





Vision

world leading research centre on design of

Crashworthy and Protective Structures

Objective

Within the field of structural impact the SIMLab Centre will concentrate on research areas that are of common interest to the industrial partners and hence create a link between Norwegian industry and some of the major actors in the global market, i.e. the automotive industry. However, in order to meet the requirement for innovation and value creation in an international market, Norwegian industry has to adopt new and original knowledge in product development. Here, 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 industrial partners, a multidisciplinary approach is needed 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 SIMLab Centre is

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

Industrial partners



















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
cooperation 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 2008 were Hydro Aluminium, BMW Group, AUDI AG, Renault, StatoilHydro, Plastal, SSAB Swedish Steel, the Norwegian Public Roads Administration and the Norwegian Defence Estates Agency. In addition the Centre cooperates with SINTEF Raufoss Manufacturing AS (SRM) in order to facilitate innovation in small and mediumsized companies.

The defined research areas for 2008 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 host institution and partners. In order to strengthen the cooperation and interaction between the partners both 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. Furthermore, an advisory scientific board of international experts provide scientific and strategic advice based on a defined mandate. The first meeting was held in June in 2008 and positive response on the Centre activities was given.

In 2008 the research work in the Centre has resulted in 19 papers published in peer review journals. Furthermore, one conference proceedings has been published in adittion to 24 oral and 13 poster presentation at conferences. The research in the Centre is carried out by strong cooperation between master's students, PhD students, post docs and scientists. In 2008 ten male and three female master's students, five male and

three female PhD students and two male post docs have been connected to the Centre. Six international students have stayed for shorter and longer periods at the Centre during the year. International cooperation and visibility are success parameters for a Centre. Thus cooperation with common publications has been established with the following universities/ research laboratories: Ecole Normale Supérieure de Cachan/Laboratoire de Mécanique et Technologie (ENS/LMT) and University of Savoie, France; University of Sao Paulo, Brazil; MIT, USA; University of Linköping, Sweden and DYNALAB, Italy. In addition the Centre has been invited to attend 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 Havard University, University of Virginia, MIT and University of Cambridge, UK.

With respect to visibility, the Centre organized an international conference on "Impact Loading of Lightweight Structures" in June 2008 with 110 participants. In addition the activities in the Centre have been presented in international and national magazines and on Norwegian television.

Several concurrent research projects have been run in parallel with the Center activities. Futhermore the Centre has been involved in two EU applications.

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 CRI 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 10 PhD students where at least three are female students. 2) To graduate 10 MSc students annually.
 3) To attract 5 foreign professors/scientists during the duration of the Centre. 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.

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.

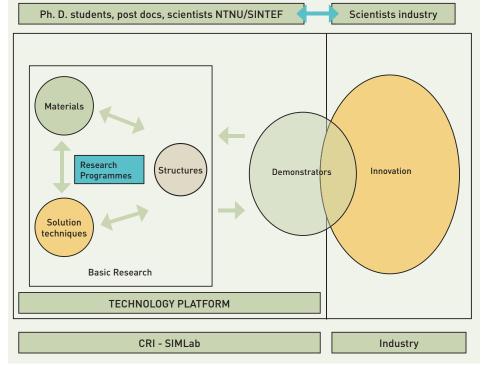
This research area 'Structures' is serving as a link between 'Materials', 'Solution techniques' and 'Demonstrators'.

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 are 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 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.
- 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 from fishing gear.
- 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 (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.



Research areas

Research organization

Structure of organization

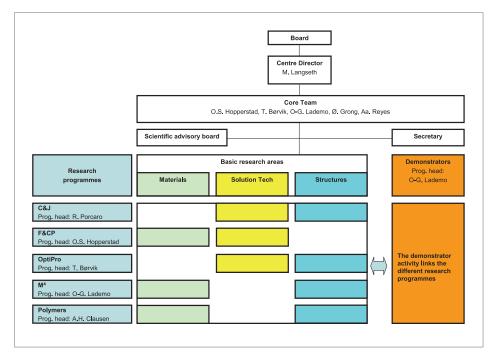
The overall management structure of the Centre consists of a board comprising members from the consortium participants. The centre director is in charge of the operation of the Centre, assisted by a core team and the research programme heads. Within each research programme, research projects are defined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

The Board

- Thomas Hambrecht, Head of Functional Design, Lightweight Structures, Audi AG
- Hariaokto Hooputra, Senior Engineer for Passive Safety Simulation, BMW Group
- 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 Department, Norwegian Defence Estates Agency
- Per Kr Larsen, Professor, Department of Structural Engineering, NTNU
- Joachim Larsson, Manager, Knowledge Service Center/Design, SSAB Tunnplåt AB
- Ole Vidar Lyngstad, Group Manager, CAE, Plastal
- Francois Moussy, Head of Materials Engineering Department, Renault
- Sigurd Olav Olsen, Director of Vehicle Section, Norwegian Public Roads Administration
- Svein Remseth, Professor, Department of Structural Engineering, NTNU (Chairman)
- Ingvald Strømmen, Dean, Faculty of Engineering Science and Technology, NTNU

Centre Director

Magnus Langseth, Professor,
 Department of Structural Engineering,
 NTNU



Structure of the organization

Core Team, programme heads and secretary

- Tore Børvik*, Dr. ing., Norwegian Defence Estates Agency
- Arild Holm Clausen, Professor,
 Department of Structural Engineering,
 NTNII
- 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

Scientific Advisory Board

- Professor Ahmed Benallal, LMT-Cachan, France
- Professor David Embury, MacMaster University, Canada
- * Adjunct Professor at Department of Structural Engineering (20% position)

- 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
- Industrial partners
 - Audi AG
 - BMW Group
 - Hydro Aluminium
 - Plastal
 - Renault
 - SSAB Swedish Steel
 - StatoilHydro
 - The Norwegian Defence Estates Agency (NDEA)
 - The Norwegian Public Roads Administration (NPRA)

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 to perform the work, while each industrial partner has participated based on their defined contribution in kind.

The contributions in kind for NPRA and Renault were taken care of by PhD students working half time in 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, in order to strengthen the cooperation within the main research group (NTNU and SINTEF) and between the partners the following actions have been taken:

Programme and project meetings: 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, an internal seminar was held each second



Seminar in Paris

week including a short presentation of a research topic by one of the Centre members

Seminar November 2008: A seminar with participation from all partners was held in Paris on 5-6 November 2008. The main objective of the seminar was to present the research and development carried out so far and to get input from the industrial partners with respect to their needs and expectations. In order to cover the interest of all partners, all presentations were generic in nature and covered relevant topics from the research programmes. In addition the research plans for 2009 were presented and discussed. Based on the discussion during the seminar, the partners were satisfied with the progress and the obtained results so far. They pointed out that the activities in the Centre show a good link between physics, mechanics, modelling and industrial applications.

National Cooperation

In order to facilitate innovation in small and medium-sized companies (SMEs) in Norway, the Centre has cooperated with SINTEF

Raufoss Manufacturing AS (SRM) which 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. SRM is serving approximately 100 companies where 50 of them are SMEs and international companies in the Raufoss region employing approximately 4500 staff. SRM is not a partner in the Centre, but one scientist from SRM has spent approximately one month at the Centre in 2008 working on the OptiPro programme. Further, the extensive degree of participation by SINTEF scientists ensures that the open technology becomes readily available to Norwegian industry through contract research.

New partners from 2008

SSAB Swedish Steel, Plastal and StatoilHydro entered the Centre as new partners from 1 January 2008. In addition Hydro Aluminium replaced Hydro Aluminium Structures, Hydro Aluminium Metals and Hydro Aluminium Products from January 2008. However, BMW Group has decided to withdraw from the Centre from 1 February 2009.

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



Research programmes and demonstrators

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

Fracture and Crack Propagation (F&CP)

Programme head: 0.S. Hopperstad

Introduction

In numerical simulations of quasi-static and dynamic ductile fracture, e.g. in the 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. Two examples of alternative strategies are node splitting coupled with adaptive meshing and extended finite element methods. There is a need to evaluate established methods against other possible approaches to ductile fracture and crack propagation, and 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, high-strength steels and

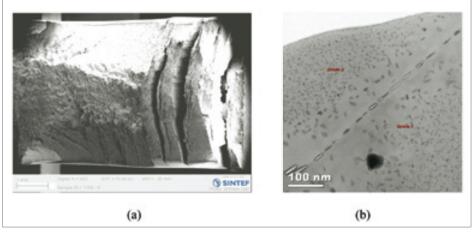


Figure 1 – Complex fracture mode with secondary cracking for fibrous alloy obtained in Charpy V-notch impact test (a) and precipitate-free zone and grain-boundary precipitates for the same alloy (b).

polymers. In 2008, there have been projects running within the following research areas:

- 1. Damage mechanics modelling
- 2. Adaptivity and node splitting algorithms
- 3. Experimental validation tests
- 4. Optical measuring techniques
- 5. Dynamic fracture mechanisms and modelling
- 6. Plastic instabilities and fracture

Selected research activities are highlighted

Dynamic fracture of aluminium alloys – mechanisms and modelling

The long-term objective of this research activity is to establish more knowledge about the mechanisms leading to damage and fracture in recrystallized and fibrous aluminium alloys for automotive applications - and thereby to establish physically based damage and fracture models for these materials. In a previous project, four aluminium alloys (AA6060, AA6082, AA7003 and AA7108 in temper T6) were characterized by dynamic tensile tests and Charpy V-notch impact tests. In the Charpy tests, a variety of complex fracture modes with secondary cracking occurred (Figure 1a), depending on the microstructure of the alloy. This year, detailed metallurgical studies of the fracture

surfaces in the tensile and Charpy specimens were carried out with the objective to disclose the mechanisms leading to the complex and somewhat quasi-brittle failure modes. The difference between fracture in recrystallized and fibrous alloys, the competition between transgranular and intergranular fracture, and the role of precipitate-free zones adjacent to the grain boundaries and grain-boundary precipitates were emphasized (Figure 1b). Modelling of the complex fracture modes using physically-based damage mechanics models will be pursued in 2009.

Plastic instabilities and fracture

Plastic instabilities of various kinds are often precursors to fracture in ductile materials. Ductile fracture is typically the final of a series of phenomena, and its prediction rests on accurate description of these foregoing events. The objective of this activity is to develop models that are able to describe various instability and fracture phenomena. This year, the Portevin-Le Chatelier (PLC) effect in aluminium alloys has been studied experimentally, theoretically and numerically. The PLC effect is caused by dynamic strain aging (DSA) due to diffusion of solute atoms to dislocations temporarily arrested at obstacles in the slip path. The result is a bounded region of negative steady-state strain-rate dependence of the flow stress.

The alloy exhibits serrated or jerky flow in this region, which is associated with repeated propagation of deformation bands (see Figure 2). The PLC effect reduces the formability of the material and gives rise to unsightly markings on the surface. The objective is to arrive at a validated mathematical model for DSA and PLC effects in aluminium alloys, which is applicable in large-scale simulations of plastic forming.

Field measuring techniques

There is a strong need for improved validation tests in conjunction with the numerical simulation of dynamic fracture and crack propagation. In this PhD project, the aim is to develop and evaluate optical measurement techniques to quantify crack propagation in critical components subjected to accidental loads (collisions, explosions and penetration). Typical parameters are the propagation velocity and extension of the crack and the strain field in vicinity of the crack tip.

A Digital Image Correlation (DIC) code is currently being developed and evaluated, where a global solution to the image correlation problem is sought for a mesh of Q4-elements. Main topics of interest are:

- Expansion of the algorithms to handle discontinuous as well as continuous surfaces, i.e. both strain fields and crack propagation.
- Expansion of the algorithms to handle the correlation of images series from a single camera as well as correlation between images recorded from multiple cameras, obtaining strain fields and deformations in a three-dimensional domain.
- Reduction of processing time by parallelization of the code and implementation on multi-core CPUs and/or General Purpose GPU (GPGPU).

Some results are shown in Figure 3.

Connectors and Joints (C&J) Programme head: R. Porcaro

Introduction

The connection between two or more structural members is denoted as structural joint, and is very important for the strength, ductility and safety of the structure. The strength

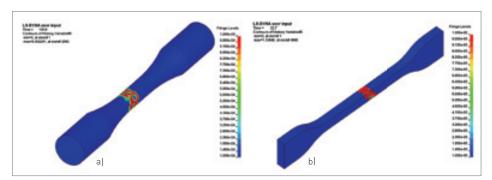


Figure 2 – Finite element analysis of PLC band propagation in tensile specimens with (a) circular and (b) rectangular cross section. Fringes of plastic strain rate are shown on the deformed shapes.

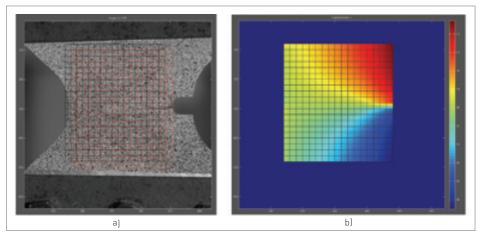


Figure 3 – Results from Arcan test of an aluminium alloy: (a) Cracked specimen with virtual grid for field measurements of displacements and strains, (b) measured vertical displacement field in the specimen.

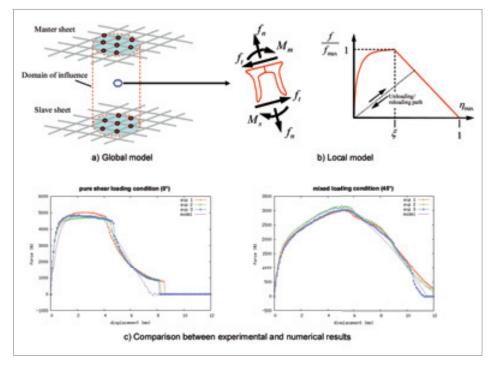


Figure 4 - New SPR point connector model.

of each individual connector is well documented in the relevant structural standards, but this information is not sufficient for large-scale simulations as their complete load-deformation characteristics are not given. By use of FEM, detailed 3D models can be established and used for studies of the local joint performance including failure. However, due to their computational expenses, such models cannot be directly used in large-scale simulations and shell-based models have to be used. Such models have to produce robust and reliable results from the onset of loading until failure.

In this programme experimental methodologies and set-up are developed to characte-

rize the behaviour of connectors subjected to static and dynamic loading conditions. Furthermore, based on the experimental results models for large-scale FE simulations using shell elements are derived and validated.

During the last two years this programme has mainly focused on the behaviour and modelling of self-piercing riveted structures. During these years a new experimental test set-up was developed for the testing of riveted connections of different materials and a new model for self-piercing riveting (SPR) point connector model was developed and made available as a UMAT routine in LS-DYNA. In addition, an activity has started,

during 2008, to study self-piercing riveted connections of two aluminium sheets using an aluminium rivet.

Selected research activities are highlighted below.

SPR point-connector model

A new SPR point-connector model was developed during the last two years. The model was calibrated and validated against experimental results obtained using self-piercing riveted connections of aluminium-to-aluminium sheets. The model is easy to calibrate and is able to accurately replicate the mechanical behaviour of a self-piercing riveted connection under different loading conditions, Figure 4.

Experimental database

The objective was to test SPR connections for novel material combinations. A new test rig was developed for the testing of simple specimen geometry with only one self-piercing rivet under combined shear and pull-out quasi-static loading, Figure 5. Simple specimen geometry was defined that was easy to assembly for different material combinations. An extensive experimental programme was carried out for different material combinations. The resultant mechanical properties and failure modes that form the different material combinations have been systematically investigated. Figure 5 shows typical result from the experimental programme.

Aluminium rivets

The objective of this project is to study selfpiercing riveted connections of two aluminium sheets using an aluminium rivet. The use of aluminium rivets instead of steel rivets is an advantage with respect to recycling and to weight reduction. During 2008 a feasibility study of the self-piercing riveting process using aluminium rivets was carried out. During this study experimental tests and numerical simulations of the riveting process were carried out. The aluminium rivet had the same geometry as the steel rivet commonly used today. Different aluminium alloy were used in this study. Figure 6 shows the cross section of a successful joint using an aluminium rivet compared with a similar one obtained with a steel rivet.

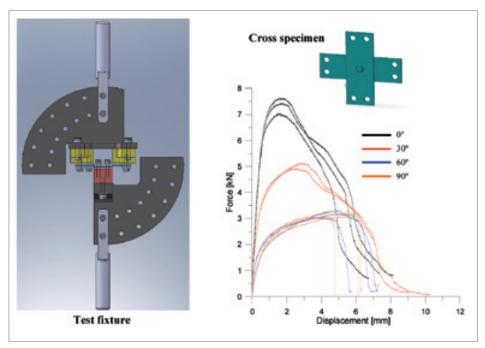


Figure 5 – Test set-up and experimental results.

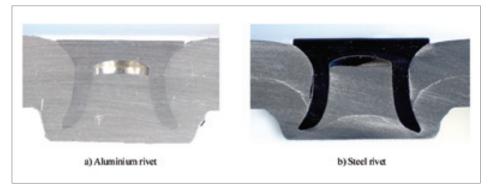


Figure 6 – Cross sections of riveted connections.

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 and military engineering applications and for the safety of citizens in general. 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 using the finite element method (FEM) in order to have a safe and cost effective design. These new designs 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 lightweight protective structures for both civilian and military applications using advanced computational tools. In 2008, the main focus has been on the following research activities.

- 1. Strengthening techniques
- 2. Blast loading using FEM
- 3. Lightweigh protective structures
- 4. Impact loading of high-strength steel components
- 5. Modelling of road restraint systems
- 6. Impact against pipelines

It should be noted that several sub-projects are carried out within each main activity, and only some selected research activities are highlighted below.

Lightweight protective structures

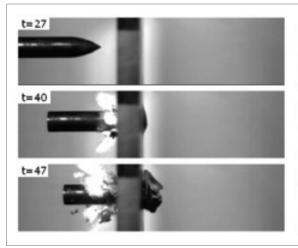
Thin plates of high-strength steel are frequently being used both in civil and military ballistic protection systems. Such plates may either be monolithic or layered with or without spacing. The reason for using layered instead of monolithic plates is an attempt to increase the ballistic perforation resistance of the target in an optimized structure. It is also found that the perforation resistance increases steeply and linearly with yield stress, indicating that strength is a more important parameter than ductility. The overall goal in these studies is to combine high-strength steel and/or aluminium plates in layered targets to save weight in protective structures. However, high-strength aluminium alloys have special features that first must be better understood.

AA7075-T651 is a widely used high-strength aluminium alloy. Due to its high strength-to-density ratio the alloy has also been extensively used for armour applications. In this activity, the mechanical properties of AA7075-T651 have been revealed based on a number of material tests (tensile tests at low to high strain rate, compression tests and instrumented Charpy tests). The obtained data were used to calibrate a modified version of the Johnson-Cook constitutive relation and the Cockcroft-Latham fracture criterion. Component tests using 20 mm diameter,

197 g mass projectiles with various nose shapes have been carried out in a compressed gas-gun to determine the perforation resistance of the alloy. The component tests revealed that the alloy was quasi-brittle, showing both fragmentation and delamination during impact, see Figure 7. This is caused by the very complex microstructure of the alloy, with a precipitation free zone along grain boundaries. The results have been compared to FE simulations using LS-DYNA and the calibrated material model. Even though the simulations were not able to describe the failure process of the aluminium plates in full detail, reasonable agreement between the experimental and predicted results was obtained. The next goal in this activity is to try to model more of the complex fracture process of AA7075-T651 using a more physically based fracture criterion.

Out-of-plane deformation measurements of plate subjected to impact loading

An optical system based on structured light and close-range photogrammetry has been developed and has been used in this sub-project to continuously measure the full-field out-of-plane deformation of aluminium plates subjected to low-velocity impact loadings. During testing, square AA-5083-H116 aluminium plates with thickness 5 mm were mounted in a circular frame and penetrated by a 30 mm diameter blunt-nose projectile with velocities ranging from 7 to 11 m/s while the out-of-plane deformations were measured on the opposite side. A fringe pattern was projected onto the target surface by a slide projector and the variations in the



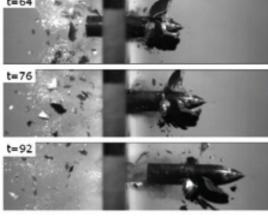


Figure 7 – Perforation of a 20 mm thick AA7075-T651 target plate by a 20 mm diameter, 197 g mass ogival nose projectile $(v_i = 278 \text{ m/s}, v_r = 186 \text{ m/s})$.

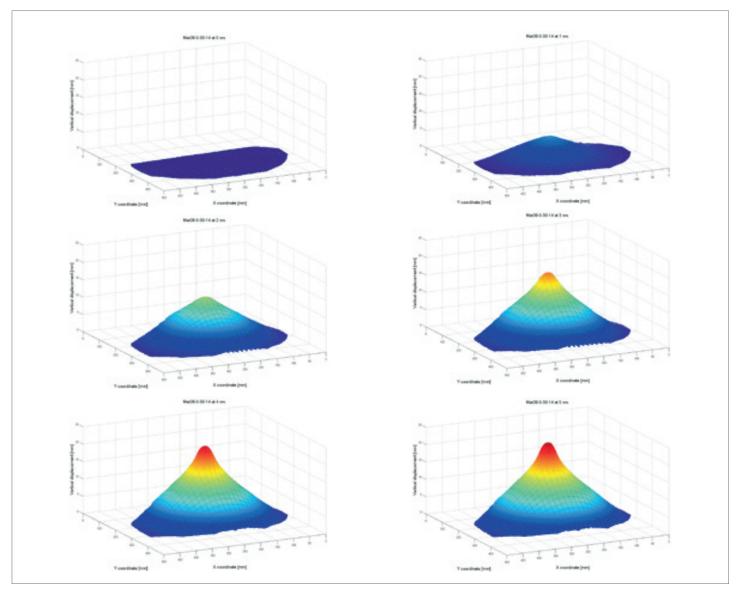


Figure 8 – A selection of 3D topography maps of the plate surface, calculated from recorded images of a low-velocity impact on a 5 mm thick AA5083-H116 aluminium plate.

pattern during penetration were observed by a high-speed camera recording 10000 images a second. The recorded images were then computer processed to provide full-field topography information of the target surface during the penetration process, see Figure 8. Degradation of measurement data due to impact induced vibration has been evaluated and reduced to a minimum by isolating the optical system from the mechanical experiment. The experimental out-of-plane data was compared to non-linear finite element LS-DYNA simulations, and the agreement between experimental and predicted results was in general found to be good.

Perforation resistance of high-strength steel plates subjected to small-arms projectiles

In this sub-project the perforation resistance of five different high-strength steels have been determined and compared against each other. The considered alloys were Weldox 500E, Weldox 700E, Hardox 400, Domex Protect 500 and Armox 560T. The yield stress for Armox 560T is about three times the yield stress for Weldox 500E, while the opposite yields for ductility. In order to certify the perforation resistance of the various targets, two different ballistic protection classes according to the European norm

EN 1063 have been considered. These are BR6 (7.62 mm Ball ammunition) and BR7 (7.62 mm AP ammunition), where the impact velocity of the bullet is about 830 m/s in both. Perforation tests have been carried out using adjusted ammunition to determine the ballistic limit of the various steels. In the tests, a target thickness of 6 mm and 6+6=12 mm was used for protection class BR6 and BR7, respectively. A material test programme was conducted for all steels to calibrate a modified Johnson-Cook constitutive relation and the Cockcroft-Latham fracture criterion, while material data for the bullets mainly were taken from the literature. Results from

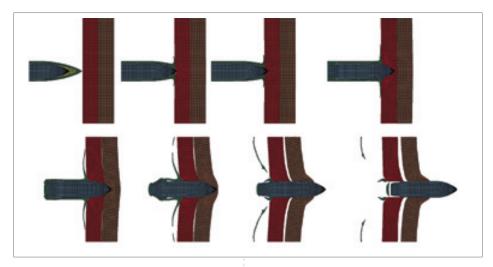


Figure 9 – Plots showing perforation of a 2×6 mm thick Armox 560T target by a 7.62 mm APM2 bullet using the Lagrangian formulation of LS-DYNA (v_r = 920 m/s, v_r = 286 m/s).

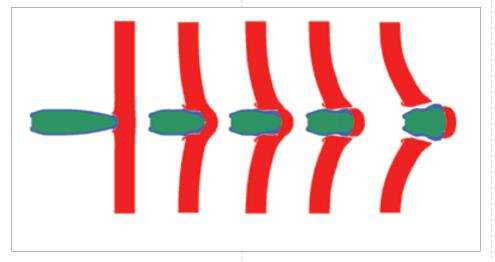


Figure 10 – Plots showing perforation of a 6 mm thick Weldox 500E plate by a 7.62 mm Ball bullet using the Eulerian-Lagrangian formulation of GRALE (v_i = 800 m/s, v_i ≈500 m/s).

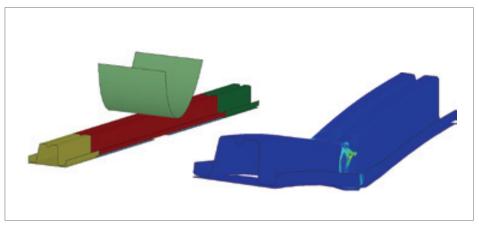


Figure 11 - Analysis of post-formed high-strength steel component subjected to stretch-bending.

2D non-linear FE simulations with detailed models of the bullets are presented. Good agreement between the FE simulations and experimental data for AP bullets was in general obtained, while it was difficult to get reliable FE results using the Lagrangian formulation of LS-DYNA for the soft core Ball bullet, Figures 9 and 10.

Impact loading of high-strength steel components

A vehicle body structure consists of hundreds of formed components. The forming process changes the properties of the material being used. Eventually, these forming processes lead to path changes in the material, meaning that the plastic strains remaining in the part after forming are different in different directions. It is therefore anticipated that the deformation behaviour of a material in crash simulations would be dependent on the history of the structure related to the forming process. This is generally ignored in the design of automotive structures even though the changes in material strength and thickness may be substantial. Therefore, for efficient application of dual-phase steels in the automotive industry for 'forming to crash' applications, it is worth investigating the effect of forming operations on the behaviour of components. An activity has therefore been carried out by testing post-formed high-strength steel components subjected to stretch-bending operations, see Figure 11.

Modelling of road restraint systems

The Norwegian authorities have a high focus on road safety, and have therefore defined a Vision Zero. This is a vision of a future situation where nobody is killed or seriously injured in road accidents. Road safety in the spirit of Vision Zero means that roads and vehicles must be more adapted to human capacity and tolerance. The responsibility for safety is shared between those who design and those who use the road transport system. Vision Zero emphasizes that the road transport system is an entity in which the different components such as roads, vehicles and road users must interact in order to ensure safety.

Head-on collisions and vehicles driving off the road are the types of accidents that cause most fatalities and serious injuries.

This activity focuses on road restraint systems made of steel which deform during a vehicle impact, see Figure 12. 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. During a crash situation these bolted connections may fracture, and thereby releasing the w-beam from the sigma post. This will again have a significant affect on the performance of the guardrail system. Thus, the aim of this activity is to get improved understanding on how bolted connections behave during a vehicle impact. In 2008 focus has been on the plastic deformation and fracture behaviour of mild steel bolts. Two experimental techniques were used to load the bolt in tension under different strain rates. To ensure different fracture modes in the bolts a purpose-made fixture was installed. Quasi-static and dynamic tests were performed, and different failure modes were obtained (thread stripping and failure in the threaded part). A finite element model of the test setup has been established in LS-DYNA. Material parameters were estimated by inverse modelling using LS-OPT and LS-DYNA, and reasonable agreement between experimental and predicted results was obtained.

Impact against pipelines

Accidental impacts between trawl gear and subsea pipelines in rich fishing areas may lead to both economic and environmental disasters. Three different loading scenarios are covered in existing design guidelines. These are 1) impact, 2) pull-over and 3) hooking. Impact is associated with the transfer of the impacting trawl-board energy to the pipeline for a short duration of time, and this normally causes local deformation of the pipeline and its coating. During pull-over, the trawl board is pulled over the pipeline by the trawl cable. The pull-over scenario has a much longer duration and may cause large transverse deformations of the pipeline. During hooking, the trawl-gear crossing of the pipeline may cause the trawl gear to get stuck underneath the pipeline. Free spans will represent an increased risk of hooking.

Design of pipelines against accidental loads is today increasingly carried out using the

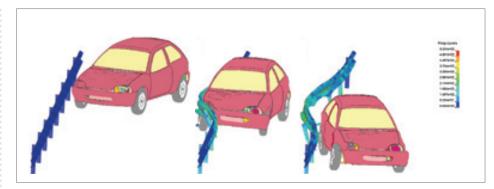


Figure 12 – Numerical simulation of a typical impact between vehicle and guiderail (plotted as fringes of von Mises stress).

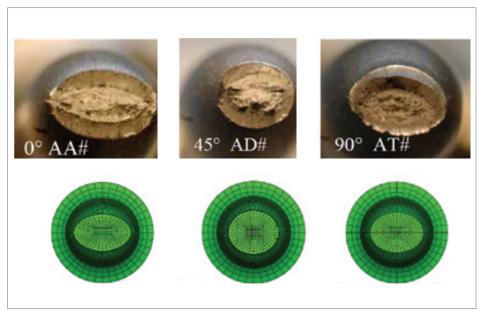


Figure 13 – Obtained and predicted fracture surfaces from tensile tests on specimens taken in three different directions with respect to the longitudinal axis of the pipe (using Hill's anisotropic yield function in the numerical simulations).

finite element method. However, to make numerical models reliable for pipelines subjected to different load scenarios a proper characterization of the pipeline material is crucial. In 2008 the main activity has been the calibration of a suitable constitutive model for a typical material used in a subsea pipeline. An extensive material test programme, using specimens cut directly from a real steel pipe, has been carried out to calibrate a material model with an anisotropic yield function (as found in the experimental tests) and a ductile failure criterion. Figure 13 shows some test results and numerical simulations.

Polymers (Poly) Programme head: A.H. Clausen

Introduction

Polymers are promising for use in several applications, and of particular interest for the Centre, such materials may have excellent energy absorption characteristics. The experience in using polymers in impact protection systems is however 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 of

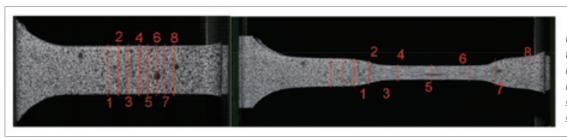


Figure 14 – Photos of tension test specimen at different deformation stages. Numbers indicate sections used in subsequent determination of strains.

handling the large temperature and strainrate effects, deformation-induced anisotropy, viscosity, only to mention some of the features commonly observed for polymers.

The main objective of this programme is thus 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 was not considered in 2008.

At the current stage of research, plates made of PEHD and PVC are applied in the experimental study. These plates were purchased from a wholesaler, and the two materials are rather generic. One being semi-crystalline and the other one amorphous. It was deliberately chosen to acquire plates of PEHD and PVC because they facilitate easy machining of material test coupons as well as specimens for the validation tests. Additionally, one of our PhD students (Virgile Delhaye) works with three PP materials delivered by Renault as a part of their contribution to the Centre.

The research within the Polymers programme can, broadly speaking, be regarded as three activities running in parallel: (i) Material tests, (ii) Constitutive model, and (iii) Component tests.

Material tests

Thermoplastics have a fundamentally different behaviour from that observed for other materials, e.g. metals, and this calls for some special precautions during material testing. Firstly, a conventional experimental set-up involving an extensometer cannot

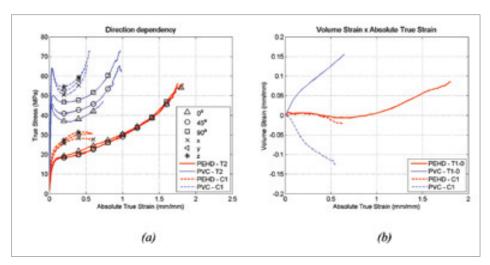


Figure 15 – (a) True stress-strain curves for PEHD and PVC in tension and compression. 0° , 45° and 90° indicate the angle of test sample with respect to the extrusion direction of the plate. x, y and z indicate the compression direction, where x is extrusion direction and z is thickness direction of the plate. (b) Evolution of volume strain for PEHD and PVC in tension and compression.

be employed because of the propagating necking and cold-drawing phenomenon. Secondly, many thermoplastics increase their volume during plastic deformation and it is therefore necessary to measure transverse strains in addition to the longitudinal strains. These challenges are treated with an optical measurement technique based on digital image correlation (DIC). The idea is that the DIC software compares digital photos of a randomly patterned surface at different deformation stages. Figure 14 shows a tension test at an initial stage and after a considerable amount of cold-drawing. Strains were determined in the sections addressed with numbers. A similar procedure was applied in compression tests.

Some selected results are shown in Figure 15. This figure reveals that the behaviour of the semicrystalline PEHD and the amorphous PVC are completely different. PEHD is the more ductile one, and seems to be

almost isotropic. On the other hand, PVC is rather anisotropic, and also exhibits significant strain softening after initial yielding. The softening may be linked to the change of volume. Indeed, cavities were observed in this material, suggesting that a damage mechanism is present.

Constitutive model

Partly based on contributions from other research groups, a constitutive model for thermoplastics has been proposed. The model captures important features observed in behaviour of polymers such as strain-rate sensitivity, difference between tension and compression, and presence of volumetric plastic strain. A fundamental assumption, see Figure 16, is that the stress σ is the sum of the stresses in a Part A representing the interaction between the molecules in the polymer, and a Part B due to straightening of the molecule chains. The model contains 10 coefficients which are easy to identify from

uniaxial tension and compression tests. The model is able to represent the response of a tension test specimen at different strain rates, see Figure 17.

Component tests

Precision tests on components subjected to relevant loading and deformation modes are an important pre-requisite for evaluation of a constitutive model. While Figure 17 compares experimental and numerical response for a tensile test sample, a more 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 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. The experimental benchmark tests should be welldefined with respect to geometry, boundary conditions, application of load, etc.

This evaluation of the model will be one of the most important activities within the Polymers programme in 2009. So far, some introductory simulations of component behaviour have been carried out which have applied the new constitutive model. As an example, Figure 18 shows a prediction of a crash box made of polypropylene during deformation. Clearly, the numerical model is able to represent a reasonable buckling pattern. In general, however, the response of such components in finite element analyses is highly dependent on the initial imperfection and contact formulation.



Figure 18 – Crash box during deformation in a numerical simulation involving the new constitutive model.

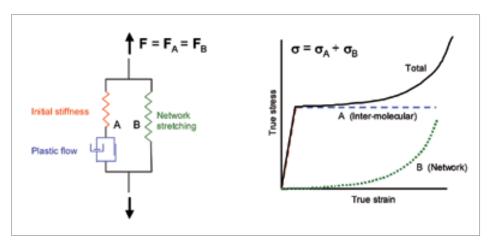


Figure 16 - Outline of the constitutive model for thermoplastics.

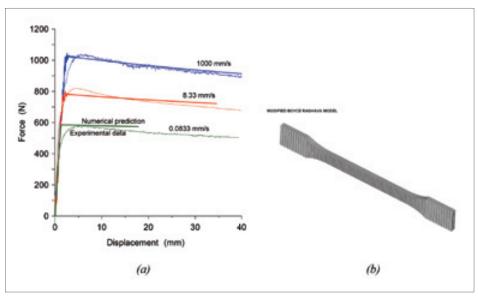


Figure 17 – (a) Force-displacement curves in tension at different rates as found from experimental tests and with LS-DYNA applying the constitutive model. (b) Numerical discretization of the tension test specimen.

Multi-scale Modelling of Metallic Materials (M⁴)

Programme head: 0-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 the ones who can realize an integrated perspective of their alloy, process and product development. The integrated perspective requires quantitative models, where as many quantitative links as possible must be

established, so that needs with respect to the cost and performance of a product 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 fairly accurate phenomenological constitutive models of metals have been developed and made available in commercial FE codes. These models represent the macroscopically observed

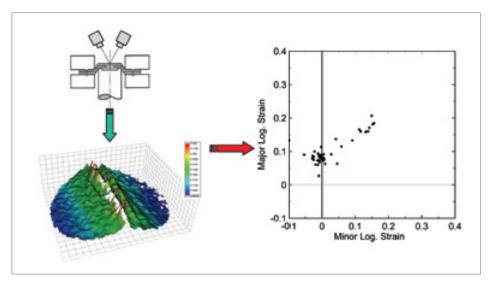


Figure 19 – Typical use of BUP600 (Marciniak-Kuczynski formability test set-up) and strain field measurements to determine the forming limit diagram for a material.

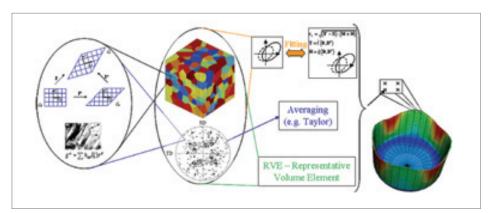


Figure 20 - Multiscale approaches.

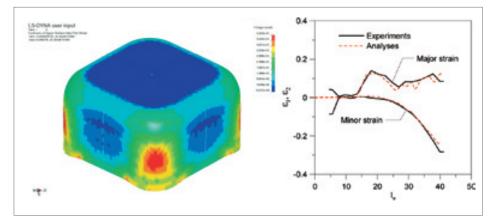


Figure 21 – Example of results from validation analysis of a square-cup drawing test. Analysis model and experimental and predicted principal strain profiles.

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 in enhancing 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 characterization 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 searched.

Selected research activities from 2008 are highlighted below.

Experimental-numerical infrastructure

Extensive hand-in-hand experiments and numerical analyses are essential for the M⁴ research programme. 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 (being) established with catalogued optimized numerical models of the various experimental techniques. The database further gathers experimental and numerical data, including all experimental specimen geometries used within the Centre.

A multi-purpose hydraulic sheet metal forming machine and a set of high resolution cameras have been acquired and installed. A typical application using these facilities is the establishment of forming limit diagrams, Figure 19.

In need-driven, or top-down, multi-scale modelling there are several approaches

for including physics-related features. 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, Figure 20.

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 been successfully modelled as validation cases.

Work has been performed on calculating yield surfaces from measured textures. 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. Initial attempts have also been made to run 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

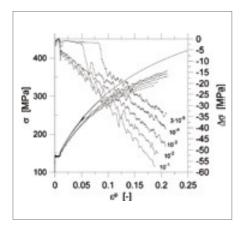


Figure 22 – Negative SRS of AA5182 alloy with associated serrated flow.

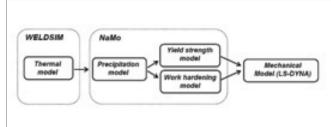


Figure 23 – Through process modelling concept combining WELDSIM for thermal analysis, NaMo for calculation of the resulting microstructure field, and LS-DYNA for the mechanical analysis.

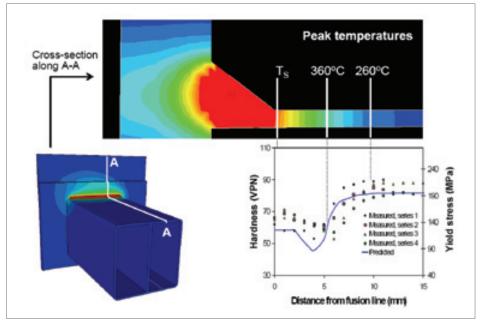


Figure 24 - Example of welding simulation results.

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.

Application oriented activities

A series of papers based on the work within modelling of (de-)formability of sheet metals has been published. The publications document experimental-numerical investigations on the formability of extruded 6xxx and 7xxx alloys and the rolled 6016 alloy, covering the influence of various 'formability limiting phenomena' and various methods and technologies for identification of governing model parameters, Figure 21.

Strain-Rate Sensitivity (SRS) effects for rolled 5xxx aluminium alloys and related models have been addressed but an accu-

rate model of DSA and the related Portevin-Le Châtelier (PLC) effect is still lacking. In order to underpin the SRS modelling an extensive experimental database is established, including a test series exploiting the use of Digital Infrared Thermography. An example demonstrating the complex SRS of a 5182 alloy is shown in Figure 22.

A novel through process modelling approach for the analysis of the properties of welded structures of age-hardenable Al-Mg-Si aluminium alloys has been established, Figure 23. The concept relies upon the thermal module of the FE code WELDSIM for welding simulations, advanced microstructure models for the precipitate evolution during welding and heat treatment, and microstructure-based models for strength and work hardening. The non-linear structural analysis is performed with the general-purpose non-linear FE code LS-DYNA.

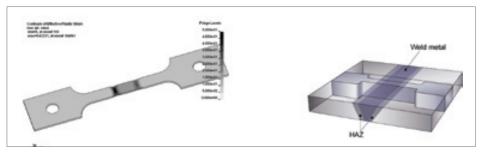


Figure 25 – Predicted strain localization in shell-based model of a tensile test with HAZ, b) cross weld tensile test programme undertaken to validate the modelling concept.

A numerical study has been performed to evaluate available solutions methods for finite element (FE) simulations of plastic failure (i.e. necking and strain localization in the necked region) in the heat-affected zone (HAZ) of welded aluminium structures on the basis of the established model concept, Figure 24. An extensive experimental programme on flat welded plates has been performed and numerical studies are now undertaken with the aim to further evaluate the predictive capability of the modelling approach, Figure 25.

Demonstrators (Demo) Programme head: 0-G. Lademo

Introduction

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 thermomechanical 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 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.

Aluminium front-end concept

An aluminium front-end concept attached to a crash car has been used as a demonstrator for the state of the art of prediction of failure in material and joints, Figure 26. The applied load case is the front offset crash 45 km/h using a deformable barrier



Figure 26 – Full-scale model of a front-end concept.

with 40 % overlap to intentionally produce fracture in the car components and joints. 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 is taken into account

Welded aluminium structures

This activity is linked to the 'Throughprocess modelling' concept for welded structures, developed in the research programme 'Multi-scale Modelling of Metallic Materials'. A series of experimental tests and FE simulations on welded crash-boxes and mixed material bumper beam systems has been performed. Figure 27 presents the three different levels of complexity addressed by the various test series on welded structures. The flat extruded profiles serve as a fundamental evaluation of the predictive quality of the established modelling procedure, as mentioned above. The more complex test series are defined as industrial demonstrators. On the basis of these tests and analyses, preliminary modelling guidelines have been established that are currently being used by Hydro Automotive Structures.

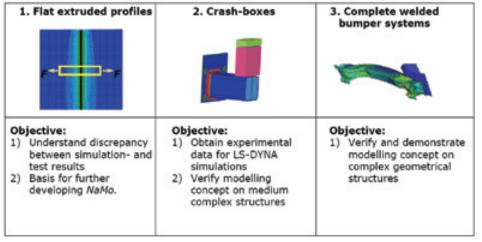


Figure 27 – Generic welded components with different levels of complexity.

Evaluation of the research carried out at the Centre

The first scientific advisory board meeting was held in Trondheim on 16 June 2008. A mandate was defined where the board was asked to evaluate:

- The research carried out with respect to the defined objective for the Centre.
- Relevance of the research with respect to the industrial and public partners.
- · Scientific quality.

The board wrote the following report after the meeting.

Evaluation

The board members were invited to assess the progress of the Centre for Research-based Innovation (CRI) in the Structural Impact Laboratory (SIMLab), at the completion of the first one and a half year of a eight-year research programme, 2007 – 2014. Documents and research papers were forwarded to the board members prior to the meeting on 16 June 2008. During the meeting, oral presentations were delivered by the principals of the major research programmes. Adequate time was allotted for discussion, and all points raised by the board members were answered competently. The following brief report provides an overview of the current status of the CRI, largely from the perspective of the progress of the research programme and the industrial interaction.

Broadly speaking, the main thrust of the CRI is the development of a scientific underpinning for the design of lightweight structures, which are important for energy-saving in transportation systems consistent with improved safety, protection systems against terrorist threats and other impact events, and for many other industrial applications.

The board observed that the programme was well focussed and highly relevant to the mandate. It has developed excellent cooperation with industry, which the board recognizes is often a very time-consuming activity. The Centre is to be congratulated on this success. This outcome is largely due to the clear leadership and well formulated vision of this programme.

In addition, the board noted that good cooperation has been developed with several relevant international academic establishments: this initiative could provide the programme with important expertise and a source of high quality graduate students, post-doctoral fellows and visiting staff.

The board noted that the five major areas of activity (fracture and crack propagation, connectors and joints, polymers, multi-scale modelling, optimal energy-absorption and protection) are well-balanced and are led by world-class scientists who have international reputations established through their publication records, and who are familiar with recent developments in their respective research fields. Most of the activities are a combination of theoretical analyses and numerical studies which are supported by excellent laboratory facilities. The output of the CRI builds on these fundamental contributions, and extends them in a way which will lead to new industrial developments in due course. The board recognizes that this engineering research is at the highest level and anticipates that a number of important contributions will emerge in the years ahead.

The board agreed that it was worthwhile to complete this report with several general points which emerge from their own experience:

- 1. A research activity on this scale requires special consideration because of the local and national visibility of the output and the nature of the industrial cooperation. It wondered if some of the administrative and teaching duties of the key professors could be relieved through internal sabbaticals, for example, and by engaging extra assistance.
- 2. We encourage the appointment of visiting experts to maintain the scientific base and to strengthen certain aspects of some programmes, e.g. polymers. To maintain the momentum of the programme, visiting experts can assist in maintaining the high quality international thrust and provide expertise to strengthen selective areas as they are exposed over the duration of the programme.
- We encourage the publication of a newsletter and a home page to maintain interaction between the participants, and is a good way of reaching out to the industrialists.
- 4. We encourage contacts with the Norwegian energy sector using the suggestion in point 3 above as well as running short courses directed at engineers in this sector.
- 5. We discussed the universal difficulty of recruiting good engineering doctoral students since the existing methods patently do not work well. More emphasis should be given to the career opportunities of PhD graduates rather than on the special research programmes which they will undertake. Generally speaking, studies have shown that they have a wider choice of career options and a more satisfying career, that their lifetime income is higher than someone without a PhD degree and that they are more likely to find a new job in a recession because of their broader knowledge base. It might be worthwhile for a university-level, or even a national, committee, to consider these points and others, and conduct research into the careers of engineering alumni.

The board is unanimous in congratulating Professor Magnus Langseth for assembling an outstanding team, and in encouraging and sustaining excellent interaction between the team members and the industrial partners. The outstanding outcome of the first one and a half year of the CRI bodes well for the remaining years of the eight-year programme.

New equipment

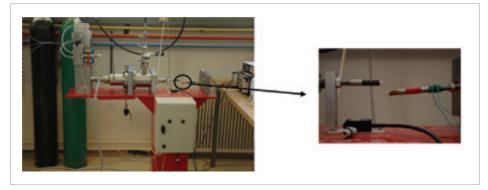
- Hydro-Pneumatic Machine (Minibar):
 The Hydro-pneumatic machine provides an experimental technique for performing material tests at strain rates in the range from approximately 0.1 to 100 s⁻¹. Strain rates at this level are relevant in crash and metal processing situations.
 The working principle of the rig is a rapid evacuation of the water chamber driven by a pressurized nitrogen gas causing a movement of the piston at constant speed and loading of the test coupon to fracture.
- Upgrading of the Instron biaxial testing machine: A new 2-axis system is installed in order to control the position, load, angle and torque. In addition, a 3rd axis controller is installed to monitor the internal pressure.
- Heating system: A new induction heating system (MSI Automation 5 kW Bench top system) has been bought in order to carry out high rate testing at elevated temperatures.
- Concurrent research projects

The following selection of research projects have been run in 2008 utilizing the competence developed at the Centre:

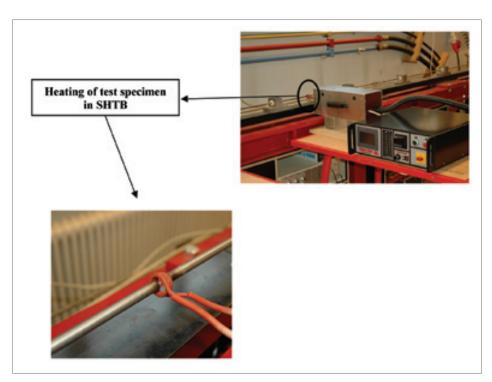
• ROBDES: NTNU and SINTEF in cooperation with VOLVO/Ford, Gestamp Hardtech, SSAB Tunnplåt, Hydro Aluminium Structures, the University of Linköping and the Research Council of Norway have established a Userdriven Innovation Project (BIP) on Robust Design of Automotive Structures (2005-2008). Three projects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

- PolyCrash: NTNU and SINTEF are involved in another BIP project called PolyCrash for the period 2006-2009. The main objective of 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 Roads Administration.
- EU project: NTNU and SINTEF are involved in an EU project called 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.
- PhD project: Heidi Moe has done her PhD research at SIMLab, and her disputation will be on March 26th 2009. The PhD project was funded by the Research Council of Norway through the IntelliSTRUCT programme (Intelligent Structures in Fisheries and Aquaculture) at SINTEF Fisheries and Aquaculture. The main goal of this PhD project was to develop a method for non-linear strength analysis of net structures applied in the aquaculture and fishing industries. The work focused on the aquaculture net



Minibar for medium strain rate testing of materials



Heating system

cage, and included research to establish knowledge within material properties and failure modes of traditional netting materials for aquaculture.

- JIP CO2PIPETRANS: SINTEF is involved in the JIP led by DNV for the period 2008-2009. The main objective of this project is to establish a Recommended Practice for development, design, construction, testing, operation and maintenance of steel pipelines for the transmission of CO2 in dense, high pressure phase. SINTEF has evaluated the applicability of using numerical tools for the prediction of running ductile fracture.
- JIP Fracture Control: The applicability
 of the plasticity models developed at the
 Centre is explored in applications related
 to crack growth and fracture mechanics
 analysis of steel pipelines.
- Impact against pipelines: One SINTEF scientist has been rented to StatoilHydro to assist in their activities to protect pipelines against trawl board impact.

Based on the core competence at the Centre, the associated SINTEF team has been involved in a number of initiatives for new industrial projects during 2008. Several applications have been supported that have a complementary research scope to the ongoing activities at the Centre.

- 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. One PhD candidate will be supervised by personnel from the Centre.
- 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.
- BIP NextGenSi: SINTEF, NTNU and TU

- Bergakademie Freiberg together with 3 PV-related companies are involved in this BIP 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: This project is based on collaboration with the research group 'Polymers and composites' at SINTEF Materials and Chemistry, and other industries than those that are involved in the Centre. There is close analogy to the activities at the Centre as this project will develop design tools for composite structures on advance continuous fibre polymer composites. One or possibly two PhD candidates will be (co-) supervised by personnel from the Centre.

EU applications

Any EU application with involvement from the partners has been discussed by the board, but so far there is no enthusiasm with respect to such an initiative. The experience the international partners have from previous EU projects is that the CRI-concept is a much better model in order to obtain a generic technical focus where theory and applications are strongly linked. In addition the financial crisis has definitely had an impact on such initiatives in 2008. Thus the strategy in 2008 has been 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 and SINTEF have been involved in two applications in 2008, but unfortunately these applications did not pass the first evaluation round, i.e.

 Performance improvement of automotive structural components by integration of cellular functionally graded materials (Cell-Foam). The coordinator of the application was Fraunhofer Gesellschaft zur Förderung der angewandten Forschung e.V., Germany Mechanical enhanced, energy efficient, fast and easily assembled and dissembled functionally graded joints. The coordinator was of the application was The Welding Institute (TWI) Ltd, UK.

Visibility

Conferences

CRI-SIMLab hosted an international conference on "Impact Loading of Lightweight Structures" in June 2008 with 110 participants. The conference was a continuation of the conference held in Florianapolis in Brazil in 2005 and dealt with aluminium, magnesium, high strength steels, polymers, foams and composites and their use as a structural material in impact loaded structures. Totally 54 oral presentations were given by academia and industry. In addition a poster session was organized with 28 posters. The presentations and the extended abstracts are gathered on a CD-ROM.





 CRI-SIMLab (NTNU and SINTEF) organized a conference on Joining Technology together with the University of Hertfordshire, The Welding Institute (TWI) in UK and the University of Palermo 18-19 September 2008. A limited number of papers were presented, among them a paper on joining of dissimilar material using self-piercing riveting from SIMLab. Good contacts were established with other research groups working in the field of joining technology.

Presentation on Norwegian television

The lightweight protection activity at SIMLab with focus on international peacekeeping operations was presented on the news on NRK1 (the main State TV Channel) on 29 June 2008, see also http://www1.nrk.no/nett-ty/indeks/136824

Invited lecture

 Professor Magnus Langseth gave a lecture at the 25th anniversary for the Fondation Franco-Norvegienne in Oslo 19 September 2008. The title of his presentation was "A success story: Aluminium components subjected to impact loading conditions – The MODIF project".

Magazines

 An article related to lightweight protection against penetration and blast was presented in the magazine Gemini, No. 2, June 2008. It should be mentioned that several related articles on this issue can be found on the internet. Furthermore, the article is also published in the magazine "Sjekkposten – Tidsskrift for FN-veteranens landsforbund nr 5/2008".



 The Faculty of Engineering Science and Technology at NTNU has worked out a prospectus where SIMLab is presented as one of the strongest research groups at the faculty, www.ntnu.no/ivt/english.

International cooperation

Research

In 2008 SIMLab had the following international research cooperation:

- LMT-Cachan, France
 - Professor Ahmed Benallal is staying at the Centre during his one year sabbatical. His research contribution is related to the experimental identification and modelling of the Portevin-Le Châtelier (PLC) effect.
 - Professor Francois Hild had a one week stay at the Centre in October in order to discuss the use of a Digital Image Correlation System for 2D and 3D field measurements.

- Common journal publications have been worked out.
- University of Sao Paulo, Brazil
 - Professor Marcilio Alves had a two week stay at the Centre in March.
 The research cooperation is related to the behaviour and modelling of polymers. One of his PhD students (Rafael Traldi Moura) had a five months stay in the Centre in 2008. Common publications are planned.
- MIT. USA
 - The cooperation with Professor Tomasz Wierzbicki has resulted in a common publication on penetration of doublelayered metal plates which was presented at the conference in Trondheim in June.
- University of Savoie, France
 - Cooperation is established between SIMLab and the University of Savoie related to the measurements of the temperature increase of structures subjected to large plastic deformations.
 Professor Odd Sture Hopperstad and Dr Stephane Dumoulin from SIMLab had a one month stay at this university in 2008. Furthermore Assoc. Professors Hervé Louche and Christophe Déprés visited SIMLab in October 2008.
- University of Linköping, Sweden
 - The well-established cooperation with Professor Larsgunnar Nilsson and his PhD student David Lönn has resulted in a common conference publication on robust design methods for automotive structures.
- MURI project
 - The University of California Santa
 Barbara (UCSB) in cooperation with
 Havard University, University of Virginia,
 MIT and University of Cambridge have
 established a Multidisciplinary University Research Initiative Project (MURI)
 titled An Integrated Cellular Materials
 Approach to Force Protection, sponsored by the U.S. Navy. Based on the
 activities in the OptiPro programme,
 SIMLab has been invited to attend the
 MURI project meetings in 2008, once at

UCSB and once in Cambridge, UK. The main idea with the cooperation in 2008 has been to share information in order to define activities of mutual interest.

DYNALAB

 Dr Carlo Albertini from DYNALAB in Italy visited SIMLab for one week in October in relation with a new testing rig that he has designed for medium strain rate testing of materials. He retired some years ago from his position as a scientist at the Joint Research Centre in Ispra, Italy, but he is now running his own company with focus on high strain rate testing techniques.

Guest lectures

The following guest lectures have been given at SIMLab in 2008:

- Professor Marcilio Alves, University of Sao Paulo, Brazil: "Structural Impact Research in Brazil".
- Professor Vikram Deshpande, University of Cambridge, UK: "Micro-mechanical modelling of the dynamic deformation and fracture of ceramics".
- Professor Francois Hild, LMT-Cachan, France: "From Measurement and Control to Mechanical Identification".
- Assoc. Professor Hervé Louche, University of Savoie, France: "Thermal filed measurements and heat sources estimations to study the behaviour of materials".
- Assoc. Professor Christophe Déprés,
 University of Savoie, France: "Studying
 plasticity with Discrete Dislocations Dynamics. Two applications 1. Fatigue damage
 prediction; 2. Dislocation-based model
 development".
- Dr Noah Philips, University of California Santa Barbara: "Ductile phase toughening in brazed joints".

Recruitment and visiting students



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

Ph.D. students

The following PhD students are linked to the Centre in 2008:

Name	Start	Planned exam	Programme	From	Male/Female
Ida Westermann*	Fall 2007	Fall 2010	M^4	Denmark	Female
Henning Fransplass*	Spring 2005	Spring 2011	OptiPro	Norway	Male
Virgile Delhaye*	Summer 2007	Summer 2010	Polymers	France	Male
Egil Fagerholt*	Winter 2008	Winter 2010	F&CP	Norway	Male
Nguyen-Hieu Hoang*	Fall 2007	Fall 2010	C&J	Vietnam	Male
A.B. Alisibramulisi**	Fall 2007	Fall 2010	M ⁴	Malaysia	Female
Gaute Gruben*	Summer 2008	Summer 2012	F&CP	Norway	Male
Anne S. Ognedal*	Fall 2008	Fall 2012	Polymers	Norway	Female

Gaute Gruben and Anne Serine Ognedal were recruited after an announcement in spring 2008. We received 37 applications for three positions – two from Norway, one from France and the rest mainly from Asia. The French applicant (a girl) was also offered a position, but declined. The rest of the applicants were not found qualified. In addition, Marion Formeau from LMT-Cachan in Paris will be employed as a PhD student from July 2009 at SIMLab. She submitted an application and based on her excellent marks she was offered a position financed by the Faculty of Engineering Science and Technology. Here, the operational costs will be covered by the Centre.

Virgile Delhaye is a PhD student at NTNU and is financed through the contribution in kind from Renault. The same is the case with Henning Fransplass who is financed by the contribution in kind from NPRA. A.B. Alisibramulisi is from Malaysia with funding from her home country. However, she is linked to the Centre and is thus receiving support related to operational cost. From January 2009, Audi will also have a PhD student linked to the Centre as a part of their contribution in kind. This is Octavian Knoll who plans to work on failure modelling of aluminium within the F&CP programme.

In order to strengthen future recruitment of Norwegian PhD students and to promote the needs in industry for the competence developed in the Centre, a seminar was organized on 23 October 2008 with contribution from the Faculty of Engineering Science and Technology and three of the partners in the Centre, i.e. Statoil Hydro, SINTEF and Hydro Aluminium.

^{* =} Salary and operational cost from the Centre

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



* Dr Alexander Kane is now employed by SINTEF Materials and Chemistry as a research scientist. The seminar was organized with a presentation from the faculty with focus on how to become a PhD student at NTNU and a presentation from each of the industrial partners with focus on needs for recruitment of candidates with a research background. The seminar was rounded off by a guided tour in the laboratory with refreshments. Totally 75 students were present and the feedback after the seminar was very positive. It is worth noting that after the seminar two students have been offered a PhD position at SIMLab after finishing their master's theses in June 2009. The salary of these positions will be covered directly by the Faculty of Engineering Science and Technology, while the operational costs will be covered by the Centre.

Master's student recruitment has also been carried out with a trip to Raufoss on 8-9 October 2008. Our fifth year students visited the Hydro Aluminium production plant for aluminium bumpers and the response from the students was very positive.

Post docs

The following post docs are linked to the Centre in 2008:

Name	Start	End	Programme	From	Male/Female
Alexander Kane*	1 Feb 2007	31 Aug 2008	F&CP + OptiPro	France	Male
Venkatapathi Tarigopula	1 June 2007	Fall 2009	F&CP + OptiPro	India	Male

Visiting students and post docs

The following international students have stayed at the Centre in 2008:

- Marc Glita from Ecole Normale Supérieure de Cachan, France stayed at the Centre for four months during his internship. He was linked to the OptiPro programme at work on the behaviour of submerged pipelines subjected to trawl gear impact.
- Rafael Traldi Moura from the University of Sao Paulo, Brazil is a PhD student and stayed at the Centre for five months working on the behaviour and modelling of polymers.
- Hussein Jama from Monash University in Australia stayed at the Centre for two weeks. He carried out material tests at elevated rates of strain using the SIMLab Split Hopkinson Tension Bar.
- Cyril Ducamp from the National Institute of Applied Science of Lyon, France was staying four months at the Centre working in the Polymer programme during his internship.
- Xinke Xiao from Harbin Institute of Technology, China is a post doc and is staying at the Centre for six months working on penetration problems and is linked to the OptiPro programme.
- Andrea Manes from Politecnico di Milano, Italy is a post doc who has been staying at the Centre for six months. He is working on modelling of pipelines subjected to trawl gear impact. He has been linked to the Optipro programme.

Master`s students

The following Master's students were linked to the Centre in spring 2008:

Student	Topic
Andreas Amundsen	Behaviour and modelling of self-piercing rivet
	connections in aluminium
Heidi Aunehaugen	The behaviour of a high-strength aluminium alloy
	during impact
Kristian Høye Børøsund	Compression test on rings made of PEHD
Anne Kristiansen Drømtorp	Finite element analyses of welded aluminium connections
Kyrre Carlsen Gallaher	Behaviour of beam connection – coped beam
Gaute Gruben	Finite element analyses of aluminium crash components
Hanne Gundersen	Capacity simulations of beam-end connections and
	welded plates
Eirik Guriby and Mats Mathiesen	Stiffness calculations for bearing type steel joints
Jørn Inge Kristiansen	Development of damage on impacted pipelines
Eirik Kristoffersen	Fracture modelling in quasi-ductile metals during impact
Ernst Richard Larsen	Use of aluminium foam to simulate blast loading
Torbjørn Svanstrøm	Numerical simulation of fracture in bumper beam systems

Annual accounts

The annual work plans for each research programme have to present a detailed description of the activities to be carried out in the Centre, allowing the Research Council of Norway (RCN) to monitor that that the research activities are within the ESA requirements. Thus the funding plan for each programme shows the funding from each of the partners in the form of "Fundamental research (F)" and "Industrial research (I)" and how funding from RCN contributes to funding of each programme. The cost plan describes each partner's participation in each of the programmes. The funding and cost plans for 2008 are shown below.

Funding 2008 (All figures in 1000NOK)

-		S	STATE AID			INDUSTRY										
Research Programme	Type of research	RCN Grant	Host (NTNU)	SINTEF	NDEA	NPRA	AUDI	ВММ	Renault	Plastal	StatoilHydro	SSAB	Hydro Aluminium	Total State Aid	Total Funding	State aid/total funding
C&J	F	1535	312				1000						150	1847	2997	0,62
C&J	1															
F&CP	F	1712	2407		200			100			50		550	4119	5019	0,82
F&CP	1															
M ⁴	F	1175	602	1100							50		160	2877	3087	0,93
M ⁴	1												2167		2167	0
OptiPro	F	668	212		1450	995		100			400	800		880	4625	0,19
OptiPro	1															
Poly	F	407	912			100			1000	150	100			1319	2669	0,49
Poly	I															
Demo	F															
Demo	1	121	212			25		600					433	333	1391	0,24
Equipment		2991	145										219	3136	3355	
Adm		2740	465		550			200			50		421	3205	4426	
Total		11349	5267	1100	2200	1120	1000	1000	1000	150	650	800	4100	17716	29736	

Cost 2008 (All figures in 1000NOK)

Research Programmes	Host (NTNU)	SINTEF	NDEA	NPRA	AUDI	ВММ	Renault	Plastal	StatoilHydro	SSAB	Hydro Al	Total
C&J	1647	850			500							2997
F&CP	3269	1550	200									5019
M ⁴	1337	1750									2167	5254
OptiPro	1705	750	1000	870						300		4625
Poly	1319	850					500					2669
Demo	258	200				500					433	1391
Equipment	3355											3355
Adm	2426	2000										4426
Total	15316	7950	1200	870	500	500	500			300	2600	29736

F = Fundamental research, I = Industrial research

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

Publications

The following lists journal publications and conference contributions generated within the Centre in 2008.

Journal publications - Published articles

- Tarigopula V., Hopperstad O.S., Langseth M., Clausen A.H., Hild F.: A study of localisation in dualphase high-strength steels under dynamic loading using digital image correlation and FE analysis. International Journal of Solids and Structures 2008; 45[2]; 601-619.
- Tarigopula V., Hopperstad O.S., Langseth M., Clausen A.H., Hild F., Lademo O-G. and Eriksson E.: A study of large plastic deformations in dual phase steel using digital image correlation and FE analysis. Experimental Mechanics 2008; 48(2);181-197.
- Tarigopula V., Hopperstad O.S., Langseth M., Clausen A.H..: Elastic-plastic behaviour of dual-phase, high-strength steel under strain path changes. European Journal of Mechanics-A/Solids 2008; 27(5); 764-782.
- Fyllingen Ø., Hopperstad O.S., Langseth M.: Simulations of a top-hat section subjected to axial crushing taking into account material and geometry variations. International Journal of Solids and Structures 2008, 45, 6205-6219
- Grytten F., Holmedal B., Hopperstad O.S., Borvik T.: Evaluation of identification methods for YLD2004-18p. International Journal of Plasticity 2008, 24, 2248-2277
- Pedersen K.O., Lademo O.G., Berstad T., Furu T., Hopperstad O.S.: Influence of texture and grain structure on strain localisation and formability for AlMgSi alloys. Journal of Materials Processing Tech. 2008. 200. 77-93
- Lademo O.G., Berstad T., Eriksson M., Tryland T., Furu T., Hopperstad O.S., Langseth M.: A model for process-based crash simulation. International Journal of Impact Engineering 2008 35, 376-388
- Alsos H.S., Hopperstad O.S., Tornqvist R., Amdahl J.: Analytical and numerical analysis of sheet metal instability using a stress based criterion. International Journal of Solids and Structures 2008, 45, 2042-2055
- Lademo O.G., Pedersen K.O., Berstad T., Furu T., Hopperstad O.S.: An experimental and numerical study on the formability of textured AlZnMg alloys. European Journal of Mechanics-A/Solids 2008, 27, 116-140
- Pedersen K.O., Roven H.J., Lademo O.G., Hopperstad O.S.: Strength and ductility of aluminium alloy AA7030. Materials Science & Engineering A 2008, 473, 81-89
- Polanco-Loria M., Hopperstad O.S., Børvik T., Berstad T.: Numerical predictions of ballistic limits for concrete slabs using a modified version of the HJC concrete model. International Journal of Impact Engineering 2008; 35:290-303.
- Børvik T., Hanssen A.G., Dey S., Langberg H., Langseth M.: On the ballistic and blast load response of a 20ft ISO container protected with aluminium panels filled with a local mass – Phase I: Design of protective system. Engineering Structures 2008; 30:1605-1620.

- Børvik T., Burbach A., Langberg H., Langseth M.: On the ballistic and blast load response of a 20ft ISO container protected with aluminium panels filled with a local mass – Phase II: Validation of protective system. Engineering Structures 2008; 30:1621-1631.
- Benallal A., Berstad T., Børvik T., Hopperstad O.S., Koutiri I., Nogueira de Codes R.: An experimental and numerical investigation of the behaviour of AA5083 aluminium alloy in presence of the Portevin-Le Chatelier effect. International Journal of Plasticity 2008; 24(10):1916-1945.
- Holmedal B, Van Houtte P, An Y G.: A crystal plasticity model for strain-path changes in metals. International Journal of Plasticity. Vol. 24, 2008, pp. 1360–1379.
- Nijs O, Holmedal B, Friis J, Nes E.: Sub-structure strengthening and work hardening of an ultra-fine grained Aluminium Magnesium alloy. Materials Science and Engineering A. Volumes 483-484, 2008, pp.51-53.
- Myhr, O.R., Grong, Ø.: Utilizing a predictive tool for designing welded aluminium components. Welding Journal; 2008, 87(5); 36-39.
- Porcaro R., Langseth M., Hanssen A.G., Zhao H., Weyer S., Hooputra H.: Crashworthiness of selfpiercing riveted connections. International Journal of Impact Engineering 2008;35(11):1251-1266.
- Reyes A., Hopperstad O., Berstad T. and Lademo O.-G.: Prediction of necking for two aluminum alloys under non-proportional loading by using an FE-based approach. International Journal of Material Forming 2008; 1(4); 211-232.

Conference proceedings

Impact Loading of Lightweight Structures,
 Trondheim, Norway 17-19 June 2008. ISBN: 827482-097-5. Structural Impact Laboratory (SIMLab),
 Department of Structural Engineering, The
 Norwegian University of Science and Technology.
 (Edited by Arild H. Clausen and Magnus Langseth)

Oral presentations at conferences

- Tarigopula V., Langseth M., Hopperstad O.S.: Influence of Element Formulation on the Axial Crushing of Thin-walled Dual-Phase Steel Square Sections. In: Proceedings of 10th International LS-DYNA® Users Conference, pp. 16.13-16.19, ISBN 0-9778540-4-3, LSTC: California, 8-10 June 2008.
- Tarigopula V., Langseth M., Hopperstad O.S., Clausen A.H., Hild F.: Characterization of localization and large plastic deformations in dual-phase steel using digital image correlation. Presented at the International Conference on Impact Loading of Lightweight Structures, Trondheim (Norway), 17-19 June 2008.
- Tarigopula V., Langseth, M., Clausen A.H., Hopperstad O.S.: Behaviour of dual-phase steel at elevated rates of strain. In: Proceedings of 5th European Conference on Steel and Composite Structures, EUROSTEEL 2008, pp. 1143-1148, ISBN 92-0147-000-90, ECCS European Convention for Constructional Steelwork: Austria, 03-05 September 2008.
- Tarigopula V., Hopperstad, O.S., Langseth M., Clausen A.H.: Numerical Modelling of the Mechanical Behaviour of Dual-Phase Steels. Invited Presentation at 21st Nordic Seminar on Computational Mechanics (NSCM-21), pp. 116-119, ISBN 978-84-96736-56-6, CIMNE:Spain, 16-17 October 2008: Trondheim (Norway).

- Polanco-Loria M., Clausen A.H., Berstad T., Hopperstad O.S.: A Constitutive Model for Thermoplastics in Structural Applications.
 Presentation at 21st Nordic Seminar on Computational Mechanics (NSCM-21), pp. 257-260, ISBN 978-84-96736-56-6, CIMNE:Spain, 16-17 October 2008: Trondheim (Norway).
- Polanco-Loria M., Clausen A.H., Berstad T., and Hopperstad O.S.: A modified Boyce-Raghava model for constitutive modelling of thermoplastics.
 Presented at the International Conference on Impact Loading of Lightweight Structures, Trondheim (Norway), 17-19 June 2008.
- Reyes A., Dørum C., Hopperstad O.S., Langseth M., Lademo O.-G., Eriksson M.: Validation study of failure prediction in crash analysis. In: Proceedings of The Ninth International Conference on Computational Structures Technology. Athens Sep 2-5, Paper 276, ISBN: 978-1-905088-23-2, Civil-Comp Press, Stirling, UK, 2008.
- Lademo O.-G., Eriksson M., Hopperstad O.S., Langseth M.: Characterisation and modelling of failure in ductile sheet metals. Presented at the International Conference on Impact Loading of Lightweight Structures, Trondheim (Norway), 17-19 June 2008.
- Lönn D., Fyllingen Ø.: Finite element robustness optimisation through trigger introduction on a sqare aluminium profile subjected to axial crushing and geometrical uncertainties. Presented at the International Conference on Impact Loading of Lightweight Structures, Trondheim (Norway), 17-19 June 2008.
- Olovsson L., Hanssen A.G., Porcaro R., Langseth M.: Behaviour and modelling of self-piercing riveted connections. Presented at the International Conference on Impact Loading of Lightweight Structures, Trondheim (Norway), 17-19 June 2008.
- Børvik T., Dey S., Hopperstad O.S., Wierzbicki
 T.: Ballistic Resistance of Double-layered Metal
 Shields. Presented at the International Conference
 on Impact Loading of Lightweight Structures,
 Trondheim (Norway), 17-19 June 2008.
- Børvik T., Dey S., Hopperstad O.S., Wierzbicki T., Teng X.: Ballistic Resistance of Double-Layered Metal Plates. Paper presented at the Ninth International Conference on Computational Structures Technology, Athens, Greece, 2-5 September 2008.
- Benallal A., Børvik T., Hopperstad O.S., Nogueira de Codes R.: Coupled thermo-mechanical analysis of PLC deformation bands in the AA5083-H116 aluminium alloy. Paper presented at the International Conference of Multiphysics (Multiphysics 2008), Narvik, Norway, 10-12 December 2008.
- 14. Fagerholt E., Børvik T.: Out-of-plane measurements of plates subjected to impact. Presented at the Scandinavian Society of High Speed Photography's conference High Speed Technique 2008, Bergen, Norway, 23-24 October 2008.
- Polanco-Loria M.: Constitutive modelling of thermoplastics using the modified Boyce-Raghava model. International Seminar on Multiscale Modelling of Polymer Materials, Trondheim (Norway), 13-14 October 2008.
- 16. Polanco-Loria M., Clausen A.H., Berstad T., and Hopperstad O.S.: Numerical modelling of thermoplastic materials for structural applications. The Nordic LS-DYNA Users Forum, Gothenburg

- (Sweden), 2 October 2008.
- Holmedal B, Skaret P C, Nes E.: Abrupt strainrate changes in high-purity binary Al-Mn alloys.
 Oral presentation and in the Proceeding of the international conference on aluminium alloys 2008. [ICAA11] Aachen, Germany, September 22-26, 2008. Wiley-VCH Weinheim. ISBN 978-3-527-32367-8. p.1449.
- Haaland B Ø, Westermann I, Holmedal B, Nes E,: Microstructure and properties of as-deformed and annealed ac-cumulated roll-bonded aluminium alloys. Oral presentation and in the Proceeding of the international conference on aluminium alloys 2008. (ICAA11) Aachen, Germany, September 22-26, 2008. Wiley-VCH Weinheim. ISBN 978-3-527-32367-8. p. 1468.
- 19. Porcaro R., Langseth M., Weyer S., Hooputra H.: An experimental and numerical investigation on self-piercing riveting. 11th ESAFORM2008 conference on material forming, April 23, 24 & 25, 2008, Lyon, France.
- Porcaro R., Hanssen A.G., Langseth M.: Modelling of self-piercing riveted connections. Innovations in Joining Technology. 18 Sep 2008 - 19 Sep 2008, Abington Hall Conference Centre, Cambridge, UK.
- Dørum C., Hopperstad O.S., Berstad T. and Laukli H.I.: A probabilistic approach for modelling of fracture in die-casting. 8th. World Congress on Computational Mechanics (WCCM8), 5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008), Venice, Italy (2008).
- Dørum C., Dispinar D., Berstad T. and Hopperstad O.S.: A probabilistic approach for modelling of fracture in magnesium die-castings. High Tech DieCasting, Montichiari, 9-10 April 2008, 23
- Laukli H.I. and Dørum C.: Through-process Modelling of Al-Si Die-Castings. 11th International Conference on Aluminium Alloys, 22-26 September, Aachen, Germany.
- Benallal A., Berstad T., Børvik T., Hopperstad O. And Nogueira de Codes R.: On the Measurement and Evaluation of the Width of Portevin-Le Chatelier Deformation Bands with Application to AA5083-H116 Aluminium Alloy. In Proceedings of IUTAM Symposium held at Cape Town, South Africa, January 14-18, 2008. IUTAM Bookseries, Vol. 11 Daya Reddy, B. (Ed.) 2008, XVIII, 390 p., Hardcover ISBN: 978-1-4020-9089-9.

Poster presentations at conferences

- Delhaye V., Clausen A.H., Hopperstad O.S., Moussy F., and Othman R.: Experimental characterization of the polypropylene P108MF97. Poster Presentation, International Conference on Impact Loading of Lightweight Structures, Trondheim (Norway), 17-19 June 2008.
- Dumoulin S., Hopperstad O.S. and Berstad
 T.: Framework for Crystal Plasticity. Poster
 Presentation, International Conference on Impact
 Loading of Lightweight Structures, Trondheim
 (Norway), 17-19 June 2008.
- Dørum C., Hopperstad O.S., Berstad T., and Laukli H.I.: Modelling of fracture in die-castings. Poster Presentation, International Conference on Impact Loading of Lightweight Structures, Trondheim (Norway), 17-19 June 2008.
- 4. Fagerholt E., Grytten F., Auesatd T., Førre B., Børvik T., and Gihleengen B. E.: Out-of-plane deformation measurements using structure



- light and close-range photogrammetry. Poster Presentation, International Conference on Impact Loading of Lightweight Structures, Trondheim (Norway), 17-19 June 2008.
- Fyllingen Ø., Hopperstad O.S., and Langseth M.: Robustness study of a top-hat section of highstrenght steel subjected to axial crushing. Poster Presentation, International Conference on Impact Loading of Lightweight Structures, Trondheim (Norway), 17-19 June 2008.
- Grytten F., Børvik T., Langseth M., and Hopperstad O.S.: Low-velocity perforation of aluminium plates. Poster Presentation, International Conference on Impact Loading of Lightweight Structures, Trondheim (Norway), 17-19 June 2008.
- Holmedal B.: Modelling strain rate sensitivity in tensile tests at room temperature. Poster Presentation, International Conference on Impact Loading of Lightweight Structures, Trondheim (Norway), 17-19 June 2008.
- Kane A., Børvik T., Hopperstad O.S. and Langseth M.: Fracture modelling for ballistic perforation of steel plates. Poster Presentation, International Conference on Impact Loading of Lightweight Structures, Trondheim (Norway), 17-19 June 2008.
- 9. Moura R.T., Clausen A.H., Domoulin S., and Alves M.: Material tests on PEHD and PVC using DIC.

- Poster Presentation, International Conference on Impact Loading of Lightweight Structures, Trondheim (Norway), 17-19 June 2008.
- Moura R.T., Clausen A.H., Fagerholt E., Auestad T., Alves M., and Langseth M.: Impact on plates made of PEHD and PVC. Poster Presentation, International Conference on Impact Loading of Lightweight Structures, Trondheim (Norway), 17-19 June 2008.
- Polanco-Loria M., Clausen A.H., Berstad T., and Hopperstad O.S.: A modified Boyce-Raghava model for constitutive modelling of thermoplastics. Poster Presentation, International Conference on Impact Loading of Lightweight Structures, Trondheim (Norway), 17-19 June 2008.
- Reyes Aa., Dørum C., Hopperstad O.S., Langseth M., Lademo O.-G., and Eriksson M.: Validation of one failure prediction approach in crash analyses.
 Poster Presentation, International Conference on Impact Loading of Lightweight Structures, Trondheim (Norway), 17-19 June 2008.
- Tarigopula V., Langseth M., Hopperstad O.S., Clausen A.H., Hild F.: Characterization of localization and large plastic deformations in dualphase steel using digital image correlation. Poster Presentation, International Conference on Impact Loading of Lightweight Structures, Trondheim (Norway), 17-19 June 2008.





