Annual Report 2011

Centre for
Research-based
Innovation

SIMLab

Centre for Research-based Innovation

SIMLab on Discovery Channel

SINTEF

NTNU – Trondheim
Norwegian University of
Science and Technology

Objective

Within the field of structural impact SIMLab is concentrating on research areas that are of common interest to the industrial partners and hence create a link between Norwegian industry and some of the major actors in the global market, e.g. the automotive industry. However, in order to meet the requirement for innovation and value creation in an international market, Norwegian industry has to adopt new and original knowledge in product development. Here, an efficient modelling of the whole process chain, through process modelling, is a key requirement for success where a strong coupling is made between materials, product forms, production process and the structural behaviour. In order to meet the future challenges in product development foreseen by these partners, a multidisciplinary approach is used where researchers from the partners and academia contribute. This is only achievable through activities at the Centre with long-term objectives and funding. Thus, the main objective of the Centre is

> *to provide a* ***technology platform*** *for the development of safe and cost effective structures*

Vision

Our vision is to establish SIMLab as a world-leading research centre for the design of

Crashworthy and Protective Structures

The main quantitative goals of the Centre are as follows:

INDUSTRIAL:

1 To implement the developed technology by mutual exchange of personnel between the Centre and the industrial partners.
2 To arrange annual courses for these partners.
3 To facilitate employment of MSc and PhD candidates at the industrial partners.

ACADEMIC:

1 To graduate 19 PhD candidates where at least 4 are female.
2 To graduate at least 10 MSc students annually.
3 To attract at least 5 non-Norwegian professors/scientists during the duration of the Centre.
4 To publish at least 15 papers in international peer reviewed journals annually in addition to conference contributions.
5 To arrange two international conferences between 2007 and 2014.

Industrial partners in 2011

HYDRO, Statoil, Forsvarsbygg (Norwegian Defence Estates Agency), Audi, Renault, SSAB, Statens vegvesen, BMW, Toyota, Benteler Automotive

Summary

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

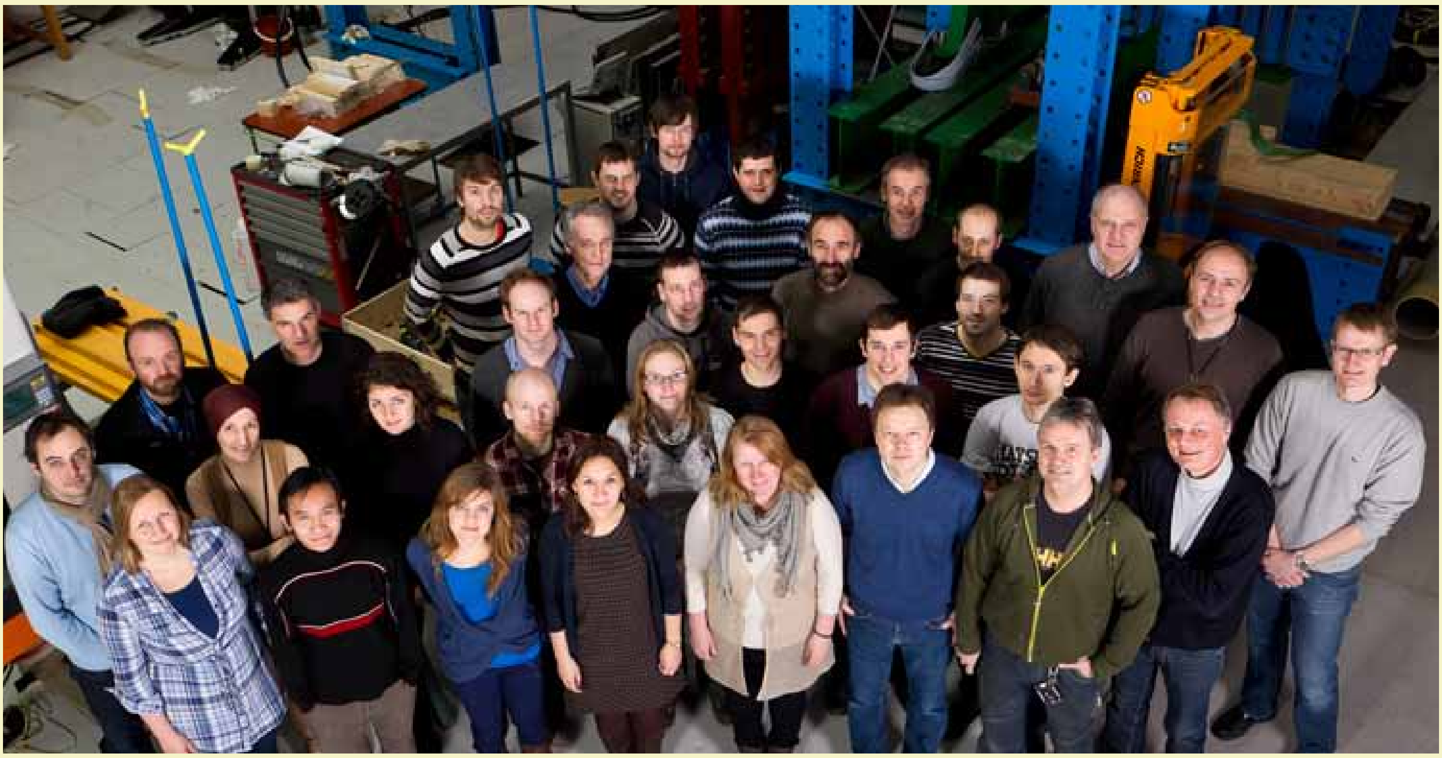
The main objective of the Centre is to develop a technology platform for safe and cost-effective structures in aluminium, high-strength steels and polymers through advances in the following research areas: *Materials, Solution techniques* and *Structures*. The ability of lightweight structures to withstand 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 2011 were Hydro Aluminium, Audi AG, Renault, Toyota Motor Europe, BMW Group, Benteler Aluminium Systems, Statoil, SSAB Swedish Steel, the Norwegian Public Roads Administration and the Norwegian Defence Estates Agency. BMW, Toyota Motor Europe and Benteler Aluminium Systems became new partners from January 2011.

The overall management structure of the Centre consists of a board comprising members from the consortium participants. A director is in charge of the operation of the Centre, assisted by a core team which together with the research programme heads run the research in the Centre. Furthermore, a Scientific Advisory Board of international experts provides scientific and strategic advice based on a defined mandate. In order to strengthen the female representation in the Centre Board, Dr Astrid Vigtil from NTNU became a new member in 2011. She is head of the research section at the Faculty of Engineering Science and Technology at NTNU.

The defined research areas for 2011 are linked with research programmes with focus on *Fracture and Crack Propagation (F&CP), Connectors and Joints (C&J), Polymers (Poly), Multi-scale Modelling of Metallic Materials (M⁴)* and *Optimal Energy Absorption and Protection (OptiPro)*. For each research programme annual work plans are defined with contributions from PhD candidates, post docs and scientists from the partners. The *Demonstrator* activity serves as a link between the basic research and the industrial needs for the technology developed. All material models developed in the Centre are gathered in a SIMLab Tool Box for implementation at the industrial partners during 2012.

Workshops and seminars are organized in order to strengthen the idea generation in the Centre, the transfer of technology from the Centre to the user partners and to initiate cooperation between the industrial partners. In this context the *Polymers* programme organized a seminar in Munchen in October 2011 where Statoil, Audi, Renault and Toyota Motor Europe were present. The seminar resulted in an agreement regarding future research as well as common demonstrators to validate the developed polymer model. In addition the annual SIMLab seminar, the Board meeting as well as the Scientific Advisory Board meeting were hosted by Statoil in



The research group. Photo: Ole Morten Melgård.

Trondheim on 17-18 March 2011. During the technical presentations, the PhD candidates and their work was focused on with great success.

The main conclusions from the Scientific Advisory Board were that they were impressed by the maturity of of the presentations given by the PhD candidates as well as the progress of the research in the Centre. They also advised that the research carried out should be maintained after 2014. In this context they pointed out that *"the expertise of SIMLab in experimental testing (including structural and material properties), theoretical modelling and numerical expertise for impact related studies is unique and should be maintained. Security and Protection is a growing area of public and industrial interest and SIMLab is ideally suited to focus on this research area after 2014"*.

The NTNU part of the SIMLab Centre was evaluated by the Faculty of Engineering Science and Technology at NTNU in 2011 and the grades of the research group were excellent (i.e. grade 5) on 1) scientific quality and production, on 2) relevance and impact and on 3) strategy, organization and research cooperation.

In 2011 the research work in the Centre has resulted in 18 papers published in peer reviewed journals and 2 book chapter contributions. In addition, the research group has given 33 conference and seminar contributions and among them one keynote lecture and four invited lectures.

The research in the Centre is carried out through close cooperation between master's, PhD candidates, post docs and scientists. In 2011, 21 male and 5 female master's students and 12 male and 4 female PhD candidates have been connected to the Centre. Further, 1 female and 1 male post doc are employed at SIMLab. International students from Italy (1), France (3), Brazil (1), Netherlands (1) and Germany (2) have also stayed at the Centre during 2011. PhD candidates Ida Westermann and Nguyen-Hieu Hoang have defended their thesis on the *"Work-hardening behaviour in age-hardenable Al-Zn-Mg(-Cu) alloys"* and *"Behaviour and modelling of self-piercing riveted connections using aluminium rivets"* respectively.

International cooperation and visibility are success parameters for a Centre. Thus the Centre has had cooperation with the following universities/research laboratories in 2011: Ecole Normale Supérieure de Cachan/Laboratoire de Mécanique et Technologie (ENS/LMT), France; University of Savoie, France; Ecole Centrale de Nantes, France; Technical University of Madrid, Spain; University of São Paulo, Brazil; MIT, USA; Politecnico di Milano, Italy; Karlsruhe Institute of Technology, Germany and Impetus Afea Sweden. In addition the Centre is involved in the Multidisciplinary University Research Initiative Project (MURI) titled *An Integrated Cellular Materials Approach to Force Protection* and sponsored by the U.S. Navy. The partners are the University of California Santa Barbara (UCSB) in cooperation with Harvard University, the University of Virginia, MIT, and the University of Cambridge, UK.

With respect to visibility, Professor Tore Børvik and Professor Øystein Grong received international awards for their research contribution in 2011, while Professor Arild Holm Clausen was awarded the Civil and Environmental Engineering teaching prize for 2011. The activities in the Centre have also been presented in national newspapers and on Discovery Channel as a part of the programme Mega World Norway in December 2011.

Several concurrent research projects have been run in parallel with the Centre's activities. Furthermore, the Centre has been involved in two applications for a research project with European funding. The EUROSTARS application was approved.

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' serves as a link between 'Materials', 'Solution techniques' and the "Demonstrators" activity, see figure below. The selection of demonstrators is carried out in close cooperation with the industrial partners. The interaction between the activities denoted 'Basic Research' and 'Demonstrators' is crucial with respect to validation and possible refinement of the technology developed at the Centre as well as the transfer of technology to the industrial partners.

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

The basic research areas **Materials, Solution techniques** and **Structures** are linked by Research programmes. The following research programmes have been running in 2011:

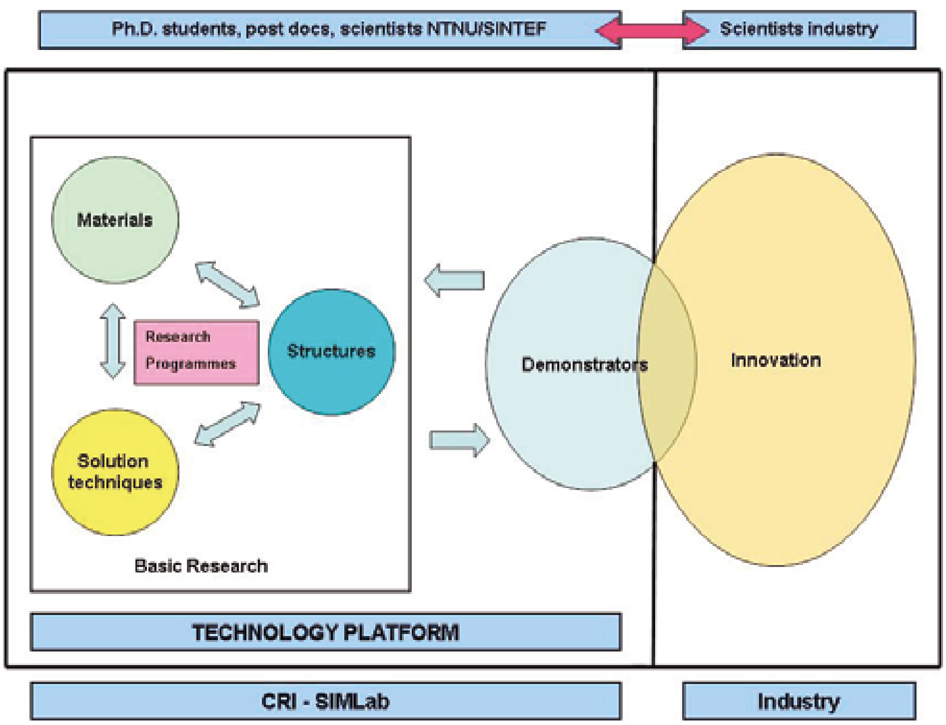
- **Fracture and Crack Propagation (F&CP):** Validated models for fracture and crack propagation in ductile materials including rolled and extruded aluminium alloys, high-strength steels, cast aluminium and polymers will be developed. Formulations for shell structures and solid bodies will be established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

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

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

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

- **Connectors and Joints (C&J):** Information about the behaviour and modelling of point connectors (with and without addesive bonding) subjected to static and dynamic loading conditions is obtained. Special focus is placed on the establishment of models to be used for large-scale shell analyses.



Research areas

Research organization

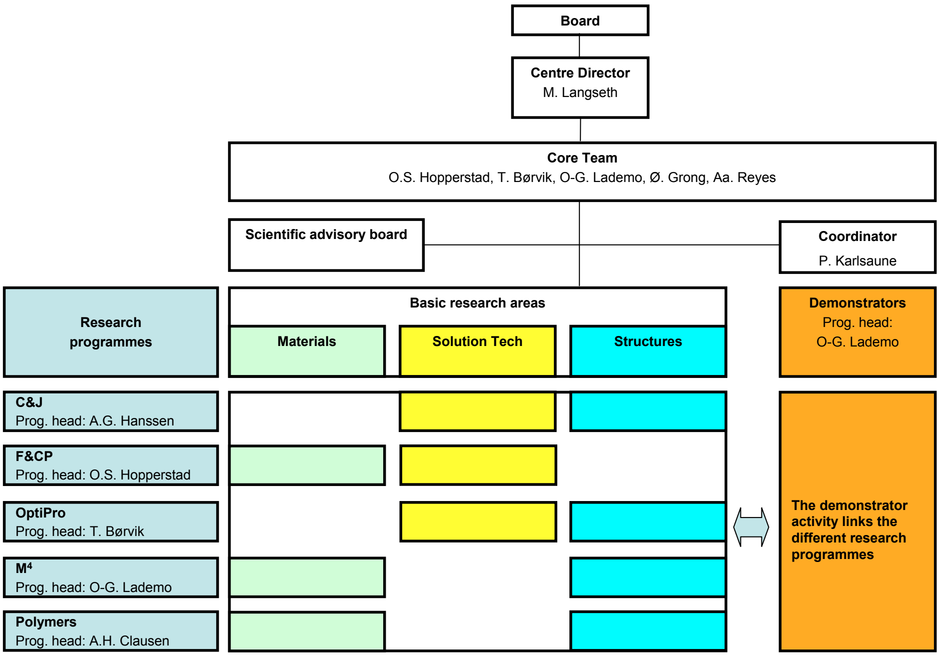
Structure of the organization

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

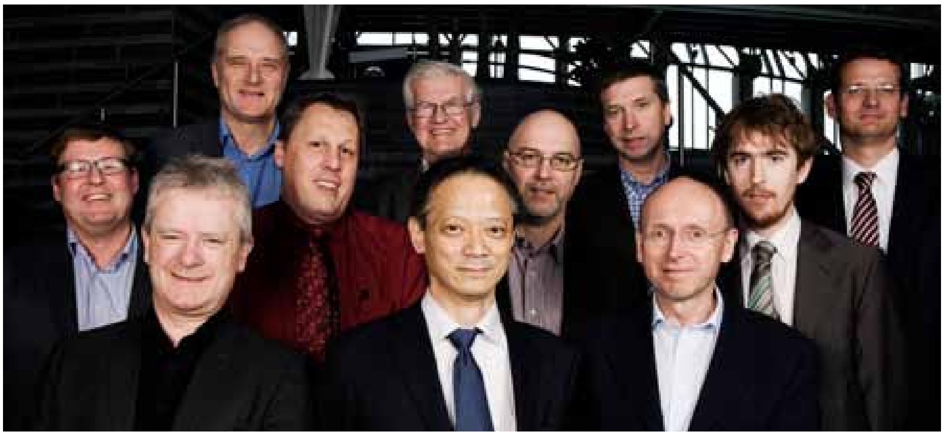
The Board

- Karl Vincent Høiseth, Professor/Head of Department, Department of Structural Engineering, NTNU (Chairman)
- Thomas Hambrecht, Head of Functional Design, MLB, Audi AG
- Torstein Haarberg, Executive Vice President, SINTEF Materials and Chemistry
- Håvar Ilstad, Principal Researcher, Statoil
- Helge Jansen, Senior Vice President, Hydro Aluminium
- Helge Langberg, Head of Research Department, Norwegian Defence Estates Agency
- Per Kr. Larsen, Professor Em., Department of Structural Engineering, NTNU
- Joachim Larsson, Manager, Structural Technology, SSAB
- Jürgen Lescheticky, Head of Process Functional Design Layout Body, BMW Group
- Kenji Nakaya, Senior manager, Toyota Motor Europe
- Sigurd Olav Olsen, Director of Transport Supervision, Norwegian Public Roads Administration
- Tore Tryland, Adjunct Professor. Advanced Development, Benteler Aluminium Systems
- Eric Vaillant, Head of Analysis and Material Behaviour Department, Renault
- Astrid Vigtil*, Head of Research Section, Faculty of Engineering Science and Technology, NTNU

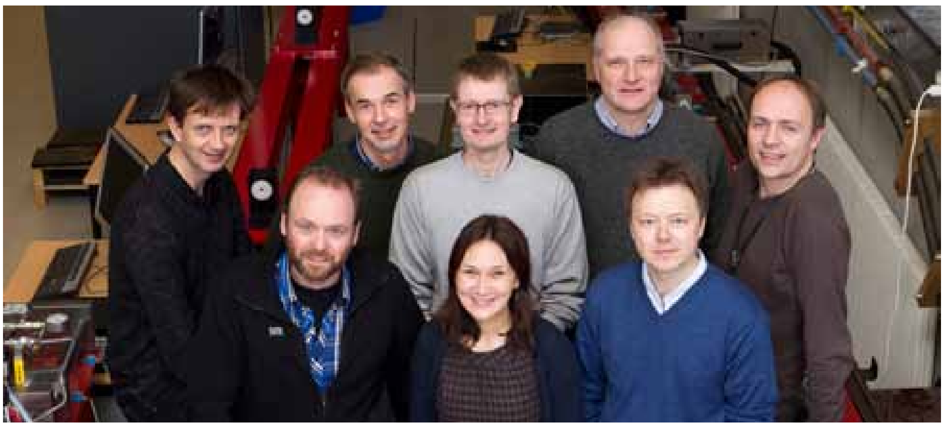
* Replacing Ingvald Strømmen, Professor/ Dean, Faculty of Engineering Science and Technology, NTNU



Structure of organization in 2011.



Partners and members of the Board. From left: Håvard Ilstad (Statoil), Torstein Haarberg (SINTEF), Magnus Langseth (SIMLab), Jürgen Leschetícky (BMW Group), Per Kr Larsen (NTNU), Koushi Kumagai (Toyota Motor Europe), Eric Vaillant (Renault), Helge Langberg (NDEA), Helge Jansen (Hydro Aluminium), Enda Haran (Toyota Motor Europe), Thomas Hambrecht (Audi AG). *Photo: Benedikte Skarvik*



Core team and programme heads. From left: Arild Holm Clausen, Arve Grønsund Hanssen, Øystein Grong, Aase Reyes, Odd Sture Hopperstad, Magnus Langseth, Tore Børvik, Odd-Geir Lademo.
Photo: Ole Morten Melgård

Centre Director

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

Core Team and programme heads

- Tore Børvik*, Dr. ing., Norwegian Defence Estates Agency
- Arild Holm Clausen, Professor, Department of Structural Engineering, NTNU
- Øystein Grong, Professor, Department of Materials Technology, NTNU
- Arve Grønsund Hanssen*, Dr. ing., Impetus Afea AS
- Odd Sture Hopperstad, Professor, Department of Structural Engineering, NTNU
- Odd-Geir Lademo*, Dr. ing., SINTEF Materials and Chemistry
- Aase Reyes, Professor, Department of Structural Engineering, NTNU

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

Other key personnel

- Peter Karlsaune, Centre coordinator
- Laila Irene Larsen, Accounts secretary
- Trond Auestad, Engineer
- Tore Wist, Engineer

Peter Karlsaune – Centre coordinator.
Photo: Ole Morten Melgård

Scientific Advisory Board

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

- Professor Klaus Thoma, Ernst Mach Institute, Germany

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

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

Cooperation and interaction between partners
The annual work plans for each programme were defined with contributions from each partner. Scientists from NTNU and SINTEF and PhD candidates and post docs have been the main contributors to perform the work, while each industrial and public partner has participated based on their defined contribution in kind. The contributions in kind for NPRA and Audi are mainly taken care of by PhD candidates working half time at the Centre and half 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. The cooperation and spread of information within the main research group (NTNU and SINTEF) and between the industrial partners and the research group has been based on using programme and project meetings as well as seminars.

Programme and project meetings: Once a week the Centre director has had a meeting with the programme heads and the core team members. These meetings are used to coordinate the activities in the research programmes and to ensure that the progress and cost plan as well as the deliverables are in accordance with the defined annual work plans. In addition, specific project meetings were held within each research programme when necessary with participation from all involved partners. In this context the *Polymers* programme organized a seminar in Munchen in October 2011 where Statoil, Audi, Renault and Toyota Motor Europe were present. The seminar resulted in an agreement regarding future research as well as common demonstrators to validate the developed polymer model. The project meetings were also supported by telephone meetings with our international partners 1-3 times a year. In order to strengthen the spread of information within the Centre, a seminar was held each second week including a short presentation of a research topic by one of the Centre members (professors, scientists, PhD candidates and post docs).

Annual SIMLab seminar March 2011: The annual SIMLab seminar with participation from all partners was hosted by Statoil Research Centre in Trondheim on 17-18 March 2011. Senior Vice President Karl Johnny Hersvik bid welcome with an overview of the Statoil company as well as presenting some of the research challenges in the offshore industry. He especially mentioned the innovative transfer of technology in the Centre between the automotive and offshore industry with respect to material behaviour and modelling. The partners are using the same computer codes with the same material models, but for different applications.

An introduction to each research programme was given by the programme heads followed by selected topics presented by the PhD candidates and post docs. As during previous seminars the participation of the Scientific Advisory Board was very important and their questions and subsequent discussions were good training for the PhD candidates. All partners as well as the Scientific Advisory Board were pleased with the progress and obtained results.
It is worth mentioning that the Scientific Advisory Board in their report stated that they were *"impressed with the maturity of the presentations given by the students"*.

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

SIMLab seminar at Statoil Research Centre 17–18 March 2011

Photo: Benedikte Skarvik

K. J. Hersvik

G. Gruben

H. Ilstad

Seminar participants


J. Lescheticky and K. Thoma


F. Moussy, D. Embury and E. Vaillant


D. Embury and J. Hutchinson


A. Saai, H. Moe, A. S. Ognedal and Aa. Reyes


K. Pedersen and S. Dumoulin


G. Gruben, A. Strating and O. Knoll

The verdict

At SIMLab, we take pride in what we do. We love our work and think we're quite good at it. Still, one's own judgment can never compare to that of others.

This year we present five of our partners. We have also asked them to describe what it is like to work with SIMLab and give their opinion about us.

Their verdict covers the next 13 pages.

Text: Albert Collett

Photo: Ole Morten Melgård

Audi

NPRA

Hydro Aluminium

NDEA

Statoil

NDEA: Norwegian Defence Estates Agency
NPRA: Norwegian Public Roads Administration

Popular partner

SIMLab partner Audi wrote history in 2011. Never before have deliveries increased so sharply. 1.3 million cars were sold, revenue rose to 44 billion euro and its operating profit was over 5.3 billion euro.

It would be a far cry to give SIMLab all the credit. On the other hand, it is always pleasant when your partners succeed. This is not only because of success itself, but because of the sign that your partner represents high quality and high professional standards. Such things matter. They have a tendency to reflect on you.

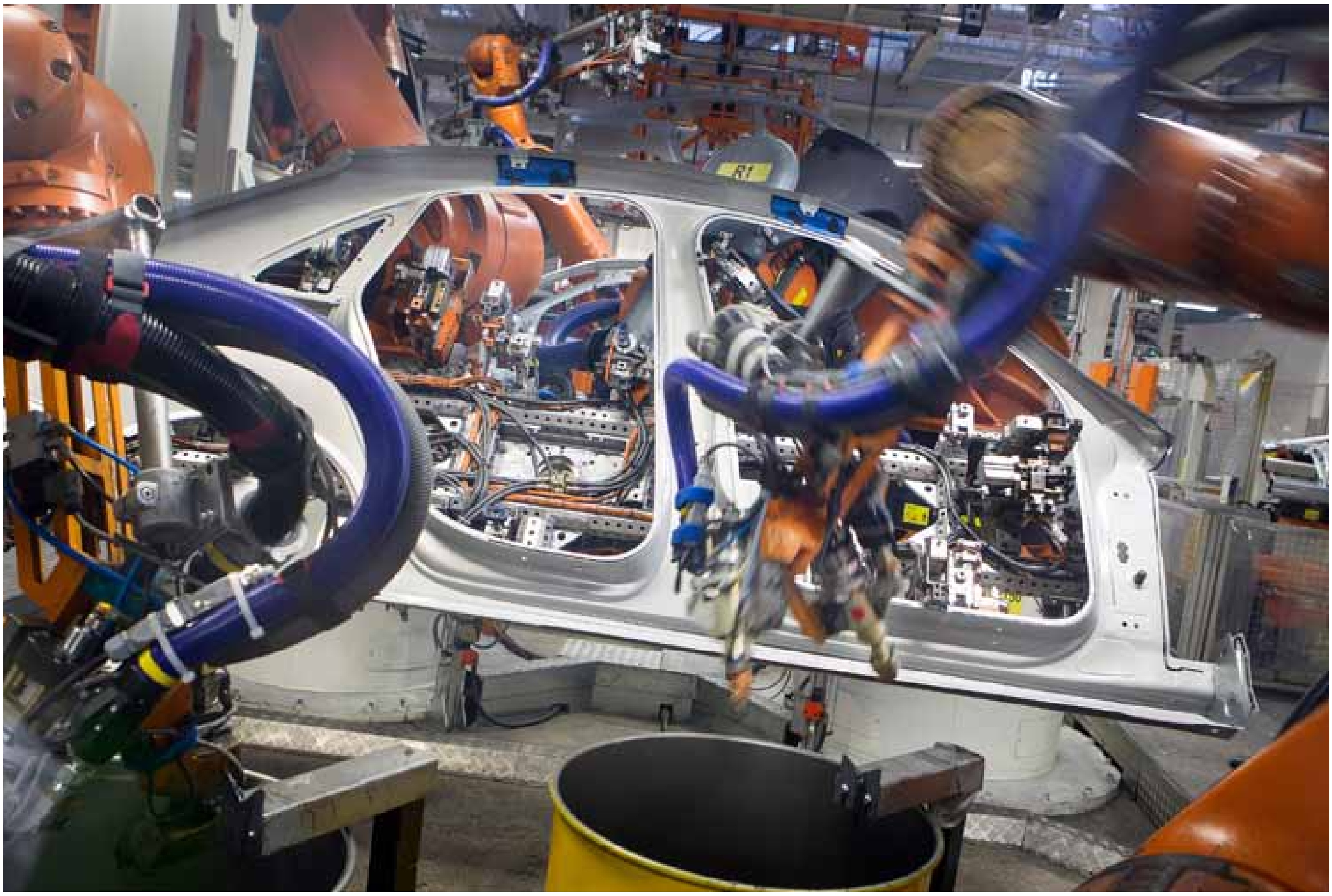
Fascinating figures

Sometimes, statistics are fascinating reading. Last year's Audi deliveries by region are a good example. For example, the figures tell us that one in four Audis were delivered in China and that sales in China are almost three times as high as in the US. We all know which markets are on the rise and can draw our own conclusions. One of Audi's own conclusions is the construction of a new plant in South China, ready for production next year.

Contrary to the image created by the European crisis, it is also fascinating to note that Audi will hire more people in Germany this year. An additional 1200 experts will join the team, in particular in the future-oriented fields of lightweight construction and electric mobility. It goes without saying that some of the lightweight specialists will become familiar with SIMLab in the years to come.

Lamborghini

More facts: in addition to the German factories in Ingolstadt and Neckarsulm, Audi has production plants in Hungary and Belgium. Audis are also built at VW Group (VAG) factories in Slovakia, Spain, China and India. Then, of course, there is the Lamborghini, Audi's Italian subsidiary, which is built in Italy.



Corporate executives Thomas Hambrecht, left, and Dominic Seibert inside the Audi factory in Ingolstadt, Europe's largest industrial site, with 38 000 employees.

Aluminium pioneers

Without a doubt, Audi is the aluminium pioneer of the car industry. The presentation of the Audi Space Frame (ASF) in 1993 established this fact. Developments since then have served to strengthen the status further.

The ASF was an outstanding innovation: it made use of entirely new construction principles that amounted to far more than mere substitution of aluminium for steel as the structural material. The Audi Space Frame principle created a high-strength aluminium framework into which the larger sheet aluminium elements were integrated and performed a load-bearing function. The extruded aluminium sections of the frame were linked by pressure die-cast nodal elements.

40 patents

New manufacturing technologies had to be developed for the new construction principle, and also improved light alloys and process techniques. In addition to welding and adhesive bonding, self-piercing rivets were used as a joining technique for the first time in the automobile manufacturing industry. More than 40 patents and patent applications are ample evidence of the novelty of the ASF concept. In 1994, after the Geneva Motor Show, the ASF concept car was translated into series-production form: the Audi A8 with its all-aluminium body celebrated its world premiere – a milestone in automobile construction.

Wider repertoire

The ASF and A8 were both produced at Audi's plant in Neckarsulm, where the company set up its Aluminium Centre. Today's A8 is still produced in the same place. However, a lot has happened since 1993. The new A8 is a lot more influenced by the present Audi philosophy, "Put the right material in the right place". The aim is still to reduce weight, but with a wider repertoire, including polymers, magnesium and composites.

As far as aluminium and polymers are concerned, SIMLab is an important contributor to the developments in Neckarsulm.

Outstanding

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

As you can probably tell from the quote, this is not a piece of highly critical investigative journalism about either Audi or SIMLab. Still, the quote is genuine. It comes from two of Audi's key research executives.

Thomas Hambrecht is the head of functional design, including crash simulations and ride comfort. Dominic Seibert is in charge of pedestrian safety.

Huge

There's more. "In addition to the excellence, the relation with SIMLab is very personal and pleasant", they add.

While Thomas Hambrecht spends half his time in the more aluminium oriented plant in Neckarsulm, Dominic Seibert is permanently placed in Ingolstadt, where we met them both. The place is impressive. Although you cannot see it, just knowing that you are in the middle of the largest industrial site in Europe, totalling 38 000 employees, is enough to overwhelm anyone.

Crisis? What crisis?

Entering one of the factory buildings is like walking into a sci-fi cartoon from the old days; robots everywhere, performing the most impressive operations. Indeed, their versatility has helped Audi avoid layoffs during the last crisis in 2009/2010, since the robots don't depend on receiving whole series of the same model. As we watch, there are changing models passing by all the time. This way, Audi has been able to produce exactly the cars that have been ordered and there are no parking lots outside with unsold cars. On the contrary, they have problems keeping up with demand. As we enter the new vehicle pick-up, new clients seem to receive their keys and drive proudly out of the gate every three minutes.

Listen! Audi!

Today, Audi is part of the VAG family, the other members being Volkswagen, Skoda, Seat, Bentley, Bugatti, Lamborghini and Scania.

It all began with August Horch, born in 1868. At the age of 28, he started working for Karl Benz. Three years later he set up his own business and the first Horch car was built in 1901. Eight years after that Horch fell out with his co-owners and left the company to form a new one.

Hark! Listen!

Since the rights to the Horch brand remained with the old company, August Horch was forced to find a new name. The idea of using the Latin imperative form of his own name came from the son of one of Horch's business partners. The boy was well-versed in Latin and had overheard the discussion about the search for a new company name. So that was the solution: Horch, which means hark or listen in German, became Audi.

Long-lasting
Audi's relation with NTNU started long before SIMLab started, in the days when Audi decided that lightweight structures were the future. To start with, it was very much about aluminium. Nowadays, the strategy is to put the right material in the right place.

"The genius of the NTNU facilities was the combination of first class technology in their crash test lab, the possibility of performing modelling and simulations, and the scientists with the skills to do so. When you have researchers on the one hand and industry on the other, technology transfer is a major challenge. You need a coupling piece. In our case that is a unit that can perform large component tests. SIMLab can", says Thomas Hambrecht. His own cooperation with SIMLab goes back many years and he gladly elaborates on the dynamic characteristics of his partner.

Not pure science
"SIMLab isn't pure science. They are happy to receive our requests and do something about them although they don't strictly belong to the programme. So we can ask: can you make a software tool to visualize the simulation, and they will do so.

This ability to combine theory with application, to have contact with MIT as well as good companies, is worth a million. We know they are thought highly of in France, we know that the University in Aachen seek their collaboration and in our case we're doing a double PhD with them at the moment."

Recruit, recruit, recruit
Tracking and attracting the best people is a challenge since time immemorial. For Audi, SIMLab comes in useful here, too. PhD candidate Andreas Koukal, who works with pedestrian protection at the SIMLab/Audi programme, has brought in several students who want to take their master's degrees. This makes Dominic Seibert happy. He has already employed two of them.

Their activities in Seibert's department could be life-saving. This is where they study what happens in pedestrian accidents. Normally people are hit at leg height by the front of the vehicle and fall onto the bonnet and windscreen. The composition of the bumper matters, obviously. What is under the bonnet also matters. If the distance between the bonnet and the engine is too small, injuries could become more serious.

This is only one of the dilemmas Seibert's department faces: the constant wish for lower weight and more aerodynamic shapes may literally collide with the need to protect the pedestrian. Challenges are plentiful for the team and therefore also for the research done in collaboration with SIMLab.

Hambrecht's design work is an equally central part of the cooperation. One element here is the use of extrusion, where every part is given a unique geometry. Another is the development of new alloys. Here the tests, modelling and simulations by SIMLab are important elements in the work to obtain the optimal properties. The hunt for reduced weight is constant, not the least because of the ever increasing use of electronics. They weigh.

The CO_2 element is a constantly present parameter. This includes the development of electric vehicles, since their driving radius will increase and consumption decrease the lighter the vehicle is.

"The nice part of this fact is that CO_2 savings can refund the material price and thus make the vehicle affordable", Thomas Hambrecht sums up.

Conclusion: it is very likely that Audi and SIMLab will continue to cooperate in the years to come.

The surroundings are impressive at Hydro Aluminium's production plant in Sunndalsøra, Norway, where Senior Vice President (SVP) Helge Jansen visits regularly.

The place to be

If you want to serve the car industry, what could be better than teaming up with four of the world's leading manufacturers?

Hydro Aluminium certainly wants to serve the car industry. They do so already. A third of their production goes into cars and transportation. Moreover, every third European car contains aluminium from Hydro Aluminium. With such a market position it goes without saying that close links with the industry are fundamental.

"SIMLab give us just that; a unique possibility to understand and influence key producers", states Hydro Aluminium SVP Helge Jansen.

Brand name

As a SIMLab partner, Hydro Aluminium has had close connections with co-partners Audi and Renault for a long time. Last year, BMW and Toyota joined the team.

"This only goes to confirm that SIMLab has developed into a brand name. The most prestigious players in the business want to contribute and reap the benefits from a top class research unit. Being in there with them gives Hydro Aluminium a stronger market position. It also increases our possibilities for input", comments Jansen and goes on:

"SIMLab are good at producing knowledge as well as the use of knowledge. They bring forward models and material data of great interest and they are good at communicating their achievements. The atmosphere at SIMLab is full of energy, knowledge, creativity and good spirit. It's a good place to recruit."

Project with Audi

At the moment, Hydro Aluminium is engaged in their closest cooperation with Audi so far. The topic is aluminium with highly increased strength. This confirms not only Audi's continued dedication to aluminium as a key ingredient in keeping down the weight of their cars; it also illustrates broader interest in aluminium in the business and society as a whole.

This interest is, of course, shared by Hydro Aluminium in numerous ways. For example in an office at the headquarters in Oslo there is a huge wall-chart. The theme is an ambitious EU project to increase aluminium as a basic component in the car industry. The potential weight loss is 38 per cent, which would make a huge impact on the CO_2 statistics. Hydro Aluminium is one of many European partners in the project.

As a side effect, such ambitions trigger the fantasy: Hydro Aluminium CEO Svein Richard Brandtzæg openly admits a boyish dream to drive an all-aluminium Audi A6.

At the crossroads

In 2009, when Hydro sold their bumper division to Benteler Aluminium Systems, the question arose whether to keep up the partnership with SIMLab or not. Initially, the field of interest had been very narrow, restricted to bumper quality only.

"We're glad we decided to go on. SIMLab have been good at involving us in their findings, letting us see ever new possibilities for broader use of knowledge. They constantly come up with spinoffs pointing towards new projects and areas", says Helge Jansen.

As you read this, Hydro Aluminium has a professor from rolling systems at the R&D centre in Bonn, Germany, working with SIMLab. As is a professor in model development in Sunndalsøra, Norway, as well as people from Hydro building systems in Ulm, Germany.

Anti-terror

One new area was dramatically put into perspective on July 22nd last year, a date that changed Norway forever. The image of a small and peaceful country was literally blown away by terror. By then Hydro Aluminium and SIMLab had already worked for a while on the use of aluminium for protective purposes. Now these activities are going to expand. One field of research is window frames: how can they be constructed in order to improve protection against penetration and blasts? Can the construction help absorb the energy from the threat? What is the ideal design? What type of aluminium is best suited for the purpose? These and similar questions will be investigated in detail through modelling, simulations, investigation of structural behaviour and so on.

Oil and renewables

Energy is not only about reducing emissions, it is also about production. Offshore wind turbines and oil rigs in Arctic waters are two areas with large potential for aluminium. For instance, steel can become brittle when it gets really cold while aluminium retains its qualities.

Recirculation and new alloys is another, major challenge. Although 22 per cent of the aluminium used in the world is recirculated, this is a delicate matter. The present use of steel rivets in aluminium cars is but one of many examples that complicates matters.

There is potential for huge savings both financially and for the environment.

Internal challenge

Hydro's greatest challenge in cooperating with SIMLab is an internal one:

"Spreading the knowledge about the qualities of our cooperation, reaching the right people with the right kind of information within a worldwide organization, making sure the sales people know what the researchers have found out, taking advantage of our expertise when we market ourselves, all these are constant challenges. But then, they are also inspiring challenges", says Helge Jansen.

HYDRO ALUMINIUM IN A NUTSHELL

- Based in Norway.
- Global supplier of aluminium.
- Employs 23 000 people in more than 40 countries.
- Revenue 2010: NOK 75.7 billion.
- Activities throughout the value chain, from bauxite extraction to the production of rolled and extruded aluminium products and building systems.

After the terror

Prior to last year, few people apart from those involved with Norwegian defence knew much about the protection and security expertise of the Norwegian Defence Estates Agency (NDEA). July 22nd changed all that.

"The attack clearly made us more sought after", says Helge Langberg, head of research and development at NDEA. No wonder. Looking for better ways of protecting people and property is one of the many aspects in the multi-faceted process Norway is going through in the aftermath of the terror last summer. Today, other governmental agencies and companies are finding cooperation with NDEA's experts useful.

No small business

NDEA is Norway's largest property manager, taking care of land, buildings and installations all over the country. It is a civilian body working under the Ministry of Defence. Within its realms are such diverse properties as the historic fortress of Akershus in the centre of Oslo and the Norwegian camp in Meymaneh, Afghanistan. NDEA plan, develop, construct, lease and sell buildings and properties, they have an environmental department working on limiting the noise, air and ground pollution from defence training and activities, as well as lawyers looking after a myriad of agreements. Then there is protection, security and research.

External expertise

Helge Langberg's research and development department is not very large, according to him. The department has ten scientists and engineers, but covers a wide range of research areas.

"Because of that, we also need external national and international organizations and experts. In the university arena, SIMLab is our key partner", he says.

NDEA's main focus is the buildings and properties belonging to the Norwegian defence. However, 2011's massive attack has forced added attention to protecting possible civilian targets. Attention had already been given to this area, but now NDEA works more closely with governmental organizations outside the defence sector.

Look at the board

"To us, SIMLab is valuable because of their top class competence in the field of impact and their ability to produce numerical models and simulations. Such models are required in our numerical simulation work regarding the response of structures to explosions and penetration, and in the development of security and protective measures. It is part of our strategy to use external partners to obtain this kind of competence.

The quality of SIMLab's work is very high. So is their rating internationally. They have therefore attracted some of the top international experts and professors to their scientific advisory board. SIMLab has developed into an international player to reckon with in their field", says Langberg.

New professorship

The cooperation with SIMLab is important to NDEA also for recruitment reasons, including candidates who will go on to join private consultancies, as NDEA will need their future services.

"We need to attract students' attention to our areas of work. One of these is structures subjected to dynamic loads. We perform small- and full-scale tests, we analyse, we work on concepts and methods for limiting the effect of accidents and terrorist attacks, but we can do nothing unless we have people with the right kind of expertise.

In order to generate interest, we have to make sure the relevant topics are covered in the universities. We must also have people there to attract attention to these topics. That is one of the reasons that the cooperation with SIMLab is important for us. We have had one of our scientists as part of the SIMLab team for a long time. When he was appointed professor in a new professorship at SIMLab from January 2012, he will continue to have focus on topics of importance to us.

The covered central office building of the Norwegian government is a solemn monument after July 22nd last year. The attack has given new challenges to NDEA head of research and development, Helge Langberg.

The new professor knows the academic environment he will work in extremely well. He defended his doctoral thesis at NTNU, has worked there ever since, has been a vital part of SIMLab for years and has very good links to the rest of the academic area.

In his new position he will be able to develop tasks that will be interesting both to us and the students. We're happy to say that this has been a successful strategy also in the time leading up to the new professorship", says Langberg.

Long-lasting

NDEA and SIMLab have worked together for a number of years. As an example, a lightweight aluminium shield against bullets and explosions to be used as add-on protection for containers in foreign military operations has been jointly developed.

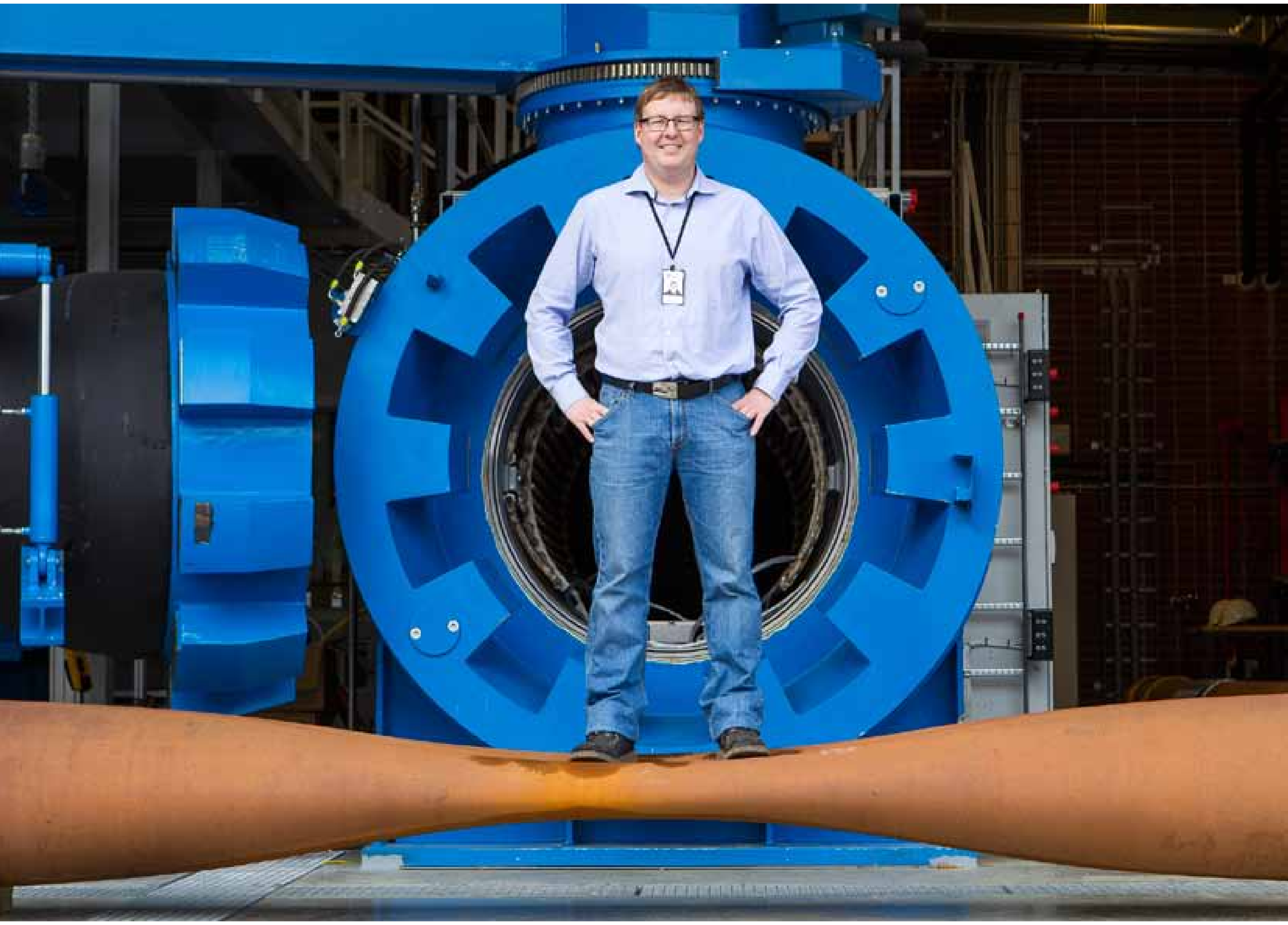
"We look to SIMLab for basic research. We are more concerned with the application of the findings. SIMLab's competence is complementary to that of our scientists and engineers, and we certainly hope the cooperation will go on beyond this project period", says NDEA's head of research and development.

NDEA IN A NUTSHELL

- 1375 employees.
- Revenue 2010: NOK 6.3 billion.
- Manages 325 000 acres of land.
- Leases, operates and maintains 13 400 buildings and facilities for the Armed Forces.
- Develops, builds and rehabilitates.
- Sells property that is no longer needed.
- Provides special expertise in security, protection, fortification, cultural heritage management and environmental services.

Costly anchors

Last year's annual report told the story of a fascinating picture. An image of fish investigating a pipeline. The pipeline was deformed. It had been hit by an anchor; the kind of nightmares that keep Statoil's Håvar Ilstad busy, if not awake.



Dr Håvar Ilstad outside the pressure vessel at Statoil's research centre in Trondheim. The pressure it delivers is sufficient to collapse the pipeline Dr Ilstad is standing on.

"Worse still are trawls", he admits. "They get heavier by the day and represent a formidable challenge. We have an absolute condition from the regulatory authorities that pipelines should survive any impact from fishing equipment. It's a constant driver in our work to improve their design."

Billions

Luckily, the fascinating picture is from the only major incident of its kind in Norwegian waters. The repair work took half a year and cost billions in lost revenues. The spill was minimal, but the damage was too serious to go on as if nothing had happened. Next time, Håvar Ilstad hopes the pipeline has the characteristics to avoid a full stop.

That's SIMLab country. Statoil is a key partner and SIMLab's research is fitting very well into Statoils R&D programme for pipelines. The topic is testing and modelling of fractures, how to predict them, what properties a polymer or steel pipeline should have.

The verdict

Håvar Ilstad is today working at the Statoil research centre in the Pipeline technology department and certainly a demanding customer. Ilstad is very satisfied with the research cooperation and says: "SIMLab has the best available competence when it comes to the coupling of material technology and analysis and the coupling of material understanding and construction. Up till now, construction and materials have lived separate lives. There's been a missing link. With SIMLab's help the two worlds are closing in on each other to create physically based material models. SIMLab is at the forefront of this development."

Generic

And he goes on: "The other really good thing about SIMLab is that they are generic. They develop tools we can start using commercially right away. They deliver results in the form of products that we can pass on, like software or ready-to-use test procedures.

We can tell them about a supplier that might need a helping hand, and they will help. The people at SIMLab are enthusiastic, brave and honest. Their approach is fabulous. They move forward step by step in their quest for physical understanding, working their way down. This gives us results and added value at a very early stage."

Able to listen

Statoil's interim evaluation of SIMLab delivered to the Research Council of Norway was not entirely filled with top scores. It was very positive all in all but also had some critical remarks.

"One of the weak points in our opinion was SIMLab's ability to communicate professional challenges that were common for the participating partners. But again I'm impressed. They have been very good at improving their performance after we presented this criticism. They really listen", Ilstad says.

Look, we are partners

SIMLab's performance benefits Statoil in many ways. One is the constant upgrading of the company's own consultants. Thanks to their partner, they know the state of the art and what to ask of their suppliers. This serves the suppliers in turn. The effect from spinoff projects is substantial. The CRI partnership also gives Statoil access to a lot of ideas they wouldn't have come across otherwise, e.g. from the automotive partners in the Centre.

"We have learnt a lot from the car industry's demands towards their suppliers", Ilstad confesses. He's not sad about SIMLab's good overall reputation, either.

STATOIL IN A NUTSHELL

- Based in Norway.
- Norwegian state majority owner.
- 21 000 employees in 36 countries world-wide.
- Revenue 2010: NOK 530 billion.
- The world's 13th largest oil and gas company, and the largest company in the Nordic region.

What happens afterwards?

Imagine an accident. A car hits a safety barrier. What happens after the crash depends on a lot of factors: the speed, direction and weight of the vehicle and the properties of the barrier, to name but a few.

This is where the Norwegian Public Roads Administration (NPRA) comes in. They are responsible for an important part of traffic safety. Their overall view is that roads, streets and vehicles must be much 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. Due to this NPRA contributes to the development of new knowledge and wants to facilitate the work of educational institutions so that they can implement programmes to ensure academic quality and recruitment to the NPRA.

Impressed

"When we first heard about the plans for SIMLab, we could see quite easily that it would be a good idea for us to join", says NPRA Director of Transport Supervision, Sigurd Olav Olsen:

"SIMLab is a good meeting place for the industry and public authorities like ours. Working together provides a basis for synergies and this potential has increased as SIMLab has been able to attract more partners. For us, this partnership is a big advantage also because it gives us a common technology platform and common tools in the analysis of accidents", he adds.

SIMLab's resources when it comes to tests, modelling and simulations are also extremely cost-effective as opposed to the full-scale tests of the past. This includes the analysis of accidents. As an example, new insight is gained in optimal procedures that may eventually lead to new legislature concerning responsibility.

As the present programme draws to a close, Olsen sums up his experience with SIMLab like this:

"I'm impressed by the achievements of Professor Langseth and his team. He takes great interest in his work, shows a lot of enthusiasm and is constantly eager to promote further development."

Complex

For the time being, NPRA finances a PhD candidate working with the properties of the steel bolts used in safety barriers. An optimal barrier should work like a hammock; gently containing and redirecting the vehicle back onto the road without bouncing it into the oncoming lane. To achieve this, the bolt has to break at exactly the right moment to obtain the hammock effect.

Potentially life-saving as they may be, the bolts are of course a tiny fracture of the overall traffic safety picture. NPRA takes the position that all aspects can be improved.

"To us, of course, the safety barrier isn't the root of the problem. The technology of the vehicles is constantly developing, deformations are not what they used to be, speed can be traced more easily; the whole picture is extremely complex. The point is that we certainly belong to this picture and want to be part of it", Olsen says.

Crucial in recruitment

In Norway, engineers are in constant demand. NPRA is only one of the many institutions affected. Competition is fierce to

Director of Transport Supervision at NPRA, Sigurd Olav Olsen, needs SIMLab to recruit top engineers. There's a lot that can be done to make traffic safer.

recruit the most competent candidates. One of the obvious reasons why good people are needed is that the many departments of NPRA will be unable to make satisfactory regulations if their staff is not highly qualified and understand the challenges they face. This is an important reason alone for supporting Norwegian universities and is why NPRA has a special unit working to serve the universities and sponsor candidates and projects.

Cooperation

NPRA collaborates with corresponding authorities in other countries:

"In this international environment we interact in modelling and analysis of accidents. We often notice how our contribution is valued and taken into consideration when we send our best people. It is also noticeable how a PhD is received with added respect in international forums. More than once has this has given us surprisingly good results", Sigurd Olav Olsen observes.

NPRA IN A NUTSHELL

- 7 000 employees.
- Revenue 2011: NOK 36 billion.
- Plans, builds and maintains 57 000 km of public roads.
- Registers vehicles.
- Issues driving licences.

Research programmes and demonstrators

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

Fracture and Crack propagation (F&CP)
Programme head: Odd Sture Hopperstad

Introduction
In the F&CP programme, mathematical models and numerical algorithms for damage, fracture and crack propagation in ductile and semi-brittle materials are developed and validated against laboratory tests. The materials considered are rolled, extruded and cast aluminium alloys and high-strength steels. In 2011, projects have been running within the following research areas:

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

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

Numerical aspects of fracture and crack propagation (study by Gaute Gruben, PhD candidate)
The fracture characteristics of a cold-rolled, high-strength steel sheet (Docol 600DL) have been established under quasi-static loading conditions using several different test set-ups. Optical field measurements with digital image correlation were used to determine the strain fields to fracture. An extended version of the Cockcroft-Latham fracture criterion, denoted the ECL criterion, has been developed and calibrated to the fracture properties of the steel sheet. The ECL criterion was shown to give good predictions of the fracture strain for different stress states and has been used in explicit finite-element simulations of ductile crack propagation. The simulation results were compared to experiments conducted on five different types of specimens and the agreement was found to be satisfactory. The force-displacement curves from experiments and simulations and the simulated fracture modes are illustrated in Figure 1 for three of the tests. In these simulations material softening was accounted for and a fine discretization of the geometry was used.

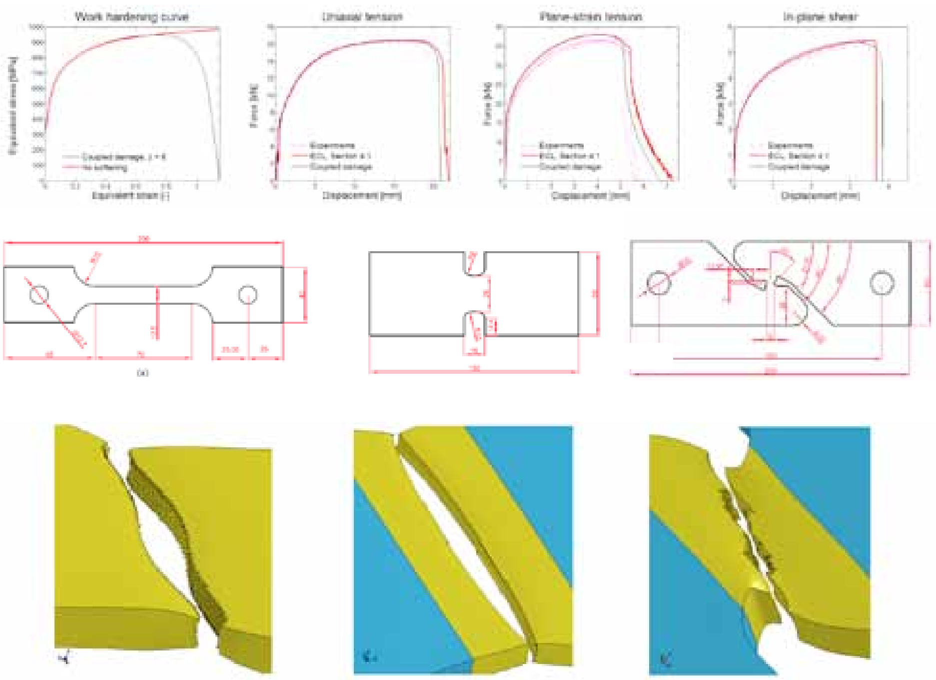


Figure 1 – Experimental and simulated force-displacement curves (top), specimen geometries (middle) and simulated fracture modes (bottom) in uniaxial tension, plane-strain tension and shear, respectively, using the ECL criterion with material softening and fine discretization.

Fracture in age-hardening aluminium alloys – mechanisms and modelling (study by Marion Fourmeau, PhD candidate)
The influence of plastic anisotropy and stress state on the fracture behaviour of a cold-rolled AA7075-T651 aluminium plate under quasi-static loading conditions has been studied both experimentally and numerically. Material tests in different directions of the plate were carried out on specimens with various shapes, providing a wide range of stress states. The material has marked anisotropy in the plastic behaviour, i.e. in strength and plastic flow. Fracture strains and failure modes were found to vary strongly with the stress state, but also with the loading direction. Numerical simulations adopting an anisotropic plasticity model were used to obtain local values of stress and strain at fracture. Owing to the heterogeneous stress and strain fields in the specimens at fracture, it was difficult to accurately determine the location of fracture inside the specimen and thus the fracture strain. Further, it was not possible to construct a unique fracture locus for AA7075-T651, owing to the strong directional dependence of the fracture process. The marked influence of direction on the fracture mode and fracture strain in uniaxial tension is shown in Figure 2.

Fracture in cast materials – mechanisms and modelling (study by Octavian Knoll, PhD candidate)
A detailed material characterization was carried out for an Aluminium High Pressure

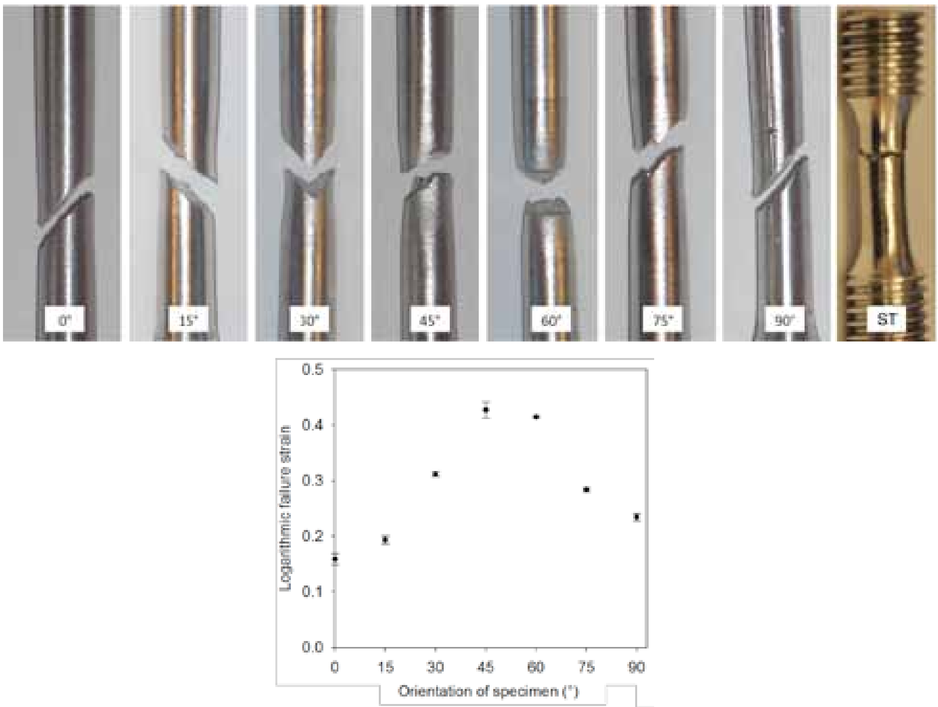


Figure 2 – Fracture modes in tensile tests in different directions with respect to the rolling direction (top) and fracture strain versus specimen orientation (bottom).

Die Casting (HPDC) alloy. Quasi-static tensile tests with specimens cut from a generic HPDC component were performed to analyse the variation of the mechanical properties. Based on this material characterization, the heterogeneity and local scatter of the material properties were determined. The considerable local scatter demonstrated the stochastic character of the ductility of HPDC alloys, which is a result of a distribution of casting defects. Based on these conclusions, a rather simple constitutive model with a stochastic approach to model fracture was established for cast aluminium alloys. Figure 3 presents the results from bending tests of the HPDC component. The large scatter in the force and displacement at fracture is observed, illustrating the stochastic nature of the failure process for the cast aluminium alloy.

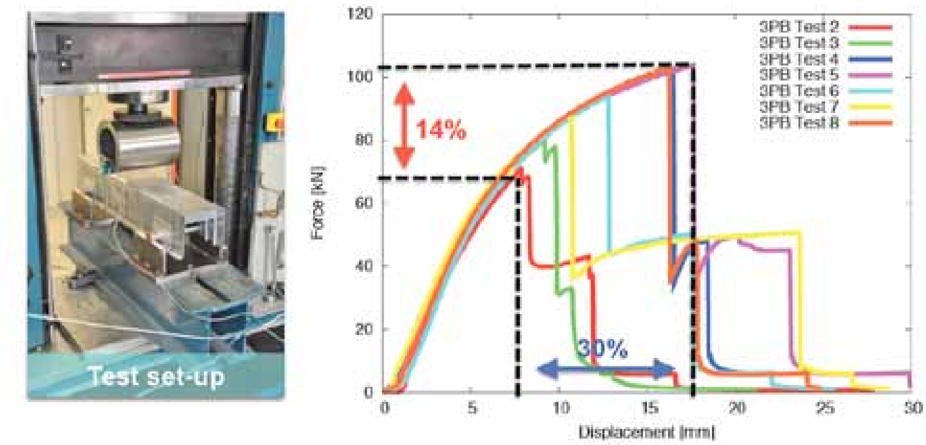


Figure 3 – Bending tests of HPDC component. The test set-up is shown to the left, whereas the right diagram shows the scatter of the force-displacement curves between parallel tests.

Optical measuring techniques (study by Egil Fagerholt, PhD candidate)

Two-dimensional digital image correlation (2D-DIC), incorporating a node-splitting mesh, has been applied to investigate fracture in a small-scale Single Edge Notch Tensile (SENT) test of a pipeline steel. The node-splitting approach proved to be valuable in measuring fracture mechanics parameters such as crack path, crack length, Crack Tip Opening Displacement (CTOD) and Crack Mouth Opening Displacement (CMOD) as well as capturing the discontinuous displacement and strain fields of the cracked SENT specimen. The results from the DIC analysis were compared with traditional clip-gauge measurements, and the agreement was good. Figure 4 illustrates the evolution of the strain field in one of the cracked SENT specimens.

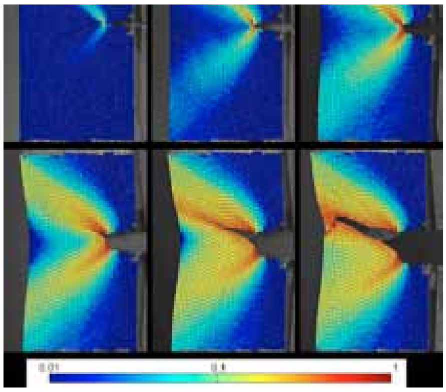


Figure 4 – Evolution of the strain field in a small-scale SENT specimen of a pipeline steel obtained by DIC.

Optimal Energy Absorption and Protection (OptiPro)
Programme head: Tore Børvik

Introduction

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

The main objective with the OptiPro research programme is to be able to design safer, more cost effective and lightweight protective structures for a variety of engineering applications using advanced computational tools. In 2011, the main focus has been on the following research activities; 1) Strengthening techniques, 2) Blast loading using FEM, 3) Light-weight protective structures, 4) Impact loading of high-strength steel components and 5) Impact against pipelines. In the following, only a few selected research activities are highlighted. It should be noted that several sub-projects are carried out within each main research activity, and that there has been a close collaboration between the OptiPro and the F&CR research programmes also in 2011.

Blast loading using FEM
The effect of blast loading on various structures has become more and more important for modern society. Since it is both difficult and expensive to validate protective structures against blast loading experimentally, we have to rely on numerical tools like the finite element method. In 2010, the main focus was on the structural response of a stainless steel plate subjected to the combined blast and sand impact loading from a buried charge. This was done using a fully coupled approach in which a discrete particle method was used to determine the load due to the high explosive detonation products, the air shock and the sand, and a finite element method predicted the plate deflection. In 2011, this technique was further developed and used to simulate a model system assembled by friction stir welding of extruded sandwich panels with a triangular corrugated core made from a 6061-T6 aluminium alloy, see Figure 5, and the results were compared to full-scale experimental tests, Figure 6. The fully coupled simulation approach enabled the relationships between the soil-explosive test charge design, panel geometry, spatially varying material properties and the panel's deformation and dynamic failure responses to be explored. In most of the simulations excellent agreement between experimental tests and numerical predictions was obtained. This work was carried out in collaboration with Impetus Afea and the MURI-project "An Integrated Cellular Materials Approach to Force Protection" in USA.

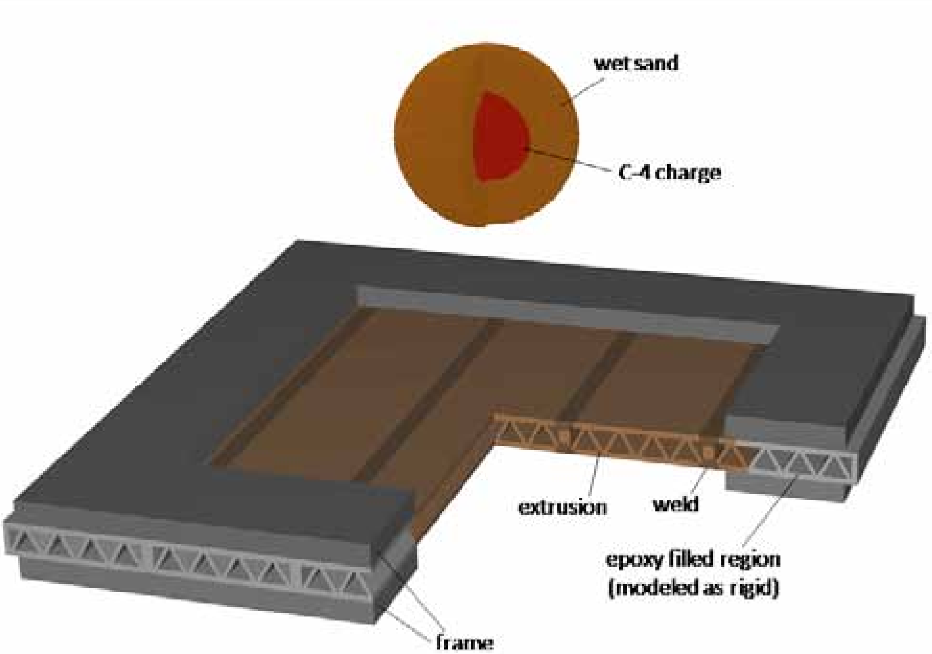


Figure 5 – General view of finite element model prior to charge detonation.

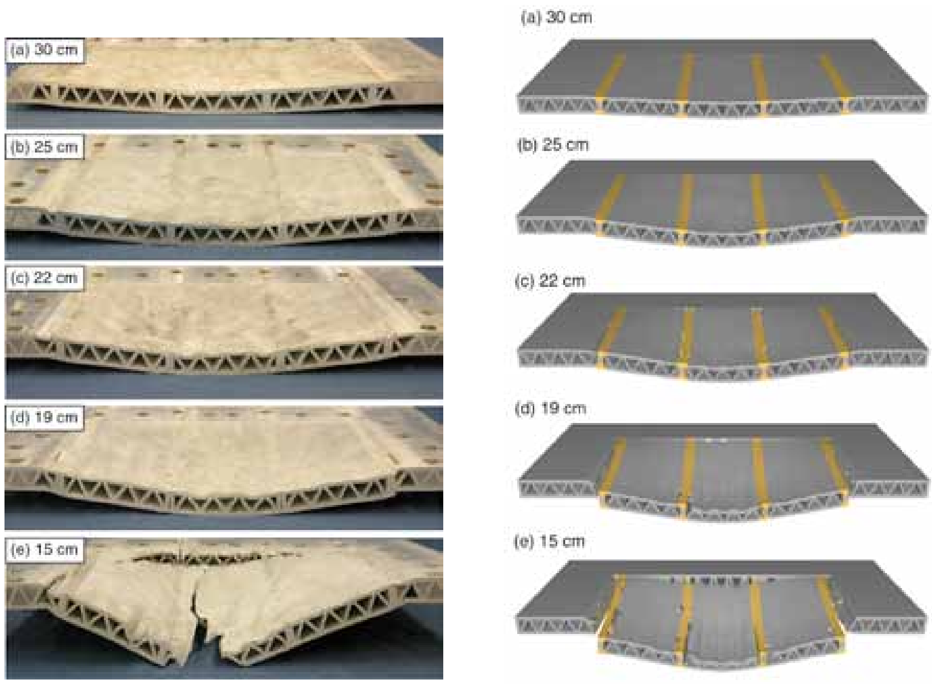
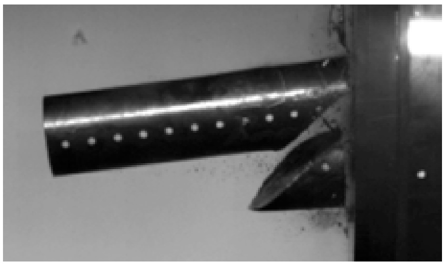


Figure 6 – Deformed experimental and numerical sandwich panel shapes for various standoff distances. The yellow regions mark the HAZ in the finite element models.

Experimental and numerical study on fragmentation of steel projectiles (study by Knut G. Rakvåg, PhD candidate)
During impact and perforation of high-strength materials, the projectile and/or the target may fragment upon impact. When this happens, the projectile loses most of its penetrating ability and the target loses all of its energy-absorbing capacity almost instantaneously. If this is not properly taken into account in computer-aided design of protective structures, severe errors in the prediction of the capacity of the protection may result. Thus, it is very important to understand fragmentation during projectile impact on protective structures.

In this study, the fragmentation of projectiles during impact has been studied both experimentally and numerically using so-called Taylor impact tests. In the component tests, projectiles with various hardnesses were fired into a rigid wall. During impact, the behaviour of the projectile was photographed by a high-speed camera system, and the deformation (mushrooming) and fragmentation as a function of impact velocity and initial hardness were studied. In 2011, quasi-static and dynamic fracture mechanics tests using notched specimens in 3-point bending and instrumented Charpy tests were carried out to determine the fracture toughness of the various projectile materials. The data were used to calibrate cohesive zone models for use with solid elements available in LS-DYNA. It was however found difficult to use cohesive zone models on this particular problem. Figure 7 shows a comparison between an experimental test and a numerical simulation of a Taylor test using a steel projectile hardened to HRC 53. The numerical model utilizes a refined mesh, a random distribution of the material properties from mechanical tests and element erosion. Good agreement between the experimental results and the numerical predictions was obtained. This work will continue in 2012 using alternative numerical techniques (such as node splitting) and additional experimental data.



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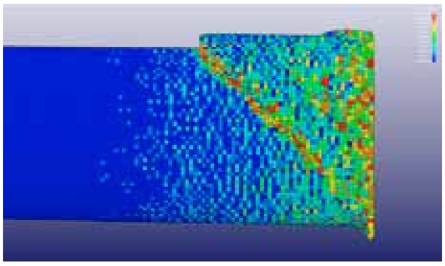


b)

Figure 7 – Comparison between an experimental test and a numerical simulation of a Taylor test using a steel projectile hardened to HRC 53.

Impact against pipelines (study by Martin Kristoffersen, PhD candidate)
During the last few years, discussions have been carried out with the Norwegian offshore industry regarding fundamental research on the behaviour, modelling and design of subsea production systems subjected to impact loads from dropped objects and fishing gear. The discussions have been motivated by the lack of knowledge related to the interaction between the water, the impactor and the structure, and how this will influence the structural response. Thus, a fundamental research programme is needed to explore these issues in more detail in order to ensure that oil production in the future will be safe, reliable and environmentally friendly. Guidelines exist on how to design subsea pipelines in rich fishing areas subjected to interference by trawl gear. Other accidental loads related to marine activities, such as anchor impacts, may also have to be taken into consideration in the design of subsea pipelines.

One topic of special interest for the offshore industry is pipelines first subjected to impact loading before being dragged along the seabed. Such loading scenarios may introduce large global deformations and local strains in the pipe. After impact, the pipe is straightened due to rebound and the axial forces present. The material in the highly deformed zone will experience a complex stress and strain history, which subsequently can cause leakage or full failure.

Impact against offshore pipelines has been studied both experimentally and numerically. The experiments consisted of two steps; first impact and then stretching. Scaled pipes were first impacted in the pendulum accelerator at SIMLab, before stretching the dented pipes in Statoil's laboratory in Trondheim. Both empty and water-filled pipes were tested in 2011, Figure 8. The water-filled pipes were either open or sealed with a steel membrane. Fracture occurred in all pipes during the stretch phase. Material test specimens

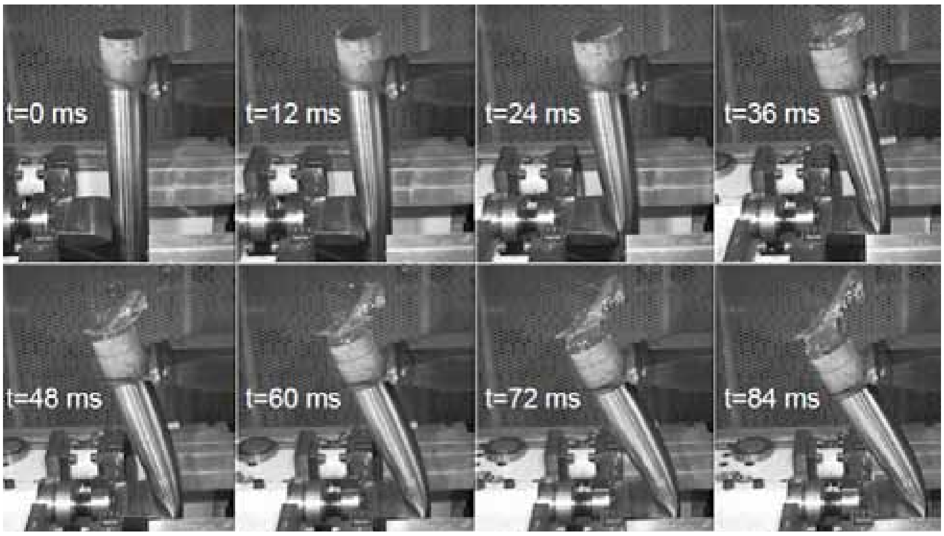


Figure 8 – Impact against an open water-filled pipe.

were taken from the actual pipe wall and tested quasi-statically and dynamically. A constitutive relation, taking isotropic and kinematic strain hardening and strain rate hardening into account, in addition to a simplified fracture criterion, were calibrated for use in the numerical analyses. The pipes were modelled in Abaqus/Explicit using either shells or volume elements, and the experiments were recreated numerically. The global response in the experiments and the numerical simulations agreed very well, but the numerical simulations were not able to predict the fracture accurately. In 2012, the main focus in this project will be on the modelling of the different fracture mechanisms occurring in the impacted zone during stretching.

Polymers (Poly) Programme head: Arild Holm Clausen

Introduction

Polymers are promising for use in several applications. In particular, such materials are light; they may be very ductile and hence have excellent energy absorption characteristics. There are, however, several challenges which call for research. An important one is the lack of robust material models for use in commercial finite element codes. In general, the behaviour of polymers is fundamentally different from the typical response of metals. Some of the features commonly observed for polymers are pressure sensitivity, which means that the material properties are different in tension and compression. They also have a strong dependence on temperature and strain rate.

The main objective in the Polymers research programme is to develop validated material models for polymers subjected to impact. A hyperelastic-viscoplastic model which is suited for numerical simulations involving large deformations and elevated strain rates has been developed in previous years. The main features of this model are illustrated in Figure 9. An important prerequisite and sub-goal is still to establish a set of test methods for material characterization, and generate a database with results from different component tests.

The Polymers programme is mainly separated in three closely related projects running in parallel: (i) Material tests, (ii) Constitutive model, and (iii) Component tests. Three PhD candidates were affiliated to the programme in 2011. Anne Serine Ognedal is investigating deformation and damage in thermoplastics subjected to large plastic strains, and is seeking to explain how the mechanism of void formation within the material affects the response. Marius Andersen started his PhD study in June 2011. His project is concerned with the viscous response of polymers. Finally, Audi has engaged Andreas Koukal as a PhD student. Formally connected to the Technical University of Munich, thus he has a weaker affiliation with SIMLab. He works on fibre-reinforced thermoplastics.

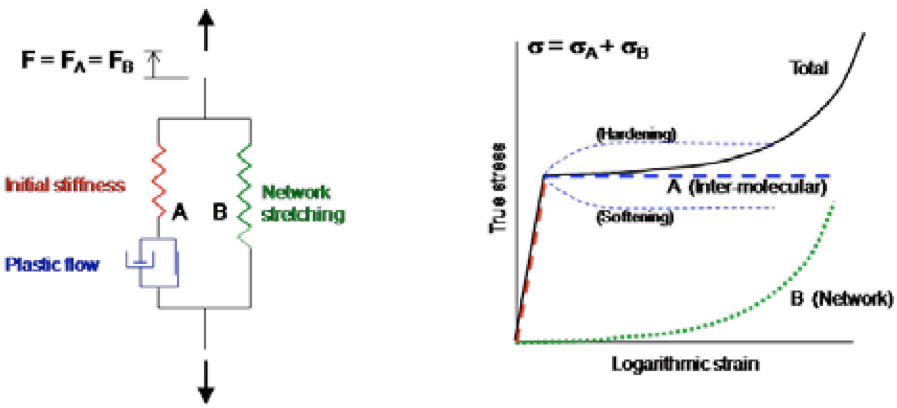


Figure 9 – Outline of the viscoelastic-viscoplastic constitutive model.

Material tests

The material tests serve two purposes. First, they are needed for the determination of the parameters in the material model shown in Figure 9. Calibration of this model requires tests in both tension and compression, and also tests at different strain-rates. The second purpose is to provide a priori information to a model development activity in order to get input about which features a model should cover. As a preparation for the work on a viscoelastic model, two master's students wrote their theses on an experimental study of viscoelastic response of a semi-crystalline high-density polyethylene (HDPE) and an amorphous polyvinylchloride (PVC).

An important task also in 2011 was to continue the study on the mechanisms causing a change of volume. This feature is closely related to growth of voids in the material and a subsequent fracture. It is anticipated that the triaxial stress state has a major influence on the fracture strain. A common technique to study the effect of triaxiality levels in tension is to apply samples with different notch radii. Figure 10 presents such a specimen with a circular cross section with minimum diameter 6 mm and a notch radius of 2 mm. Four different notch radii were explored. The results provide useful information for fracture modelling, and can also be applied in a validation study of the model outlined in Figure 9.

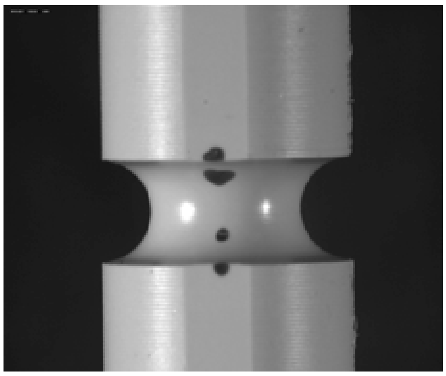


Figure 10 – Notched tension test sample that helps to investigate how stress triaxiality affects the fracture strain.

For an upcoming activity on modelling of fibre-reinforced thermoplastics, some basic information about the response of such materials is also required. This has been a part

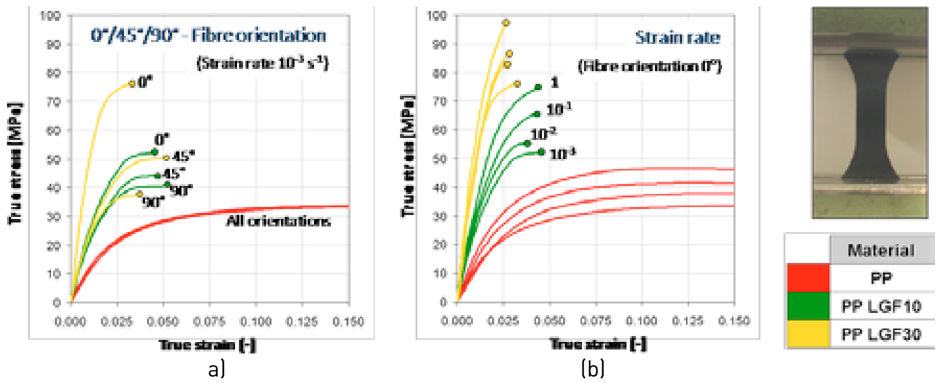


Figure 11 – Stress-strain curves from tension tests on PP with different amounts of long glass fibres (0%, 10% and 30%). (a) Effect of fibre orientation. (b) Effect of strain rate.

of Andreas Koukal's PhD project. A special feature is that this study involves three different amounts of glass fibres, i.e. 0%, 10% and 30%, in the same polypropylene (PP) matrix. Stress-strain curves obtained in tension tests carried out at different loading modes and strain-rate levels are presented in Figure 11. Clearly, a non-reinforced PP is very ductile, while the glass fibres cause rather brittle behaviour. In the tension mode, it seems that the very presence of glass fibres is far more important than the amount of fibres. Although not shown here, the situation differs in compression, where the response of the 0% and 10% cases are much closer to each other.

Constitutive model

A first version of the constitutive model for thermoplastics was published in 2010. It is a hyperelastic – viscoplastic model that captures the typical features of the behaviour for such materials. It has been implemented as a user-defined model in LS-DYNA for brick and shell elements. Some effort has been required in 2011 to transfer the model to PAM-CRASH, which is the finite element tool applied by Audi and Renault. The calibration procedure has been another task.

The model outlined in Figure 9 does not incorporate viscoelasticity. The implementation of a new hypoviscoelastic-viscoplastic model started in 2011. This development continues in 2012, and important activities will be verified and validated.

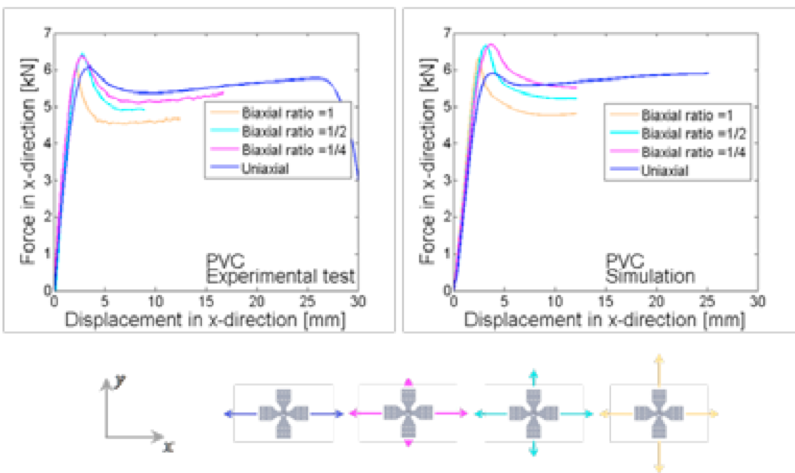


Figure 12 – Biaxial tests on PVC carried out at four different biaxial ratios. Force-displacement curves from laboratory tests (left-hand part of figure) and numerical simulations (right-hand part of figure).

Component tests

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

As an example of a validation study, which is a part of Anne Serine Ognedal's PhD project, Figure 12 compares force-displacement curves from physical and numerical tests involving biaxial tension on PVC. The experimental part of the work was carried out at Laboratoire de Méchanique et Technologie in Cachan, France, while the constitutive model depicted in Figure 9 was employed for the numerical analyses. A major intention with this particular study was to evaluate the choices of yield and plastic potential functions for cases with dominantly tensile loading.

Multi-scale Modelling of Metallic Materials (M⁴)
Programme head: Odd-Geir Lademo

Introduction

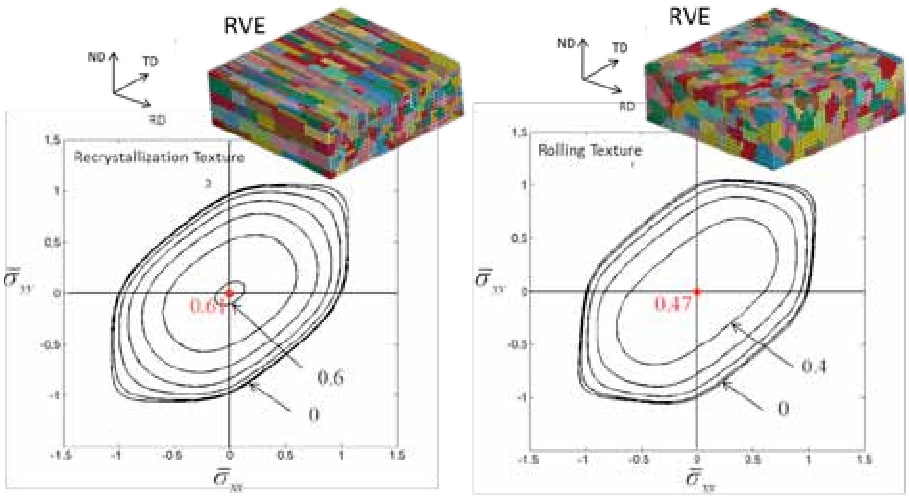
Automotive manufacturers are looking for suppliers who can develop cost efficient, optimized solutions and products with high customer value in a sustainable manner. In the long run the winning suppliers will be the ones who can realize an integrated perspective of their alloy, process and product development. An integrated perspective requires quantitative models, so that the needs with respect to a product's cost and performance can be addressed along the value chain. Proper tools allow reducing development time and costs (e.g. reduced engineering costs, reduced tooling/trimming, reduced number of prototypes and optimized performance/weight ratio).

In commercial FE codes fairly accurate phenomenological constitutive models of metals have been developed and made available. These models represent the macroscopically observed behaviour (e.g. work hardening, anisotropy, process effects) on the basis of continuum mechanics. However, they do not provide any information about the physical mechanisms responsible for the observed material response. Hence, the models do not contribute 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 sought.

In the M^4 research programme, modelling frameworks at continuum and meso-/crystal level have been established. Within these frameworks, lower-scale model approaches are used to represent micro- and nano-structural features of the materials. Below, some of the results achieved in 2011 are highlighted, divided between fundamental strategic development and application oriented projects.

Fundamentals of multiscale modelling
As mentioned, a framework for single- and polycrystal plasticity has been developed and implemented into the finite element code LS-DYNA (i.e. an FE-based crystal plasticity approach, here denoted CP-FEM).

In 2011, this framework was used to explore the effects of grain morphology and crystallographic texture on the shape of the yield surface. This was done by simulating

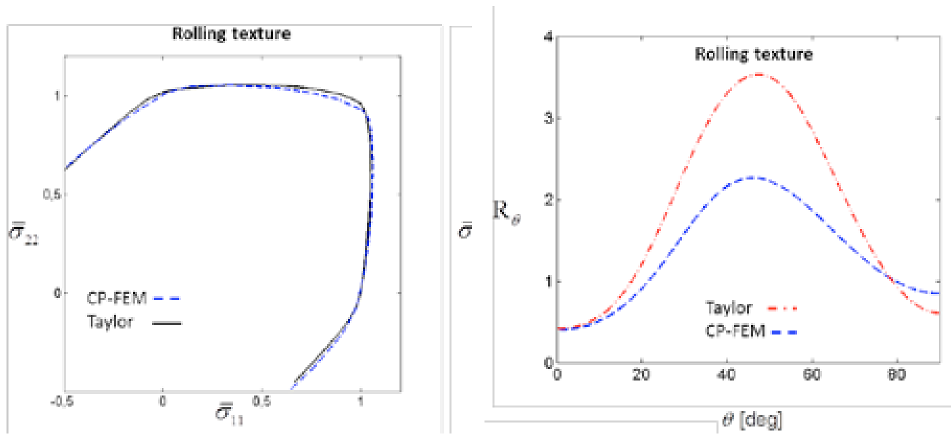


a) b)

Figure 13 – Yield surfaces for a) rolled and b) recrystallized sheet obtained by calibrating Yld2004-18p using CP-FEM.

yield surfaces for aluminium sheets with rolling and recrystallization textures. Yield surfaces were simulated using a rate-dependent single crystal plasticity model, a representative volume element with 800 grains and two different homogenization schemes (CP-FEM and full-constraint Taylor). The Yld2004-18p yield function, from Barlat and co-workers, was used to describe the yield surfaces analytically. The results showed, in accordance with experimental observations, that rolling and recrystallization textures lead to markedly different yield surfaces, see Figure 13. In particular, large differences in the yield strength in pure shear and in the directional variation of the stress and strain ratios in uniaxial tension are notable. The grain shape and stress and strain gradients within the RVE were found to be of second-order importance for incipient yielding. The results indicated that the full-constraint Taylor approach overestimates the variation of the R-value compared with CP-FEM, Figure 14.

Further, the study on anisotropic hardening in 6063-T6 using CP-FEM (initiated in 2010) has been given further attention in 2011. While the approach produced reasonable results with respect to directional dependence of flow stress and plastic strain ratios, significant deviations were disclosed in some directions indicating that other sources than crystallographic texture are present. Effects of grain discretization, grain shape and boundary conditions were assessed to identify weaknesses in the



a) b)

Figure 14 – Effect of the homogenization schemes, i.e. CP-FEM vs. full-constraint Taylor a) section of the predicted yield surface within the $\bar{\sigma}_{11} - \bar{\sigma}_{22}$ *plane and b) predicted directional strain ratio.*

approach; no noticeable effect was observed, Figure 15a. Other approaches such as FC-Taylor or visco-plastic self-consistent (VPSC) approach were also used. However, none of the approaches used are able to capture the experimental data, see Figure 15b. The weaknesses of the modelling approach are therefore attributed to prior material history originating from product processing, such as material inhomogeneity and kinematic hardening.

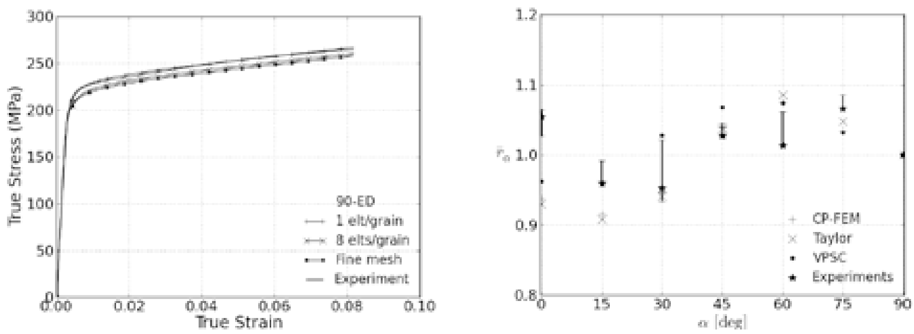
A third study focused on simulating the effect of texture and grain shape on bendability in AA7108 by use of CP-FEM, Figure 16. It was found that a large grain size reduces the bendability of the material due to earlier strain localization in the deformed grains. The simulations further indicate that grain size affects also the formation of the shear bands and their development during bending. Intensive shear bands were found to be associated to the refined grains of the rolled and recrystallized material, while heterogeneous localization of plastic strain was observed in the as-cast material due to the large grains.

Application oriented projects
Three projects in 2011 have been concerned with strain-rate dependent properties of aluminium alloys:

1. A proper understanding and a model for Dynamic Strain Ageing (DSA) has been given attention for several years at SIMLab. Such a model is required to model negative strain-rate sensitivity and the associated Portevin-Le Châtelier (PLC) effect. During 2011, a model has been implemented in the SIMLab Metal Model, see also Industrial Demonstrators.

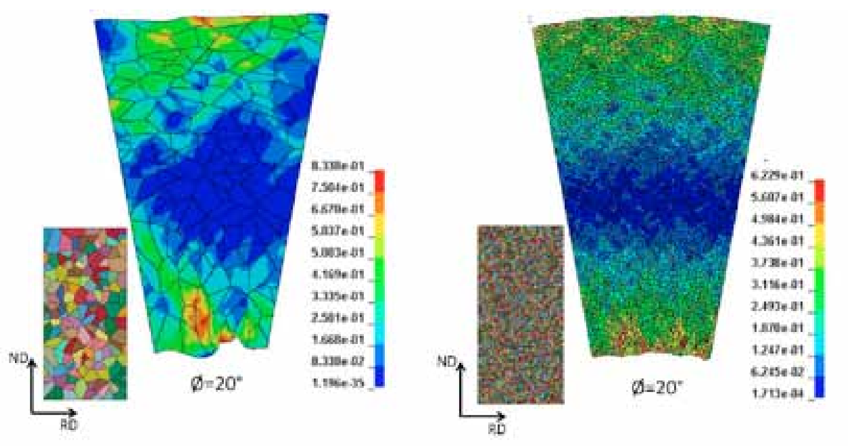
2. A variant of the SIMLab Metal Model has been used in studies of cold-drawing tubes to understand the causes for strain localization and fracture in such mechanical operations. This work has been performed in an industrial context by Hydro Aluminium, Precision Tubing Technology Centre, supported by SINTEF personnel. This activity will continue in 2012 and, ultimately will also result in a documented industrial demonstrator.

3. In 2010 the mechanical properties of the 6060 alloy at high strain-rates and high temperature were studied experimentally. In 2011, a model concept able to represent the observed response has been proposed and implemented in the SIMLab Metal Model. This will allow the constitutive model to be used in numerical simulation of extrusion. This activity was further strengthened by the initiation of a new PhD study (Vincent Vilamosa).



a) b)

Figure 15 – Description of plastic anisotropy in AA6063-T6 using CP-FEM; a) effect of mesh and grain discretization and b) comparison with other polycrystal modelling approaches.



a) b)

Figure 16 – Effect of texture and grain shape on the bendability of AA7108 in a) as cast and homogenized and b) rolled and recrystallized conditions. Fringes represent the predicted plastic strain.

The efforts to understand the shear fracturing phenomenon observed in several aluminium alloys have been intensified by the initiation of the PhD study by Dmitry Vysochinskiy. Experimental procedures and past experimental work have been evaluated and reported at the conference ESAFORM 2012 and a broad experimental programme has been defined to further characterize the formability of AA6016-T4 sheets subject to proportional and non-proportional loading. Materials have been produced by Hydro Aluminium Rolled Products GmbH, R&D Center Bonn, and experimental work is to be undertaken.

The 'through-process' modelling approach for the analysis of the properties of welded structures is still under evaluation through the PhD study by A.B. Alisibramulisi. In parallel models for 7xxx alloys are being investigated based on data from the PhD study by Ida Westermann. Ida Westermann was awarded her PhD degree in 2011, while A.B. Alisibramulisi will defend her thesis in 2012.

In the project related to bake-hardening in advanced high-strength steels a manuscript has been prepared that documents the extensive experimental programme carried out in past years' activities. The simple model concept investigated in 2010 is now numerically implemented in the SIMLab Metal Model.

Connectors and Joints (C&J)
Programme head: Arve Grønsund Hanssen

Introduction

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

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

In this context the following activities have been carried out in 2011:

- Behaviour and modelling of self-piercing riveted connections using aluminium rivets.
- The behaviour and modelling of bolted connections in road restraint systems.
- The modelling of self-piercing riveted-bonded connections for crashworthiness applications.

Within each of these research areas, a PhD project or post doc work has been defined. Some results from these research projects are briefly described below.

Behaviour and modelling of self-piercing riveted connections using aluminium rivets (study by Nguyen-Hieu Hoang, PhD candidate)

One of the activities in the work by PhD candidate Nguyen-Hieu Hoang was to evaluate the structural behaviour of T-components joined by using aluminium self-piercing rivets and to compare the results with the corresponding components using steel rivets. The tests were carried out under quasi-static loading conditions; and the test results were compared in terms of force-displacement curves and deformation modes of the components, see Figure 17. It can be seen that the overall structural behaviour of the T-components joined by using aluminium rivets was comparable to those by using steel rivets. The components using aluminium rivets showed a maximum force level which was approximately 5-8% lower than for the components using steel rivets. However the ductility of the T-components based on aluminium rivets was approximately 50% less than those based on steel rivets.

The test database was then used to evaluate the SIMLab SPR point-connector model, which has been developed for large scale crash shell analysis. The comparison between the test results and analyses revealed that the SPR model was able to predict the behaviour of riveted connections with reasonable accuracy up to final failure, see Figure 18.

The behaviour and modelling of bolted connections in road restraints systems (study by Henning Fransplass, PhD candidate)

The objective of this project is to study the behaviour of bolted connections for road restraint systems. Road median and road side safety barriers are one of the most efficient measures to reduce the risk of head-on or run-off-road traffic accidents. Many types of road restraint systems are available. However, in this project we focus on safety barriers made of steel which deform during a vehicle impact.

The safety barrier is made of w-beam rails and sigma posts. The rails are fastened to the sigma post by a bolt and a hex-nut. In a situation where an errant vehicle hits the safety barrier, the bolt is designed to fail and thereby releasing the w-beam from the sigma post. The loading conditions of the bolt during an impact are typically a combination of axial force, bending and shear, see Figure 19.

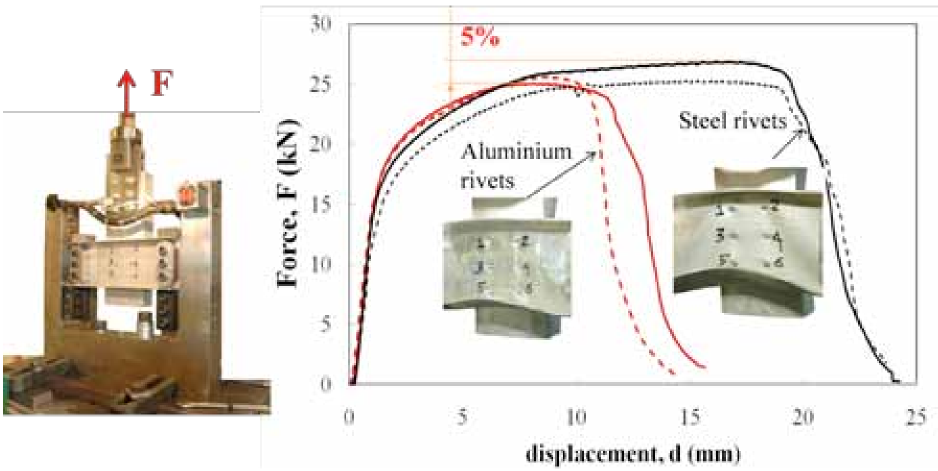


Figure 17 – Comparison between T-components using aluminium rivets and steel rivets.

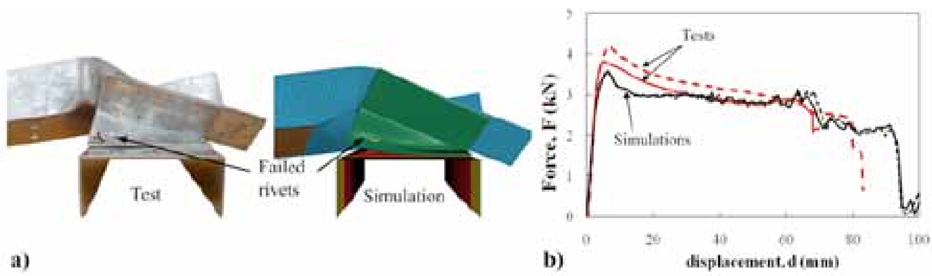


Figure 18 – Comparison between test and analysis, a) deformation mode and b) force-displacement curves.

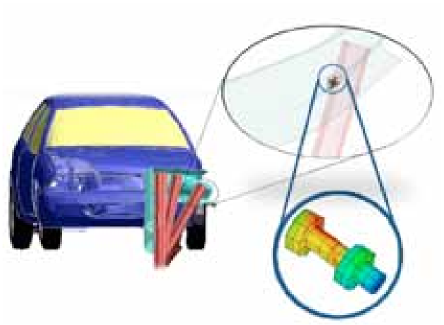


Figure 19 – Illustration of loading mode in bolted connections.

During 2011, the focus in this project has been on combined tension and shear loading of threaded steel fasteners at elevated rates of strain. This activity will continue in 2012, where a finite element model will be validated using the tests carried out as a basis for future parametric studies.

Modelling of self-piercing riveted-bonded connectors for crashworthiness applications (study by David Morin, post doc)

In this activity, the modelling of self-piercing riveted-bonded connections for crashworthiness applications is investigated. The motivation for this activity is the need the automotive industry has to produce safe and lightweight vehicles and the connections between the different parts composing the car body are then crucial. Therefore the behaviour and modelling of such connections including fracture are of great importance to ensure a reliable design of the car body. The first step of this project is to investigate the effect of adhesive bonding on the mechanical response of riveted connections. Mechanical tests on double-U specimens are carried out using the Arcan testing facility available at SIMLab to assess the strength of such connections under

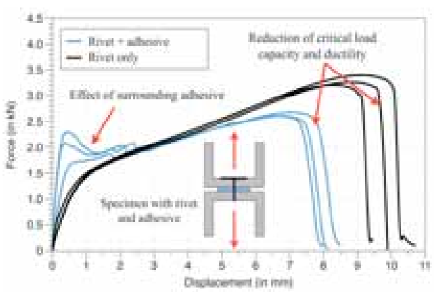


Figure 20 – Mechanical responses of double-U specimens made of aluminium with and without adhesive.

multi-axial loading conditions, Figure 20. It was found that the adhesive has a strong influence on the load-displacement curve as well as on the ductility of the connections due to a change in the interlock between the rivet and the bottom plate. Thus special attention should be paid during the design of components where a combination of bonding and self-piercing rivets is used. Preliminary simulations of the riveting process including the adhesive as a fluid as well as macroscopic modelling of such connections to predict the mechanical behaviour will continue in 2012.

Industrial Demonstrators (Demo)
Programme head: Odd-Geir Lademo

Background

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

Industrial implementation of the developed technology

Figure 21 is a schematic presentation of the relationship between basic research and the industrial implementation of the models and technology developed in the Centre. The activities within the basic research areas, which are linked with research programmes, result in engineering models and technology adopted by SIMLab's industrial partners. However, the development of new technology takes time and the transfer of technology to the partners and the industrial take-up is somewhat shifted. Our experience is that the industry needs time to implement the technology and build up their own competence. In the SIMLab Centre a Tool Box is now under construction where all models and technology developed so far are gathered and is about to be implemented at the industrial partners. The Tool Box will communicate with the software package used by each individual partner. A workshop on this issue was organized in February

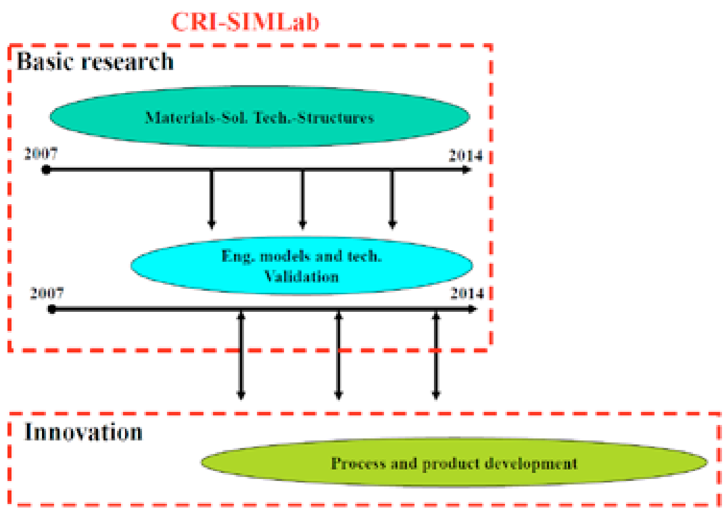


Figure 21 – Transfer of technology to the partners.

2012 where all partners got hands-on knowledge about how to use the Tool Box and thus gave valuable feedback for future improvements of the tool.

SIMLab Tool Box

Some principal outcomes from the SIMLab Centre are numerical implementations of constitutive models and failure criteria. The annual report for 2009 presents the model library we developed. A project was initiated in 2010 to maximize the industrial benefit of the research-based models, for minimized efforts from both SIMLab personnel and the industrial partners (see also presentation of 'Material Model library and MatPrePost' in annual report for 2010). In other words, the overall aim of the activity is to bring the SIMLab models to a higher (or the highest) 'technology readiness' level. This work was continued and given high priority in 2011, in preparation for a workshop that was arranged on 8-9 February 2012.

Solution strategy and product inter-dependencies

We have chosen to define a value chain for non-linear numerical analyses as illustrated in Figure 22. Four principal steps are distinguished, as seen along the timeline axis (abscissa). In short these are: 1) Experimental testing, 2) Parameter identification, 3) Numerical analysis and 4) Post processing. The desired outcome of the chain is processed results that allow proper engineering decisions. It is important to optimize the individual elements of the chain, e.g. appropriate experimental tests must be defined, proper identification procedures must be available, accurate model representation of physical response and supportive post-processing must be facilitated. The optimization of the chain, as a whole, must also be ensured, in the sense that the 'pre-fabric results' are fed efficiently along the chain.

As illustrated in Figure 22, we have chosen to develop five inter-dependent software products (orange boxes):

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

DIC:
Special purpose Digital Image Correlation tool that allows detailed studies of plastic deformation and fracture in material and component tests.

MatPrePost:
Tool for parameter identification and tailored pre- and post-processing. MatPrePost is developed based on different in-house programs and tailored for efficient industrial application. The outcome of the pre-processing utility are (e.g.) visualizations of the model concept, predicted Forming Limit Diagrams (FLDs) and fracture locus plots, and formatted and quality assured input for the user-defined material models. The tool supports output to various FE codes used by the partners in the SIMLab Centre.

SolT(s):
Solution techniques, e.g. the point connector (self-piercing rivet) model and non-local regularization schemes (see also annual report for 2009).

UMAT(s):
User-defined material models able to represent the physical phenomena of the engineering material in question. We have chosen to define customized material models for the individual materials classes. The focus so far has been on the metal plasticity model, hereafter named the 'SIMLab Metal Model'.

These five principal products constitute the important 'soft part' of the technology platform, and is the cluster of software products that we have named the SIMLab Tool Box. An important purpose of this tool box is to structure the developed competence so that it can be implemented by the Centre partners and, thereby, to contribute to their short and long-term innovative capability.

Status MatPrePost
A 'beta-version' of 'MatPrePost' has matured throughout 2011, and was made available to the partners. An internal user group of master's students and PhD candidates has been defined to evaluate and support the further development. The preliminary appearance of the tool is illustrated in Figure 23 by some selected interface windows.

Status SIMLab Metal Model
In 2011, considerable effort was put into the restructuring and development of a single and highly versatile SIMLab Metal Model. The model has been modularized as visualized in Figure 24. A draft of a Theory Manual and a User's Manual have also been prepared to ensure accurate and easy use of the model, further supported by MatPrePost.

Parameter identification and modelling guidelines

Two projects have in principle aimed to develop guidelines for crash analyses of automotive components made of aluminium, with emphasis upon the identification of material parameters using the SIMLab Metal Model and spatial discretization of the components.

Two principally different routes were followed to identify material parameters: 1) the 'classical' route where mechanical tests are used to calibrate a continuum-based constitutive model, and 2) a 'fundamental' route where only basic information (about alloy chemistry, thermal processing and grain structure) is used as input to lower-scale models. These models are next used to produce virtual experimental test data that are used to calibrate the continuum-based model. The different sets of model parameters were combined with relevant discretization techniques (shell formulations and brick elements) and analysed with relevant commercial FE codes (ABAQUS, PAM-CRASH and LS-DYNA). All numerical predictions were compared with high-precision tests, covering two mechanical load cases; axial compression and three-point bending. Some illustrative results are shown in Figure 25.

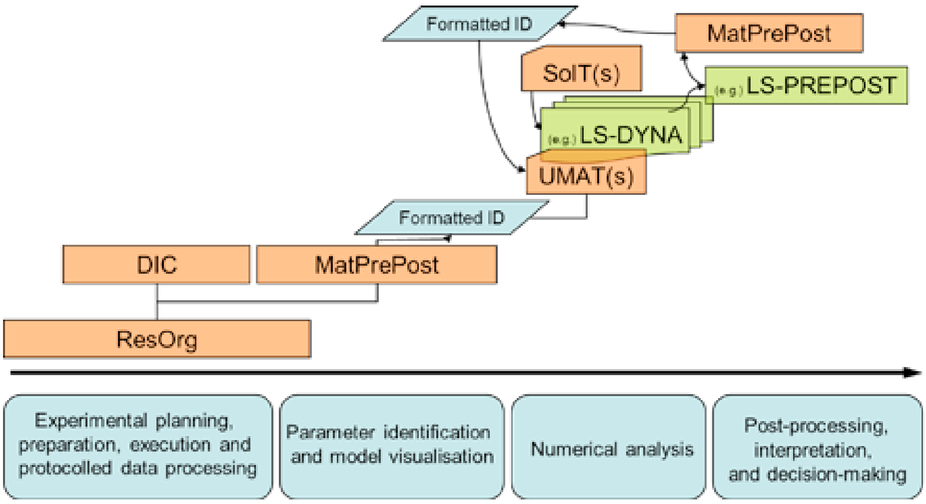


Figure 22 – SIMLab Tool Box – clustered software products.

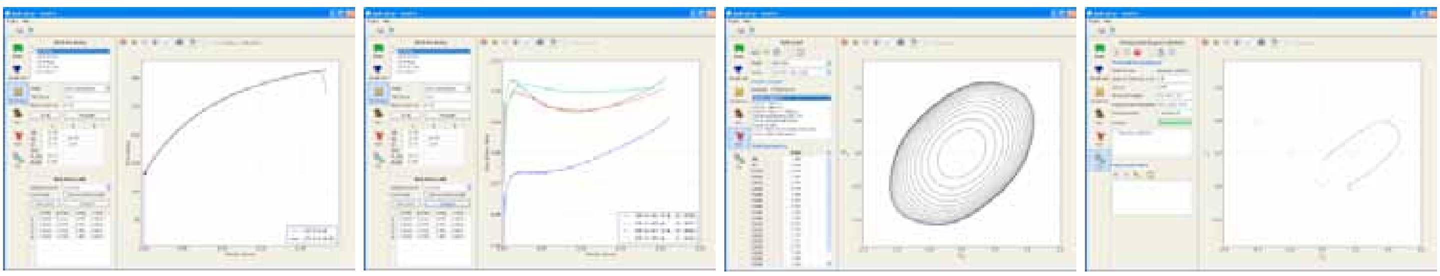


Figure 23 – Examples of the user interface of 'MatPrePost'.

Figure 24 – The modules of the SIMLab Metal Model.

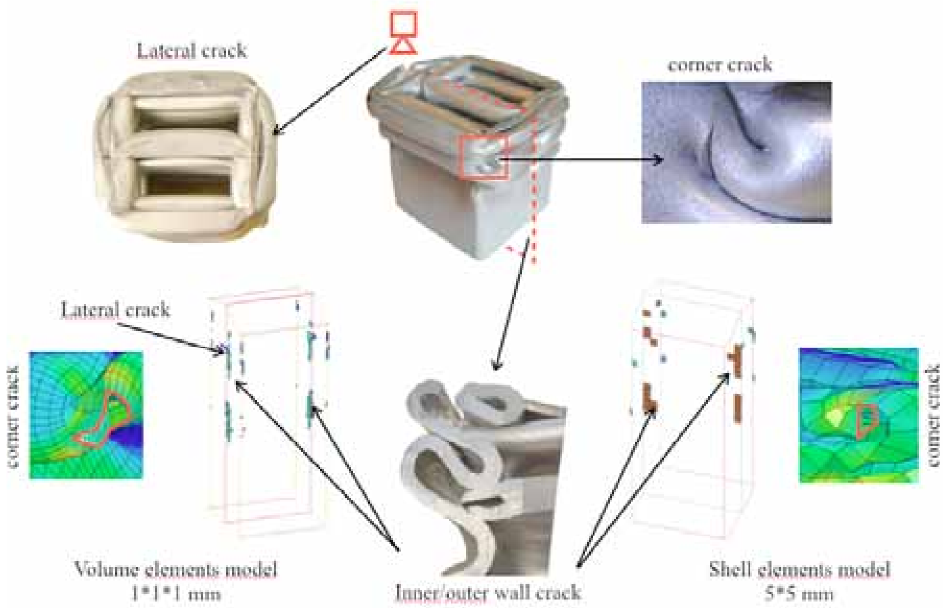


Figure 25 – Illustration of crack predictions on a quasi-static compression test using the SIMLab Metal Model.

SIMLab test facilities

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

Material testing at elevated rates of strain

Split-Hopkinson tension bar (SHTB)

The split-Hopkinson tension bar, see Figure 26, is a device for material testing at strain rates in the range between 200 and 1500 s^{-1}. It consists of two steel bars with diameter 10 mm. They are denoted input and output bars, having lengths of 8 m and 7 m, respectively. The sample is mounted between the two bars. Before the test, the input bar is clamped by a locking mechanism located 2 m from the sample. Thereafter, the external 6 m of this bar is prestressed by means of a jack attached at the end of the bar. By releasing the lock, an elastic stress wave is released, propagating towards the sample with a velocity of 5100 m/s. Applying one-dimensional wave theory, the response of the specimen, i.e. stress, strain and strain rates, is determined from records of strain gauges glued to each bar. High-speed camera instrumentation is also feasible. Moreover, an induction heater facilitates tests also at elevated temperatures.

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

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

Figure 26 – Split-Hopkinson tension bar.

Photo: Melinda Gaal.

Split-Hopkinson pressure bar (SHPB)

The new split-Hopkinson pressure bar at SIMLab, Figure 27, consists of a high-pressure chamber unit in order to accelerate a projectile against the end of the input bar. The diameter of the projectile and thus the input and output bars, which are made of steel, are in the range 16-32 mm. The length of the projectile is 1750 mm, giving a maximum pulse length of 70 ms. The high-pressure chamber has the capacity to accelerate a projectile with a diameter of 32 mm up to an impact velocity of 20 m/s. The data acquisition of the new bar is the same as for the split-Hopkinson tension bar, i.e. the relative deformation of the compressed specimen as a function of time can be calculated from strain gauge measurements on the input and output bars and one-dimensional stress wave theory.

Hydro-pneumatic machine (HPM)

The hydro-pneumatic machine (HPM), see Figure 28, is a device for tensile material testing. It operates in the strain–rate range between 1-200 s^{-1}. The specimen, which has the same dimensions as the sample applied in the split-Hopkinson tension bar, see Figure 26, is connected to two bars with diameter in the range 8-12 mm. The facility is mainly operated by gas and water with a lightweight movable piston made of steel or aluminium. The movement of the piston is controlled by the difference in pressure between the two chambers. Prior to testing, both chambers are brought to equal pressure by introducing nitrogen gas in one chamber and water in the other. The pressure difference is established by firing a rapid valve located in the exhaust line to the water chamber causing a rapid evacuation of the water through an orifice, thus allowing the piston to move at a constant velocity and stress the test specimen to fracture. The piston velocity and the hence the rate of loading is controlled by the size of the orifice. The load applied to the specimen is measured by using strain gauges on the bars. The specimen elongation is measured by means of a displacement transducer sensing the displacement of a metallic strip connected to the piston shaft.

Figure 27 – Split-Hopkinson pressure bar. Photo: Ole Morten Melgård

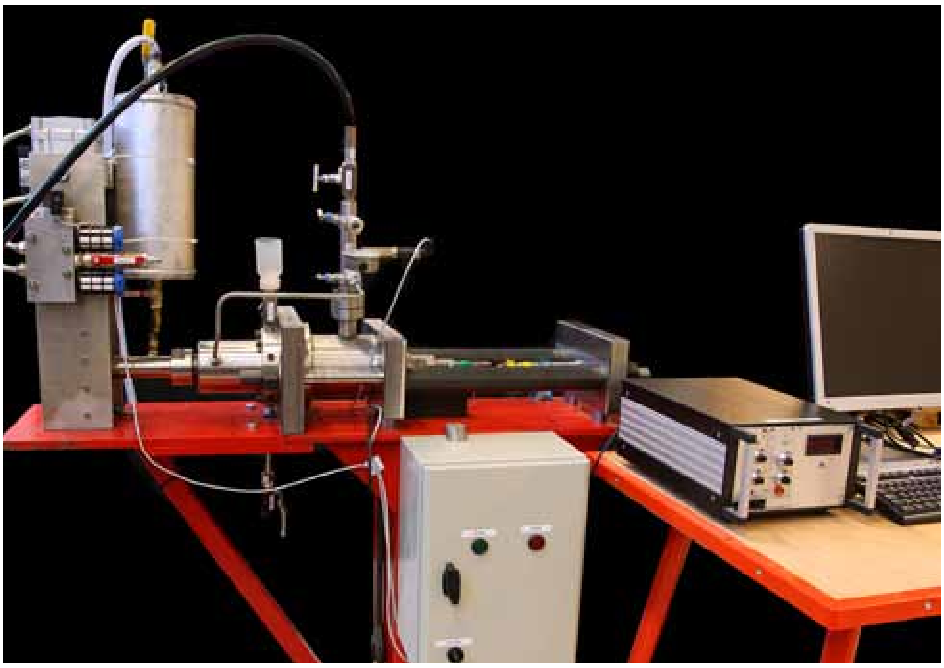


Figure 28 – Hydro-pneumatic machine. Photo: Melinda Gaal

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

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

Component and structural testing

Sheet metal testing machine (BUP 600)
This fully PC-controlled multi-purpose hydraulic sheet metal forming machine, see Figure 29, is designed for testing the formability of sheet metals in accordance with the most common standards and procedures. Its main advantages are an easy and rapid inter-changeability of the test tools, availability of tools for all well-known test standards and procedures, low cylinder-piston frictions delivering accurate measurement acquisitions and excellent reproducibility, and numerous modular possibilities of extensions. These features make this machine an excellent means for performing advanced research in studying forming processes and for validation of numerical models. The machine has a 600 kN load capacity, a maximum clamping force of 50 kN, a maximum test stroke of 120 mm and a maximum test speed of 750 mm/min. It is compact with a volume a 1000x1485x1280 mm^3. The machine at SIMLab has currently tooling for earing tests, Nakajima and Marciniak-Kuczynski formability test set-ups, square cup drawing tests and bulge tests.

The machine has been equipped with a pair of high resolution black and white Prosilica cameras GC2450, with a resolution of 2448x2050 pixels, and a frame rate of 15 fps at full resolution. The cameras are PC-controlled by software for image acquisition. A frame has been built on the machine that allows easy positioning of the cameras and image acquisition during testing, thereby providing the opportunity for strain field measurement on the upper surface of the test pieces.

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

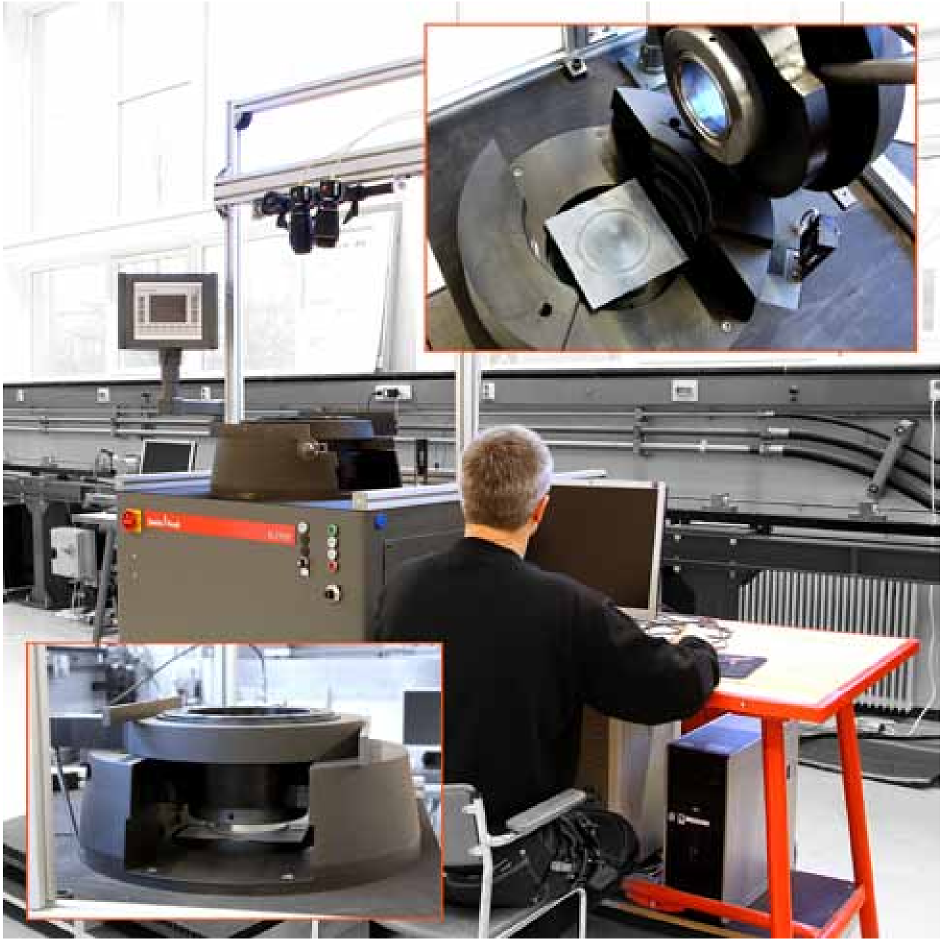


Figure 29 – BUP 600 machine. Photo: Melinda Gaal.

Figure 30 – Pendulum accelerator. Photo: Ole Morten Melgård

Pendulum accelerator (Kicking machine)
The pendulum accelerator is a device for impact testing of components and structures, Figure 30. The test rig accelerates a trolley on rails towards a test specimen fixed to a reaction wall. The reaction wall, which was re-built in 2010, has a total weight of 150 000 tonnes and is floating on the laboratory floor by using special-purpose designed shock absorbers. The accelerating system consists of an arm that rotates around a set of bearings. The arm itself is connected to a hydraulic/pneumatic actuator system which provides the moving force and accelerates the trolley up to the desired velocity. The connection of the actuator piston rod to the arm introduces a 1/5 lever action, i.e. the force acting on the trolley is 1/5 of the piston force, but the velocity is 5 times greater. Based on the maximum working pressure in the hydraulic piston, the maximum energy delivered to the trolley is approximately 500 kJ. At present the mass of the trolley is in the range between 800 -1500 kg, giving a maximum velocity between 35 m/s and 26 m/s. The velocity is measured with a photo-cell system. In case the specimen does not have sufficient energy absorption capabilities to stop the trolley, a secondary energy absorbing system is installed.

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

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

Pneumatic accelerator
In this test rig, see Figure 31, a projectile with a mass of 50 kg can be accelerated up to a velocity of 25 m/s. The rig consists of an accelerator tube (with an internal diameter of 160 mm) which is connected to a compressed air chamber at the top and

a projectile which is designed to act as a piston inside the accelerator tube during testing. The projectile consists of a central rod, a replaceable nose and is equipped with guides and an interchangeable mass.

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

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

Compressed Gas Gun
A compressed gas gun for ballistic impact studies is also available at SIMLab, Figure 32. The main components of the gas gun are the 200 bar pressure tank, the purpose-built firing unit for compressed gas, the 10 m long smooth barrel of calibre 50 mm and the closed 16 m^3 impact chamber. Due to the size of the impact chamber, large structural components can be tested full scale. The gas gun is designed to launch a 250 g projectile/sabot package to a maximum velocity of 1000 m/s when helium is used as propellant. The projectile is mounted in a sabot, allowing a variety of striker geometries and masses to be used, and the package is inserted into the rear end of the barrel. When the package leaves the muzzle, the sabot is immediatelyseparated from the projectile due to aerodynamic forces. A sabot trap allows the projectile to pass freely while the sabot parts are stopped. The projectile passes the initial velocity measurement station before it impacts the clamped target after about 2 m of free flight. To allow high-speed photography during impact, the clamping system is equipped with a framing window. If the projectile perforates the target, residual velocities are measured before all free flying bodies

Figure 31 – Pneumatic accelerator. *Photo: Melinda Gaal.*

Figure 32 – Compressed gas-gun facility. *Photo: Melinda Gaal.*

are stopped without further damage in a rag-box. After testing, the impact chamber may be opened for final inspection and measurements.

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

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

Stretch-bending rig

The stretch-bending rig, see Figure 33, applies a combined bending and axial tensile/compressive loading to the test component. The length of the specimens is 1-2 m, and they are bent around an exchangeable die with a defined curvature. The main components of the test rig are a rigid steel frame, two horizontally mounted servohydraulic actuators giving the axial action, and a vertical loading device supported on a servohydraulic actuator. All actuators have capacity 330 kN. The rig has a complete instrumentation including load cells, displacement transducers and clinometers. Cameras may also be attached. It can be operated in force as well as displacement control, and a broad variety of loading sequences may thus be defined.

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

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

Droptower impact system

In this machine, see Figure 34, impact testing of materials and small components can be carried out at low and high temperatures. The projectile's mass ranges from 2-70 kg and gives an impact velocity in the range 0.8-24m/s. All tests can be carried out with an instrumented nose which gives the impact force as a function of time. The machine has been purchased from Instron in 2011 and is denoted CEAST 9350.

FOR MORE INFORMATION:
www.instron.com

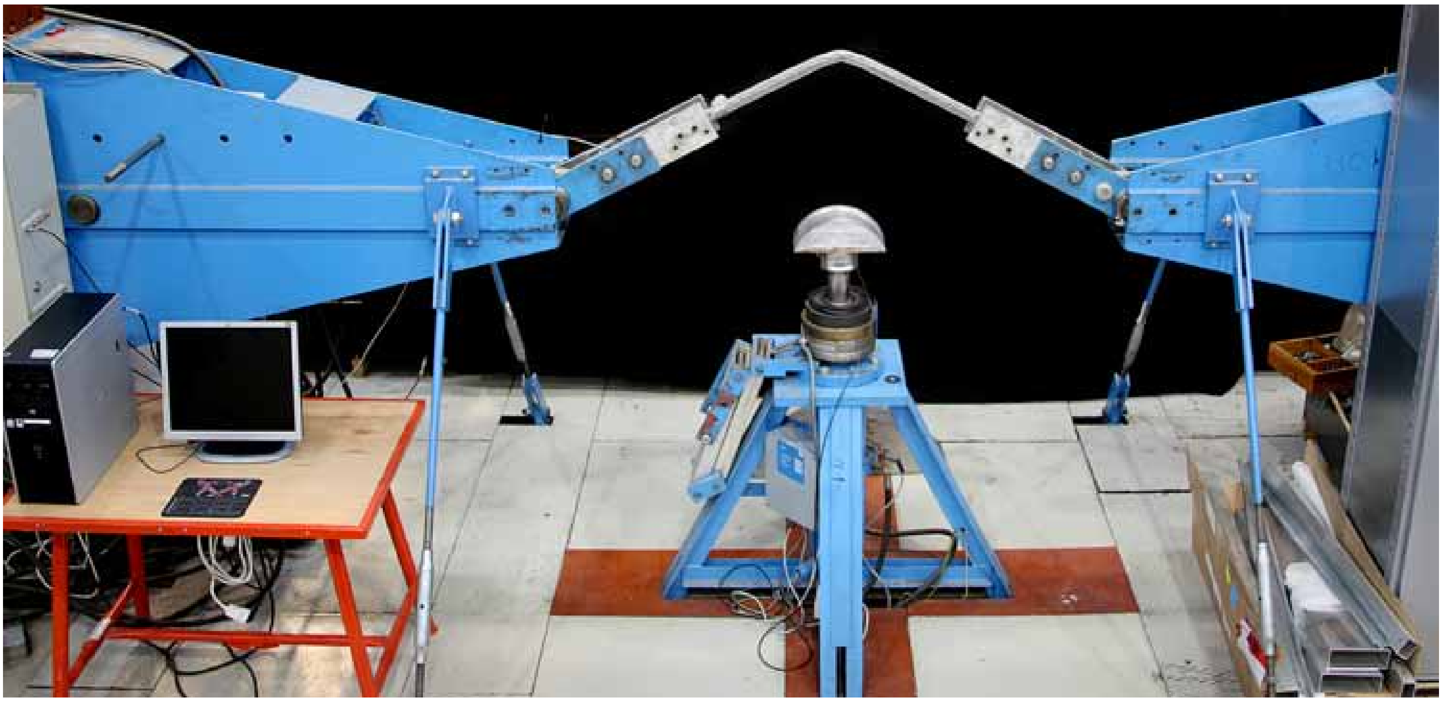


Figure 33 – Stretch-bending rig. *Photo: Melinda Gaal.*

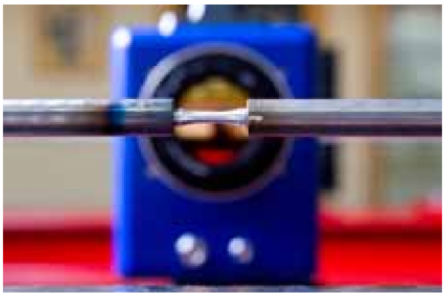
Figure 34 – Droptower impact system.
Photo: Ole Morten Melgård

Joining machine

Self-piercing riveting machine
In this machine, see Figure 35, self-piercing riveting can be carried out of sheets under industrial conditions. The machine has been purchased from Böllhoff in Germany.

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

Figure 35 – Self-piercing riveting machine. *Photo: Melinda Gaal.*



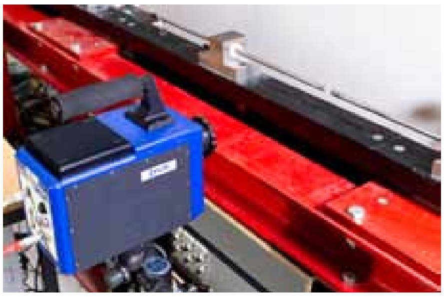


Figure 36 – Infrared camera. *Photo: Ole Morten Melgård*

Infrared camera

The infrared camera shown in Figure 36 can convert infrared radiation to a visual image that depicts thermal variations across an object or scene. Thus it can be used to measure the surface temperature of a specimen under inelastic deformations. With a resolution of 320x256 pixels the maximum frame rate is 380 per second, while at a resolution of 48x4 pixels the maximum frame rate is 31800 per second. The camera is a FLIR SC7500 and was purchased in 2011.

FOR MORE INFORMATION:
www.flir.com

Evaluation of SIMLab by the Faculty of Engineering Science and Technology, NTNU

Based on a self-evaluation report and an interview, the 29 research groups at the Faculty of Engineering Science and Technology at NTNU were evaluated by a committee of international experts. The NTNU part of the SIMLab Centre was one of the groups subjected to this evaluation. The committee evaluated the research carried out with respect to 1) scientific quality and productivity, 2) relevance and impact on society, and 3) strategy – research organization and cooperation. On a scale from 1-5, where 5 means excellent, the SIMLab research group got 5 on all the three areas of evaluation.

Advise from the Scientific Advisory Board

A Scientific Advisory Board meeting was held during the seminar hosted by Statoil on 17-18 March 2011. This time the Board was given a mandate to look ahead and give advice on research areas of interest after the termination of the Centre in December 2014. The following recommendations were given:

"The Scientific Advisory Board (SAB) came to the firm opinion that the expertise of SIMLab in experimental testing (including structural and material properties), theoretical modelling and numerical expertise for impact related studies is unique and should be maintained. ***Security and Protection*** *is a growing area of public and industrial interest and SIMLab is ideally suited to focus on this research area after 2014. It is a broad topic embracing, for example, marine and ocean engineering, civil engineering, national defence, energy security and protection of the national infrastructure. The research topics in this general area will become more severe as higher temperatures, greater pressures, or ocean depths, and extreme conditions are encountered in the winning of oil and gas, for example. SIMLab is uniquely situated in order to execute research studies on the static and dynamic material properties for materials, such as new ultra high strength steels, under extreme conditions, as well as related numerical calculations and theoretical work to inform and assist engineering designers. It appears to the SAB that the Security and Protection area would be an excellent match both for SIMLab and Norwegian industry".*

Concurrent research projects

Utilizing the competence developed at the Centre, a selection of research projects that have been run in 2011 includes:

- *International Research Institute of Stavanger - IRIS (2011):* SIMLab in co-operation with the Norwegian Defence Estates Agency has developed a protection barrier for testing of expandable downhole offshore tools exposed to high pressures and temperatures.

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

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

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

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

European Commission – funded applications

The issue of EU applications with involvement from the partners has been discussed by the Board, but so far there is no enthusiasm for such an initiative among the majority of the industrial partners. Based on experience from previous EU projects, the international partners say that the CRI-concept is a much better model in order to obtain generic technical focus where theory and applications are strongly linked. Thus the strategy in 2011 has been, as previous years, not to take any initiative for such an application, but rather try to be involved in applications where the initiative is coming from an institution outside the consortium.

With this in mind, SIMLab has been involved in the following applications in 2011:

- An EUROSTARS proposal on the development of a new non-linear simulation tool for mechanical and multi-physics problems with unsurpassed accuracy, user-friendliness and industrial robustness adapted near-100% to computing on graphics processing units (GPU), which is a new hardware technology for high computational speed. The partners behind the application are Impetus Afea Norway (coordinator), Impetus Afea Sweden, NVIDA Corporation, Centro Ricerche Fiat and NTNU. The application was approved.

- A collaborative project application within the 7th framework programme. The consortium behind the application consists of Fraunhofer Institute for Mechanics of Materials IWM (coordinator), NTNU, Politecnico di Torino, Valutec S.A., EXP S.r.l., DYNAmore and Porsche Engineering Group. The proposed project aims at finding new solutions for combining a significant weight reduction with an enhanced crash safety of electric vehicles. The primary focus and novelty of the project is the combined experimental and numerical analysis for the development of a new methodology for the simulation of fibre reinforced compounds in crash relevant scenarios.

New equipment

- *Split-Hopkinson pressure bar:* A new Split-Hopkinson pressure bar is about to be installed at SIMLab, see Figure 27.
- *Droptower impact system:* A new Drop-tower impact system (CEAST 9350) has been purchased from Instron, see Figure 34.
- *Infrared camera:* A new infrared camera, FLIR SC7500MB, has been purchased, see Figure 36.

Workshops and seminars

- CANMET-Materials Technology Laboratory, Canada, organised a workshop on Microstructural Effects on Damage, Fracture and Crashworthiness in High Performance Automotive Materials 10-11 May 2011 in Hamilton, Canada, together with Macmaster University and the University of Waterloo, Canada, and SIMLab, NTNU. The workshop was split into 3 sessions;
  1) Deformation modelling and constitutive relationships, 2) Shear localization, damage and ductile fracture and 3) High strain rate behaviour and crashworthiness.

  The workshop was closed with a panel discussion dedicated to research collaboration based on short introductions from selected participants. The workshop was sponsored by Initiative for Automotive Manufacturing Innovation (IAMI), Canada.

IAMI – CANMET Workshop 10-11 May 2011, Canada.

IAMI – CANMET Workshop 10-11 May 2011, Canada.

Visibility

Keynote lectures

- Professor Tore Børvik gave a keynote lecture at the 8th European LS-DYNA User Conference, 23-24 May 2011, Strasbourg, France, on the topic *"Are numerical simulations of ballistic impact predictive?"*

Invited and guest lectures

- Professor Tore Børvik gave a guest lecture at the Danish Centre for Applied Mathematics and Mechanics, DTU Technical University of Denmark, 2 November 2011 on the topic *"Are numerical simulations of ballistic impact predictive?"*
- Professor Odd Sture Hopperstad gave a guest lecture at Fraunhofer Ernst Mach Institute (EMI), 23 September 2011, on the topic *"Behaviour and modelling of aluminium alloys with application to automotive and protective structures"*.
- Professor Magnus Langseth gave an invited lecture at the Automotive Circle International conference 7-8 September 2011 in Bad Nauheim, Germany. The topic of the talk was *"Crashworthiness of aluminium structures: modelling and validation"*.
- Professor Magnus Langseth gave an invited lecture at the aluminium symposium in Qatar 24 November 2011. The topic of his talk was *"Aluminium in the offshore and automotive industry"*.

Magazines/Newspapers/TV

- Discovery Channel presented SIMLab as a part of the programme Megaworld Norway on 15 December 2011. The same day an article about this programme was published in the net issue of the local newspaper Adresseavisen.
- SIMLab was presented in the local newspaper Adresseavisen on 26 February, due to that Toyota Motor Europe became a new partner in the Centre.
- 40% of the international PhD candidates that graduated at NTNU are employed by Norwegian industry. One of them, Virgile Delhaye, has been a PhD candidate at SIMLab and an article about this issue was presented in the local newspaper Adresseavisen on 13 April 2011.
- The magazine Gemini presented a note in the December issue about a new full-time professor (Tore Børvik) employed at Department of Structural Engineering, NTNU. Gemini addressed in particular that the research area of the new professor is physical protection and security.

Awards

- Professor Øystein Grong was awarded the prestigious international Comfort A. Adams Memorial Award for 2011, presented by the American Welding Society (AWS). Øystein Grong received the price at the FABTECH conference in Chicago in November 2011.

Discovery Channel, 15 December 2011


Nyheter 5

Bilgigant kjøper seg inn i krasjlaboratoriet

Adresseavisen, 26 February 2011


Nye forskere blir i Norge

Adresseavisen, 13 April 2011


Skal gjøre Norge sikrere

Gemini No 4-December 2011

Øystein Grong during his Comfort A. Adams Lecture.

- Professor Arild Holm Clausen was awarded the Norconsult prize as the best teacher in the Civil and Environmental Engineering programme of study at NTNU in 2011.

Arild Holm Clausen (left) and Director John Nyheim (right) at Norconsult.

- Professor Tore Børvik, with co-authors M.J. Forrestal and T.L. Warren, have received the 2011 Peterson Award for the paper *"Perforation of 5083-H116 Aluminum Armor Plates with Ogive-Nose Rods and 7.62 mm APM2 Bullets"*, Experimental Mechanics Vol. 50(7), 969-978, 2010.

National cooperation

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

International cooperation

Visiting scientists/professors

Professor Marcílio Alves from University of São Paulo, Brazil, stayed at the Centre for three weeks in February 2011, working on research topics related to the Polymers and Connectors & Joints research programmes.

Research cooperation with organizations

The Centre has strong international cooperation due to its five international partners, i.e. Audi, BMW, Toyota Motor Europe, Renault and SSAB Swedish Steel. Furthermore, the following organizations took an active part in the Centre projects in 2011:

- *Cotutelle agreements for PhD candidates* LMT-Cachan (Professor Ahmed Benallal), France. Karlsruhe Institute of Technology (Professor Karl Schweizerhof), Germany.
- *Other organizations involved in Centre activities* University of São Paulo (Professor Marcílio Alves), Brazil. University of Savoie (Professor Laurent Tabourot) and Ecole Centrale de Nantes (Assoc. professor Ramzi Othman), France. Impetus Afea (Dr Lars Olovsson), Sweden. Politecnico di Milano (Assoc professor Andrea Manes), Italy. University of Linköping (Professor Larsgunnar Nilsson), Sweden. Harvard University (Professor John Hutchinson) and University of Virginia (Professor Hayden Wadley), USA. University of Liverpool (Dr Graham Schleyer), UK. Technical University of Madrid (Dr. Francisco Gálvez Díaz-Rubio), Spain.
- *PhD candidate and other SIMLab staff research visit abroad*
  – One of our PhD candidates, Anne Serine Ognedal spent 7 weeks at Karlsruhe Institute of Technology in May-June 2011, visiting Professor Thomas Seelig's research group at Institute of Mechanics. She worked on numerical micromechanical analysis of the cavitation process around particles in polymers.
  – Tore Wisth and Trond Auestad visited LMT-Cachan in December 2011 to discuss procedures for material testing.

Guest lectures at SIMLab

The following guest lectures were given at SIMLab in 2011:

- Dr Jürgen Lescheticky, BMW: *Crash simulations at BMW. State-of-the art and future challenges.*
- Mr François Moussy, France: *How do automotive companies manage the weight control for their cars?*
- PhD candidate Nick Underwood, University of Liverpool, UK: *Pulse pressure testing and analysis of steel plates.*
- Dr Oliver Tamfu, Wicona, Germany: *Presentation of Hydro Building Systems.*
- Dr Armin Bäumler, Wicona, Germany: *Outdoor testing at different conditions.*

Students

PhD candidates with truck driver Magnus Langseth. First row from left: Anne Serine Ognedal, Vincent Vilamosa, Marius Andersen, Mikhail Khadyko, Martin Kristoffersen, Marion Fourmeau, Gaute Gruben. Second row from left: Egil Fagerholt, Espen Myklebust, Ida Westermann, Dmitry Vysochinskiy, Knut Rakvåg.
Photo: Ole Morten Melgård.

PhD candidates

The following PhD candidates have been linked to the Centre in 2011:

NAME	START	PLANNED EXAM	PROGRAMME	FROM	MALE/FEMALE
Ida Westermann*	Autumn 2007	Autumn 2011[1]	M[4]	Denmark	Female
Henning Fransplass*	Spring 2005	Autumn 2012	C&J	Norway	Male
Egil Fagerholt*	Winter 2008	Spring 2012	F&CP	Norway	Male
Nguyen-Hieu Hoang*	Autumn 2007	Autumn 2011[2]	C&J	Vietnam	Male
Gaute Gruben*	Summer 2008	Autumn 2012	F&CP	Norway	Male
Anne S. Ognedal*	Autumn 2008	Autumn 2012	Polymers	Norway	Female
Octavian Knoll*	Summer 2009	Autumn 2012	F&CP	Germany	Male
Marion Fourmeau**	Autumn 2009	Autumn 2013	F&CP	France	Female
Knut Rakvåg**	Summer 2009	Summer 2013	OptiPro	Norway	Male
Dmitry Vysochinskiy**	Spring 2010	Spring 2014	M[4]	Russia	Male
Mikhail Khadyko**	Autumn 2010	Autumn 2014	M[4]	Russia	Male
Martin Kristoffersen*	Autumn 2010	Autumn 2014	OptiPro	Norway	Male
Espen Myklebust**	Autumn 2009	Autumn 2013	F&CP	Norway	Male
Marius Andersen*	Autumn 2011	Autumn 2015	Polymers	Norway	Male
Vincent Vilamosa*	Autumn 2011	Autumn 2014	M[4]	France	Male
A.B. Alisibramulisi**	Autumn 2007	Autumn 2012	M[4]	Malaysia	Female

*= Salary and operational cost from the Centre,
**= Operational cost from the Centre – salary from other sources
[1] Defended the thesis 30 September 2011
[2] Defended the thesis 4 November 2011

New PhD candidates in 2011

- Marius Andersen and Vincent Vilamosa started as PhD candidates respectively in June and September 2011. Marius Andersen is a former master's student at SIMLab, while Vincent Vilamosa has his master's degree from ENS Cachan in Paris. It is worth mentioning that Vincent Vilamosa stayed at SIMLab in the spring 2011, doing his master's thesis.

Related PhD candidates in 2011

- Andreas Koukal is a PhD candidate at the Technische Universität München. He was recruited by Audi to work on behaviour and modelling of polymers and is thus linked to the Centre through Audi.

Equal opportunity

In 2011 four of the 16 PhD candidates, were females.

Post docs

The following post docs were linked to the Centre in 2011:

NAME	START	END	PROGRAMME	FROM	MALE/FEMALE
David Morin	Autumn 2010	Autumn 2014	C&J	France	Male
Afaf Saai*	Autumn 2009	Autumn 2011	M4	Syria	Female

*Dr Saai is now employed by SINTEF as a scientist.

Visiting students

The following international students have stayed at the Centre in 2011:

- PhD candidate Andrea Gilioli from Politecnico di Milano, Italy, stayed at SIMLab for one week in 2011.
- Master's student Gillaume Zègre from Ecole Nationale Supérieure des Mines, St Etienne, France, stayed at the Centre for 4 months during his internship. He was linked to the C&J programme.
- PhD candidate Mathieu Vautrot from the University of Savoie, France, stayed at the Centre for 1 month. Professor Odd Sture Hopperstad is co-supervisor of this student.
- Master's student Renato Ramirez Neves from the University of São Paulo, Brazil, stayed at the Centre for 6 months as a part of his master's thesis. He was linked to the C&J programme.
- Master's student Maurice Beusink from TU Eindhoven, the Netherlands, stayed at the Centre for 3 months, and was linked to the M^4 programme.
- Master's student Vincent Vilamosa from ENS Cachan, France, stayed at the Centre for 4 month as a part of his master's thesis, and was linked to the M^4 programme.
- PhD candidate Martin Helbig from Karlsruhe Institute of Technology, Germany, stayed at the Centre for 1 month and was linked to the Polymers programme.
- PhD candidate Philipp Hempel from Karlsruhe Institute of Technology, Germany, stayed at the Centre for 1 month, and was linked to the Polymers programme.

Master's students

The following master's students were linked to the Centre in 2011:

STUDENT	TOPIC
L. Aune	Wave slamming forces on jacket in shallow water
I. Birkeland	Joints in buildings
E.B. Bjerknes	Time-dependent response of thermoplastics
A. Dahlen	Plastic deformation and fracture of polymer materials
J.G. Fornes and S. Gabrielsen*	Impact against offshore pipelines
G. Gjessing	Cyclic response of thermoplastics
S. Hallset and J.S. Haagenrud*	Combined fragment and blast loading on plates
G. Haug	Running fractures in a H_2 pressurized pipeline: from small scale material testing to full scale experiments and simulations
Ø.J. Hjort and M.E.H. Andersen*	Modelling procedures for non-linear analysis of metallic structural components
E. Hofseth and Ø. Sæveland*	Design of structural frame for tidal stream turbine
S. Kalstad and T.S. Nord*	Fragmentation of metallic materials during impact
F.T. Karlsen	Joints for elements of hollow sections
J. Karstensen and K. Frøysnes*	Modelling procedures for non-linear analysis of metallic structures components
I.M. Larsen	On the fracture locus of ductile materials
A.H. Malvik	Void growth in calcium carbonate filled PVC
B. Nesland	Perforation resistance of lightweight protective structures. An experimental and analytical study.
V.R. Rørsand	Fibre-reinforced thermoplastics
M.M. Saltnes	Fibre-reinforced thermoplastics
R.B. Stormoen	Experimental investigation and numerical modelling of sheet metal formability
S. Valheim	Running fracture in a H_2 pressurized pipeline: characterization and simulation of dynamic ductile fracture in two X65 pipeline steels

* Joint thesis

PhD disputation

IDA WESTERMANN defended her thesis on 30 September 2011 with an excellent statement by the committee. The topic of her thesis was *"Work-hardening behaviour in age-hardenable Al-Zn-Mg(-Cu) alloys"* while the public lecture was on *"Bake Hardening Steels and Aluminium Alloys in Automotive Structures"*. Her supervisors were Professor Odd Sture Hopperstad from Department of Structural Engineering and Professors Knut Marthinsen and Bjørn Holmedal from Department of Materials Technology, NTNU. The evaluation committee had three members; Professor Birger Karlsson from Chalmers University of Technology, Sweden, and Dr Jostein Røyset from Hydro Aluminium, Norway, while Professor Aase Reyes from NTNU acted as administrator.

PhD disputation for Ida Westermann – supervisors and committee.
From the left: Odd Sture Hopperstad, Jostein Røyset, Ida Westermann, Bjørn Holmedal, Knut Marthinsen, Aase Reyes and Birger Karlsson.

NGUYEN-HIEU HOANG defended his thesis on 4 November 2011 with an excellent statement by the committee. The topic of his thesis was *"Behaviour and modelling of self-piercing riveted connections using aluminium rivets"*. The public lecture was on the *"Behaviour and Modelling of Glass under Extreme Loadings"*. The supervisors were Professor Magnus Langseth and Adjunct Professor Arve Grønsund Hanssen from NTNU, and PhD Raffaele Porcaro from SINTEF. The evaluation committee had three members; Professor René Billardon from University Paris 6 (UPMC)/LMT-Cachan, France, and Professor Michael Worswick, University of Waterloo, Canada, while adjunct Professor Tore Børvik from NTNU was administrator.

PhD disputation for Nguyen-Hieu Hoang – supervisors and committee.
From the left: Raffaele Porcaro, Arve Grønsund Hanssen, Nguyen-Hieu Hoang, Tore Børvik, René Billardon, Michael Worswick and Magnus Langseth.

Annual accounts

The annual work plans for each research programme have to present a detailed description of the activities to be carried out in the Centre, allowing the Research Council of Norway (RCN) to monitor that that the research activities are within the ESA requirements. Thus the funding plan for each programme shows the funding from each of the partners in the form of "Fundamental research (F)" and "Industrial research (I)" and how funding from RCN contributes to funding of each project. The cost plan describes each partner's participation in each of the programmes. The funding and cost plans for 2011 are shown below.

SIMLab: Funding 2011 (All figures in 1000 NOK)

		STATE AID			INDUSTRY												
Research Programme	Type of research	RCN Grant	Host (NTNU)	SINTEF	NDEA	NPRA	AUDI	BMW	Renault	Toyota	Statoil	SSAB	Benteler	Hydro Aluminium	Total State Aid	Total Funding	State aid/total funding
C&J	F	1244	312		100	870	300	100						65	1556	2991	0.52
C&J	I																
F&CP	F	2328	1173		200		500								3501	4201	0.83
F&CP	I																
M^4	F	900	1346	1100								100		2608	3346	6054	0.55
M^4	I																
OptiPro	F	1308	343		1546			51			350	200			1651	3798	0.43
OptiPro	I																
Poly	F	1670	1243						660	450					2913	4023	0.72
Poly	I																
Demo	F																
Demo	I	83	212		100	100	150	100	100	100	100	100	300	212	295	1657	0.18
Equipment		1568	275		4		50	199	50			150	200	64	1843	2560	
Adm		1378	694		250	150		50	190		200	250		1151	2072	4313	
Total		**10479**	**5598**	**1100**	**2200**	**1120**	**1000**	**500**	**1000**	**550**	**650**	**800**	**500**	**4100**	**17177**	**29597**	

F = Fundamental research
I = Industrial research

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

SIMLab: Cost 2011 (All figures in 1000 NOK)

Research Programme	Host (NTNU)	SINTEF	NDEA	NPRA	AUDI	BMW	Renault	Toyota	Statoil	SSAB	Benteler	Hydro Al	Total
C&J	2121			870									2991
F&CP	2084	1417	200		500								4201
M^4	2096	1258								100		2600	6054
OptiPro	2248	350	1000							200			3796
Poly	2373	1150					500						4023
Demo	267	1190									200		1657
Equipment	2560												2560
Adm	2944	1369											4313
Total	**16693**	**6734**	**1200**	**870**	**500**	**0**	**500**	**0**	**0**	**300**	**200**	**2600**	**29597**

Publications

The following lists journal publications and conference contributions generated within the Centre in 2011:

Journal publications

1. Achani D., Lademo O-G., Engler O., Hopperstad O.S.: *Evaluation of constitutive models for textured aluminium alloys using plane-strain tension and shear tests.* International Journal of Material Forming 4 (2011) 227–241.
2. Benallal A., Berstad T., Børvik T., Nogueira des Codes R., Hopperstad O.S.: *Computational aspects in presence of negative strain-rate sensitivity with applications to aluminium alloys exhibiting the Portevin-Le Chatelier effect.* Modelling and Simulation in Material Science and Engineering 19 (2011) 1-15.
3. Børvik T., Olovsson L., Dey S., Langseth M.: *Normal and oblique impact of small arms bullets on AA6082-T4 aluminium protective plates.* International Journal of Impact Engineering 38 (2011) 577-589.
4. Børvik T., Olovsson L., Hanssen A.G., Dharmasena K., Hansson H., Wadley H.N.G.: *A discrete particle approach to simulate the combined effect of blast and sand impact loading of steel plates.* Journal of the Mechanics and Physics of Solids 59 (2011) 940-958.
5. Chen Y., Clausen A.H., Hopperstad O.S., Langseth M.: *Application of a split-Hopkinson tension bar in a mutual assessment of experimental tests and numerical predictions.* International Journal of Impact Engineering 38 (2011) 824–836.
6. Delhaye V., Clausen A.H., Moussy F., Othman R., Hopperstad O.S.: *Influence of stress state and strain rate on the behaviour of a rubber-particle reinforced polypropylene.* International Journal of Impact Engineering 38 (2011) 208–218.
7. Dey S., Børvik T., Hopperstad O.S.: *Computer-aided design of protective structures: Numerical simulations and experimental validation.* Applied Mechanics and Materials 82 (2011) 686-691.
8. Erice B., Gálvez F., Cendón D., Sánchez-Gálvez V., Børvik T.: *An experimental and numerical study of ballistic impacts on a turbine casing material at varying temperatures.* Journal of Applied Mechanics 78 (2011) 051019-051030.
9. Fourmeau M., Børvik T., Benallal A., Lademo O-G., Hopperstad O.S.: *On the plastic anisotropy of an aluminium alloy and its influence on constrained multiaxial flow.* International Journal of Plasticity 27 (2011) 2005-2025.
10. Fransplass H., Langseth M., Hopperstad O.S.: *Tensile behaviour of threaded steel fasteners at elevated rates of strain.* International Journal of Mechanical Sciences 53 (2011) 946-957.
11. Gruben G., Fagerholt E., Hopperstad O.S., Børvik T.: F*racture characteristics of a cold-rolled dual-phase steel.* European Journal of Mechanics - A/ Solids 30 (2011) 204–218.
12. Hoang N-H., Langseth M., Porcaro R., Hanssen A.G.: *The effect of the riveting process and aging on the mechanical behaviour of an aluminium self-piercing riveted connection.* European Journal of Mechanics - A/Solids 30 (2011) 619-63.
13. Kane A., Børvik T., Berstad T., Benallal A., Hopperstad O.S.: *Failure criteria with unilateral conditions for simulation of plate perforation.* European Journal of Mechanics A/Solids 30 (2011) 468–476.
14. Kouba S., Othman R., Zouari B., El-Borgi S.: *Finite-element analysis of errors on stress and strain measurements in dynamic tensile testing of low-ductile materials.* Computers and Structures 89 (2011) 78-90.
15. Nogueira de Codes R., Hopperstad O.S., Engler O., Lademo O-G., Embury J.D., Benallal A.: *Spatial and temporal characteristics of propagating deformation bands in AA5182 alloy at room temperature.* Metallurgical and Materials Transactions A 42 (2011) 3358-3369.
16. Pedersen K.O., Børvik T., Hopperstad O.S.: *Fracture mechanisms of aluminium alloy AA7075-T651 under various loading conditions.* Materials and Design 32 (2011) 97–107.
17. Saai A., Dumoulin S., Hopperstad O.S.: *Influence of Texture and Grain Shape on the Yield Surface in Aluminium Sheet Material Subjected to Large Deformations.* AIP Conference Proceedings 1353 (2011) 85-90.
18. Westermann I., Snilsberg K.E., Sharifi Z., Hopperstad O.S., Marthinsen K., Holmedal B.: *Three-Point Bending of Heat-Treatable Aluminum Alloys: Influence of Microstructure and Texture on Bendability and Fracture Behavior.* Metallurgical and Materials Transactions A 42 (2011) 3386-98.

Book Chapters

1. Myhr O.R., Grong Ø.: *Factors Influencing Heat Flow in Fusion Welding.* ASM Handbook, Volume 6A, Welding Fundamentals and Processes. ASM International, Ohio, USA (2011) 67-81.
2. Myhr O.R., Grong Ø.: *Modeling of Metallurgical Microstructure Evolution in Fusion Welding.* ASM Handbook, Volume 6A, Welding Fundamentals and Processes. ASM International, Ohio, USA (2011) 797-818.

Keynote lectures

1. Børvik T., Hopperstad O.S., Langseth M., Berstad T.: A*re numerical simulations of ballistic impact predictive?* Proceedings of 8th European LS-DYNA Users Conference, 23- 24 May 2011, Strasbourg, France.

Invited lectures

1. Børvik T.: *Are numerical simulations of ballistic impact predictive?* DCAMM Seminar, DTU, 8 November 2011, Lyngby, Denmark.
2. Hopperstad O.S.: *Behaviour and modelling of aluminium alloys with applications to automotive and protective structures.* Fraunhofer EMI, 23 September 2011, Freiburg, Germany.
3. Langseth M.: *Crashworthiness of aluminium structures: modelling and validation.* Vehicle Property Validation 2011, 7-9 September 2011, Bad Nauheim, Germany.
4. Langseth M.: *Aluminium in the offshore and automotive industry.* QATALUM site visit and aluminium symposium, 23-24 November 2011, Qatar.

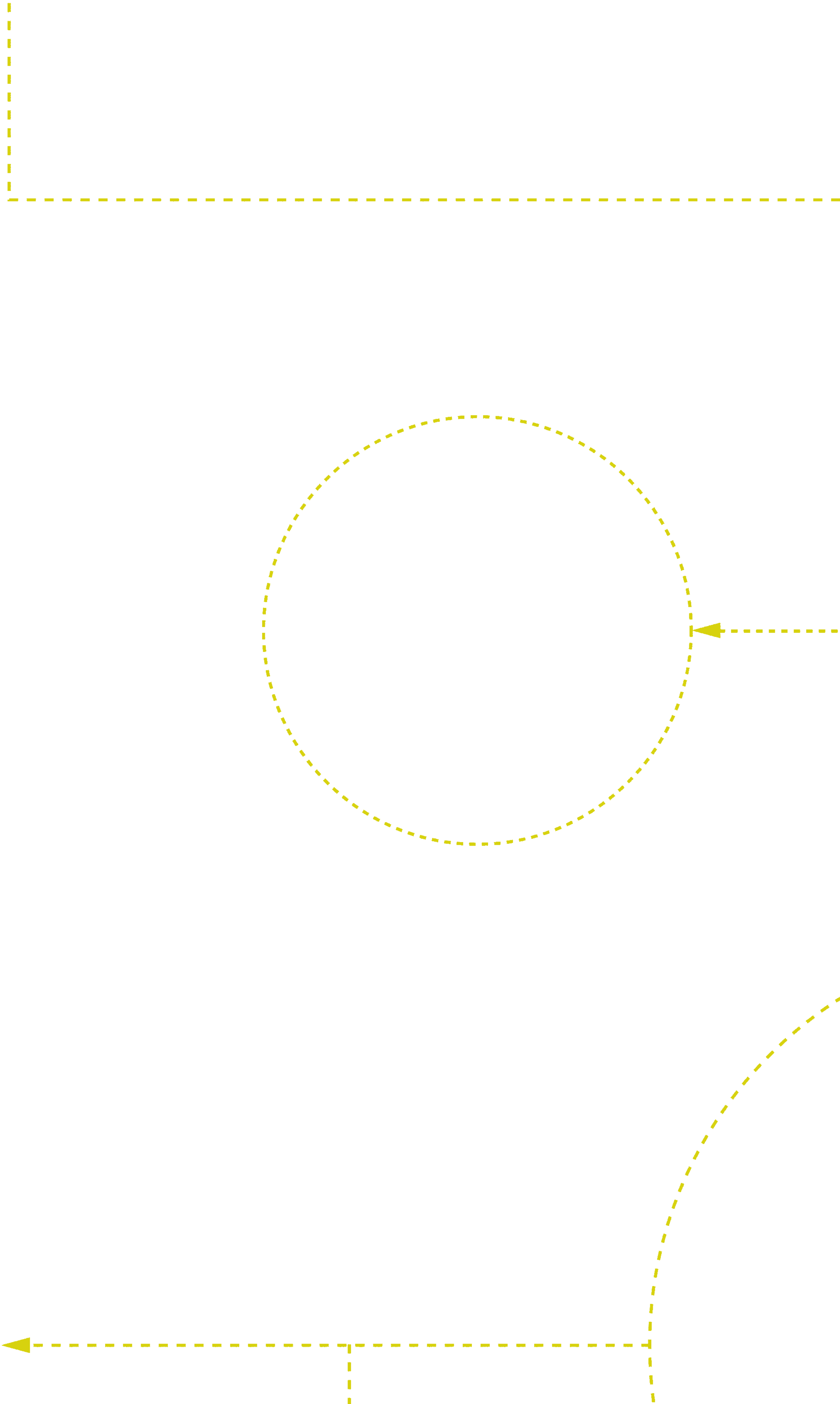
Oral presentations at conferences

1. Børvik T., Wetzel J.J., Dharmasena K.P., Hanssen A.G., Hopperstad O.S., Hutchinson J., Langseth M., Olovsson L., Wadley H.: *Deformation and fracture of impulsively loaded sandwich panels: Simulation of fracture.* MURI-workshop on Explorations of Cellular Concepts for High Intensity Dynamic Load Mitigation, 6 April 2011, University of Virginia, Charlottesville, USA.
2. Børvik T.: *Modelling of light-weight protection.* IAMI CANMET - Workshop, 10-11 May 2011, Hamilton, Ontario, Canada.
3. Børvik T., Hopperstad O.S., Langseth M.: *On the validity of computer-aided design for optimized protective structures.* The 3rd International Symposium on Plasticity and Impact (ISPI2011), 8-12 December 2011, Hong Kong, China.
4. Clausen A.H., Polanco-Loria M., Berstad T., Hopperstad O.S.: *A constitutive model for thermoplastics with some applications.* 8th European LS-DYNA Users Conference, 23-24 May 2011, Strasbourg, France.
5. Delhaye V., Clausen A.H., Hopperstad O.S., Moussy F., Othman R., Nesa D.: *Behaviour and modelling of a rubber-modified polypropylene.* 3rd International Conference on Impact Loading of Lightweight Structures (ICILLS 2011), 28 June – 1 July 2011, Valenciennes, France.
6. Dey S., Børvik T., Hopperstad O.S.: *Computer-aided design of protective structures: Numerical simulations and experimental validation.* Proceedings of the Third International Workshop on Protective Structures (PROTECT2011), 30 August – 1 September 2011, Lugano, Italy.
7. Fourmeau M.: *Anisotropic fracture mechanisms of the AA7075-T651 aluminium alloy.* IAMI CANMET - Workshop, 10-11 May 2011, Hamilton, Ontario, Canada.
8. Fourmeau M, Børvik T, Benallal A, Hopperstad O.S.: *Computation of the fracture behaviour of a high-strength aluminium alloy at low stress triaxialities.* Conference on Computational Modeling of Fracture and Failure of Materials and Structures - CFRAC 2011 , 6-9 June 2011, Barcelona, Spain.
9. Fourmeau M., Børvik T., Benallal A., Hopperstad O.S.: *Fracture of aluminium alloy AA7075-T651.* 3rd International Conference on Impact Loading of Lightweight Structures ICILLS 2011, 28-31 July 2011, Valenciennes, France.
10. Gálvez F., Erice B., Cendón D., Sánchez-Gálvez V., Børvik T.: *An experimental and numerical study of ballistic impacts on a turbine casing material at varying temperatures.* Proceedings of 26th International Symposium on Ballistics (ISB2011), Miami, USA, 12-16 September, 2011.
11. Gruben G.: *Fracture characteristics of a dual-phase steel.* IAMI CANMET - Workshop, 10-11 May 2011, Hamilton, Ontario, Canada.
12. Hoang N-H., Hanssen A.G., Langseth M., Porcaro R.: *An Experimental and Numerical Study of the Structural Behaviour of Aluminum Riveted Joints.* 3rd International Conference on Impact Loading of Lightweight Structures (ICILLS 2011), 28 June – 1 July 2011, Valenciennes, France.
13. Hopperstad O.S.: *Identification and validation of constitutive model and fracture crite-rion for AlMgSi alloy with application to sheet forming.* IAMI CANMET - Workshop, 10-11 May 2011, Hamilton, Ontario, Canada.
14. Hopperstad O.S., Børvik T.: *Experimental and numerical investigation of the behaviour of AA5083 aluminium alloy in presence of the Portevin-Le Chatelier effect.* IAMI CANMET - Workshop, 10-11 May 2011, Hamilton, Ontario, Canada.
15. Knoll O., Schweizerhof K., Hopperstad O.S., Langseth M.: *Failure modelling in aluminium HPDC components: Using a probabilistic approach.* 4th GACM Colloquium on Computational Mechanics for Young Scientists from Academia and Industry, 31 August- 2 September, Dresden, Germany.
16. Koukal A., Baier H., Clausen A.H., Seibert D.: *Influence of the fibre content on the mechanical behaviour of polymers for pedestrian protection.* 3rd International Conference on Impact Loading of Lightweight Structures (ICILLS 2011), 28 June – 1 July 2011, Valenciennes, France.
17. Langseth M.: *Crashworthiness of Aluminium Structures.* IAMI CANMET - Workshop, 10-11 May 2011, Hamilton, Ontario, Canada.
18. Langseth M.: *Crashworthiness of Aluminium structures.* The 3rd International Symposium on Plasticity and Impact (ISPI 2011), 8-11 December 2011, Hong Kong, China.
19. Morin D., Lauro F., Clausen A.H., Hopperstad O.S., Langseth M.: *Modeling of bonded joints for crashworthiness applications.* 3rd International Conference on Impact Loading of Lightweight Structures (ICILLS 2011), 28 June – 1 July 2011, Valenciennes, France.
20. Peroni M., Solomos G., Pizzinato V., Hopperstad O.S., Børvik T., Langseth M.: *Impact behaviour testing of amluminium foam.* 3rd International Conference on Impact Loading of Lightweight Structures (ICILLS 2011), 28 June – 1 July 2011, Valenciennes, France.

21. Rakvåg K.G., Børvik T., Schleyer G.K., Underwood N., Hopperstad O.S.: *Pulse-pressure loading of pre-damaged plates.* Third International Conference on Impact Loading of Lightweight Structures, 28 June - 1 July, Valenciennes, France.
22. Saai A., Westermann I., Dumoulin S., Hopperstad O.S., Berstad T.: *Influence of Microstructure and Texture on the Bendability of AA7108 Aluminium Alloy.* Proceeding of the 10th International Conference on Technology of Plasticity, ICTP, 25-30 September 2011, Aachen, Germany.
23. Saai A., Dumoulin S., Hopperstad O.S.: *Influence of Texture and Grain Shape on the Yield Surface in Aluminium Sheet Material Subjected to Large Deformations.* The 14th International ESAFORM Conference on Material Forming. AIP Conf. Proc. Volume 1353, 27-29 April 2011, Belfast, Ireland.

Poster presentations at conferences

1. Gruben G., Hopperstad O.S., Børvik T. and Fagerholt E.: *Fracture characteristics of a dual phase steel and the application of the two modified versions of the Mohr-Coulomb criterion for ductile fracture.* Proceedings of 3rd International Conference on Impact Loading of Lightweight Structures, 28 June – 1 July 2011, Valenciennes, France.
2. Knoll O., Hopperstad O.S., Langseth M., Schweizerhof K.: *Numerical modelling of aluminium die-castings using a probabilistic approach.* 3rd International Conference on Impact Loading of Lightweight Structures (ICILLS 2011), 28 June – 1 July 2011, Valenciennes, France.
3. Kristoffersen M., Børvik T., Ilstad H., Langseth M., Hopperstad O.S.: *Impact against offshore pipelines.* Proceedings of 3rd International Conference on Impact Loading of Lightweight Structures, 28 June – 1 July 2011, Valenciennes, France.
4. Ognedal A.S., Clausen A.H., Hopperstad O.S., Polanco-Loria M., Benallal A., Raka B.: *Biaxial deformation of PVC and HDPE.* 3rd International Conference on Impact Loading of Lightweight Structures (ICILLS 2011), 28 June – 1 July 2011, Valenciennes, France.
5. Polanco-Loria M., Clausen A.H.: *A novel methodology applied to the identification of material parameters for thermoplastics.* 3rd International Conference on Impact Loading of Lightweight Structures (ICILLS 2011), 28 June – 1 July 2011, Valenciennes, France.



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Annual Report for SIMLab Centre for Research-based Innovation 2011

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