardrail system. A report on bolted connections has been delivered in 2007. Figure 16 shows an impact between a guardrail and a vehicle.

Figure 16 - Impact between guardrail and a vehicle.

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 have 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.

Objective and scope
The main objective of this research area is to establish a link between the basic research and real structures for validation and possible refinements of the developed technology.

Demo-2007-1: Aluminium front-end concept
An aluminium front-end concept attached to a crash car (rear end beam framework) was used as a demonstrator for the state-of-the-art of prediction of failure in material and joints, Figure 17. The applied load case is the front offset crash at 45 km/h using a rigid barrier with 40 % overlap. The test results are compared with the simulation performed using the Instability-Ductile-Shear failure criteria and the self pierce rivet failure model in ABAQUS. The pre-deformation due to the deep drawing process for the significant parts are taken into account. The detailed analysis of the results is still in progress.

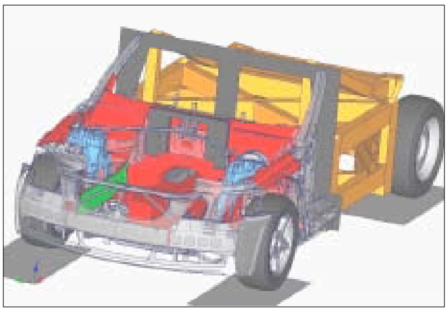


Figure 17 - Full-scale model of front-end concept

Demo-2007-2: Tube-to-plate welding tests
Series of experiments and related FE simulations of generic tests on 6xxx and 7xxx crash-boxes have been performed, Figure 18. This has led to preliminary modelling guidelines that are currently used by Hydro Automotive Structures.

Figure 18 - Experimental test on generic welded component.

Concurrent research projects

The following research projects have been run in parallel with the Centre activities:

- **ROBDES:** NTNU and SINTEF in cooperation with VOLVO/Ford, Gestamp Hardtech, SSAB Tunnplåt, Hydro Aluminium Structures, the University of Linköping and the Research Council of Norway have established an innovation project (BIP) on Robust Design of Automotive Structures (2005-2008). Three projects have been defined: 1) Deterministic material modelling of high-strength steel for forming and crash analyses. 2) Methods development for multi-disciplinary stochastic crash problems. 3) Robustness study of a crash member taking variations in the material properties and geometry into account. Two Ph.D. students are linked to the project, one student at NTNU and one student at the University of Linköping, Sweden.

- **PolyCrash:** NTNU and SINTEF are involved in a BIP project called PolyCrash. The main objective with the project is to develop road restraint systems where the poles are made of recyclable plastics. The industrial partners are Plasto, Vik Verk, Gjerde, RTIM and The Norwegian Public Road Administration.

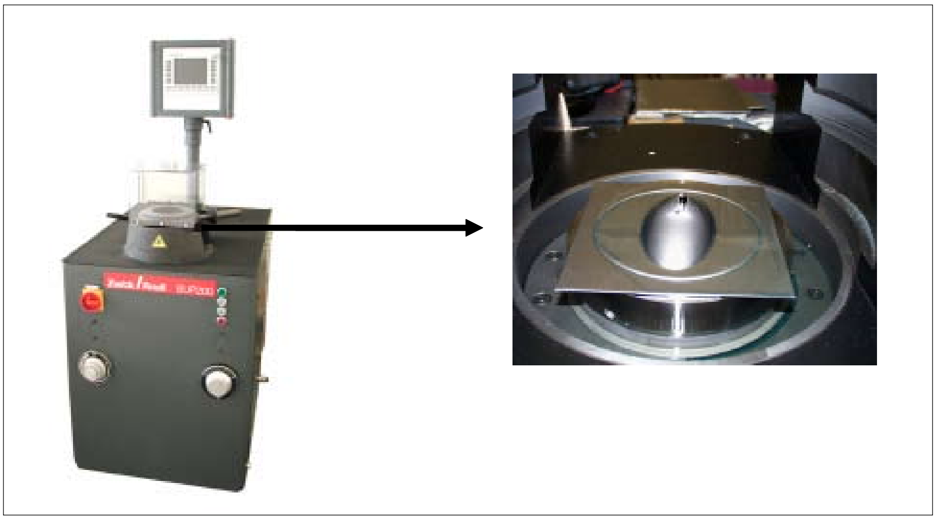
- **NADIA:** NTNU and SINTEF are involved in a EU project named NADIA for the period 2006-2009. The project deals with new automotive components designed for and manufactured by intelligent processing of light alloys based on aluminium and magnesium. The NADIA project has 24 partners.

New equipment

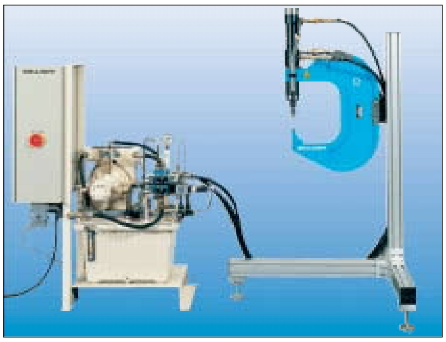
- *Sheet metal forming machine:* A multi-purpose hydraulic sheet metal forming machine with 600kN load capacity (Zwick/Roell BUP 600) and multiple forming tools has been purchased. This machine is considered to be an ideal tool for advanced research on the fundamentals of forming and formability, for validation of constitutive models including fracture as well as for educational training of MSc and PhD students.

- *Self piercing riveting machine:* A machine to carry out riveting of materials under industrial conditions is purchased from Böllhoff in Germany.

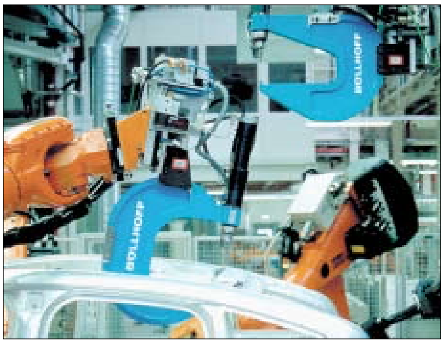
- *Field measurements:* Two cameras have been purchased to carry out field measurements when using the Digital Image Correlation System.



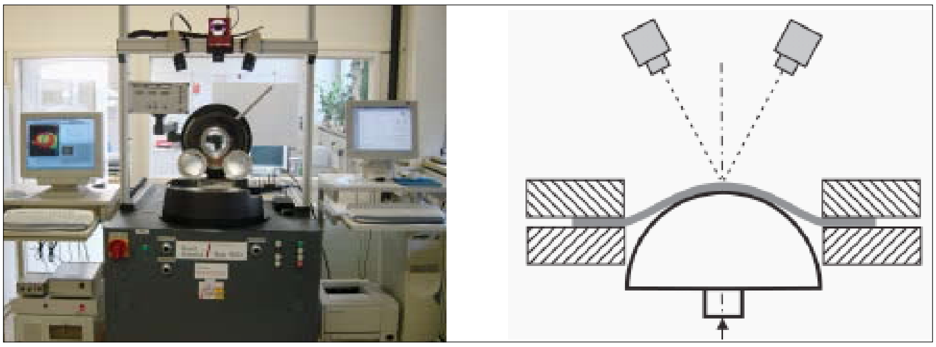
BUP-machine



Rivet machine



Automotive application of a riveting system

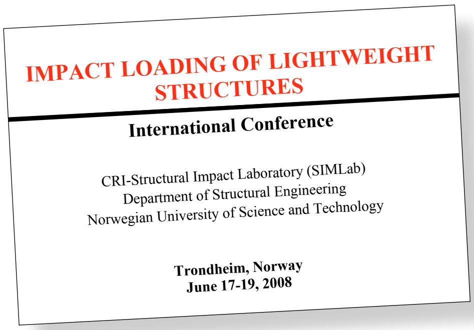


BUP-machine with a camera system for field measurements

Visibility

Conferences

- SIMLab will host an international conference on "Impact Loading of Lightweight Structures" in June 2008. The conference is a continuation of the conference held in Florianapolis in Brazil in 2005 and will deal with aluminium, magnesium, high strength steels, polymers, foams and composites and their use as a structural material in impact loaded structures. Totally 70 abstracts have been received with contributions both from industry and academia.


IMPACT LOADING OF LIGHTWEIGHT STRUCTURES

International Conference

CRI-Structural Impact Laboratory (SIMLab)
Department of Structural Engineering
Norwegian University of Science and Technology

Trondheim, Norway
June 17-19, 2008

- SIMLab will together with the University of Hertfordshire and The Welding Institute (TWI) in UK organise a conference 18-19 September 2008 on Joining Technology. Papers are invited to cover topics related to developments including, seam welding, self-piercing riveting, friction stir welding, laser welding, adhesive bonding etc.

Exhibition

- SIMLab participated at the Technoport exhibition in Trondheim from 18-20 October 2007.

Keynote and guest lectures

- Dr Thomas Warren from Sandia National Laboratories, Albuquerque, USA, gave in March two guest lectures at the Centre on penetration mechanics.
- Professor Magnus Langseth gave a guest lecture at the Instituto Superior Technico in Lisbon in June this year. The topic of his lecture was related to the research activities in the Centre.
- Professor Odd Sture Hopperstad gave a keynote lecture at the at 6th European LS-DYNA Users' Conference, Gothenburg, 2007.

Magazines and journals

- The Centre was presented in the local newspaper "Byens Næringsliv-Nr. 10" 22 May 2007.
- Professor Magnus Langseth has by Elsevier been appointed as the Editor-in-Chief of the International Journal of Impact Engineering. In addition Professor Odd Sture Hopperstad has been appointed as an Assoc Editor and Adjunct Professor Tore Børvik as a member of the Scientific Advisory Board of the same journal. Furthermore, Professor Langseth is on the Editorial Boards of the International Journal of Mechanics and Materials in Design, Journal of Multidiscipline Modeling in Materials and Structures, and Journal of Ships and Offshore Structures.

International cooperation

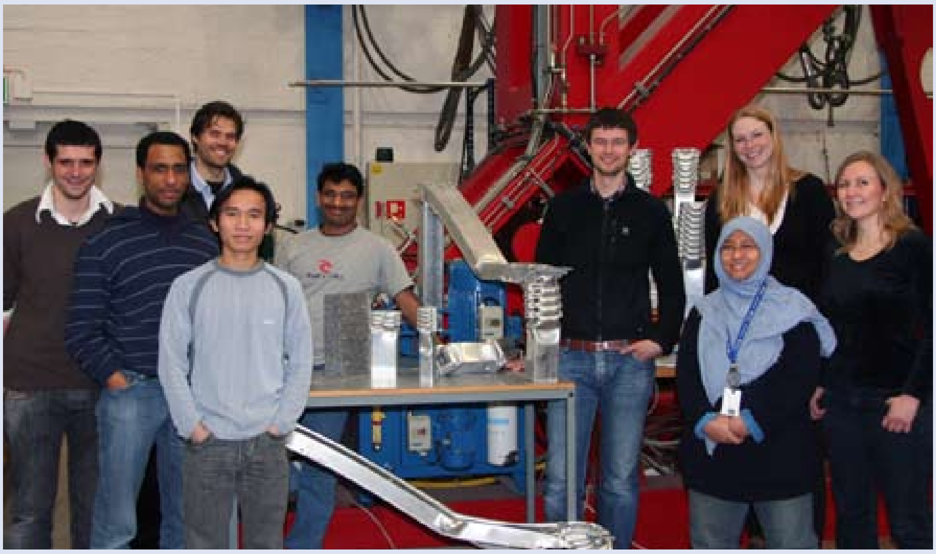
Ecole Normale Supérieure de Cachan/ Laboratoire de Mécanique et Technologie (ENS/LMT) and European Commission - DG JRC, Institute for Protection and Security of the Citizen, Ispra, Italy, have signed memorandum of understandings with SIMLab. These agreements regulate exchange of scientific personnel and students and seminars and have resulted in the following in 2007:

- SIMLab in cooperation with LMT-Cachan organised a seminar in Frejus, France from 31 May to 1 June 2007. During the two day seminar, 24 presentations were given by SIMLab and LMT scientists on various topics of relevance for the Centre. Totally 35 people attended the seminar and a lot of new ideas for future research were generated.
- Professor Odd Sture Hopperstad was on sabbatical in 2007. He stayed two months at the Ecole Normale Supérieure de Cachan/Laboratoire de Mécanique et Technologie (ENS/LMT) in Paris and two months at the European Commission - DG JRC, Institute for Protection and Security of the Citizen, Ispra, Italy .
- Adjunct Professor Tore Børvik had a one month stay at the LMT Cachan in Paris.
- Professor Ahmed Benallal from LMT Cachan had a two weeks stay at SIMLab.
- Two students from Ecole Normale Supérieure de Cachan in Paris stayed in the Centre during their three months internship.

In addition PhD student Giuseppe Brando from the University of Chieti-Pescara "G. d'Annunzio", Faculty of Architecture - Pescara, had a three month stay in Centre in 2007. He was linked to the Connectors and Joints research programme.

Seminar in Frejus, France

Recruitment



PhD students and post docs from Denmark, India, France, Malaysia, Norway and Vietnam

Ph.D. students

The following PhD students are so far linked to the Centre:

Name	Start	Planned exam	Programme	From	Male/Female
Ida Westermann*	Sept 2007	2011	M^4	Denmark	Female
Henning Fransplass*	March 2005	2009	OptiPro	Norway	Male
Virgile Delhaye*	June 2007	2010	Polymers	France	Male
Egil Fagerholt*	Jan 2008	2011	F&CP	Norway	Male
Nguyen-Hieu Hoang*	Nov 2007	2011	C&J	Vietnam	Male
A.B. Alisibramulisi**	Oct 2007	2011	M^4	Malaysia	Female

* = Salary and operational cost from the Centre,

** = Operational cost from the Centre only – salary from other sources

Ida Westermann, Egil Fagerholt and Nguyen-Hieu Hoang were recruited based on an announcement in March 2007. We got 77 applications for five positions - four from Norway, one from Denmark and the rest mainly from Asia. Based on an evaluation of the applicants and contact with their professors, three applicants were found qualified and hence offered a position. After discussions with the Board, it was decided to postpone the next announcement to spring 2008. If necessary, the partners are willing to contribute to increase the salary somewhat in order to compete with the salaries in the industry. Based on the postponed employment of two PhD candidates, the investment of scientific equipment was advanced.

Mr Virgile Delhaye is a PhD student at NTNU and is financed through the contribution in kind from Renault. The same is the case with Mr Henning Fransplass who is financed by the contribution in kind from NPRA. Ms A.B. Alisibramulisi is from Malaysia with funding from her home country. However, she is linked to the Centre and will thus receive support related to operational cost.

In order to attract good foreign students preferably from Europe, the Centre is discussing the possibility of having dual degree programmes with leading international universities. At present such a programme has to be approved by the NTNU board, and we hope that the programme can be in operation spring 2008.

Post docs

The following post docs are linked to the Centre:

Name	Start	End	Programme	From	Male/Female
Alexander Kane	Feb 2007	Jan 2009	F&CP + OptiPro	France	Male
Venkatapathi Tarigopula	June 2007	May 2009	F&CP + OptiPro	India	Male

Master students

The following Master students were linked to the Centre spring 2007:

Student	Topic
Hans Olav Bakken and Håkon Iversen	Road restraint systems
Harald Andreas Wathne and Jonathan Wiggen	Trawl gear impact
Vegard Alme Ulstein and Alf Morten Nøstvold	Plated structures subjected to explosion
Kjartan Hervig Johansen and Øyvind Gundersen	Bolted connections in aluminium
Anders Lønnå Lunde	Pipeline joining
Ida Westermann	Development of microstructure in aluminium during cold forming

Accounts

The annual work plans for each research programme present a detailed description of the activities to be carried out in the Centre, allowing the Research Council of Norway (RCN) to monitor that that the research activities are within the ESA requirements. Thus the funding plan for each programme shows the funding from each of the partners in the form of "Fundamental research (F)" and "Industrial research (I)" and how funding from RCN contributes to funding of each research programme. The cost plan describes each partner's participation in each of the programmes. The funding and cost plan for 2007 is shown at the next page.

Funding 2007 (All figures in 1000NOK)

Research Programme	Type of research	STATE AID			INDUSTRY								Total State Aid	Total Funding	State aid/total funding
		RCN Grant	Host (NTNU)	SINTEF	NDEA	NPRA	AUDI AG	BMW Group	Renault	Hydro AL Metals	Hydro AL Products	Hydro AL Structures			
C & J	F	1317	412				500						1729	2229	0.78
C & J	I							300						300	0
F&CP	F	870	1045		200								1915	2115	0.91
F&CP	I														0
M^4	F	1405	300	1100									2805	2805	1.00
M^4	I									400	450	2083		2933	0
OptiPro	F	611	1036		2000	870	50						1647	4567	0.36
OptiPro	I														0
Poly	F	1012	1012						500				2024	2524	0.80
Poly	I														0
Demo	F														0
Demo	I	200						500				616	200	1316	0.15
Equipment		446				173	110	40	200			100	446	1069	
Adm		708	1000			77	340	160	300	150	100	200	1708	3035	
Total		6569	4805	1100	2200	1120	1000	1000	1000	550	550	2999	12474	22893	

F = Fundamental research, I = Industrial research

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

Cost 2007 (All figures in 1000NOK)

Research Programmes	Host (NTNU)	SINTEF	NDEA	NPRA	AUDI AG	BMW Group	Renault	Hydro AL Metals	Hydro AL Products	Hydro AL Structures	Total
C & J	1179	850			500						2529
F&CP	1065	850	200								2115
M^4	855	1950						400	450	2083	5738
OptiPro	1747	950	1000	870							4567
Poly	1374	650					500				2524
Demo		400				500				416	1316
Equipment	896	173									1069
Adm	1358	1677									3035
Total	8474	7500	1200	870	500	500	500	400	450	2499	22893

Publications

In the following journal publications and conference papers/presentations generated within SIMLab in 2007 are listed. Included are also publications obtained in related activities which are relevant to the SIMLab programmes.

Journal publications

1. Wang T., Hopperstad O.S., Lademo O-G., Larsen P.K.: *"Finite Element Modelling of Welded Aluminium Members Subjected to Four-Point Bending"*. Thin-Walled Structures 2007; 45(3); 307-320.
2. Holmedal, B. *"On the formulation of the mechanical threshold stress model"*. Acta Mater. 2007; 55(8); 2739-2746.
3. Solberg J.K., Leinum J.R., Embury D., Dey S., Børvik T., Hopperstad O.S.: *"Localised shear banding in Weldox steel plates impacted by projectiles"*. Mechanics of Materials 2007; 39:865-880.
4. Dey S., Børvik T., Teng X., Wierzbicki T., Hopperstad O.S.: *"On the ballistic resistance of double-layered steel plates: An experimental and numerical investigation"*. International Journal of Solids and Structures 2007; 44:6701-6723.
5. Grytten F., Fagerholt E., Auestad T., Førre B., Børvik T.: *"Out-of-plane deformation measurements of 5083-H116 aluminium plates during quasi-static perforation using structured light and close-range photogrammetry"*. International Journal of Solids and Structures 2007; 44;5752-5773.
6. Hopperstad O.S., Børvik T., Berstad T., Lademo O-G., Benallal A.: *"A numerical study on the influence of the Portevin-Le Chatelier effect on necking in an aluminium alloy"*. Modelling and Simulation in Materials Science and Engineering 2007; 15:747-772.
7. Teng X., Dey S., Børvik T., Wierzbicki T.: *"Protection performance of double-layered metal shields against projectile impact"*. Journal of Mechanics of Materials and Structures 2007;2(7):1309-1331.
8. Aretz H., Hopperstad O.S., Lademo O-G.: *"Yield function calibration for orthotropic sheet metals based on uniaxial and plane strain tension tests"*. Journal of Materials Processing Technology 2007; 186(1-3);221-235.
9. Hanssen A.G., Artelius A., Langseth M.: *"Validation of the simplified super folding element theory applied for axial crushing of complex aluminium extrusions"*. International Journal of Crashworthiness, IJCrash 2007 Vol. 12 No. 6;591-596.
10. Dørum C., Hopperstad O.S., Lademo O-G., Langseth M.: *"Energy absorption capacity of thin-walled AM60 castings using a shear bolt principle"*. Computers & Structures 2007; 85(1-2);89-101.
11. Dørum C., Hopperstad O.S., Lademo O-G., Langseth M.: *"Numerical modelling of the structural behaviour of thin-walled cast magnesium components using a through-process approach"*. Materials & Design 2007; 28(10).
12. Fyllingen Ø., Hopperstad O.S., Langseth M.: *"Stochastic simulations of square aluminium tubes subjected to axial loading"*. International Journal of Impact Engineering 2007;34(10);1619-1636.
13. Wang T., Hopperstad O.S., Lademo O-G, Larsen P.K.: *"Finite element analysis of welded beam-to-column joints in aluminium alloy EN AW 6082 T6"*. Finite Elements in Analysis and Design (Print) 2007; 44(1-2);1-16.
14. Børvik T., Gjørv O.E., Langseth M.: *"Ballistic perforation resistance of high-strength concrete slabs"*. Concrete International 2007; 29(6);45-50.
15. Moe H., Olsen A., Hopperstad O.S., Jensen Ø., Fredheim A.: *"Tensile properties of netting materials used in aquaculture net cages"*. Aquacultural Engineering 2007;37(3);252-265.

Conference proceedings – presentations

1. Hopperstad O.S., Berstad T., Lademo O.G., Langseth M.: *"Modelling of material behaviour and fracture for aluminium alloys with applications to plastic forming and crashworthiness"*, Keynote lecture at 6th European LS-DYNA Users' Conference, Gothenburg, 2007.
2. Lademo O-G., Eriksson M., Hopperstad O.S., Langseth M.: *"Characterisation and modelling of failure in ductile sheet metals"*. NAFEMS Seminar: "Materials Modeling – FEA Simulations of the Behaviour of Modern Industrial Materials Including their Failure", March 20-21, 2007, Oslo, Norway.
3. Chen Y., Hopperstad, O.S., Lademo, O.-G., Clausen, A.H., Berstad, T., Langseth, M.: *"Preliminary simulations of the instrumented Charpy V-notch impact test"*. In: MekIT'07, Fourth national conference on Computational Mechanics pp. 135-141, ISBN 978-82-519-2235-7, Tapir Academic Press: Trondheim, 23-24 May 2007.
4. Achani D., Eriksson M., Hopperstad O.S., Lademo O-G.: *"Modelling of local necking and fracture in aluminum alloys"*. Numiform 2007, Porto, June 17-20.
5. Clausen A.H., Hopperstad O.S., Berstad T., Ilstad H., Melve B.: *"Modelling of thermoplastics: State-of-the-art and challenges"*. NAFEMS Seminar: „Materials Modelling – FEA Simulations of the Behaviour of Modern Industrial Materials Including their Failure", March 20-21, 2007, Oslo, Norway.
6. Tarigopula V., Hopperstad O.S., Clausen A.H., Langseth M.: *"Effect of pre-straining on the dynamic mechanical behaviour of dual-phase high-strength steel alloys"* In: Proceedings of 9th international symposium on Plasticity and Impact Mechanics, IMPLAST 07 pp. 159-166, ISBN 978-3-89966-266-5, The University Press: Bochum, 21-24 August 2007.
7. Chen Y., Clausen A.H., Hopperstad O.S., Langseth M.: *"Behaviour of aluminium alloys under elevated rates of strain"* In: Proceedings of 9th international symposium on Plasticity and Impact Mechanics, IMPLAST 07 pp. 87-94, ISBN 978-3-89966-266-5, The University Press: Bochum, 21-24 August 2007.
8. Kokkula S., Hopperstad, O.S., Langseth, M., Lademo, O.-G.: *"High speed offset impact behaviour of an automotive bumper beam-longitudinal system"*, In: Proceedings of 9th international symposium on Plasticity and Impact Mechanics, IMPLAST 07 pp. 78-83, ISBN 978-3-89966-266-5, The University Press: Bochum, 21-24 August 2007.
9. Porcaro R., Hanssen A.G., Langseth M.: *"Behaviour and modelling of self-piercing riveted connections"*. ATA Conference on Materials and Technologies for Transportation Industry, Napoli, Italy, 2007.
10. Dey S., Børvik T. *"Ballistic penetration and perforation of layered steel plates: An experimental and numerical investigation"*. Presented at 23rd International Symposium on Ballistics (ISB2007), Spain, 16-20 April, 2007.
11. Hanssen A.G., Olovsson L., Børvik T., Langseth M.: *Close-range blast loading of aluminium foam panels:* "A numerical study. Paper presented at IUTAM Symposium on mechanical properties of cellular materials". September 17-21, 2007, LMT-Cachan, Paris, France.
12. Hopperstad O.S., Børvik T., Berstad T., Lademo O-G, Benallal A.: *"Simulation of the Portevin-Le Chatelier effect and plastic instability in aluminium alloys"*. Proceedings of Instabilities across the Scales (IAS07), Delft, The Netherlands, July, 2007.
13. Holmedal B., Nes E.: *"A New Microstructural Metal Plasticity Model (MMP) Applied to Aluminium Alloys"*. Presentation at TMS. Orlando, Florida, USA. 25 April-1 May 2007.

Annual Report for SIMLab Centre for Research-based Innovation 2007

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