# CASA

## Annual Report 2018

Centre for Advanced Structural Analysis

sfi Centre for Research-based Innovation

SINTEF

NTNU

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NTNU Grafisk senter

(Photo: Sølvi W. Normannsen)

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# SUMMARY

### Organization
CASA (Centre for Advanced Structural Analysis) is a Centre for Research-based innovation (SFI). It is hosted by the Department of Structural Engineering at the Norwegian University of Science and Technology, in close cooperation with Department of Materials Science and Engineering and Department of Physics, also at NTNU. SINTEF Industry is the research partner. In addition to NTNU and SINTEF, the consortium includes the following 14 industrial partners: Audi AG, Benteler Automotive Raufoss AS, BMW Group, DNV GL AS, Equinor Energy AS, Honda R&D Americas Inc., Hydro Aluminium AS, Ministry of Local Government and Modernisation, Multiconsult Norge AS, Norwegian Defence Estates Agency, Norwegian National Security Authority, Norwegian Public Roads Administration, Renault, and Toyota Motor Europe
SFI CASA's board comprises representatives from all partners. A director heads the daily operation, assisted by a core team and programme heads. CASA's Industrial Reference Group is established to monitor and facilitate industrial implementation of the results generated in the Centre. A Scientific Advisory Board of international experts has been appointed to provide scientific and strategic advice.

### History
The activities in SFI CASA are based on the research platform generated in the SFI SIMLab centre from 2007-2014. They preserve and develop further the knowledge and infrastructure generated by an investment of NOK 225 million to facilitate innovation and value creation in important business areas for Norwegian society. CASA is much broader in scope than the previous centre as it includes multi- and interdisciplinary research on different physical scales.

### Generic research
The Centre works with the development of validated computational tools for innovation with and for its partners who come from the oil and gas industry, transportation and physical security. Although the partners represent different fields, they have similar needs in advanced structural analysis. The basic research in the Centre is pre-competitive and generic. This facilitates cooperation and the transfer of knowledge across business sectors. A multi- and interdisciplinary research approach based on multiscale testing, modelling and analysis in an industrial context is applied. Another characteristic is the top-down/bottom-up approach. The main goal is always the final structure of the product.

### Research plan
The Centre's research is organized in five basic research programmes: Lower Scale, Metallic Materials, Polymeric Materials, Structural Joints, and Structures. It is worth noting that the basic research programme Metallic Materials is closely coupled with the Toppforsk project FractAl, described in more detail on page 26. The programmes Methods and Tools and Industrial Implementation focus on the transfer of knowledge and technology from the research programmes to the industrial partners.

### Meetings, seminars, and conferences
The Centre organized several technical meetings and seminars linked to the different research programmes throughout 2018. The technical meetings are an important arena for discussions with the industrial partners and help cooperation and communication within the research programmes. The annual work plans are worked out on the basis of discussions at the technical meetings. The Industrial Reference Group had several telephone meetings and met in Trondheim on 15 November. Finally, the Board had a seminar and Board meeting on 18-20 September in Oslo, Norway.

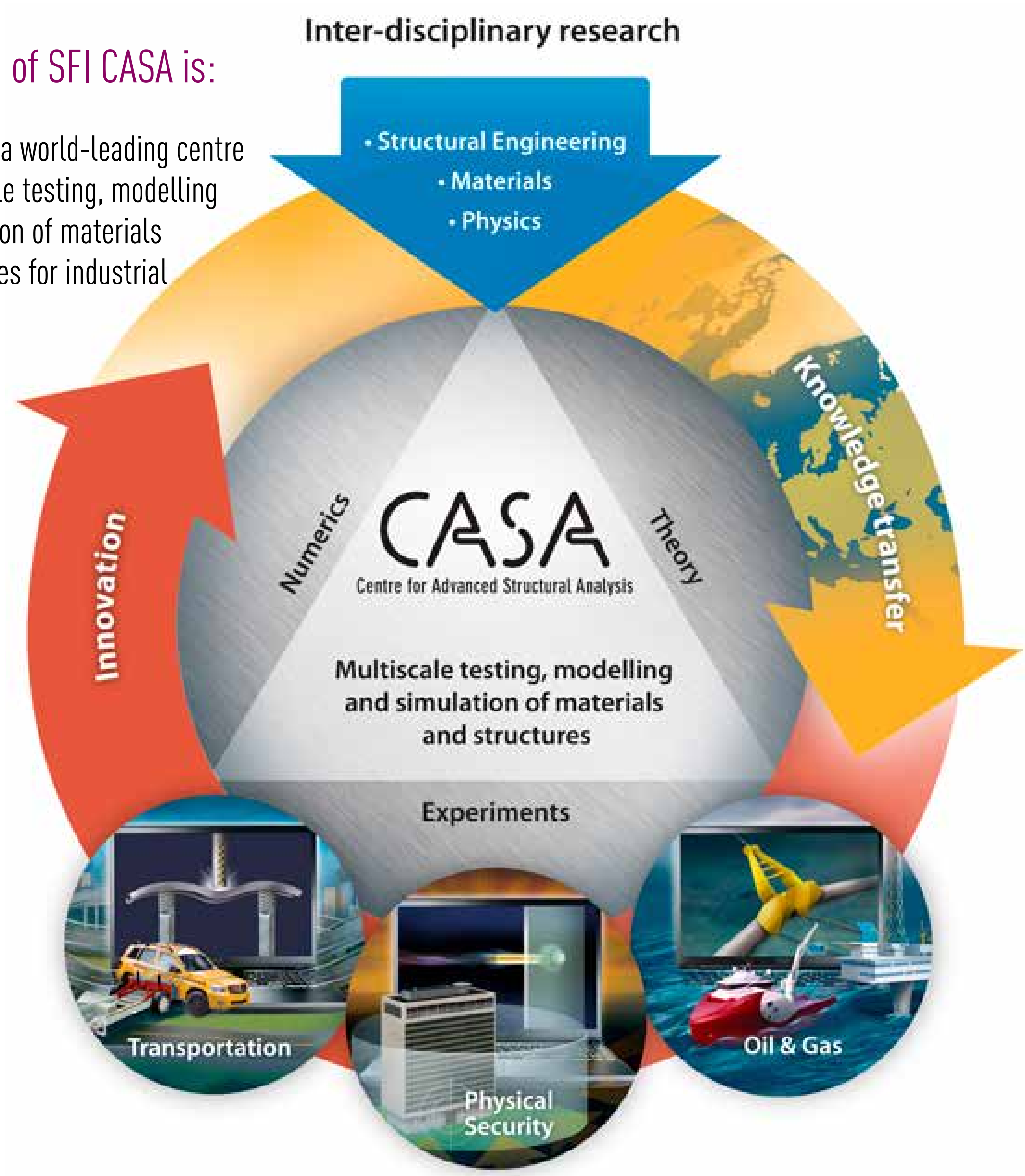
### International cooperation
International cooperation and cutting-edge research are fundamental to an SFI. The key researchers in CASA all have an extensive international network. Three of the professors are editors of leading international journals. The Centre cooperates with several research institutions and companies worldwide. In addition, the Centre has five international partners (Audi, BMW, Honda, Renault, and Toyota).

### Visibility
CASA's media strategy aims at popular science presentations of its research activities. It has been visible in the public debate in 2018 with several news stories covering CASA's work. Another aspect is making female researchers particularly visible in order to recruit new female researchers. Visibility in the research community is also important. In 2018 CASA published 19 articles in peer-reviewed journals, gave 26 conference presentations, and 9 invited and keynote lectures.

# VISION AND OBJECTIVE

## The vision of SFI CASA is:

To establish a world-leading centre for multiscale testing, modelling and simulation of materials and structures for industrial applications




## Objective

The Centre will develop validated computational tools for innovation together with and for partners in the oil and gas industry, the transportation industry (automotive and infrastructure along Norwegian roads) and in industry and public enterprises working with physical security (protection of critical infrastructure that could be subjected to terrorist acts and sabotage). Even though these partners represent different business sectors, they have similar needs in advanced structural analysis because the underlying theories and formulations behind the different computer tools are the same. Accordingly, the basic research in the Centre is precompetitive and generic in nature to facilitate cooperation between the user partners and hence transfer of knowledge across business sectors. This supports the success criteria defined by the Research Council of Norway for an SFI centre where research at a high international level aims to create a platform for innovation and value creation. Our major research initiative is only achievable for a centre with long-term objectives and funding.

Thus the main objective with CASA is:

To provide a research and technology platform for the creation and development of smart, cost effective, safe and environmentally friendly structures and products through multiscale testing, modelling and simulation.

GOALS AND RESEARCH PLAN

(Photo: Melinda Gaal)

## Goals

The main quantitative goals of the Centre are as follows:

**Industrial:** 1) To develop methods and tools for implementation at the user partners. 2) To ensure the transfer of technology across business sectors. 3) To arrange courses and case study seminars at the user partners. 4) To facilitate concurrent research projects with the user partners and cooperation between partners. 5) To facilitate employment of post docs, MSc and PhD candidates at the user partners to strengthen the industrial implementation.

**Academic:** 1) To graduate 20 PhD candidates and employ 5 post docs. 2) To graduate 100-200 MSc students. 3) To attract 10 non-Norwegian professors/scientists to the Centre. 4) To publish 100-150 papers in international peer-reviewed journals in addition to conference papers. 5) To arrange two international conferences.

**Media:** 1) To implement a strategy for popular science presentations of the research activities in magazines, newspapers, on television, radio and the web. 2) To establish a media strategy where the female researchers are made particularly visible in order to recruit female PhDs and post docs and contribute to a more even gender balance in this research field.

## Research questions

Discussions with the partners have revealed that more extensive use of advanced numerical simulations will improve their competiveness in making cost-effective, safe and environmentally friendly structures and products. This industrial need is the basis for the three research questions defined as the point-of-departure for the research activities in CASA. The research questions encompass the entire first five-year period as well as the potential subsequent three-year period of the Centre, but additional research questions may emerge in the later phases of the SFI.

**RQ1:** How can we establish accurate, efficient and robust constitutive models based on the chemical composition, microstructure and thermo-mechanical processing of a material?

**RQ2:** How can we apply knowledge of material, geometry and joining technology to obtain optimal behaviour of hybrid structures for given load situations?
**RQ3:** How can we describe the interaction between the load and the deformable structure under extreme loading scenarios?
Motivated by these research questions, five basic research programmes are defined in order to increase the prediction accuracy of numerical simulations.

## Research programmes

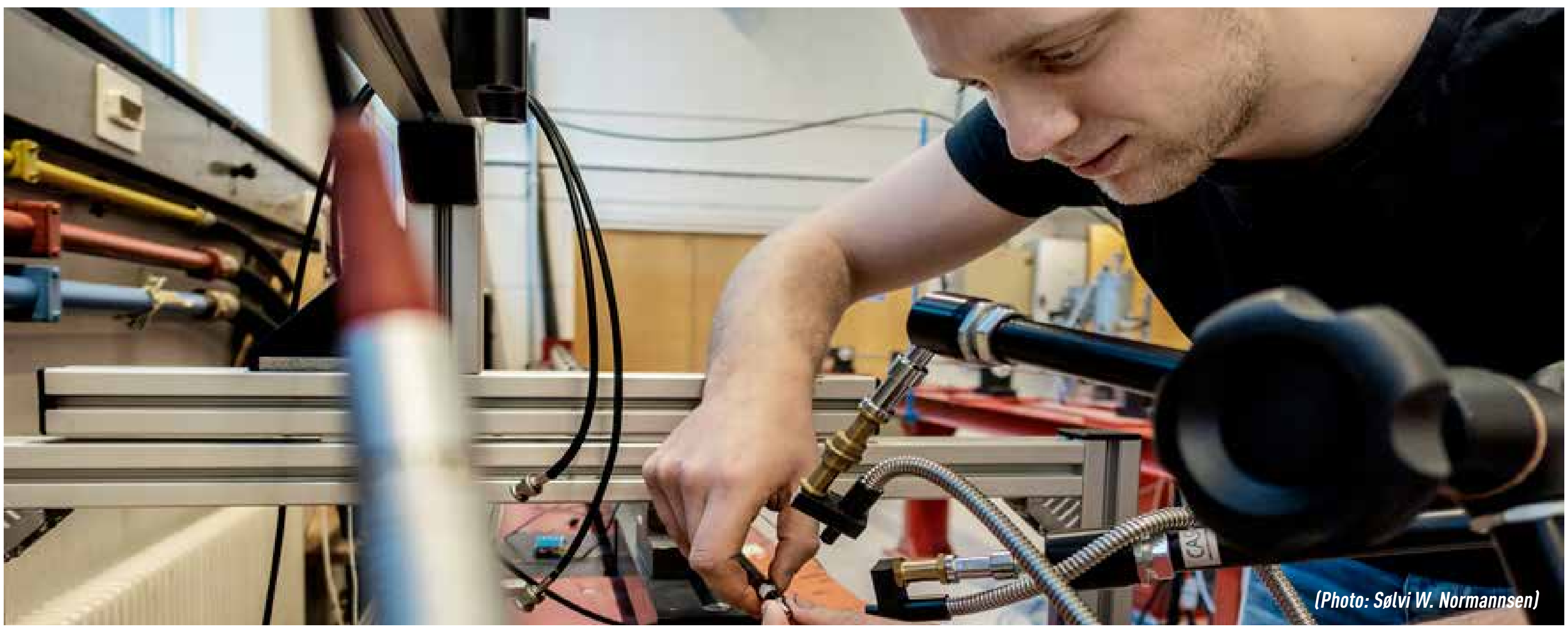
**Lower Scale:** This programme will concentrates on the lower length scales of materials, from atomic up to the micrometre scale, and will provide experimental and modelling input to the multiscale framework from the lower scale.

**Metallic Materials:** This will develop a physically based and experimentally validated multiscale framework providing constitutive models for crystal plasticity, continuum plasticity, damage and fracture of metallic materials. The main emphasis will be on aluminium alloys and steels. In many critical structural applications, material properties beyond standard testing conditions are required; hence high and low temperatures, high pressures (from blast waves or water depths) and elevated rates of strain (including shock loading) will be given special attention.

**Polymeric Materials:** This research programme will develop and improve material models representing the thermo-mechanical response up to fracture for polymers, i.e. thermoplastics with or without fibre reinforcement and elastomers. The models will be developed for application in an industrial context. Particular attention is paid to validation and efficient identification, of the parameters involved in the models.

**Structural Joints:** This programme will provide validated computational models for multi-material joints applicable in large-scale finite element analyses. The scope is limited to the behaviour and modelling of structural joints made with screws, adhesive bonding and self-piercing rivets - as well as possible combinations of these. The considered materials are steel, aluminium and reinforced polymers.

**Structures:** This research programme will develop advanced computational tools and establish validated modelling guidelines for computer-aided design of safer and more cost-effective structures. Another objective will be to replace phenomenological models with physical models in a top-down/bottom-up multiscale modelling approach in order to reduce the number of mechanical tests as much as possible in the design phase. With respect to protective structures, the emphasis in this research programme will not be on traditional fortification installations, but on innovative lightweight and hybrid structures to meet the future needs of the user partners. Actual materials are those typically used in protective structures such as steel, aluminium, polymers, glass, foams, ceramics and concrete.


*(Photo: Sølvi W. Normannsen)*

# RESEARCH METHODOLOGY AND SCOPE

The activities in CASA will represent a step change for advanced structural analysis for industry and public enterprises as it is based on multi- and interdisciplinary research on different physical scales. The research methodology adopted to meet the overall objective is presented in Figure 1. As illustrated, a structure or product can be studied on different physical scales just like the modelling scales (there is also a time scale which reflects the duration of the physical events to be studied, but this is not shown in the figure). By using a top-down/bottom-up approach the main goal of the research will always be the final structure or product. In some cases, microstructural modelling or even modelling on atomic scale may be required to understand the underlying physical mechanisms of the observed material response to loading, whereas for joints or components the behaviour may be sufficiently well understood on the continuum scale. In all cases, research at the Centre will be designed to obtain modelling frameworks on the material and structural levels that are suitable for industrial applications. Many research topics and activities are addressed on the various scales: testing and modelling of materials and structures, numerical solution techniques, experimental techniques, verification and validation approaches, and optimization methods and parametric studies. Verification is the process of determining that a computational model accurately represents the underlying mathematical model and solution, whereas validation deals with the relationship between the computational model and the physical reality. Figure 2 illustrates the important interlink between Basic research, Technology transfer and Industry. The Methods & Tools programme is a synthesis of Basic research, where guidelines and recommended practice for credible numerical structural analysis is established. The Industrial implementation programme is the link between the Methods & Tools programme and the industrial use of the research and technology developed at the Centre for innovation.

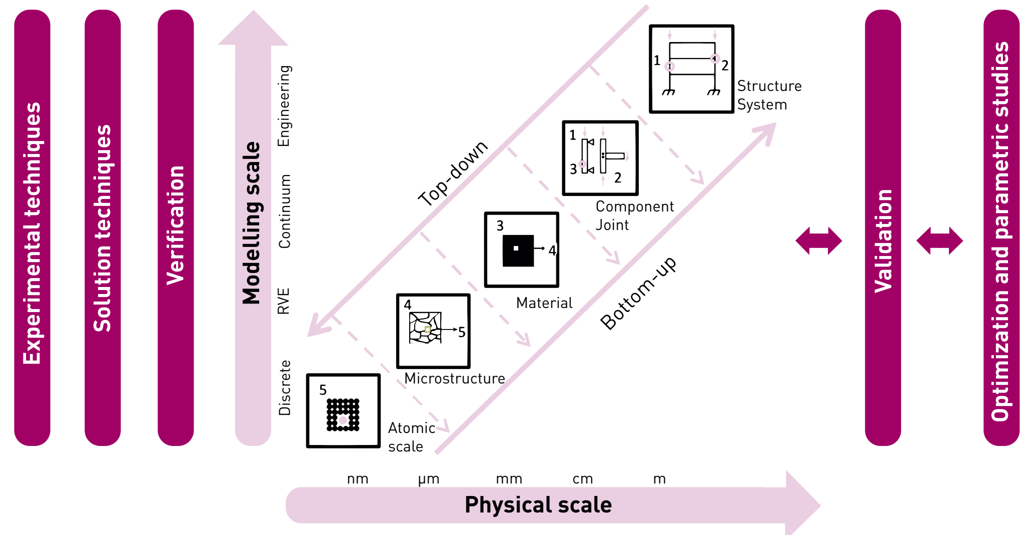



*Figure 1: Research methodology.*

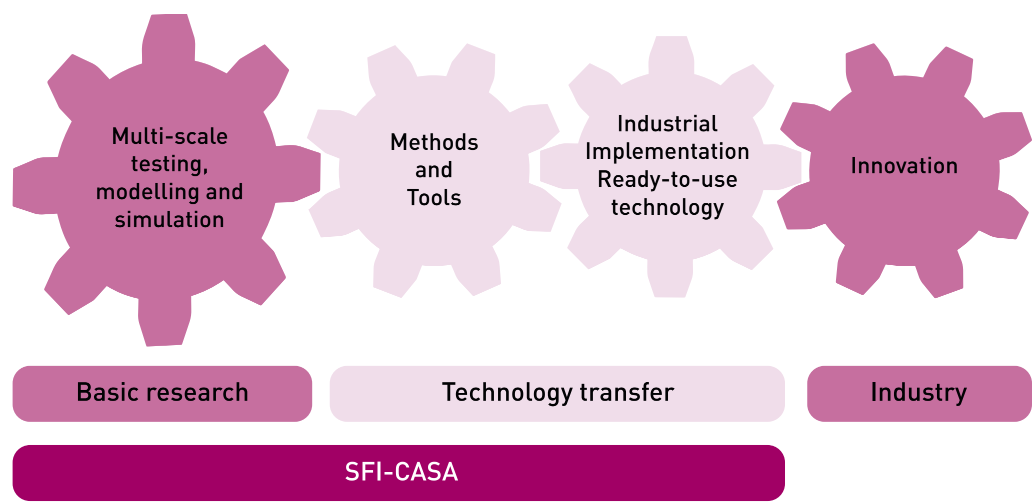



*Figure 2: Structure of research, technology transfer and industrial implementation.*

# RESEARCH ORGANIZATION

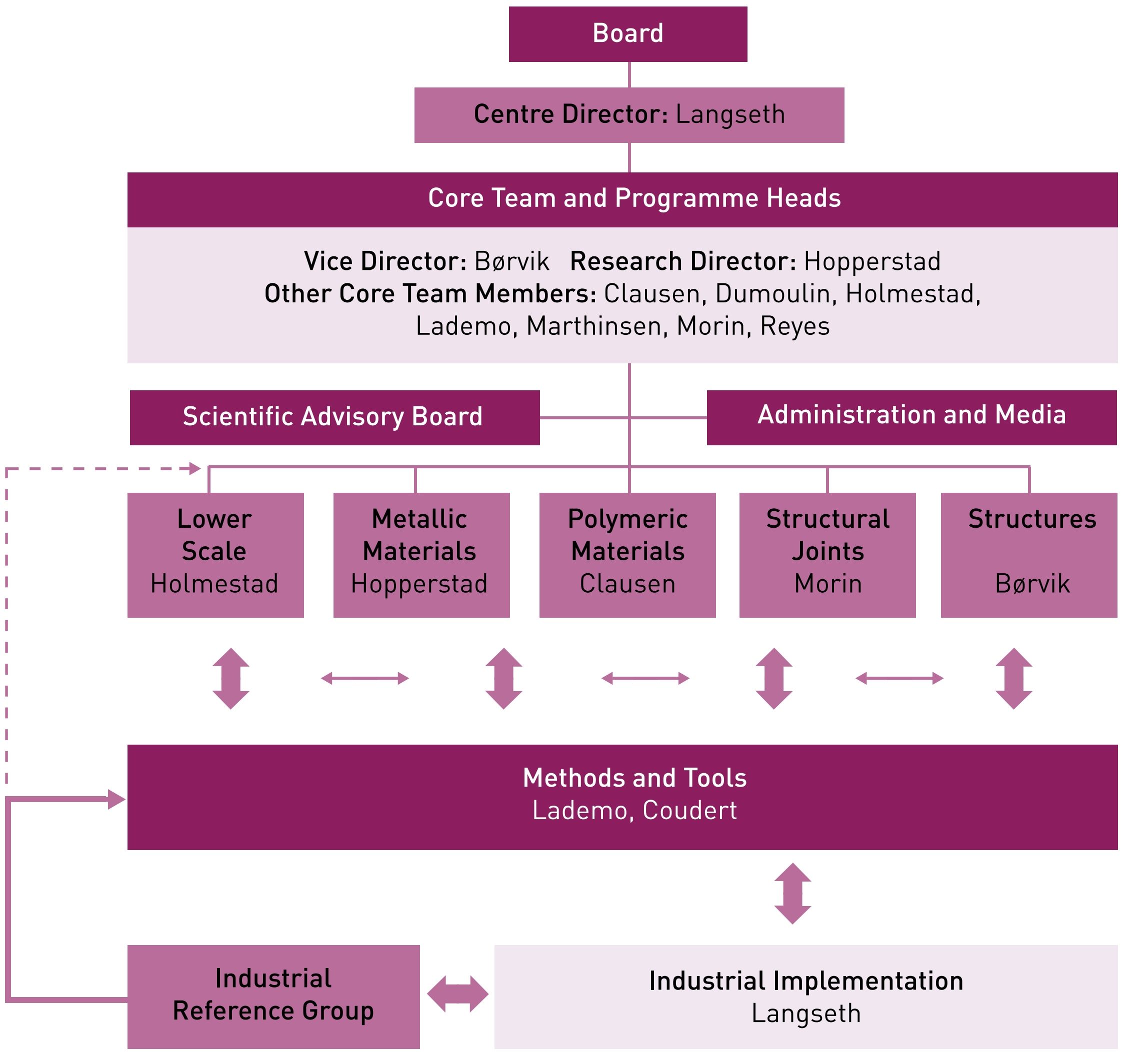



*Figure 3: Structure of the organization in 2018.*

The overall management structure of the Centre is shown in figure 3. The Centre consists of a board comprising members from the consortium participants. The Board's mandate is to formulate the strategy for the Centre, approve annual operational plans, monitor the performance of the Centre according to the performance indicators described in the project description and annual targets, and propose corrective actions when needed. The Centre director is in charge of the operation of the Centre, assisted by a core team. A Scientific Advisory Board of international experts provide scientific and strategic advice. Each of the five research programmes is led by a programme head. These programme heads are responsible for the verification and validation of the developed models and technology. Cooperation across the research programmes ensures the transfer of technology and allow possible synergies. The Methods & Tools programme is the main instrument to link the research programmes in the Centre and the Industrial implementation at the industrial partners. These activities are also led by programme heads. The Centre has a clear strategy for the management of intellectual property issues, including any assignment for commercialization or development and the distribution of any commercial returns.

## The Board

Anders Artelius, Benteler Automotive Raufoss AS
Olav Bolland, NTNU (Chair)
Ketil Bonesmo, Norwegian National Security Authority
Jørn Brunsell, Norwegian Defence Estates Agency
Ole Daaland, Hydro Aluminium AS
Ana Fernandez, Renault
Agnes Marie Horn, DNV GL AS
Håvar Ilstad, Equinor Energy AS
Rolf Jullum, Ministry of Local Government and Modernisation
Octavian Knoll, BMW Group
Andreas Koukal, Audi AG
Christian Nørgaard Madsen, Multiconsult Norge AS
Satoru Miyagano, Toyota Motor Europe
Brian O'Hara, Honda R&D Americas Inc.
Rudie Spooren, SINTEF Industry
Gina Ytteborg, Norwegian Public Roads Administration

## Scientific Advisory Board

Professor Ahmed Benallal, LMT/ENS Paris-Saclay, France
Professor Em. David Embury, McMaster University, Canada
Professor Jonas Faleskog, Royal Institute of Technology, Sweden
Professor Norman Fleck, University of Cambridge, UK
Professor John Hutchinson, Harvard University, USA
Professor Frank Schäfer, Ernst Mach Institute, Germany

## Centre Director

Magnus Langseth, Professor, Dept. of Structural Engineering, NTNU

## Core team and programme heads

Tore Børvik, Professor, Dept. of Structural Engineering, NTNU
Arild Holm Clausen, Professor, Dept. of Structural Engineering, NTNU
Térence Coudert, Research Scientist, SINTEF Industry
Stéphane Dumoulin, Research Scientist, SINTEF Industry
Randi Holmestad, Professor, Dept. of Physics, NTNU
Odd Sture Hopperstad, Professor, Dept. of Structural Engineering, NTNU
Odd-Geir Lademo*, Research Manager, SINTEF Industry
Knut Marthinsen, Professor, Dept. of Materials Science and Engineering, NTNU
David Morin, Associate Professor, Dept. of Structural Engineering, NTNU
Aase Gavina Reyes, Professor, Dept. of Structural Engineering, NTNU

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

## Scientific staff

Vegard Aune, Associate Professor, Dept. Of Structural Engineering, NTNU
Torodd Berstad, Researcher, Dept. of Structural Engineering, NTNU
Borja Erice, Researcher, Dept. of Structural Engineering, NTNU
Egil Fagerholt, Researcher, Dept. of Structural Engineering, NTNU
Jesper Friis, Senior Research Scientist, SINTEF Industry
Gaute Gruben, Research Scientist, SINTEF Industry
Hieu Nguyen Hoang, Senior Research Scientist, SINTEF Industry
Joakim Johnsen, Researcher, Dept. of Structural Engineering, NTNU
Martin Kristoffersen, Researcher, Dept. of Structural Engineering, NTNU
Calin Marioara, Senior Research Scientist, SINTEF Industry
Afaf Saai, Research Scientist, SINTEF Industry
Ida Westermann, Associate Professor, Dept. of Materials Science and Engineering, NTNU

## Other Key Personnel

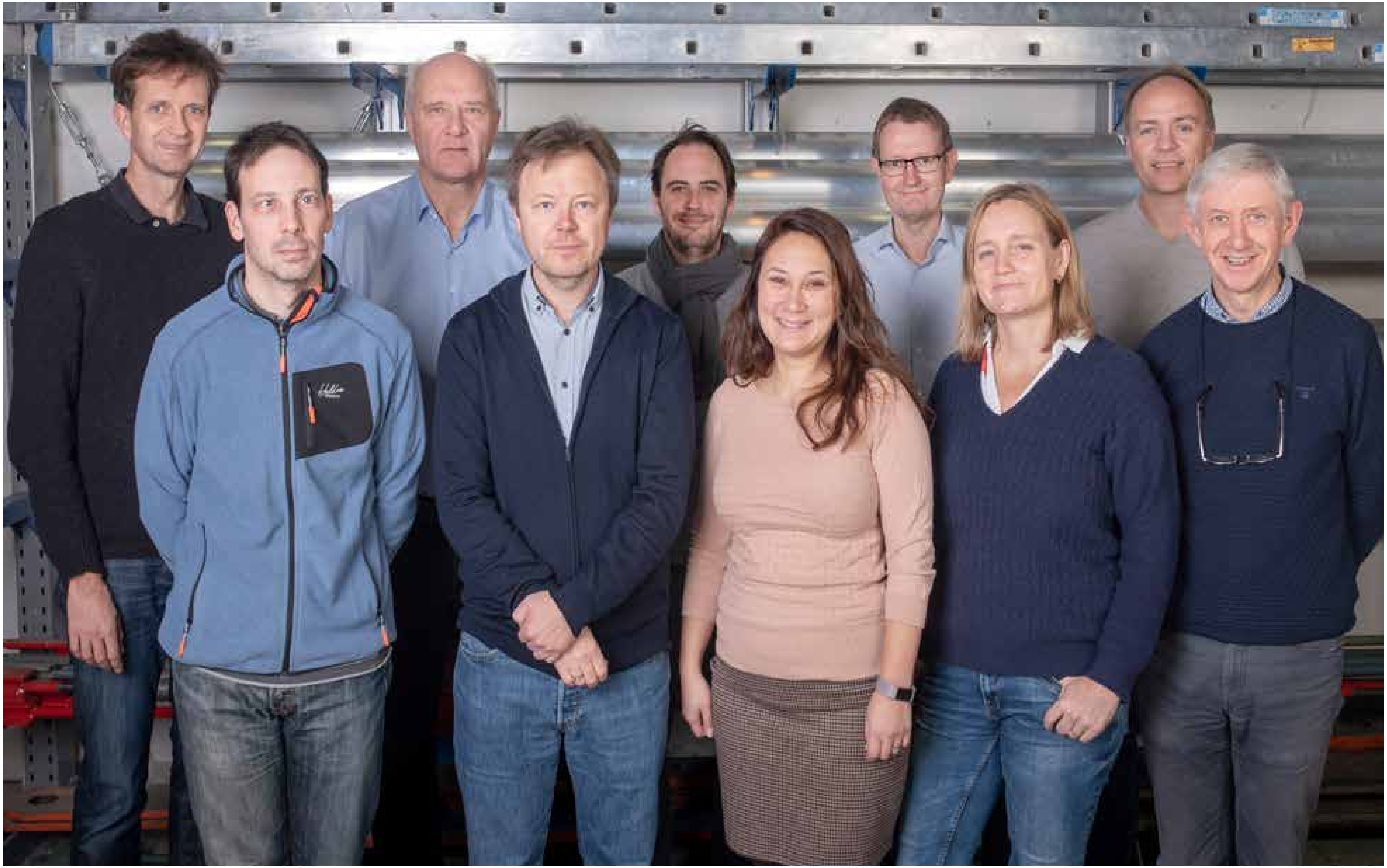
Trond Auestad, Senior Engineer, Dept. of Structural Engineering, NTNU
Peter Karlsaune, Project Coordinator, Dept. of Structural Engineering, NTNU
Laila Irene Larsen, Accountant, Dept. of Structural Engineering, NTNU
Sølvi W. Normannsen, Communication Officer, Dept. of Structural Engineering, NTNU
Tore Wisth, Senior Engineer, Dept. of Structural Engineering, NTNU

## Partners in 2018

**Host institution**
NTNU

**Research partner**
SINTEF Industry

**Industrial partners**
Audi AG
Benteler Automotive Raufoss AS
BMW Group
DNV GL AS
Honda R&D Americas Inc.
Hydro Aluminium AS
Ministry of Local Government and Modernisation
Multiconsult Norge AS
Norwegian Defence Estates Agency
Norwegian National Security Authority
Norwegian Public Roads Administration
Renault
Equinor Energy AS
Toyota Motor Europe



***CASA CORE TEAM:*** *From left: Arild Holm Clausen, Stéphane Dumoulin, Magnus Langseth, Tore Børvik, David Morin, Aase Reyes, Odd Sture Hopperstad, Randi Holmestad, Odd-Geir Lademo, Knut Marthinsen. (Photo: Lena Knutli)*

***The Board seminar in Oslo in september.*** *Front from left: Mario Polanco-Loria (Equinor), Tania Wåge Leporowski (Multiconsult), Eric DeHoff (Honda R&D Americas), Jean François Vittori (Renault), Norman Fleck (University of Cambridge), John Hutchinson Back (from left) Rolf Jullum (Ministry of Local Government and Modernisation, Norway), Andreas Koukal (Audi), Octavian Knoll (BMW), Ole Daaland (Hydro), Jørn Brunsell (Norwegian Defence Estates Agency), Johan Kolstø Sønstabø (Multiconsult), Frank Schäfer Holmen (NTNU), Satoru Miyagano (Toyota), Arild Holm Clausen (NTNU), Albert H. Collett (NTNU), Peter Karlsaune (NTNU), Rudie Spooren (SINTEF), Odd Sture Hopperstad (NTNU).*


(Harvard University), Ahmed Benallal (LMT/ENS Paris-Saclay), Olav Bolland (NTNU), Randi Holmestad (NTNU), Agnes Marie Horn (DNV-GL), Sølvi W. Normannsen (NTNU), Tore Børvik (NTNU), Aase Reyes (NTNU) Knut Marthinsen (NTNU), David Morin (NTNU).
(Ernst Mach Institute), Nicolas Neumann (Multiconsult), Knut Gaarder Rakvåg (Multiconsult), Magnus Langseth (NTNU), Anders Artelius (Benteler), Espen Frøisland (Norwegian Public Roads Administration), Jonas Faleskog (Royal Institute of Technology), Jens

# COOPERATION WITHIN THE CENTRE

The annual work plans for 2018 were based on the project description in the SFI CASA application, the work done in 2017, and discussions with the industrial partners. In-depth discussions took place in technical meetings in the research programmes throughout 2018. The aim was to ensure that the technical content was according to the defined plans and to prepare the work plans for 2019. SFI CASA's Industrial Reference Group (IRG) was established in 2016. The IRG met on 15 November in Trondheim in addition to several telephone meetings. Each industrial partner has one member in the IRG. Its mandate is to give advice on how implementation should be facilitated and to evaluate the implementation work at each partner.

The research in the Centre is mainly carried out by NTNU (PhD candidates, post docs, scientists and professors) and SINTEF (scientists) personnel. The main contribution from the partners is to guide the direction of the research to be carried out and to be active in the implementation of the technology. SINTEF, DNV GL, Norwegian Public Roads Administration and Hydro Aluminium AS are sponsoring one Adjunct Professor position each at the Department of Structural Engineering, NTNU. This ensures a link between the industry and the PhD and MSc students at SFI CASA. Furthermore, the Core Team has a meeting every week, led by the Centre Director. Every two weeks the CASA group has had a seminar on a variety of topics in order to spread knowledge and information in the Centre's research group.

The Centre's annual seminar and Board meeting was held at the Radisson Blu Scandinavia Hotel in Oslo, Norway on 18-20 September. The Scientific Advisory Board was also present during the seminar in order to evaluate the quality and relevance of the research. During the seminar, the user partners presented their long-term research and technology needs in a 5-10 year perspective. Furthermore, they were asked to evaluate their needs for implementation of the developed technology. The research and implementation needs were linked to the areas onshore and offshore structures (Equinor, DNV GL, Multiconsult, Norwegian Public Road Administration and Hydro Aluminium), automotive structures (Audi, BMW, Honda, Renault, Toyota, Benteler and Hydro Aluminium) and protective structures (Norwegian Defence Estates Agency, National Security Authority, Norwegian Ministry of Local Government and Modernisation, Multiconsult and Hydro Aluminium). Each area had a moderator who presented the outcome at the seminar. A very fruitful discussion followed where the Scientific Advisory Board took an active part.

*Left: Norman Fleck (University of Cambridge), Frank Schafer (Ernst Mach Institute), John Hutchinson (Harvard University). Photos: Sølvi W. Normannsen*

*Left: Peter Karlsaune (SFI CASA) Jørn Brunsell and Oda Toreskås (Norwegian Defence Estates Agency)*

*Left: Arild H. Clausen (SFI CASA), Andreas Koukal (Audi), Octavian Knoll (BMW).*

# INTERNATIONAL COOPERATION AND LEADING-EDGE RESEARCH

*Above left: Sverre Gulbrandsen-Dahl (SINTEF Raufoss Manufacturing), Espen Frøisland (Norwegian Public Roads Administration) and Magnus Langseth (SFI CASA). Above right: Eric deHoff (Honda). Below: Olav Bolland (Chairman of The Board), Ahmed Benallal (leader SAB).*

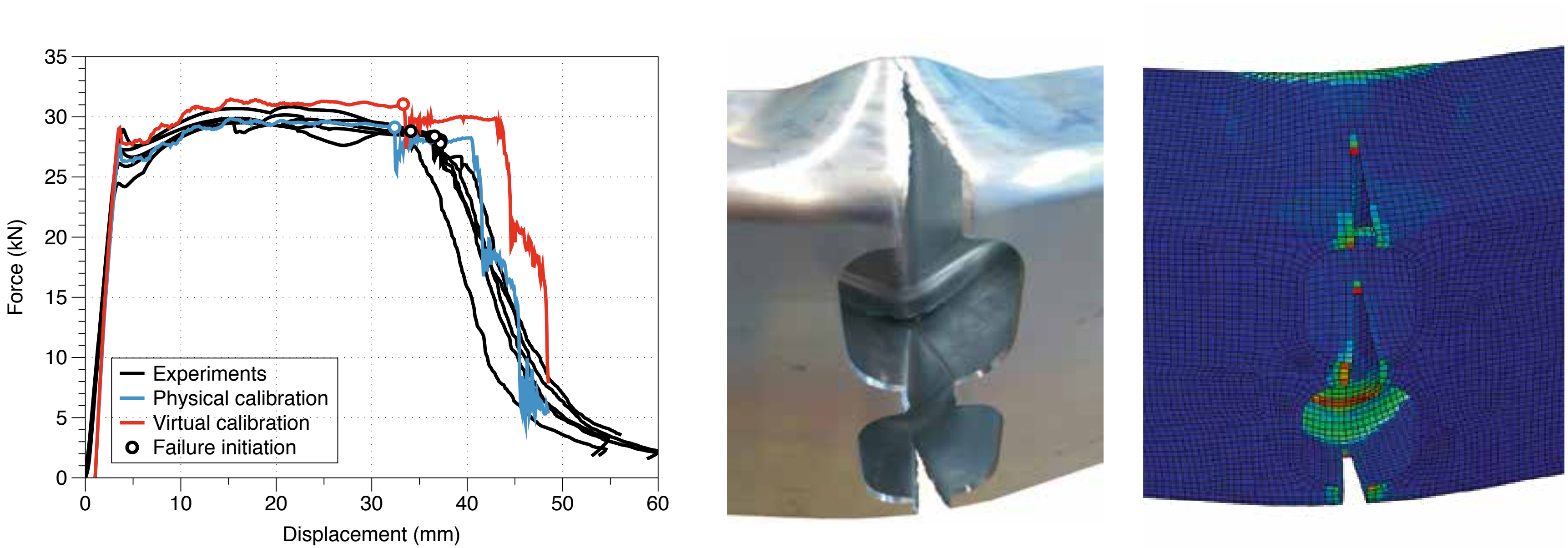
International cooperation is one of the success criteria for an SFI centre. Five of the industrial partners in SFI CASA are from outside Norway. SFI CASA also has strong interaction with universities, companies and research organizations abroad. The key researchers in SFI CASA all have an extensive international network. This is a result of many years of high quality research made visible through publications in peer-reviewed journals and conference contributions. In addition, three of the Centre professors are editors in highly ranked international journals. The cooperation with top international research groups ensures that the Centre transfers leading-edge technology to the partners and at the same time is able to define innovative research areas of importance to the partners.

SFI CASA aims at being world-leading. Reaching that goal requires advice from the best. A Scientific Advisory Board (SAB) of international experts has been appointed. The SAB participated at CASA's seminar in Oslo on 18-20 September 2018 (see also page 27).

SFI CASA has had cooperation with the following research institutions and companies in 2018: Joint Research Centre, Institute for the Protection and Security of the Citizen, Italy; McMaster University, Canada; Université de Montréal, Canada; Xi'an Jiaotong University, China; Grenoble INP, France; LMT/ENS Paris-Saclay, France; Indian Institute of Technology (IIT) Delhi, India; University of Toyama, Japan; Tokyo Institute of Technology, Japan; Eindhoven Technical University, the Netherlands; IMPETUS Afea AB, Sweden; Laboratory of Thermomechanical Metallurgy, EPFL, Switzerland; University of Cambridge, UK; University of California Los Angeles, USA.

MAIN RESEARCH ACHIEVEMENTS

# Towards a Virtual Laboratory for Design of




*(a)* *(b)*

*Figure 4: Extruded profile with holes subjected to three-point bending: (a) Force-displacement curves from experiments and simulations with physical and virtual calibration, and (b) comparison between the failure mode in experiment and simulation. Physical calibration means that mechanical testing has been used to calibrate the plasticity and fracture model, while virtual calibration implies that no mechanical tests have been used.*

A microstructure-based modelling approach has been developed in a joint effort between CASA and the Toppforsk project FractAl. The long-term objective of this activity is to establish a virtual laboratory for the design of aluminium structures in the ultimate limit state and the accidental limit state.

The proposed approach has already been applied to the modelling of extruded aluminium profiles subjected to axial loading and three-point bending with good results, see Figure 4. Another case studied is the failure of stiffened aluminium panels subjected to quasi-static and low-velocity impact loading, where the microstructure-based modelling approach again gave reliable results.

The modelling chain has four main ingredients as illustrated in Figure 5:

1. Nanostructure modelling based on chemical composition and temperature history gives the precipitate size distribution, the yield stress and the work hardening of the aluminium alloy.
2. Crystal plasticity modelling based on measured crystallographic texture and grain morphology as well as the stress-strain response from the nanostructure modelling is used to establish the yield surface of the aluminium alloys.
3. Combining the yield surface from the crystal plasticity modelling with the stress-strain curve from the nanostructure modelling enables an anisotropic metal plasticity model to be obtained. This model is then used in unit cell

# Aluminium Structures

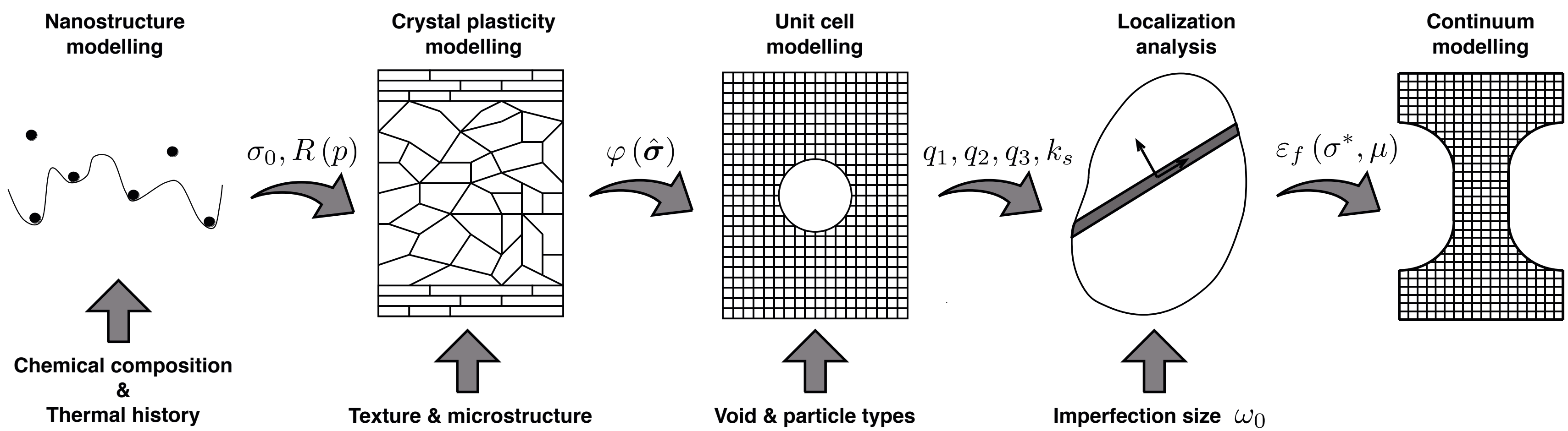



*Figure 5: Modelling chain for aluminium alloys.*

simulations with input from measurement of the initial content of voids and primary particles in the aluminium alloy. Based on the unit cell simulations the parameters of an anisotropic porous plasticity model are calibrated, which describes plastic anisotropy, work hardening and void nucleation and growth.

4. Localization analyses with the imperfection band approach are used to establish a failure criterion for the aluminium alloy. The material outside the imperfection band is modelled with the anisotropic metal plasticity model, whereas the material inside the band is modelled with the anisotropic porous plasticity model, adopting the same porosity as in the unit cell simulations.

The established failure criterion is then used with the anisotropic metal plasticity model in simulations of the behaviour and failure of structures and structural components made of the aluminium alloy.

# Probabilistic Strength Prediction Model for Float and Laminated Glass

In recent years, a considerable number of studies have been carried out to analyse the behaviour of glass plates under blast and impact loading by use of the finite element method. This has proven to be challenging, as the response of the glass is dominantly brittle, and is caused by microscopic flaws randomly distributed on the surface. Fracture mainly initiates in these flaws. This leads to high variability in the glass strength that depends on the geometry, boundary conditions and loading situation. Consequently, the identification of the probabilistic fracture strength of glass for application in finite element analyses is not straightforward.

In an attempt to model the response of various types of glass under blast and impact loading, our research has so far involved three main activities:

1. To develop and validate a stochastic strength prediction model for annealed float glass where both the fracture strength and the origin of fracture can be predicted.
2. To conduct series of quasi-static and dynamic blast and impact tests on both annealed float glass and laminated glass.
3. To model both annealed float glass and laminated glass exposed to blast and impact loading in a finite element solver by use of a novel 3D node-splitting technique.

Figures 6 and 7 show a comparison between high-speed camera images and numerical predictions of annealed float glass and laminated glass exposed to blast loading in the SIMLab Shock Tube Facility. The agreement between the experimental results and the numerical predictions is generally satisfactory. However, further work is required to make these methods more reliable and thus increase their prediction accuracy.

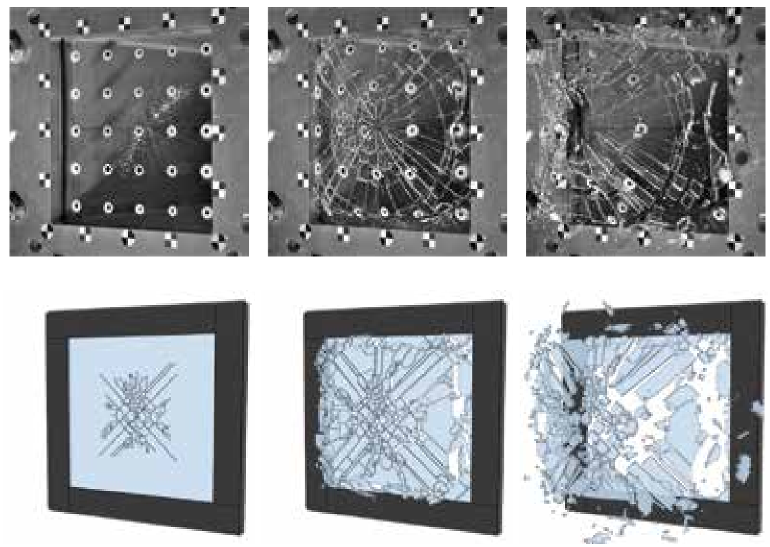


*Figure 6: Comparison between high-speed camera images and numerical predictions of annealed float glass exposed to blast load.*

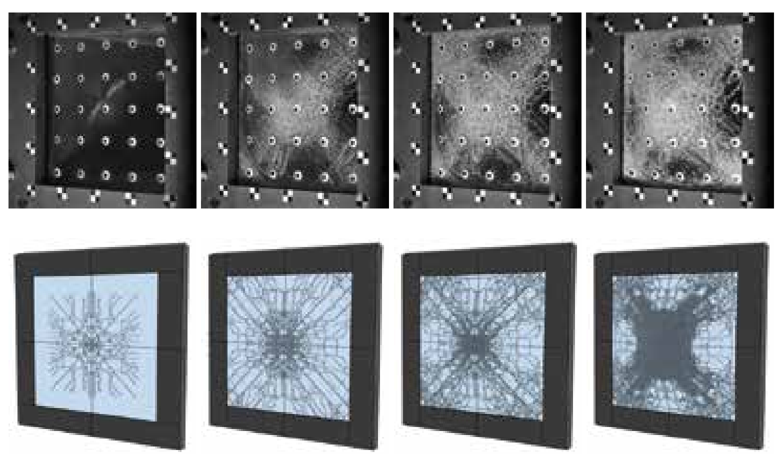


*Figure 7: Comparison between high-speed camera images and numerical predictions of laminated glass exposed to blast load.*

# Regularization Scheme for Shell Element Modelling of Failure in Metals

In most design approaches, material failure is an unwanted event. Therefore, components and structures are usually designed to avoid the initiation of ductile failure. Several methods or models are available in the literature to predict the initiation of ductile failure. These methods are often linked to fine discretization of the metallic materials using solid element meshes and/or rather complex models, which involve many dedicated material tests to calibrate their parameters. Even though these models are accurate, they might not be applicable in an industrial context due to the high cost of calibration and computational work. Structural analyses today are mainly based on shell element models and these types of elements impose additional simplifications on the representation of the materials and the prediction of ductile failure initiation.

In the context of SFI CASA, a new regularization scheme for the modelling of failure in metals with shell elements has been proposed (Figure 8). The novelty of this regularization scheme is that the structural aspect of shell elements is used to adjust the failure parameters of the material as a function of the loading scenario. In this new regularization scheme, the failure parameters of the materials will be automatically reduced and regularized according to the mesh size for membrane dominated loading while bending dominated loadings will not alter the failure parameters of the materials. The calibration of such a model relies on simple uniaxial tension tests which are widely available, and provides thus a fast and robust procedure. If required, more material tests can be used to calibrate the ductile failure model and thus improve the overall accuracy of the numerical analyses; however, this might not be required in pre-design phase where limited information and time are available.

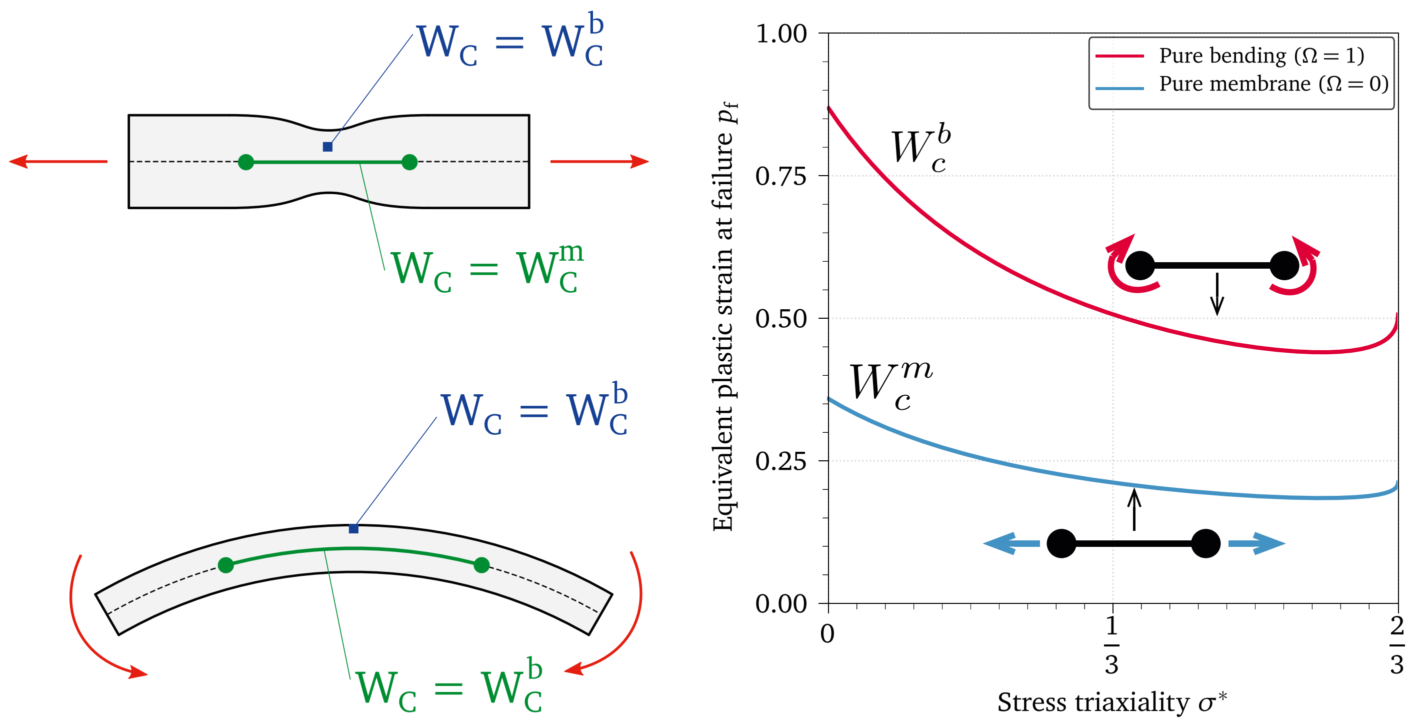



*Figure 8: New regularization scheme for shell element modelling of failure in metals.*

# Simple Model for Fibre-reinforced Polymers

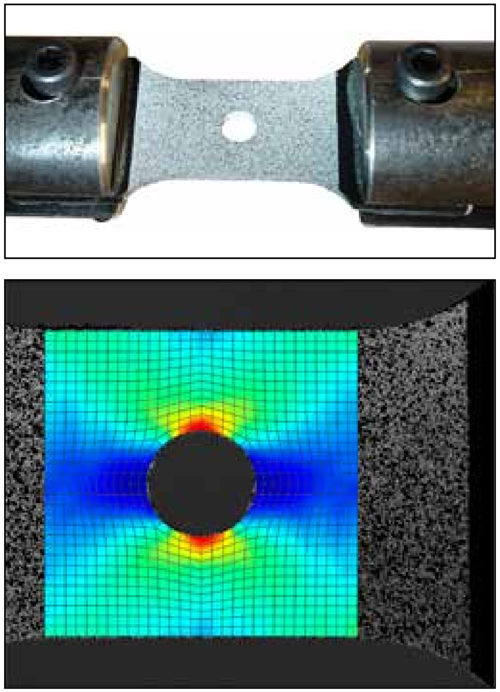


*Figure 9: Specimen used in plate-with-central-hole tests and principal strain field under deformation. The deformation direction is along the horizontal axis.*

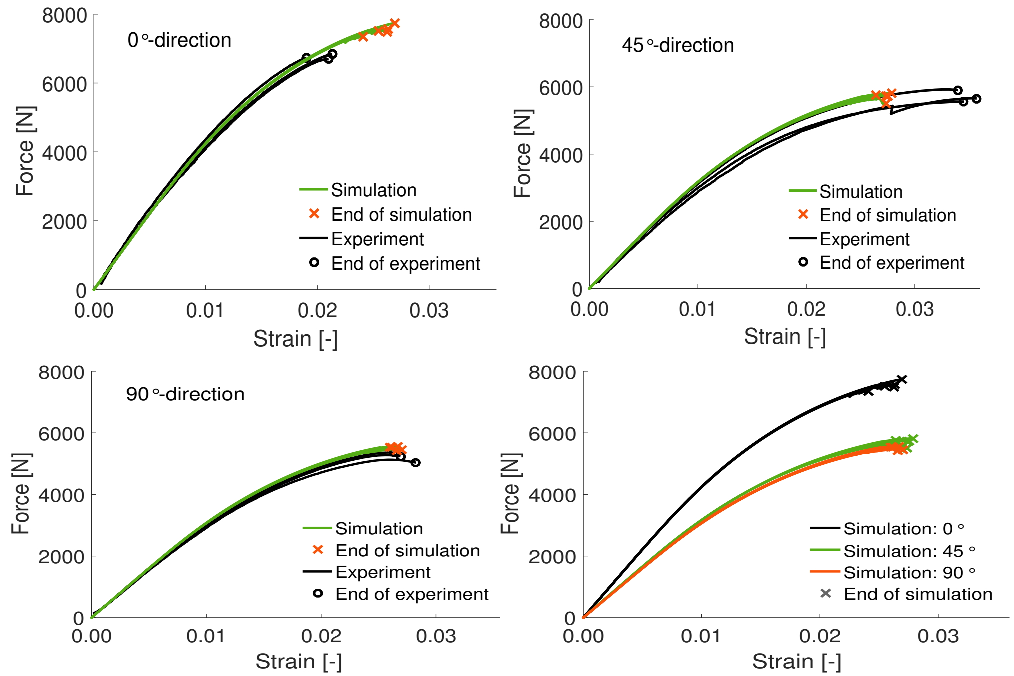



*Figure 10. Force-strain curves for plate-with-central-hole tests of PA with 30 wt.% glass fibres from tests and simulation (orthotropic elastic model with linear softening law and statistically distributed damage threshold).*

Fibre reinforcement enhances the stiffness and strength of polymeric materials at the expense of reduced ductility. Contrary to unreinforced polymers, fibre-reinforced materials are strongly anisotropic. In Petter H. Holmström's PhD thesis, it is demonstrated that orthotropic elasticity captures the anisotropy of short glass-fibre reinforced polymers very well.

Two material models for polymers reinforced with short glass fibres have been evaluated in the thesis. The first one is a simple, orthotropic elastic model with a linear softening law, where a statistically distributed damage threshold value is assigned to each element in a finite element model. The other model is a mesoscale composite material model that combines an elastoplastic matrix and a number of linear-elastic, one-dimensional fibre families, where the fibre phase is characterized by the fibre orientation distribution.

The capabilities of both models are investigated through a comprehensive validation study on injection-moulded plates. The study involves two classes of materials: polypropylene (PP) and polyamide-6 (PA), both reinforced with either 15 wt.% or 30 wt.% glass fibres. Depending on type of material, the experimental programme includes uniaxial tension tests, tests on plate with a central hole, plane strain tests, and bending tests. All types of tests are carried out at different angles relative to the mould flow direction.

Holmström's thesis finds that orthotropic elasticity is an excellent approximation for the anisotropic elastic behaviour. Further, the failure criterion associated with the linear softening law is calibrated from the tension tests in the 0° direction. It appears that this simple model gives a good prediction of the failure also in the other types of tests. As an illustration, Figure 9 shows the specimen used in plate-with-central-hole tests and Figure 10 provides both experimental results (3 replicate tests) and numerical predictions (5 simulations with different realizations of the damage threshold parameter).

When it comes to the mesoscale model, it is generally able to describe the anisotropic elastic behaviour in all tests. An interesting perspective is that, directly or indirectly, both models allow the inclusion of the effect of different fibre orientations at different locations in finite element simulations of a fibre-reinforced part.

# Testing of Polymeric Materials at a Wide Range of Rates and Temperatures

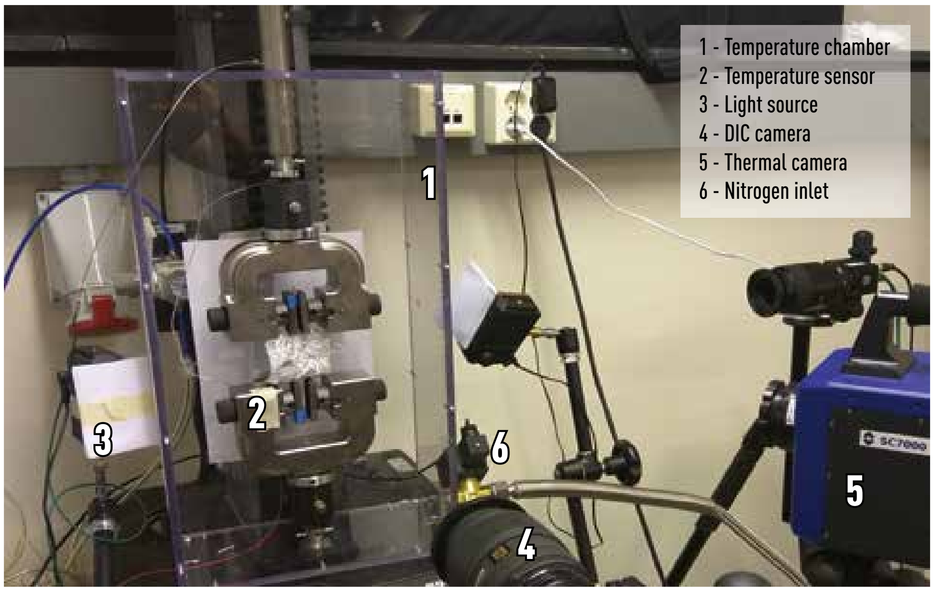



Figure 11: Experimental set-up for quasi-static material tests at low temperatures.

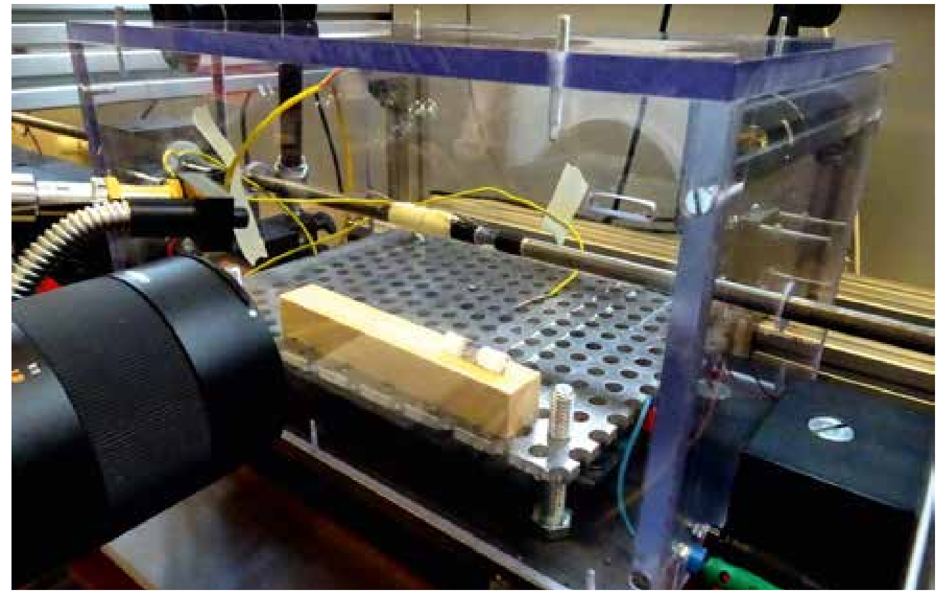


Figure 12: Experimental set-up for dynamic material tests at elevated temperatures.

Knowledge about material behaviour under different conditions is extremely important. This serves also as key information for material models in numerical simulations with the finite element method.

A characteristic feature with polymeric materials is their extensive viscosity compared with metals. Hence, the mechanical properties of polymers are strongly dependent on the strain rate and temperature. As a rule of thumb, an increase in strain rate with one decade, for instance from $10^{-3}$ to $10^{-2}$ $s^{-1}$, gives an increase in strength of about 10%. Temperature is also a crucial parameter. The maximum temperature of operation for many common polymers is less than 100 °C, while the minimum temperature before the material gets brittle often is somewhere between 0 and –50 °C. Hence, the window of operational temperatures is comparatively narrow. Furthermore, rather small changes of temperature may have a strong impact on the mechanical behaviour.

Polymers are applied in parts and components that may be exposed to a wide spectrum of rates and temperature. Taking the automotive industry as an example, the strain rate in a crash situation is typically of order $10^2$ $s^{-1}$, and the temperature might go down to –30 °C as well as up to +50 °C. A similar or even wider domain of rates and temperatures might be encountered by the offshore industry.

Experimental protocols for characterization of polymeric materials at different rates and temperatures have been an important research activity at CASA. The temperature spectrum is handled with a transparent chamber made of polycarbonate, see Figure 11, allowing for instrumentation with digital cameras. For testing at low temperature, the chamber is connected to a supply of liquid nitrogen. An experimental environment warmer than room temperature is obtained by introducing heating elements in the chamber. The temperature chamber was developed and explored in the past PhD projects of Joakim Johnsen and Arne Ilseng.

When it comes to rates, the split-Hopkinson bar is the most widely applied apparatus to get strain rates of order $10^2$ to $10^4$ $s^{-1}$. SIMLab has possessed a split-Hopkinson tension bar (SHTB) made of steel since 2001. This works well for the testing of metals. When it comes to polymers, however, the impedance mismatch between the metal bar and the much softer polymeric sample is a challenge that has motivated the development of bars made of nylon in many labs. As a part of the ongoing PhD project of Einar Schwenke, it is demonstrated that the steel SHTB at SIMLab works also for polymers (PP and XLPE). Further, the set-up is augmented with a temperature chamber to allow for low or high temperatures. Figure 12 shows the chamber with a heating element, a specimen, part of the SHTB and two cameras.

# An Eye for Details: A Deeper Understanding of Mechanisms for

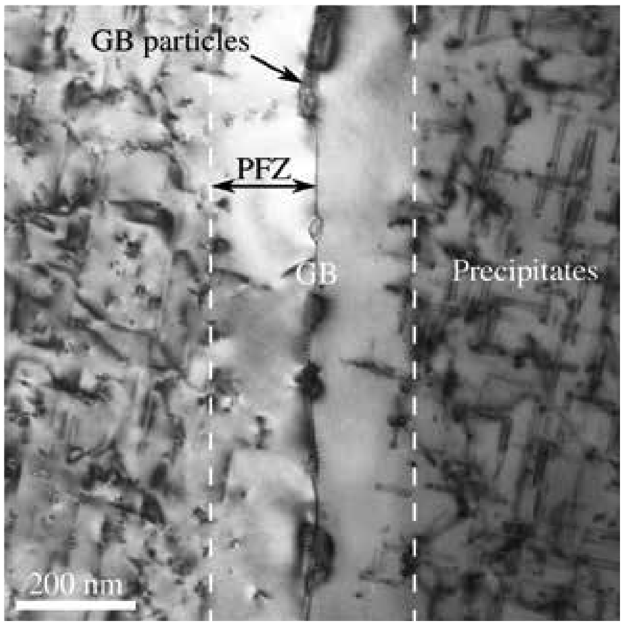



*Figure 13: A TEM image of a grain boundary (marked "GB") in AA6060 at peak hardness (T6 temper). The PFZ on either side is indicated with dashed lines. The absence of strengthening precipitates makes the PFZ vulnerable to strain localization.*

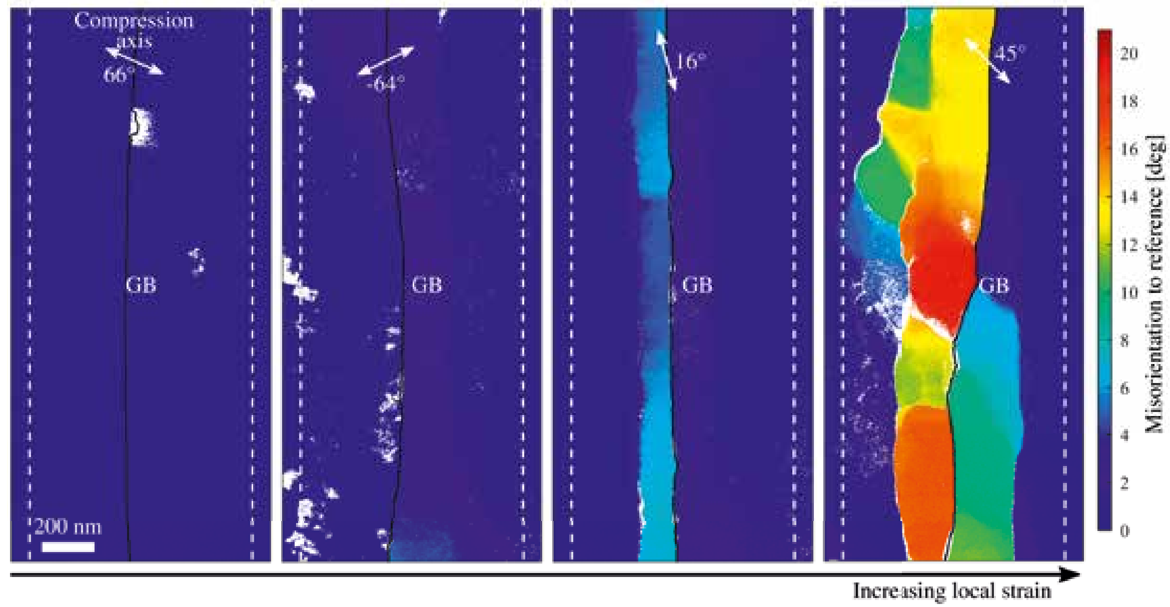



*Figure 14: Misorientation maps from scanning precession electron diffraction experiments conducted in a TEM of four grain boundaries in AA6060 (T6 temper) after 20% uniaxial compression. The grain boundary is labelled GB and marked with a black line, while the global compression axis is illustrated with a double arrow. The angle between the global compression axis and the grain boundary plane is shown as well. The misorientation values on either side of each grain boundary are calculated using the average orientation within the dashed region of the corresponding side as a reference."*

The Lower Scale programme at CASA is providing a foundation for the development of physically based models for plasticity, damage and fracture. This is done by studying the fundamental processes occurring in metallic materials, such as aluminium alloys and steels, during deformation. Because these fundamental processes occur at the micrometre and nanometre scales (and below), this programme is essentially devoted to investigations of interactions between atoms and dislocations, and to connect these length scales to the larger length scales needed in continuum modelling. Some of these investigations are performed using experimental techniques such as advanced electron microscopy, and some are carried out using models and simulations.

In 2018, the Lower Scale programme has provided deeper understanding of strain localization in soft precipitate free zones (PFZs) in aluminium alloys through a peer-reviewed research article.[1] An example TEM image of a grain boundary PFZ in an AA6060 alloy in T6 temper is presented in Figure 13. Different PFZs in the same material can respond very differently to applied loads. They will contain very few dislocations (and thus work harden very little), contrary to what is expected in current models. However, some of the PFZs can develop subgrains with significant misorientations relative to their parent grains, as shown in Figure 14. The current hypothesis is that the local strain at the PFZ provides the driving force for this subgrain formation. In particular, this strain localization is expected to depend on the orientation of the grain boundary relative to the global loading axis. It is also suggested that the different PFZ features engender different work hardening rates and possibly affect the nucleation of intergranular fracture. In addition, a peer-reviewed research article reporting on in situ scanning electron microscope (SEM) deformation of

# Grain Boundary Deformation at the Nanoscale

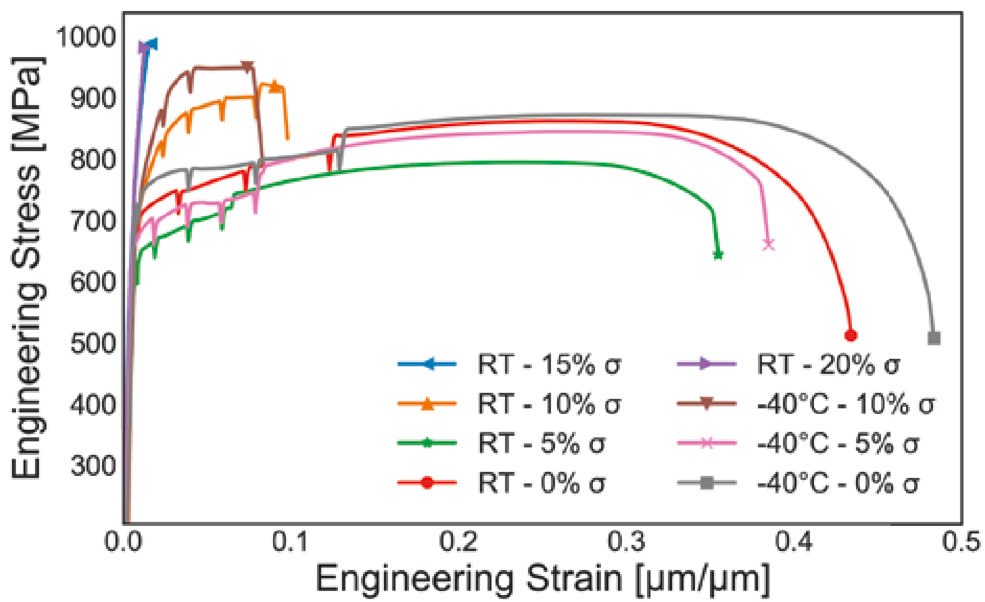



*Figure 15: Tensile test curves obtained during the in situ tensile tests. The drops in the curves are when the test is paused for acquiring EBSD data. The curves labelled RT in the legend are the tensile tests carried out at room temperature and similarly the -40 °C legends referring to the tensile test are carried out at -40 °C.*

super duplex stainless steels (SDSS) containing σ-phase was published.[2] This study investigated SDSS with 0%, 5% and 10% σ-phase in the microstructure using a tensile test device placed inside the vacuum chamber of a SEM. In situ tensile tests were carried out at both room temperature and -40 °C. During the tensile tests, the microstructure was recorded using electron backscatter diffraction (EBSD) at different strain levels. The results showed that the ferrite grains accommodated more deformation compared to the austenite grains during the tensile tests carried out at room temperature. Conversely, during the tensile tests carried out at -40 °C both phases have a more equal deformation behaviour. At low temperature, with σ-phase present, the material had slightly higher flow stress and lower ductility. However, by looking at the tensile curves in Figure 15, it can be concluded that the most important aspect when it comes to the deformation of SDSS is the amount of σ-phase present in the microstructure. The presence of this phase alters the phase balance between ferrite and austenite and deteriorates the mechanical properties.

Through the meticulous studies carried out on the lower scale, CASA is gaining a more complete picture of the processes that determine the ultimate response of metallic materials. This enables CASA to connect results from materials testing and simulations of structures to the real physical processes of our materials, and thereby to validate our models. This also plays an important part in the development of the virtual laboratory and the through scale modelling approach, as it lays the foundation for the first link in the multiscale chain.

[1] E. Christiansen, C. D. Marioara, K. Marthinsen, O. S. Hopperstad, and R. Holmestad, Materials Characterization 144, 522-31, 2018, 10.1016/j.matchar.2018.08.002. [2] C. O. Paulsen, R. L. Broks, M. Karlsen, J. Hjelen and I. Westermann, Metals 8, 478, 2018, 10.3390/met8070478

# Multiscale Modelling Framework for Structural Joints

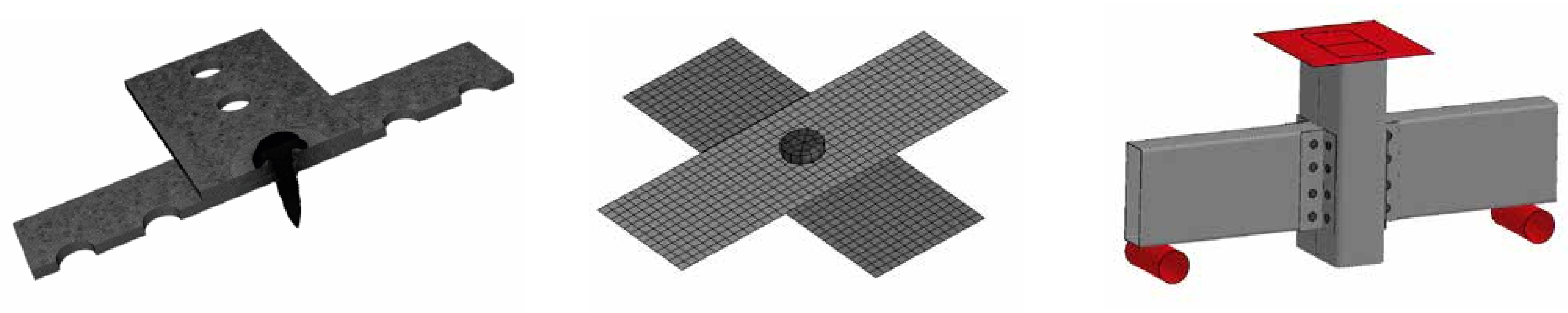


*Figure 16: Multiscale modelling framework for structural joints.*

Accurate design of lightweight structures requires knowledge about the strength and ductility of their joints. At the component level, failure is linked to the capacity of the materials to sustain a given load without triggering a ductile or brittle failure mode. However, at the structural level the components are fixed together with joints which often control the overall capacity of the structure to sustain the design load. Therefore, knowledge and methods linked to the capacity of structural joints are required to ensure proper design.

Structural analyses require specific models to incorporate the behaviour and failure of joints. These macroscopic models must retain sufficient accuracy to predict the overall stiffness, strength and ductility of the joints and avoid influencing the computational efficiency of the structural analyses. Today, these models are available for several types of connections used in the automotive industry. To comply to the industry's standards, in terms of modelling technology, simplifications are made in the representation of the joints. These simplifications imply that the parameters required by the macroscopic models are valid only for a specific connection in terms of material grades, thicknesses and type of fastener. A new set of parameters will then have to be identified for every new structural joint.

The calibration of macroscopic models for joints is carried out using a set of specific tests. Up to 45 tests might be involved in such a calibration and this procedure is too time consuming and costly to be included in the pre-design phase where many combinations of materials, thicknesses and fasteners might be of interest.

The proposed multiscale modelling framework for structural joints developed at SFI CASA is illustrated in Figure 16. In this framework, the structural analyses are carried out using validated macroscopic models where their parameters are identified by virtual tests rather than physical tests. Virtual tests for structural joints are based on detailed finite element models of the connections using mesoscopic models. These mesoscopic models incorporate an accurate geometry of the mechanical fasteners and a proper representation of the materials involved in the connection. If required, the potential variations of mechanical properties of the materials linked to the joining process might be included in such a model by simulating the joining process and use these results as input to the mesoscopic model. Besides the cost and time savings due to the virtual calibration of macroscopic models, the multiscale modelling framework changes the focus from specific joint testing to knowledge about materials. This procedure will enable proper calibration of macroscopic models for structural analyses even in the pre-design phase resulting in reduced time and cost for the user partners.

# Extension of the Nanostructure Model NaMo to Include Strain Rate and Temperature Effects

The nanostructure model NaMo has been developed over the last 20 years by Ole Runar Myhr and co-workers at Hydro and NTNU. The model consists of three sub-models: the precipitation model, the yield stress model and the work hardening model. Based on the chemical composition and thermomechanical processing of an Al-Mg-Si alloy (i.e., an alloy within the AA6000-series), NaMo predicts the size distribution of hardening precipitates, the amount of alloying atoms in solid solution, the yield strength and the work hardening. Until now, NaMo could only predict the room-temperature behaviour of Al-Mg-Si alloys. This has restricted the use of the model in structural applications, where the strain rate and temperature play important roles.

In 2018, in a joint project between Hydro, FractAl and CASA, NaMo was extended to account for the influence of strain rate and temperature on the stress-strain behaviour, see Figure 17, which opens up a wide range of new applications.

A unique feature of the enhanced version of NaMo is that the plastic response of the material can be predicted for varying strain rates and temperatures considering the simultaneous changes in the microstructure induced by the thermomechanical process. The model has been demonstrated to exhibit a high degree of predictive power as documented by good agreement between predictions and measurements. It is deemed well suited for simulations of thermomechanical processing of Al-Mg-Si alloys where plastic deformation occurs at various strain rates and temperatures. Also, it is well suited in simulations of aluminium structures under transient accidental loads such as blast loading and structural impact.

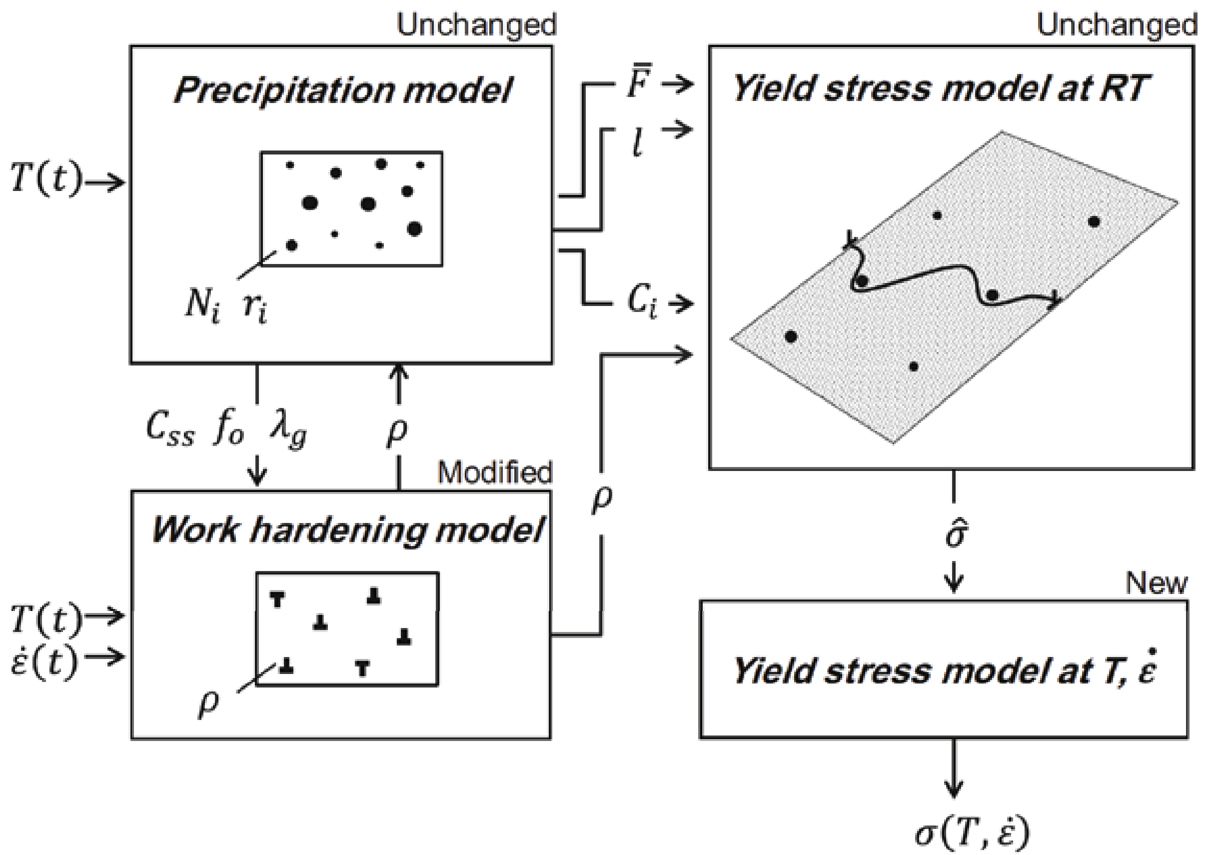



*Figure 17: Illustration of the coupling of the different sub-models in NaMo, and the transfer of data between the sub-models.*
*Reprinted by permission from: Springer Nature, Metallurgical and Materials Transactions A. Myhr, Hopperstad, Børvik (2018): A Combined Precipitation, Yield Stress, and Work Hardening Model for Al-Mg-Si Alloys Incorporating the Effects of Strain Rate and Temperature.*

CONCURRENT PROJECT

# Toppforsk Project FractAl: A New Way to Design Aluminium Structures

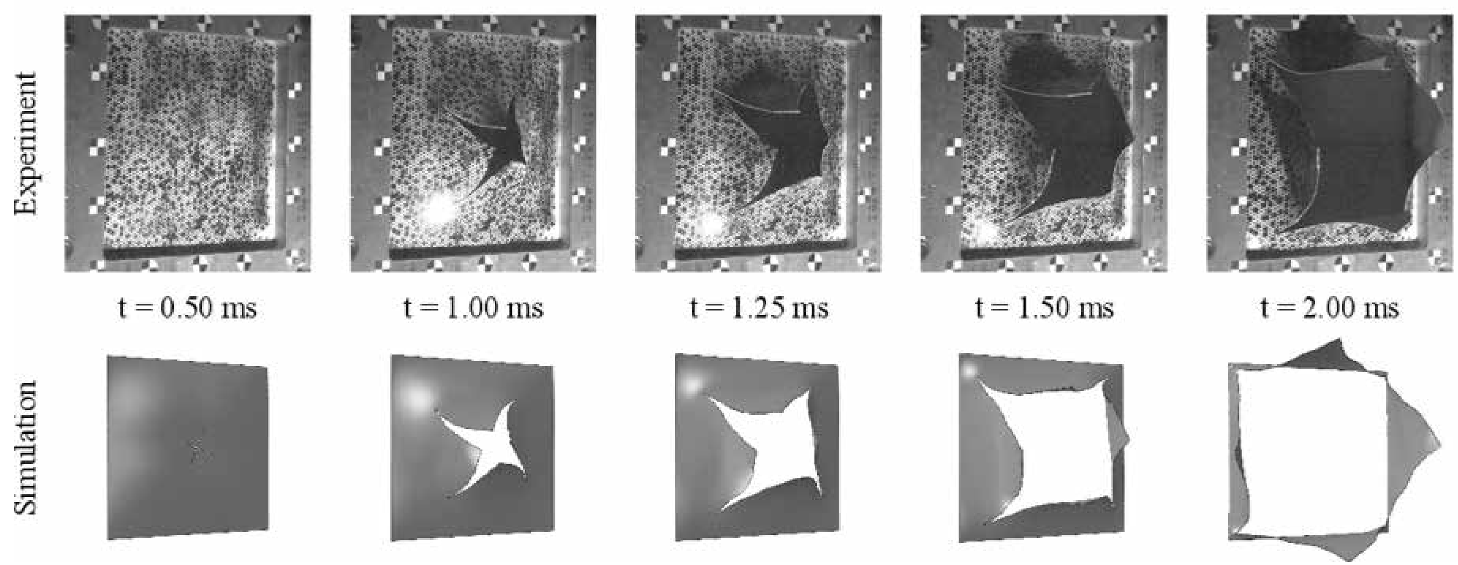



*Figure 18: Dynamic tearing of aluminium plate with initial defects: Experiment versus simulation with shell elements.*

Toppforsk funding is a targeted initiative for providing substantial, long-term support to research groups with the potential to reach the top of their field internationally. When the programme was launched in 2016, Prime Minister Erna Solberg pointed out that the project is a key step in cultivating more world-leading academic groups in Norway. Funding is only allocated to projects that have received the highest score after being reviewed by international referee panels.

The core team of the project consists of Professors Odd Sture Hopperstad (principal investigator) and Tore Børvik at SIMLab, Department of Structural Engineering NTNU, and principal engineer Ole Runar Myhr (Hydro) who also is adjunct professor at SIMLab.

The project deals with microstructure-based modelling of ductile fracture in aluminium alloys. In the design of aluminium structures against failure, the material's strength and ductility are important factors. To design lightweight structures, it is often necessary to use high strength aluminium alloys, while taking advantage of ductility in full. For aluminium alloys, increased strength often comes at the expense of the ductility of the material. This can increase the risk of structural failure. Therefore, it is important to have good models for the ductility of aluminium alloys under different load situations.

In FractAl a new microstructure-based modelling framework for ductile fracture in aluminium alloys will be developed and validated. It involves modelling and simulation at multiple scales as well as customized laboratory experiments.

Besides building a basic understanding of ductile fracture in aluminium alloys, the modelling framework will enable designers and engineers to select the most suitable aluminium alloy for a given structure with fewer time-consuming and costly mechanical tests. The framework can also be used to tailor alloys with ideal strength and ductility for a given structure. This could pave the way for a completely new way to design aluminium structures.

Currently 5 PhD candidates and 1 postdoc are working together with the core team. Professors Jonas Faleskog from KTH in Stockholm and Ahmed Benallal from ENS Paris-Saclay in Paris are also taking part in the project.

The results obtained in FractAl are implemented in the SIMLab Tool Box and will thus be made available to the partners of CASA as well as for other industry contacts.

# The SAB report: «Major progress in a Wide Range of Topics»

The title is the introduction in the second report by the Scientific Advisory Board (SAB) of CASA on the Centre. The report was given in September, and an 8-point summary follows:

*Scientific Advisory Board. From left: Norman A. Fleck, University of Cambridge, United Kingdom; Frank Schäfer, University of Freibourg and EMI, Germany; John. W. Hutchinson, Harvard University, USA; Ahmed Benallal, LMT/ENS Paris-Saclay, France (Chairman); Jonas Faleskog, KTH, Sweden. (Photo: Marianne Otterdahl-Jensen)*

1. The Centre is on-track and is deeply engaged in all aspects of the programme. It is clearly working well with the industrial partners. The Centre has an admirable team spirit. The activity is highly relevant to, and strongly motivated by, the needs of the partners.

2. The activity is of high scientific quality, with a large output of journal papers, conference contributions and keynote lectures. The group continues to enjoy a high level of international recognition and plays a leading role in editorial work in both Impact Engineering and in Solid Mechanics.

3. The Centre is very successful at attracting outstanding students for master´s and PhD programmes. These students are attractive to the partners in terms of both internships and subsequent recruitment. This is a major route for technology transfer and enhances the 2-way flow of research activity.

4. The Centre's research addresses relevant problems for the partners, across business sectors. The tools developed in the Centre are based on a unique understanding of material behaviour across the length scales. The SAB applauds the focus on practical computational methods. The Centre is world leading in this regard.

5. The Centre enjoys strong and decisive leadership that has established and maintained coordinated activity at the highest international level. The activity is well-aligned with stated objectives. The Centre is working hard to ensure relevance to the partners' needs, and at the same time maintaining high scientific quality.

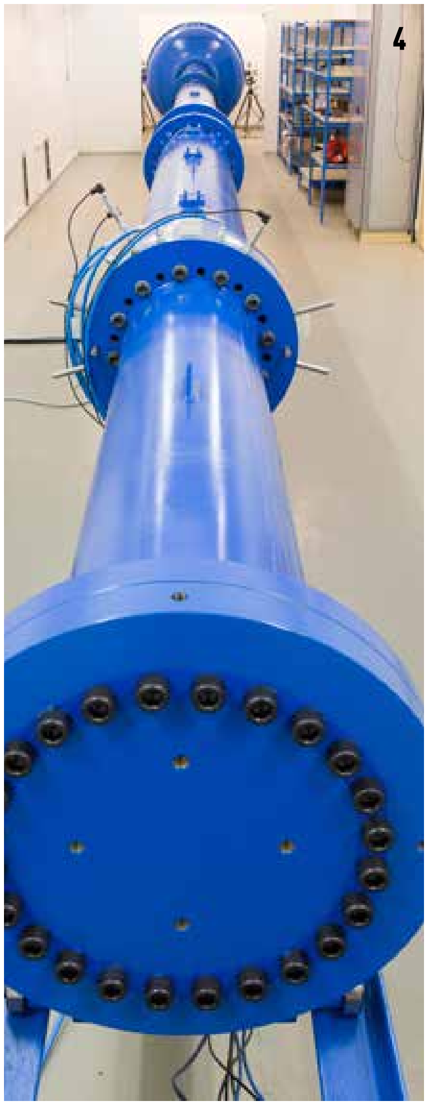
6. The Centre is maintaining an appropriate balance between fundamental and applied research, as evidenced by the high-quality publications and by statements made by the industrial partners.

7. The committee applauds the introduction of the virtual lab. It is of obvious benefit to the partners as a mechanism for speeding up and making the design process more accurate, particularly with the use of the NaMo module for aluminium alloys. The committee encourages the extension of this approach to relevant steels.

8. The SAB encourages continued dialogue between the Centre and partners on new topics. The Centre has an appropriate range of expertise and an extensive toolbox that can address a number of long-term problems raised by the partners.

# TEST FACILITIES





SFI CASA has access to test facilities in several laboratories at NTNU and SINTEF. Below is a list of the most important testing equipment. In addition, a number of uniaxial test machines are available.

**Gas gun (1)**
This is a compressed gas gun for ballistic impact studies. A variety of projectile geometries can be fired, with a maximum velocity of 1000 m/s.

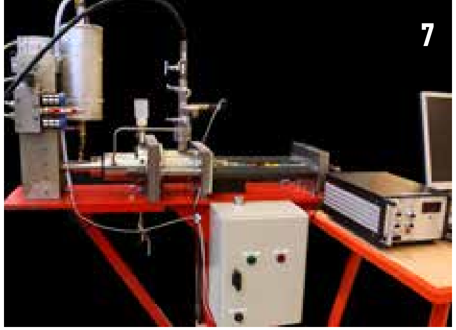
**Self-piercing riveting machine (2)**
In this machine self-piercing riveting can be carried out of sheets under industrial conditions.

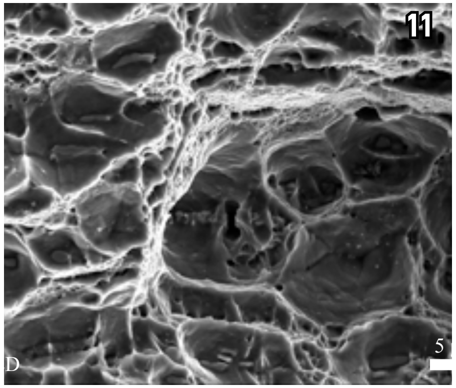
**Droptower impact system (3)**
In this machine impact testing of materials and small components can be carried out at low and high temperatures. The mass of the projectile ranges between 2 and 70 kg and gives an impact velocity in the range 0.8-24 m/s. All tests can be carried out with an instrumented nose which gives the impact force as a function of time.

**Shock tube facility (4)**
The tube is 18.2 m long and is divided into six sections. The tube ends in a 5.1 $m^3$ dump tank. The tube starts with a circular internal cross-section with a diameter of 0.34 m before it is transformed to a square cross-section of 0.3 m × 0.3 m. Threaded holes in the tube floor enable mounting of test specimens in the test section. Windows in the test section and the dump tank allow high-speed cameras to investigate the structural response during an experiment. In 2018 the tube was extended with a 0.6 m long glass channel. This gives increased insight into fluid-structure interaction effects during testing of energy absorbing components.

**Split-Hopkinson pressure bar (SHPB) (5)**
The split-Hopkinson pressure bar consists of a high-pressure chamber unit that can accelerate a striker bar against the end of the input bar. A compression stress wave is then generated in the input bar and the test sample sandwiched between the input and output bars is subjected to a dynamic loading.

**Stretch bending rig (6)**
The stretch-bending rig applies a combined bending and axial tensile/compressive loading to the test component.






*(Photos 1,2,6,7,9 13: Melinda Gaal. 3,4,5,8,12: Ole Morten Melgård), 10: Sølvi W. Normannsen 11: Bjørn Håkon Frodal*

The length of the specimens is 1-2 m, and they are bent around an exchangeable die with a defined curvature. The rig has been employed in tests where the bending operation of car bumpers is studied. It has also been used to study the behaviour of pipelines subjected to impact and subsequent stretching.

**Hydro-pneumatic machine (HPM) (7)**

The hydro-pneumatic machine (HPM) is a device for tensile material testing. It operates in the strain–rate range between 1 and 100 $s^{-1}$.

**Pendulum impactor (Kicking Machine) (8)**

The pendulum accelerator is a device for impact testing of components and structures. The test rig accelerates a trolley on rails towards a test specimen fixed to a reaction wall. The accelerating system consists of an arm connected to a hydraulic/pneumatic actuator system. Maximum energy delivered to the trolley is approximately 500 kJ. At present the mass of the trolley is in the range between 800 and 1500 kg, giving a maximum velocity between 35 m/s and 26 m/s. Sheet metal forming machine (BUP) (8)

**Split-Hopkinson tension bar (SHTB) (9)**

The split-Hopkinson tension bar is a device for material testing at strain rates in the range between 100 and 1500 $s^{-1}$. Data is recorded with strain gauges and high-speed cameras. An induction heater facilitates tests at elevated temperatures.

**Cameras (10)**

Impact testing of materials and structures are recorded using high-speed cameras. The Kirana-05M camera has a maximum frame rate of 5 000 000 per second (FPS) allowing detailed studies of crack propagation. The research group has 4 more high speed cameras and several cameras for Digital Image Correlation measurements. They also have an infrared camera for temperature measurements.

**Scanning electron microscope (SEM) laboratory (11)**

SFI CASA has access to a SEM lab with the following equipment: Zeiss SUPRA 55VP (LVFESEM, 2006), Hitachi S-4300SE (FESEM, 2002), Zeiss, Ultra 55LE, FESEM (2007), Jeol 840 (1989).
3 SEMs are equipped with EDS and EBSD. The laboratory has in-situ sub-stage systems for EBSD tensile and thermo mechanical experiments (heating and cooling down to -60 °C).

**Transmission electron microscope (TEM) laboratory (12)**

SFI CASA cooperates with the TEM Gemini Centre at NTNU, providing SFI CASA access to 5 TEMs: a JEOL double corrected ColdFEG ARM200F (2013), a JEOL 2100F (2013), a JEOL 2100 (2013), a Philips CM30 (1989) and a JEOL 2010 (1993). The TEM Gemini Centre also has a well-equipped sample preparation lab and computing facilities.

**Sheet metal forming machine (BUP) (13)**

This multi-purpose hydraulic sheet metal forming machine is designed to test the formability of sheet metals. 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.

# VISIBILITY







**Media strategy**
SFI CASA has a media strategy for popular science presentations of its research activities in magazines, newspapers, on television, radio and the web. Our aim is also to contribute to a knowledge-based and open public debate. In this respect, 2018 has been a good year, with a great deal of publicity on different media platforms.
It is also an aim to make female researchers and profiles particularly visible in order to recruit women and contribute to a more even gender balance in this research field. We continued this work in 2018.

**Webpage and Newsletter**
SFI CASA´s homepage was redesigned and improved at the end of 2018. Our monthly newsletter was distributed to 300 subscribers - partners, contacts and other people in SFI CASA's social and professional network. It is free to subscribe. The content is both research news and in-depth interviews with key personnel working with or connected to SFI CASA. Articles in the story-part of this annual report were published in the newsletter throughout the year.

**Presentation video**
The presentation video that premiered in January 2017 continues to be an effective presentation tool. It has won wide acclaim and distribution. Both partners and CASA staff have used it to present the Centre. The video confirms how organizations may benefit from generic research as a foundation for innovation. It is also used to illustrate how CASA contributes to research that benefits society as a whole.
Our lecturing staff have shown it to hundreds of NTNU students also in 2018. When visitors come to the Centre the video is almost mandatory as an introduction to guided tours in the test facilities. It was also shown to members of Parliament who visited the Centre. The video has close to 10 000 views on NTNU's Facebook page and almost 2 700 have seen it on YouTube.

**Social media**
Many of the stories in our newsletter have been published on NTNU´s Facebook site Science and Technology. Also reports from traditional media are re-posted and shared here. The page has more than 8 300 followers. Stories from our newsletter are also published on NTNU TechZone, the university´s blog about technology and natural sciences. For the time being, we choose to share our news, videos or stories on Twitter through @NTNU. This is the university´s official account with 32 500 followers.

**CASA in traditional media**
January: State Secretary Tor Kleppen Sættem and Department Director John Arne Gisnås visited CASA and the Shock Tube Facilities, marking the establishment of a new professorship funded by the Ministry of Justice and Public Security.


NTNU trapper opp forskningen på fysisk sikring:

**Når uhellet er ute, vil forskningen redde liv**

- Kommunene er altfor lite bevisste på hvor viktig fysisk sikring er ved planlegging av nye byrom, sier statssekretær Thor Kleppen Sættem i Justis- og beredskapsdepartementet.


**– Kommunene tenker for lite på sikkerhet**



Several media reported thoroughly on the news: Adresseavisen, NRK news channel Midtnytt, NRK web and Universitetsavisa.

March: Adresseavisen reported on the national evaluation of the SFI Scheme. CASA was profiled in the article.

April: Magnus Langseth published a chronicle in Dagens Næringsliv. There he warned against using timbered facades and wood as a load-bearing component in the new government administration complex in Oslo. As a result, he was called for the hearing on the subject in the Norwegian Parliament.

May: Professor Langseth was referred in the article «Security is most important» on tv2.no.
Professor Langseth was also interviewed on the TV2 news channel. The subject was the choice of materials and components in the new government administration complex.

The topic caught interest. NTB quoted TV2, and thus CASA Director Langseth figured in Norwegian media including, Byggmesteren, Klassekampen, Gudbrandsdølen & Dagningen and Teknisk Ukeblad.

July: Chronicle by Afaf Saai in Dagens Næringsliv, and research magazine Gemini. Saai is a research scientist in SINTEF Industry and is involved in SFI CASA´s Metallic Materials Programme.

October: The research magazine Gemini.no published a report on Enodo, SFI CASA's first spinoff company. The story is based on the full report published in the CASA newsletter.

Director Magnus Langseth argued for more research on societal security and object protection in a chronicle published in Adresseavisen. The chronicle was also published on Gemini.no and on NTNU TechZone.

November; The webpage of Norwegian Public Roads Administration reports on international interest for their project ferry-free E39. The report was about BBC World Service making a documentary on the project. Researchers at CASA gave interviews, and the reporters visited the Shock Tube Facility at CASA.

Report in Teknisk Ukeblad on aluminium vs steel in cars. CASA management and partners were interviewed.


*Terrorfare og ekstremvær øker kravet til sikkerhet*

**Invited and guest lectures**

- J. Friis, I.G. Ringdalen, I.J.T Jensen, C.D. Marioara, S. Wenner, S.J. Andersen, R. Holmestad. Influence of precipitate interface structure on alloy properties in the Al-Mg-Si system. International Conference on Aluminum Alloys (ICAA), Montreal, Canada, 17-21 June 2018.
- R. Holmestad, S. Wenner, J.K. Sunde, E. Christiansen, A. Lervik, C.D. Marioara. Using TEM to study precipitates in age hardenable aluminium alloys. 6th Dresden Nanoanalysis Symposium: Materials challenges for automotive industry - Micro- and nanoscale characterization, Dresden, Germany, 31 August 2018.
- O.S. Hopperstad, D. Morin, L.E. Dæhli, T. Børvik. Microstructure-based modelling and simulation of aluminium structures. 31st Nordic Seminar on Computational Mechanics, Umeå, Sweden, 25-26 October 2018.
- O.S. Hopperstad, D. Morin, L.E. Dæhli, T. Børvik, A. Benallal. Modelling of strain localization in ductile materials. ESMC18 - 10th European Solid Mechanics Conference, Bologna, Italy, 2-6 July 2018.
- O.S. Hopperstad, D. Morin, L.E. Dæhli, T. Børvik, A. Benallal. Strain localization as an indicator for ductile fracture in metals. EMMC16 – 16th European Mechanics of Materials Conference, Nantes, France, 26-28 March 2018.
- O.S. Hopperstad. Towards a Virtual Laboratory for Aluminium Structures. Technology Watch Seminar in Structural Mechanics (TWSM 2018), Trondheim, Norway, 12 December 2018.
- M. Langseth. Behaviour and design of aluminium structures. ICILSM 2018. 2nd International Conference on Impact Loading of Structures and Materials. Xi'An, China: National Natural Science Foundation on China & Northwestern Polytechnical University, 8 May 2018.
- M. Langseth. Euro NCAP: når resultater fra bilkræsjing avgjør salgstallene for teknologi. TEKMAR 2018, Trondheim, Norway, 4-5 December 2018.
- K. Marthinsen. Through thickness variations of deformation texture evolution inAlMgSi-extrusions: experiments, FEM and crystal plasticity modelling. Thermec2018, Paris, France, 8-13 July 2018.

**Guest lectures at SFI CASA**

- Rolf Jullum, the Norwegian National Security Authority, *Securing buildings. Does it work?* 26 February 2018.
- Tore Tryland, SINTEF Raufoss Manufacturing, *Design of aluminium pylon adapted for automated manufacturing.* 2 May 2018.
- Marek Niewczas, Professor, McMaster University, Hamilton, Canada, *Plasticity of Al-Mg and Al-Cr binary alloys between 4K and 300K.* 27 May 2018.
- Tanusree Chakraborty, Professor, Indian Institute of Technology Dehli, India, *Blast Resistant Design of Infrastructure.* 12 June 2018.
- Sunita Mishra, Indian Institute of Technology Dehli, India, *High Strain Rate Characterization of Rocks and its Application in Blast Analysis of Tunnels.* 12 June 2018.
- Alexis Deschamps, Professor, Grenoble INP, France, *Physical Metallurgy of Welding Precipitation Hardening Alloys: What Can We Learn from Microstructure Mapping?* 15 August 2018.
- Karthik Ramakrishnan, Postdoc, Tampere University of Technology, Finland, *Impact Response of Novel Steel-Biocomposite Hybrid Materials.* 20 August 2018.

**Guests from industrial partners**

- Christophe Grolleron and Cedric Bouton, Renault, 12-15 February 2018.
- Jakub Galazka, Toyota Motor Europe, 20-22 February 2018.
- Rolf Jullum, NSM/KMD, 26 February 2018.

**PhD defence**

- PhD candidate Johan Kolstø Sønstabø defended his thesis, *Behaviour and modelling of flow-drill screw connections*, on 15 March 2018. The PhD project was funded by Honda R&D Americas and was run as a concurrent project from 2013 to 2017.

**Research visits by SFI CASA staff**

- PhD candidate Emil Christiansen worked for CASA partner Hydro for two months during the autumn of 2018.

- PhD candidate Karoline Osnes stayed 3 months at BMW in Munich, Germany in the spring of 2018.
- Professor Randi Holmestad visited the University of Illionis, USA on 25-29 June.
- PhD candidate Ole Vestrum worked for 3 months at CASA partner Equinor's research centre in Trondheim in the spring of 2018.

**Research visits at SFI CASA**

- Marek Niewczas from McMaster University, Canada, visited CASA from 22 April to 3 May 2018.
- Associate Professor Tanusree Chakraborty, and PhD candidate Sunita Mishra from Indian Institute of Technology Dehli (IITD), India, stayed at CASA in the period 22 May-17 July 2018.
- Professor Ahmed Benallal from LMT/ENS Paris-Saclay, France, visited SIMLab (CASA and FractAl) twice, 4-27 April and 12-26 November 2018.
- Jonas Faleskog from KTH, Sweden stayed with the research group from 10 to 13 April 2018.
- Professor Alexis Deschamps from Grenoble INP, France, visited CASA from 30 July to 23 August 2018.

**MSc internships at CASA**

- Mario de Lucio Alonso, University of A Coruña, Spain, June-July 2018.
- Laura Bras, TU Einhoven, the Netherlands August-December 2018.
- Valentin Chopin, Polytech Paris-Sud, France, May-July 2018.
- Tim Koenis, TU Eindhoven, the Netherlands, November 2018-February 2019.

**Concurrent projects**

- *Aluminium alloys with mechanical properties and electrical conductivity at elevated temperatures, AMPERE* (2015-2020): The focus of this competence enhancement project is to study the properties of aluminium alloys at elevated temperatures. Professors Randi Holmestad and Knut Marthinsen are involved in this project.
- *Fundamentals of Intergranular Corrosion in Aluminium Alloy, FICAL* (2015-2020): The objective of this competence enhancement project is to establish new fundamental understanding of the mechanisms of intergranular corrosion (IGC) susceptibility. Professors Randi Holmestad and Knut Marthinsen are involved in this project.
- *Rational Alloy Design, ALLDESIGN* (2018-2022): NTNU project on digital materials design of aluminium-based alloys. PhD student Marcos Fernandez at CASA is involved in the project.
- *Microstructure based modelling of ductile fracture in aluminium alloys*, FractAl (2015-2020): This FRIPRO Toppforsk project is run by professors Odd Sture Hopperstad, Tore Børvik and Ole Runar Myhr from NTNU's Structural Impact Laboratory along with partners Ahmed Benallal LMT/ENS Paris-Saclay, France and Jonas Faleskog from the Royal Institute of Technology in Sweden. The FractAl project employs one researcher, one post doc and four PhD candidates.
- *Ferry-free coastal route E39* (2015-2018): The Norwegian Public Roads Administration heads an investigation of the possibilities for a ferry-free coastal route along the western coastline of Norway. The project funds one researcher at the SIMLab research group working with submerged floating tunnels subjected to internal blast loading.
- *FlexLinerLife* (2017-2019): The SIMLab group is involved in this project as one of several consortium participants from Norway and Brazil. The project topic is flexible risers for the offshore oil and gas industry.
- *Norwegian-Japanese Aluminium Alloy Research and Education Collaboration*: The objective of this Intpart project is to develop world leading education and research in the aluminium field in collaboration between NTNU, University of Toyama, Tokyo Institute of Technology, Kyushu University, SINTEF, Hydro and Japanese aluminium industry.

# Impact of SFI CASA - The Impello Report

Realized economic impact of + 150 MNOK. Plus, a potential for saving hundreds of millions of euro when industry implements SFI CASA's technologies and methods.

This is the summary of the realized economic impact of SFI CASA – so far. The facts and figures on the impact from the Centre's innovations and technological advances are shown in a report made by the strategic and financial advisory firm Impello Management. The report estimates the realized and potential impact of 15 technologies and methods originating from the research at SFI CASA.

**Some examples:**

The realized impact of +150 MNOK comes from Equinor. The oil and gas company has taken advantage of SFI CASA's knowhow, material models and test facilities when planning a new pipeline route. The models can be used to calculate the severity of a damage occurrence, thereby reducing the need for physical inspection and avoiding unnecessary repairs. For Equinor this led to a 5 km shorter pipeline for a tie-back to Åsgard.

Improved material and joint models enable full vehicle car crash simulations and reduce the need for physical prototypes. SFI CASA has developed new material models implemented in PAM-CRASH and LS-DYNA. These are the leading software tools for crash simulations.

The Centre has also contributed to the validation of a macroscopic model for joints.

Large car manufacturers run several crash tests every day, typically 500-1000 tests per year per car maker. Improved material models and increased use of virtual simulation models can potentially reduce the need for physical car crash testing by 50 per cent. For the major German and French car makers, the cost-saving potential is significant.

**Innovations**

The Impello report documents three internal innovations: Virtual Lab, Physical Lab and the SIMLab Toolbox.

It also outlines two commercial innovations:

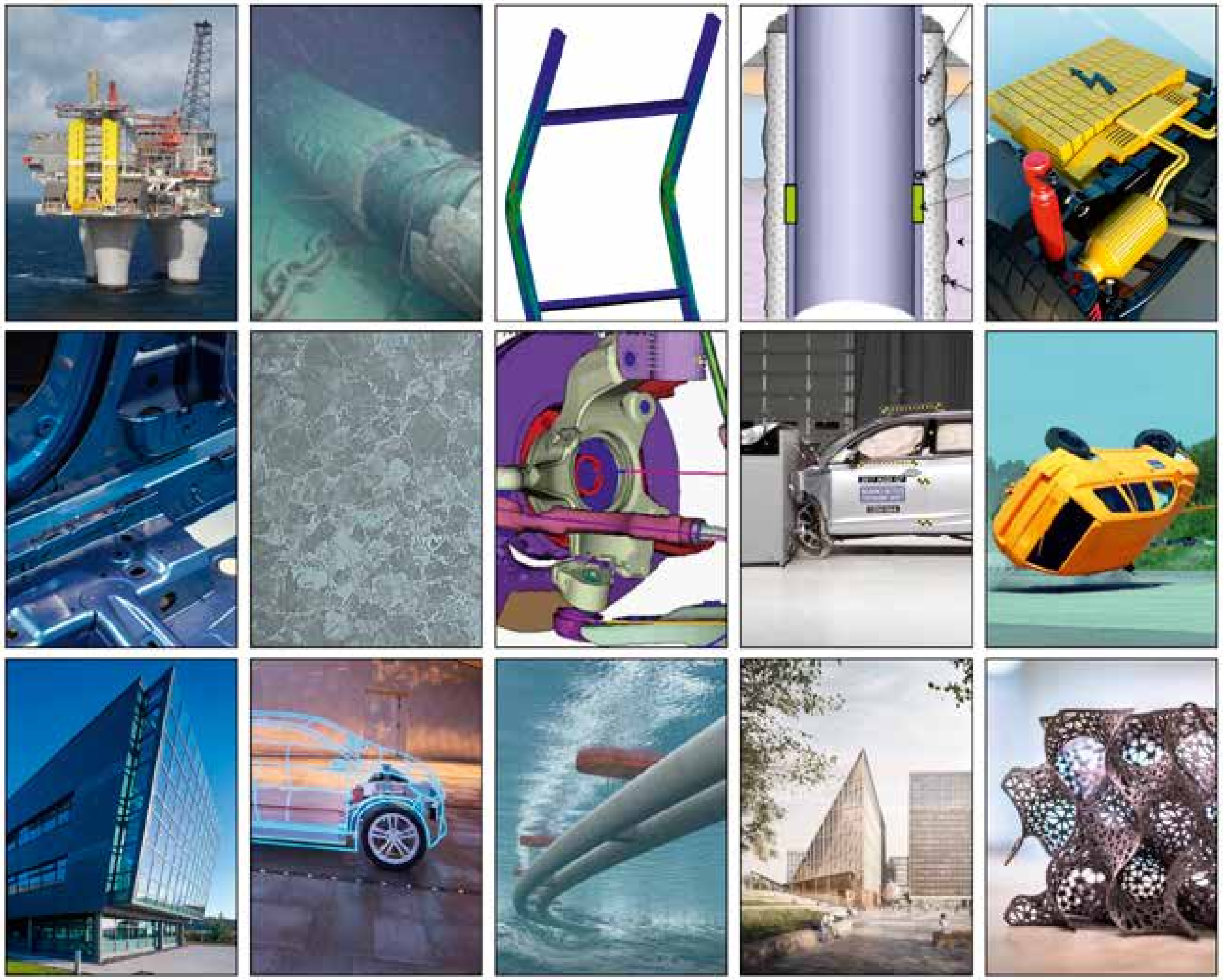
- eCorr is a commercial tool for digital image correlation used in materials specimen testing. It has been licensed to the Federal University of Rio de Janeiro State University and is also used by Equinor, Renault, SINTEF, Hydro, NTNU and the Norwegian Defence Estates Agency.

- The spinoff company Enodo develops technology and systems to provide material data for use in advanced numerical structural simulations. The objective is to be a major provider of validated material cards and material card management systems.

Several other software tools and material models are in the pipeline for commercialization.

**Financial, safety and societal impacts**

- Financial impacts include reduced costs, improved profitability and reduced time to market.
- Safety impacts mean improved car passenger safety, as well as improved design and compliance with regulatory guidelines.
- Technology impact examples are increased performance of materials, reduced use of materials, and improved and more robust design.
- Positive environmental societal impacts are due to reduced weight, less use of energy and reduced emissions.
- Education, recruitment, new employment and strengthening of Norwegian industry's international competitiveness are also on the list of societal impacts.



## 15 use cases

The report identifies 15 different use cases. For each case, the research challenge, the innovation, impact and potential are described.

1. Optimized pipeline routing at Åsgard A
2. Material models for X65 grade steel pipeline
3. Standardization of project engineering for building structures using advanced non-linear analysis
4. Innovative casing structures for super high-temperature geothermal wells
5. Lightweight battery housing for electric and fuel cell-powered cars
6. Reducing the need for physical prototypes
7. Glass failure prediction and roof strength testing
8. Virtual testing – joining technology
9. Virtual testing – metallic materials
10. Virtual testing of hybrid structures
11. Blast resistant façades with lightweight aluminium frames
12. Competitive manufacturing of automotive parts in Norway
13. Safety in submerged floating tunnels
14. Protection and physical security
15. 3D printing of metallic materials

*PhD candidates and post docs/researchers. First row from left: Sondre Bergo, Henrik Granum, Asle Tomstad, Borja Erice, Maria Jesus Perez, Emil Christiansen, Bjørn Håkon Frodal, and Kristin Qvale. Second row from left: Mikhail Khadyko, Petter Holmström, Susanne Thomesen, Jianbin Xu, John Fredrick Berntsen, Vetle Espeseth, Benjamin S. Elveli, and Marcos Fernandez. Third row from left: Lars Edvard Blystad Dæhli, Joakim Johnsen, Miguel Costas, Ole Vestrum, Jonas Frafjord, Sindre Olufsen, Einar Schwenke, and Daniel Morton. (Photo: Lena Knutli)*

# PhD candidates and post docs

**PhD candidates and post docs with funding from SFI CASA**

| Name | Topic | Position | Start | Planned exam | Programme | Nationality | Gender |
|---|---|---|---|---|---|---|---|
| John Fredrick Berntsen* | Testing and modelling of multi-material joints | PhD | 2015 | 2019 | Structural Joints | Norwegian | M |
| Emil Christiansen* | Nanoscale characterization of deformed aluminium alloy | PhD | 2015 | 2019 | Lower Scale | Norwegian | M |
| Bjørn Håkon Frodal* | Ductile fracture of aluminium alloys at low stress triaxiality | PhD | 2015 | 2019 | Metallic Materials | Norwegian | M |
| Sindre Olufsen* | Modelling of ductile failure in polymers | PhD | 2015 | 2020 | Polymeric Materials | Norwegian | M |
| Karoline Osnes* | Fragmentation of window glasses exposed to blast loading | PhD | 2015 | 2019 | Structures | Norwegian | F |
| Christian Oen Paulsen** | Experimental Characterization of Dual Phase Steel | PhD | 2015 | 2019 | Lower Scale | Norwegian | M |
| Sondre Bergo** | Localization of plastic deformations in construction steel | PhD | 2016 | 2020 | Metallic Materials | Norwegian | M |
| Jonas Frafjord* | Multiscale modelling of deformation in Aluminium alloys | PhD | 2016 | 2020 | Lower Scale | Norwegian | M |
| Daniel Morton** | Modeling of the mechanical behaviour of polymer foams | PhD | 2016 | 2020 | Polymeric Materials | Norwegian | M |
| Matthias Reil** | Behavior and modeling of steel-aluminium joints | PhD | 2016 | 2019 | Structural Joints | German | M |
| Ole Vestrum** | Optimisation of protective structures | PhD | 2016 | 2020 | Structures | Norwegian | M |
| Jianbin Xu** | Work hardening and Portevin-Le Chatelier (PLC) effect | PhD | 2016 | 2020 | Lower Scale | Chinese | M |
| Kristoffer Aune Brekken** | Modelling and Optimization of Sacrificial Claddings | PhD | 2017 | 2021 | Structures | Norwegian | M |
| Einar Schwenke** | Modelling of viscoelasticity in Polymers | PhD | 2018 | 2022 | Polymeric Materials | Norwegian | M |
| Benjamin Stavnar Elveli** | Behaviour and modelling of steel plates subjected to combined blast and impact loading | PhD | 2018 | 2022 | Structures | Norwegian | M |
| Marcos Fernandez** | Modelling of aluminium components under large deformations | PhD | 2018 | 2021 | Structural Joints | Spanish | M |
| Miguel Costas* | Modelling of ductile fracture in metallic materials and structural joints | Post doc | 2017 | 2020 | Structural Joints | Spanish | M |
| Maria Jesus Perez* | Impact of steel at low temp/Ductile fracture of high-strength steel | Post doc | 2018 | 2022 | Metallic Materials | Spanish | F |
| Panagiotis Manoleas** | Steel joints | Post doc | 2018 | 2020 | Structures | Greek | M |

** Salary and operational costs from the Centre. **Operational costs from the Centre. Salary from other sources.*

**PhD candidates and post docs on concurrent projects. The topics are highly relevant for SFI CASA**

| Name | Topic | Position | Start | Planned exam | Topic/project | Nationality | Gender |
|---|---|---|---|---|---|---|---|
| Henrik Granum | Multiscale modelling and simulation of failure in aluminium structures | PhD | 2016 | 2020 | FractAl | Norwegian | M |
| Susanne Thomesen | Multiscale characterization and modelling of ductile fracture mechanisms in aluminium alloys | PhD | 2016 | 2019 | FractAl | Norwegian | F |
| Asle Joachim Tomstad | Quasi-static and dynamic ductile fracture of aluminium alloys under low triaxiality | PhD | 2017 | 2021 | FractAl | Norwegian | M |
| Kristin Qvale | Microstructure-based modelling and simulation of ductile fracture in aluminium alloys | PhD | 2018 | 2021 | FractAl | Norwegian | F |
| Vetle Espeseth | Microstructure-based modelling and simulations of plasticity and fracture in aluminium alloys | PhD | 2018 | 2022 | FractAl | Norwegian | M |
| Lars Edvard Dæhli | Micromechanical modelling of ductile failure in aluminium alloys | Post doc | 2017 | 2021 | FractAl | Norwegian | M |
| Petter Holmström | Mechanical behaviour of short glass-fibre reinforced thermoplastics | PhD | 2013 | 2019 | Polymeric Materials/SFI SIMLab | Norwegian | M |

# Recruitment

**Three new PhD candidates started at SFI CASA in 2018:**
Einar Schwenke and Benjamin Stavnar Elveli are both former MSc students at NTNU.
Marcos Fernández García has an MSc from University of A Coruña.

In addition, Kristin Qvale and Vetle Espeseth started as PhD candidates on the concurrent project FractAl.

Borja Erice and Maria Jesus Perez Martin were respectively employed as research scientist and post doc. They both came from University of Oxford and started in August. Panagiotis Manaloeas was employed as a post doc in November. He has a PhD from Luleå University.

The Centre has had four visiting MSc students, see page 33.

SFI CASA´s ambition is to attract Norwegian candidates and improve the gender balance. Two recruitment seminars have been organized. The first one in April, for female students and future PhD candidates only. The second one in October, for future MSc and PhD candidates.

The Centre has given guided tours for a total of 180 upper secondary school students during 2018. In addition, several guided tours were given to different groups of professionals. Among these were national and international industry, members of the Norwegian Parliament, media and public agencies.

**MSc students**
**The following MSc students (17 male and 4 female) were associated with the Centre in 2018**

| Name | Sex M/F | Topic |
|---|---|---|
| Erika Krone | F | Internal Blast Loading of Submerged Floating Tunnels in Concrete |
| Mari Skarstein | F | Simulation of Ductile Crack Propagation in Steel Pipelines |
| Elise Sterner | F | Simulation of Ductile Crack Propagation in Steel Pipelines |
| Kristin Qvale | F | Static and Dynamic Crushing of Aluminium Profiles |
| Mads Bakken Iddberg | M | Experimental and Numerical Study on Perforated Steel Plates Subjected to Blast Loading |
| Benjamin Stavnar Elveli | M | Experimental and Numerical Study on Perforated Steel Plates Subjected to Blast Loading |
| Simen Kjernlie | M | Modelling of Windshields Subjected to Impact Loading |
| Tormod Grue | M | Modelling of Windshields Subjected to Impact Loading |
| Tobias Lund | M | Behaviour of Stiffened Aluminium Plates Subjected to Impact |
| Sigurd Lekve | M | Sacrificial Sandwich Panels Exposed to Blast Loading |
| Olaf Kielland | M | Sacrificial Sandwich Panels Exposed to Blast Loading |
| Vetle Espeseth | M | Micromechanical Modelling of Plasticity, Damage and Fracture in Aluminium Alloys |
| Vegard Haraldseid | M | Design of Aluminium Power Pylons |
| Anders Engebakken | M | Cold Impact Performance of Polypropylene (PP) |
| Jørgen Skjennum | M | Cold Impact Performance of Polypropylene (PP) |
| Kevin Mandt Ofstad | M | Finite Element Modelling of Steel Bridge Structures Exposed to Ship Collisions |
| Jostein Hals | M | Thermomechanical Analysis of Casing Systems for Supercritical Geothermal Wells |
| Lars-Endre Johannessen | M | Thermomechanical Analysis of Casing Systems for Supercritical Geothermal Wells |
| Christoffer Martinsen | M | Design of Die Cast Aluminium Rims |
| Torodd Lønning | M | Polymer Foam Used in Bumper Systems |
| Nikolai Korvald Skaare | M | Internal Blast Loading of Submerged Floating Tunnels in Concrete |

*CASA people in the lab. (Photo: Lena Knutli)*

# ENODO - The Very First Spinoff

The research group SIMLab at NTNU has established its very first commercial spinoff. The company is called «Enodo» and it will sell data, services and solutions for the modelling of materials exposed to extreme loadings.

Enodo is Latin and means to enlighten or analyse something or simply to untie a knot.

«We will evolve routines that able us to deliver our products quickly at competitive costs. Preferably, we should deliver both faster and at more attractive prices than our competitors», says entrepreneur and former PhD candidate at SIMLab, Jens Kristian Holmen.

**Offspring from FORNY2020 project**

The company´s customers will be in the business sectors transportation, oil and gas, and physical infrastructure security. The business idea is to offer high-quality material data combined with expertise in the modelling of materials. The product is material cards, which describe how different materials react to impact and extreme loadings. The specific customers will be in the material and production sectors, and also industry that requires advanced simulations. They all have one common requirement; reliable material cards to simulate, calculate, design and evolve their products.

It all started with the Research Council of Norway's FORNY2020 programme.

The driver behind the programme is to use publicly funded research to lead to more innovation in Norwegian industry. NTNU Technology Transfer is running the Matcards project in cooperation with the research group SIMLab.

The project is funded until the end of 2019, and the aim is about transferring knowledge to industry in the best way possible.

**Leaning on SIMLab´s research**

One Monday, early in October 2018 the entrepreneurs arrived in the TTO office for the final formalities. The end-wall of the conference room is decorated with a huge poster. It shows TTO´s management gravely overlooking the room and a message in capital letters: «Dedicated. For Action». At the end of the table there was a custom-made cake with the Enodo logo.

SFI CASA´s first spinoff became a reality.

«Now it is time to build a solid foundation for the company», states Jens Kristian Holmen. His co-partner Joakim Johnsen adds:

«We will use the experience that has been built up through many years in SIMLab and SFI CASA. Enodo will be a connecting link between the academic research in the Centre and industry».

**Quicker, more efficient and more reasonable**

Magnus Langseth, CEO in SFI CASA states that «The FORNY2020 project has made the utility-value of our own research clear to us. Industry is supportive. This process has been long, but it has been great value».

Karl Vincent Høiseth who is the Head of Department for Structural Engineering at NTNU, says that he is impressed and proud of SFI CASA:

«This is the ultimate attainment of an objective for a Centre for Research-based Innovation. Also, the FORNY2020 project is in itself an acknowledgement. It means that decision-makers have confidence in what CASA does».

**Reply to the challenges**

Oddbjørn Rødsten, the TTO project manager says that in many ways Enodo answers the challenges faced by CASA and other Centres for Research-based Innovation (SFI):

The industrial partners can see that the research findings are interesting and useful. The problem is that industry often lacks the resources to transfer these findings into innovation. At the same time this the most important success criterion for an SFI.

**Refrain from secretiveness**

Enodo is heading for a market where competition is tough. Some of the material cards that are offered today are based on models with a high degree of secretiveness. According to Rødsten, this lack of transparency could affect customers´ confidence.

Enodo wants to make the most of this. Jens Kristian Holmen says that the company will be more open and pragmatic:

«Our customers will not only be offered high quality and accurate data. They will also be given insight in how the modelling of the materials is done. Matcards is an offspring from world-leading research. On the other hand, customers want products that are reliable, easy to handle and easy to understand».

**Automotive industry upfront**

Car-manufacturers have been using material cards longer than any other actors in the market. A new car model consists of 300-500 different materials. Material cards are of special importance for components that have to do with safety: bumpers, bumper zones, joints and so on.

«This is exactly the special expertise of SIMLab and SFI CASA. We also believe that glass and polymers could be market areas of interest for us», adds Oddbjørn Rødsten.

**Good response from possible customers**

Through FORNY2020 Matcards runs pilot projects with Audi, Hydro and Dynamore Nordic. They follow the recipe of SIMLab: steel and aluminium alloys are subjected to different loads, physical tests are modelled and analysed, then the data ends up in new material cards.

Irrespective of whether it is car manufacturers, producers of special alloys or software companies. The customers are all focused on strengthening their positions in their respective markets. According to Rødsten there are also a couple of other big players who are showing interest in the tools and services from Enodo.

**Shorter time of delivery – at lower costs**

The project manager lists three challenges that have to be solved in the near future:

- Evolve a good workflow, so that material cards are produced quickly and in the most cost-efficient way
- Build up strategic partnership with pilot customers
- Develop business-models that fit the needs of different groups of customers.

He underlines that innovation occurs in partnership with industry and that they are dealing with demanding customers. «This is not research performed in a vacuum. It is research tuned in with clearly articulated needs».

**Able to grow without external finance**

Enodo is about to meet a large and mature market. Potential customers are knocking on their door. Rødsten believes Enodo might manage without investor or other external capital before they are up and running.

Jens Kristian Holmen expects to see the first revenues and a fully operative company towards the end of 2019. Nevertheless, he is down-to-earth. Most importantly he underlines that, in spite of interest from some large industrial players, no obligations have been made.

*«Now it is time to build a solid foundation for the company», states entrepreneur and former PhD at SIMLab, Jens Kristian Holmen. (Photo: Sølvi W. Normannsen)*

*Time-saving tool.*
*Associate professor David Morin is convinced that the Virtual Lab is a tool ready for commercial use within a few years.*
*(Photo: Sølvi W. Normannsen)*

# A Tool for SAVING Time & Money

Imagine a Virtual Lab where physical crash tests are history and the test time is dramatically reduced. If you are a car manufacturer, savings could be significant.

It might sound too good to be true, but it is happening right now.

«It will be an enormous time-saving tool. It means that you can reduce the time from when a new idea is born until it is fully tested, from 2 months to 24 hours».
David Morin (34) heads SFI CASA's Structural Joints Programme. The Virtual Laboratory is one of the main achievements at CASA – but it is still in the making.

**Ready for commercial use within five years**
The idea is to obtain all parameters required for the design of a structure from lower scale analyses, thus making physical tests superfluous.

It is a team effort, which involves each of the research programmes at CASA. Several tools and different models go in, it might be a bit too complex to have an impact in the short term. Still, Morin is convinced that this is a tool that will be ready for commercial use within a few years.

To put this in perspective: If car manufacturers run three car crashes on prototypes every day, six days a week, all year long and each prototype costs between 0.5 and 1 million euro, the Virtual Lab can bring considerable cost savings.

**The point of contact – in person**
David Morin is playing a major role in making SFI CASA's research findings available for the industrial partners. Sort of a messenger.
One of the messages is to make it clear that the input comes from industry. The researchers are not the ones that implement the innovation. Instead, CASA gives its industrial partners the opportunity to execute CASA's findings into new, better, cheaper and safer solutions that benefit all.

Where there is no interaction between research and industry, there is a barren land for innovation, according to David Morin. He picks up his smartphone: «If you think about this», he says, and points out the huge range of different skills that merged along the way before these tiny gadgets ended up in our pockets, invading our lives.

**«I am left with only the fun parts»**
«It is obvious. It is very difficult to achieve something, if you only have one field of competence. SFI CASA is all about research-based innovation, but I do not believe in innovation without interaction with industry».

While the classic professor spends his or her time divided between research, teaching, supervising and administration, Morin is stripped from the burden of the latter, and hence spends more time interacting with the partners. «I am left with only the fun parts», he states.

**Competitors with common interest**
He comes from France, grew up in Compiegne north of Paris, and was educated at the University of Valenciennes. In 2010 he was hired as a post doc. at CASA's forerunner SFI SIMLab.

The automotive industry has a tighter time frame than most of CASA's partners. «There is always a question of time frames, the need to integrate news, they always have the next model on their drawing table. Unfortunately, this is not always compatible with research-based innovation. However, that is the game for the SFI», Morin says.

Five of the world´s leading car manufacturers are onboard: Honda, Audi, Toyota, BMW and Renault. They compete mercilessly against each other, but they all share common interest in CASA's research.
As Morin puts it: «They design cars, not joints or materials. We create the tools that they are all using».

The aim is to provide them with macroscopic models for multi-material connections, mainly involving aluminium, steel and fibre reinforced polymers. These model simulations are based on a fundamental understanding of the behaviour of the joints but should, at the same time, be efficient in large-scale analyses. This combination of accuracy and efficiency is one of the challenges of CASA's Structural Joints Programme.

**Effective work flow - a must**
One example of CASA's progress is the PhD project of Johan Kolstø Sønstabø. He had a research stay and worked with Honda, who also co-funded his project. Sønstabø defended his thesis on Flow Drill Screw (FDS) connections in March 2018. Now the outcome is used both by Renault and Toyota.

And the story goes on: PhD Mathias Reil, co-funded by BMW, is now working with self-piercing rivets combined with adhesive. John Fredrick Berntsen is funded by CASA, working with a thesis on structural bonding. In addition, post doc. Miguel Costas is studying the effects of the pre-hole on the strength of flow drill screw connections, as a continuity to Sønstabø´s PhD thesis.

«CASA is an 8-year-long project. We see that the partners want results on a shorter term than that. To interact, cooperate, share data and modelling techniques like this is a way to give them the findings faster».

# From Pioneer in SIMLab to VICE PRESIDENT in Equinor

Birgit Søvik Opheim never considered a PhD until a couple of people gave her a personal, gentle push. A push that changed her life and led the way to her present position as Vice President of Project Development Early Phase in Equinor.

«To me, taking a PhD was the same as sitting lonely, bored and sad in an office. I thought of it as something for nerds that would take too much of my life».

Birgit Søvik Opheim laughs when she looks back on what started as a knock on her office door and ended in the PhD thesis «Bending of Thin-walled Aluminium Extrusions».

Still it has its regular space on the abundant bookshelf in Professor Magnus Langseth´s office. He is the director of CASA and together with Professor Per Kristian Larsen they gave research assistant Opheim at the Department of Structural Engineering that gentle push back in 1991.

«Suddenly, I felt that the idea attracted me. We were going to be a team. People, working together with related topics and with Magnus, Per Kristian and professor Svein Remseth as supervisors. We were going to provide knowledge that was needed. Hydro was financing a scholarship».

**Joined the team of pioneers**

She has always enjoyed teamwork and thrives when she can discuss with other people. PhD candidates Torodd Berstad and Arne Aalberg also joined the team. They became the pioneers that later formed the research group SIMLab. Now the group hosts its second Centre for Research-based Innovation - CASA.

«I shouldn´t do it all by myself. In many ways, SIMLab and CASA use the same working model today. I think that is the recipe for the success of the Centre. There is a sense of community that goes beyond eating lunch together».

**A part of the SIMLab puzzle**

Now she sees her thesis as one piece in a big picture. An early and important part of the puzzle that later became SIMLab and CASA. Birgit Søvik Opheim is still part of the CASA community. Her employer Equinor is one of the Centre's 14 partners. The company has the largest offshore pipeline network in the world. They have used the SIMLab methodology to solve engineering issues that have helped to increase safety and reduce costs.

From time to time Opheim helps CASA with recruitment by giving presentations to potential master's and PhD candidates.

**Numerous reasons to do a PhD**

She enjoys doing that and is excited if she can inspire more young people to take a doctorate.

She has weighty arguments about the usefulness of a PhD: It teaches you to learn and acquire knowledge quickly. It helps you to understand relevant questions faster. You gain respect for other people´s competence. You learn to give reasons for your opinions and statements and to ask the right questions. It gives you a form of personal confidence. Credibility. And you get an incredible range of career possibilities.

**Maximum load of difficult stuff**

She studied what is now Civil and Environmental Engineering at NTNU and attended courses at the Department of Structural Engineering. Simply because she loved maths, theoretical and complex subjects. Her strategy was to put in a maximum load of difficult stuff - as she was studying anyway. It was simply because she likes to achieve her real potential.

After she defended her thesis, she moved to Stavanger with husband and oldest son who was born during her PhD studies. «When I left Trondheim, I thought I would never ever have so much fun again».

Obviously, it did not turn out that bad. She admits that she has had a lot of fun later in her working life too. Before taking a position in Equinor in 2005, she worked for Exxon. Her thesis was about aluminium in cars, but she has as much knowledge about structural engineering. She knows how to analyse. For a period in Exxon she worked with strength calculations for oil platforms.

**«Look at it as an ordinary job».**

Since 2016, Opheim has been head of Equinor's Early phase project development unit, world-wide. This is the phase between a significant oil or gas discovery or renewable energy opportunity has been found to be commercially viable. The phase after is when a field development concept is selected.

It is well known that SIMLab and SFI CASA struggle with attracting female students and researchers. Can she give some advice on how to succeed?

«I don't think that there should be a difference in what men and women can do. I just think there are some people who need an extra, personal push by someone who sees their potential. I was not very eager to stand out. I would never have considered a PhD if it was not for those who motivated me with that small, positive push».

*Birgit Søvik Opheim is one of the pioneers that formed the research group SIMLab. She is still part of the CASA community, and her employer Equinor is one of the Centre's 14 partners.*


*Henrik Hindsefelt controls the MIG robot as it welds a prototype battery tray. Above: research engineer Bjørn Olsson (left) and Ole Daaland, Vice President Innovation & Technology. (Photo: Lena Knutli)*

# From Cannonballs to Battery Trays

In 1580, the Swedes produced cannons and cannonballs in Finspång. Today, they friction stir weld battery trays for electric vehicles: welcome to the Innovation & Technology hub of Hydro Extruded Solutions.

If there is such a thing as the original SIMLab and SFI CASA partner, Hydro competes for the title. The links between NTNU and one of Norway's largest and most international enterprises go back more than a century. The mutual interest is still obvious. Aluminium producers look for optimal alloys and structures. They need engineers who can make the right decisions. Researchers need a purpose.

**The hub**

Back to Finspång, southwest of Stockholm. Out of Hydro's 35 000 employees, 23 000 belong to Extruded Solutions. 80 of them work at Innovation & Technology, industry's term for research and development. They are spread around the globe, but more than half are based in Finspång, where they concentrate on the needs of European customers. This may include developing a prototype battery tray for a new electric vehicle.

Working this close with the customer carries with it a certain degree of secrecy. During our visit, not a word is mentioned about the name of the customer. Photography is strictly limited. Only details that don't reveal design or other features may be shown.

**Fast and cheap**

So, where does SFI CASA belong in the picture? The link between research engineer Bjørn Olsson in Finspång and Associate Professor David Morin in Trondheim may serve as an illustration: Olsson is very interested in SIMLab's modelling of aluminium extrusions and in particular the ability to predict failure. SIMLab's models are simple, relatively fast, and cheap. They don't solve every problem in the world, but then, they don't pretend to.

A bonus for Olsson is that the models are available for use with the commercial solvers that industry uses. This enables him to support Hydro's customers regardless of solver: money saved, since he would otherwise have had to buy a material card for each.

**A good mix**

This development of new products in close collaboration with the customers is one aspect of the activities in Finspång. The other is the improvement of in-house processes.

Ole Daaland, Vice President Innovation & Technology and CASA Board member explains:

"The work we do is project oriented. 70 per cent consists of specific research projects. The rest is direct help in the production process, including problem solving and training.

This is a good mix. It is important for the projects that our researchers and other co-workers understand what goes on in the production process. Because of this, we prefer staff that are able to perform in both aspects. One day they may hunt for an improved alloy, the next they can help with a problem that needs solving immediately."

**Pasta**

Hydro Extruded Solutions is the world's largest producer of aluminium profiles. Extrusion is pasta, aluminium style: you heat the billet in your desired alloy to a certain point, and then extrude. From there, only fantasy limits the variety of forms.

Ole Daaland wants more fantasy:

"We want to move further down in the value chain, with forming, welding and machining. Hot forming is one example.

We also want to trigger more innovation processes. Research and development must strive to avoid the traps of routine and rather aim to think out of the box," he says.

**CASA as living forum**

"We should involve larger parts of our organization. We need to develop further the inherent belief that research and development adds value, that it is indeed worthwhile. This involves the understanding of hybrid and joint materials, 3D printing and other trends that could shape future products," Daaland adds.

"Can CASA play a role in this?"

"Certainly. For instance, automotive is one of our priorities. The fact that CASA has five world-leading car manufacturers as partners is impressive in itself. The highly visible activity and the living forum character of the Centre is very attractive to us."

**MIT and Manchester**

Hydro Innovation & Technology has several research partners, including MIT, as well as the University of Manchester on the topics of surface treatment and corrosion. However, Ole Daaland points to the cooperation with CASA as unique:

"We have a very long relationship with the Norwegian research environment, where NTNU and SINTEF are the most prominent players."

# HOT Stuff

Think Iceland. Think pressure cooker 5 000 metres below the geysers. Think 500 degrees centigrade at 300 bar. Now, that IS hot stuff.

In this case, hot stuff for Equinor, SINTEF, and a number of other partners. Their own description goes like this: "In geothermal energy, a huge potential lies in hydrothermal reservoirs where an ultra-high temperature fluid can be utilized to multiply the power production output."

**Growing ambitions and interest**

The desire to use the energy resources below Iceland is far from new. With improving technology, ambitions to reach further down have grown. The Icelandic Deep Drilling Project was founded in 2000, with the national energy agency and a number of Icelandic energy companies as partners. Various international research groups have been involved over the years. Interest from industry is growing. SFI CASA partner Equinor is among the companies involved in ongoing research and development projects.

**Well in place**

Two years ago, Equinor and their Icelandic partners managed to drill down to almost 5 000 metres. This well is now in a "stimulation period". What follows is a production-testing phase where the objective is to confirm reservoir performance, well integrity and power production potential.

Closely linked to this, Equinor recently initiated the HotCaSe project. Backed by the Research Council of Norway, it has a budget of 30 MNOK. The project seeks to solve the challenges meeting wells under supercritical conditions. A short quote from Wikipedia may serve to illustrate what they are up against: "A supercritical fluid is any substance at a temperature and pressure above its critical point, where distinct liquid and gas phases do not exist."

A more practical illustration is the photos from previous failed efforts: casings in the wells have imploded and buckled, pipe joints have suffered tensile failure, hydrogen embrittlement and corrosion have caused fractures.

This points to casing constructions as a central matter of attention in the project.

**The link to CASA**

There are several links to CASA. The HotCaSe project is owned and led by Equinor, and administered by SINTEF. Project leader Hieu Hoang defended his PhD at SIMLab in 2011. Gaute Gruben heads the HotCaSe work package on mechanical characterization and constitutive modelling. He also has his PhD from SIMLab, the host research group for SFI CASA.

Their positions in the project are closely linked to their past. SIMLab is a world leader in the behaviour of materials and structures subjected to extreme loadings; know-how much needed in this pioneering work. Even better, this is also linked to their present positions as administrators of SFI CASA's Methods and Tools programme, SINTEF organizes the synthesizing process where research from SIMLab is gathered in the SIMLab Tool Box. Although the structure in HotCaSe is totally different, the research methodology is equally fruitful.

**Full-scale prototype**

The aim of HotCaSe is to deliver a structure that is fit to survive and build a full-scale prototype by 2021. However, there are many steps remaining. The ambition of this project is to reach level four on the Technology Readiness Level scale going from zero to nine.

As far as CASA is concerned, HotCaSe may bring back valuable knowledge from the supercritical environment that could prove useful to the automotive and other partners in the SFI.

**Result of brainstorm**

HotCaSe is one of the results from a joint brainstorming session between Equinor and SINTEF at executive level. When it became clear that both companies had previous experience from geothermal projects and the industrial wish was established, the go ahead was given to explore future possibilities. Before long, the project caught international interest, with a three-day workshop identifying innovative well designs as a starting point. International industrial partners have decided to join, including the French companies Curistec and IMERYS Aluminates

**Still in a checking-out position**

Although eagerly involved, Equinor is still in a checking-out position. SINTEF is also looking, possibly including other partners, at potential business cases where Hot stuff is on fire. Still, at this stage, nothing is decided.

*From their position as administrators of CASA's Methods and Tools programme, SINTEF organizes the synthesizing process where research from SIMLab is gathered in the SIMLab Tool Box. Although the structure in HotCaSe is totally different, the research methodology is equally fruitful. Térence Coudert (left) and Hieu Hoang. (Photo: Sølvi W. Normannsen)*


*Can wood be used as a major component in the new government buildings in Oslo? This was the topic of a hearing in Parliament on 16 March. SFI CASA Director Magnus Langseth was summoned. (Screenshot from streaming, Norwegian Parliament)*

# Parliament asks SIMLab about WOOD

The terrorist bomb blast in Oslo on 22 July 2011 killed eight and wounded more than 200. It also caused massive material damage. Several government buildings were rendered useless, some beyond repair.

As a consequence of the destruction, new buildings are being planned. The ambition is to gather almost all ministries in a cluster in the centre of the capital. A winner of the architecture competition was announced October 2017. Projecting costs are expected to reach NOK 1 billion alone.

**Four parties**

The sheer dimensions of the complex raise all kinds of questions, including how to display Norwegian industries and building traditions, opportunities for developing new skills and products, and environmental friendliness.

All these elements have motivated a motion from four of the opposition parties to make wood a major component in the new buildings. This was the background for the open hearing.

**No standards**

After presenting himself, Professor Langseth went straight to the issue of dimensioning structures subjected to extreme loads.

"As far as wood, steel, concrete and aluminium are concerned, we have standards describing how structures should be dimensioned to tackle snow, wind and payload. However, there are no such standards for impact, penetration and blasts, with the exception of military installations," he stated.

In spite of this, concrete, steel and aluminium are widely used in protective structures. This is possible because of the extensive research that has been carried out on these materials to understand how structural elements, connections and systems behave and therefore should be dimensioned. Such knowledge is scarce when it comes to wood.

Professor Langseth pointed to the importance of the deformation capacities of a material and the ability of a structure to redistribute forces. If a column is blown away, the structure has to be dimensioned in such a way that it does not collapse.

**Not recommended**

He went on: "I am not against the use of wood in the project. However, I will not recommend the use of wood as load-carrying component in areas that could be exposed to severe loads. This includes both primary and secondary load-carrying components like facades and glass interiors. This is due to our current lack of knowledge about the properties of wood exposed to gunfire, impact and explosions. Considerable research and development work is needed before wood can become a protective material. The planning process for the new government building complex is at a stage where it is unlikely that there is time to wait for new research projects."

**"Everybody drives cars"**

At the end of his presentation, Professor Langseth pointed to the proponents' wish for environmentally friendly solutions as an argument for wood instead of steel and concrete.

"It puzzles me that you do not mention aluminium. The material is Norwegian, produced with Norwegian hydroelectricity and we have Norwegian, world-leading expertise on the use of the material in protective structures and glass facades. Aluminium is light and has just as good energy-absorbing properties as steel. Everybody drives cars. They contain a lot of aluminium that tackles the loads from an impact," he pointed out.

**Only scientist**

Langseth was the only scientist to appear before the parliamentarians. He was summoned in his capacity as head of the SIMLab research group at NTNU; world leaders in the design of crashworthy and protective structures. This position is confirmed by Professor Langseth's decade-long editorship in the Journal of Impact Engineering.

The main presentation was given by a representative from the Norwegian Defence Estates Agency. They have a key role in the security aspects of the planning. The rest of the speakers represented interest groups and businesses from the wood, concrete, steel and aluminium industries as well as environmentalists and consulting engineers.

**Happy to do research on wood**

In the following question round from the parliamentarians, Professor Langseth was asked how much time would be needed to perform a research project on the protective qualities of wood.

He warned against such a project being linked to the government building complex, since it would probably take ten years to get the necessary answers needed for projecting and design purposes.

On the other hand, he argued that it is a public responsibility to secure research and education within the field of public infrastructure security.

"...and I am happy to challenge you as parliamentarians to finance a large research project on wood. We will happily take on the responsibility to lead the project, no problem," he summed up.

The hearing was organized by the Standing Committee on Local Government and Public Administration.

# Reaching out for the Masters of the FUTURE

The extreme version of doing a doctor´s degree is spending 4 years studying one single screw. Another version is that it is the most fantastic ego trip you can imagine.

Storytelling is the key when SFI CASA is out hunting talent. Last year the Centre held two such events, one was exclusively for female students. The challenge is this: female representation is low in the potential student groups in our field of engineering. In addition, many choose other subjects when they reach master's level. CASA aims to motivate students to take a master's or even a PhD degree in advanced structural analysis. The method we use is inspired lectures from successful speakers who have followed that path.

**From PhD to "CPR Annie"**

Anne Serine Ognedal defended her PhD on polymers at SIMLab in 2012. This was followed by two years as a post doc. Her message about the life of a PhD student was this:
«You can focus on exactly the matters that interest you most, you learn a lot. It's incredible. If you need to go to Paris to perform a test, you can do so, and you organize your own time. People really don't know how great it is to do a PhD."
Ognedal now works at Laerdal Medical. The company is famous for their computerized medical manikins. Most famous of them all is the mannequin popularly named "CPR Annie". When Ognedal told her story to the students she said how in 2014, Laerdal offered her a temporary position. She was not impressed and replied: "Look, I have a PhD. Then they decided to employ me permanently."

**Engineer porn**

Kjersti Kvalheim Dunham from CASA partner Norwegian Public Roads Administration heads the NOK 120 billion ferry-free E39 road project on Norway's west coast.
"We have more than 50 PhD candidates and post docs working on the project. We are going to need many more and this really is engineer porn: we need to build bridges that are able to move in all directions, we plan electric roads that will pull trucks up the hills and we may build submerged tunnels, which have never been done before. You cannot say no to having this much fun at work," she concluded.
Associate professor Siri Øyslebø Sørensen at NTNU's Department of Interdisciplinary Studies of Culture specializes in gender studies and social studies of science and technology. She praised CASA for organizing the seminar. In her lecture she used Anne Serine Ognedal's manikin to illustrate the importance of including both genders in research. For decades, male manikins were standard. The first pregnant manikin came as late as 1996. In general, diversity in a research group influences the results.

**Lecturers from Equinor, Multiconsult and Benteler**

Representatives from Equinor, Multiconsult and Benteler joined the second of last year´s recruitment seminars. As he came on the stage Johan Kolstø Sønstabø took the opportunity to rename CASA the «Centre for Challenging, Interesting, Cutting Edge, World Class and Relevant Structural Analysis».
Sønstabø also made the following enthusiastic remark: «If you want to join the national team in structural analysis and get a job this is the place to be».

**Spent 4 years studying one screw**

His doctoral thesis was about the behaviour and modelling of flow-drill screw connections. He joked that the extreme version of it was that he used 4 years studying one single screw. However, he did assure the students that it was not because of that one screw that Multiconsult hired him permanently. That came as a result of all the knowledge he gained along the way.
Mario Polanco, principal researcher at Equinor, was an expert in earthquakes when he moved from Mexico to Norway. When he arrived, he found that earthquakes in Norway were rare events. But Polanco´s point was that as a master's student or a PhD candidate you acquire tools that are useful in many different fields.

**Helped Equinor save a lot of money**

Equinor has thousands of kilometres of pipelines on the seabed in Norwegian and more distant waters. Polanco presented case studies where SIMLab methodology is used to solve different engineering problems.
One was how to introduce the mechanical contribution of polymeric protection in pipelines against trawl board impact. Another was assessment of mooring line impact on coated steel pipelines. According to Polanco CASA has helped to solve the challenges and thus helped the company to increase safety and reduce economical costs.

**Cool & relevant from industry**

«Very exciting, many good lecturers and it was very cool with so many relevant representatives from industry. They really made it clear for us how we can put our education to use», said one of the students at the seminar, Eyvind Evensen.
Companies introducing themselves for students at NTNU stand in line. But the future mechanical engineer thought that the SIMLab session stood out.
«Many of these presentations are very open and general, and address students from many different studies. This one was specially arranged for us and our subjects. I liked that».

*Photos: Lena Knutli (above) and Sølvi W. Normannsen)*


# PUBLICATIONS & ANNUAL ACCOUNTS

The following lists journal publications and conference contributions generated in 2018.

**Journal publications**

1. V. Aune, F. Casadei, G. Valsamos, M. Langseth, T. Børvik. A Shock Tube Used to Study the Dynamic Response of Blast-Loaded Plates. Proceedings 2(8) (2018) 503.
2. E. Christiansen, C.D. Marioara, K. Marthinsen, O.S. Hopperstad, R. Holmestad. Lattice rotations in precipitate free zones in an Al-Mg-Si alloy. Materials Characterization 144 (2018) 522-531.
3. M. Costas, D. Morin, O.S. Hopperstad, T. Børvik, M. Langseth. A through-thickness damage regularisation scheme for shell elements subjected to severe bending and membrane deformations. Journal of the Mechanics and Physics of Solids 123 (2018) 190-206.
4. L. E. Dæhli, D. Morin, T. Børvik, O.S. Hopperstad. A Lode-dependent Gurson model motivated by unit cell analyses. Engineering Fracture Mechanics 190 (2018) 299-318.
5. J. Johnsen, J.K. Holmen, T.L. Warren, T. Børvik. Cylindrical cavity expansion approximations using different constitutive models for the target material. International Journal of Protective Structures 9(2) (2018) 199-225.
6. J. Johnsen, A.H. Clausen, F. Grytten, A. Benallal, O.S. Hopperstad. A thermo-elasto-viscoplastic constitutive model for polymers. Journal of the Mechanics and Physics of Solids (2018). DOI:10.1016/j.jmps.2018.11.018.
7. M. Kristoffersen, M. Langseth, T. Børvik. Combined three-point bending and axial tension of pressurised and unpressurised X65 offshore steel pipes – Experiments and simulations. Marine Structures 61 (2018) 560-577.
8. M. Kristoffersen, J.E. Pettersen, V. Aune, T. Børvik. Experimental and numerical studies on the structural response of normal strength concrete slabs subjected to blast loading. Engineering structures 174 (2018) 242-255.
9. M. Kristoffersen, K.O. Hauge, T. Børvik. Blast loading of concrete pipes using C-4 charges. Proceedings 2(8) (2018) 428.
10. D. Morin, O.S. Hopperstad, A. Benallal. On the description of ductile fracture in metals by the strain localization theory. International Journal of Fracture 1-2 (2018) 27-51.*
11. D. Morin, M. Fourmeau, T. Børvik, A. Benallal, O.S. Hopperstad. Anisotropic tensile failure of metals by the strain localization theory: An application to a high-strength aluminium alloy. European Journal of Mechanics. A, Solids 69 (2018) 99-112. *
12. O.R. Myhr, O.S. Hopperstad, T. Børvik. A Combined Precipitation, Yield Stress, and Work Hardening Model for Al-Mg-Si Alloys Incorporating the Effects of Strain Rate and Temperature. Metallurgical and Materials Transactions. A 49A (2018) 3592-3609.
13. R.R. Neves, H. Fransplass, M. Langseth, L. Driemeier, M. Alves. Performance of Some Basic Types of Road Barriers Subjected to the Collision of a Light Vehicle. Journal of the Brazilian Society of Mechanical Sciences and Engineering 40 (2018) 274.
14. K. Osnes, T. Børvik, O.S. Hopperstad. Testing and modelling of annealed float glass under quasi-static and dynamic loading. Engineering Fracture Mechanics 201 (2018) 107-129.
15. K. Osnes, O.S. Hopperstad, T. Børvik. Quasi-Static and Dynamic Testing of Annealed Float Glass. Proceedings 2 (8) (2018) 495.
16. Aa. Reyes, T. Børvik. Quasi-static behaviour of crash components with steel skins and polymer foam cores. Materials Today Communications 17 (2018) 541-553.
17. J.K. Sønstabø, D. Morin, M. Langseth. Testing and modelling of flow-drill screw connections under quasi-static loading. Journal of Materials Processing Technology 255 (2018) 724-738.
18. J.K. Sønstabø, D. Morin, M. Langseth. Static and dynamic testing and modelling of aluminium joints with flow-drill screw connections. International Journal of Impact Engineering 115 (2018) 58-75.
19. O. Vestrum, M. Kristoffersen, M. Polanco-Loria, H. Ilstad, M. Langseth, T. Børvik. Quasi-static and dynamic indentation of offshore pipelines with and without multi-layer polymeric coating. Marine Structures 62 (2018) 60-76.

*Funding from CASA and concurrent project FractAl

**Publications on projects closely related to SFI CASA**

1. H. Granum, O.R. Myhr, T. Børvik, O.S. Hopperstad. Nanostructure-based finite element analyses of aluminium profiles subjected to quasi-static axial crushing. Thin-Walled Structures 131 (2018), 769-781.
2. M. Khadyko, J. Sturdy, S. Dumoulin, L.R. Hellevik, O.S. Hopperstad. Uncertainty quantification and sensitivity analysis of material parameters in crystal plasticity finite element models. Journal of Mechanics of Materials and Structures 13 (2018), 379-400.
3. O.R. Myhr, O.S. Hopperstad, T. Børvik. A Combined Precipitation, Yield Stress, and Work Hardening Model for Al-Mg-Si Alloys Incorporating the Effects of Strain Rate and Temperature. Metallurgical and Materials Transactions. A 49A (2018), 3592-3609.
4. S. Thomesen, O.S. Hopperstad, T. Børvik. On the Material Characterization of an Aluminium Alloy Using Different Specimens and Identification Methods. Proceedings 2 (8) (2018) 400.

**Book chapter**

1. A.H. Clausen. Tensile Testing Using the Kolsky-Hopkinson Bar Machine. In *The Kolsky-Hopkinson Bar Machine*. Selected Topics, pp 27-74. Springer 2018.

**Invited, plenary and keynote lectures**

1. J. Friis, I.G. Ringdalen, I.J.T Jensen, C.D. Marioara, S. Wenner, S.J. Andersen, R. Holmestad. Influence of precipitate interface structure on alloy properties in the Al-Mg-Si system. International Conference on Aluminum Alloys (ICAA), Montreal, Canada, 17-21 June 2018.
2. R. Holmestad, S. Wenner, J.K. Sunde, E. Christiansen, A. Lervik, C.D. Marioara. Using TEM to study precipitates in age hardenable aluminium alloys. 6th Dresden Nanoanalysis Symposium: Materials challenges for automotive industry - Micro- and nanoscale characterization, Dresden, Germany, 31 August 2018.
3. O.S. Hopperstad, D. Morin, L.E. Dæhli, T. Børvik. Microstructure-based modelling and simulation of aluminium structures. 31st Nordic Seminar on Computational Mechanics, Umeå, Sweden, 25-26 October 2018.
4. O.S. Hopperstad, D. Morin, L.E. Dæhli, T. Børvik, A. Benallal. Modelling of strain localization in ductile materials. ESMC18 - 10th European Solid Mechanics Conference, Bologna, Italy, 2-6 July 2018.
5. O.S. Hopperstad, D. Morin, L.E. Dæhli, T. Børvik, A. Benallal. Strain localization as an indicator for ductile fracture in metals. EMMC16 – 16th European Mechanics of Materials Conference, Nantes, France, 26-28 March 2018.
6. O.S. Hopperstad. Towards a Virtual Laboratory for Aluminium Structures. Technology Watch Seminar in Structural Mechanics (TWSM 2018), Trondheim, Norway, 12 December 2018.
7. M. Langseth. Behaviour and design of aluminium structures. ICILSM 2018. 2nd International Conference on Impact Loading of Structures and Materials. Xi'An, China: National Natural Science Foundation on China & Northwestern Polytechnical University, 8 may 2018.
8. M. Langseth. NCAP: når resultater fra bilkræsjing avgjør salgstallene for teknologi. TEKMAR 2018, Trondheim, Norway, 4-5 December 2018.
9. K. Marthinsen. Through thickness variations of deformation texture evolution in AlMgSi-extrusions: experiments, FEM and crystal plasticity modelling. Thermec2018, Paris, France, 8-13 July 2018.

**Conference contributions**

1. V. Aune, F. Casadei, G. Valsamos, M. Langseth, T. Børvik. A Shock Tube Used to Study the Dynamic Response of Blast-Loaded Plates. ICEM 2018 - 18th international conference on experimental mechanics, Brussels, Belgium, 1-6 June 2018.
2. J.F. Berntsen, D. Morin, A.H. Clausen, M. Langseth. Mechanical behaviour of a ductile polyurethane adhesive. DYFP2018, the 17th International Conference on Deformation, Yield and Fracture of Polymers, Kerkrade, the Netherlands, 26-29 March 2018.
3. E. Christiansen, S. Sævareid, B.H. Frodal, C.D. Marioara, O.S. Hopperstad, R. Holmestad. Precipitate Free Zones and Crack Propagation in Al-Mg-Si Alloys. 16th International Conference on Aluminium ALloys (ICAA16), Montreal, Canada, 17-21 June 2018.
4. L.E. Dæhli, D. Morin, T. Børvik, O.S. Hopperstad. A modified Gurson model accounting for Lode-dependent void growth. 16th European Mechanics of Materials Conference, Nantes, France, 26-28 March 2018.
5. J. Frafjord, B. Holmedal, R. Holmestad, I.G. Ringdalen, S. Ofstad, J. Friis. Ab Initio Calculations of Dislocation Core Using a Cluster Model Approach. 9th International Conference on Multiscale Materials Modelling, Osaka, Japan, 29 October 2018.
6. J. Frafjord, I.G. Ringdalen, R. Holmestad, I.H. Svenum, O.S. Hopperstad, J. Friis. Pressure Dependent Yielding in Solute Strengthened Aluminium – An Ab Initio Study. 16th International Conference on Aluminium Alloys (ICAA16), Montreal, Canada, 17-21 June 2018.
7. H. Granum, V. Aune, T. Børvik, O.S. Hopperstad. Aluminium Plates with Pre-Formed Slits Subjected to Blast Loading. DYMAT 2018, 12th International Conference on the Mechanical and Physical Behaviour of Materials Under Dynamic Loading, Arcachon, France, 9-14 September 2018.*
8. J.K. Holmen, J. Johnsen, M. Costas, D. Morin, T. Berstad, T. Børvik, O.S. Hopperstad, M. Langseth. Applications of *MAT_258: A through-thickness regularization model for shells. Nordic LS-DYNA User's Conference 2018, Gothenburg, Sweden, 18-19 October 2018.
9. J.K. Holmen, T Børvik. Impact behaviour of high-strength steel at low temperatures. 2nd International Conference on Impact Loading of Structures and Materials (ICILSM 2018). Xi'an, China, 8 May 2018
10. R. Holmestad, J.K. Sunde, S. Wenner, E. Christiansen, C.D. Marioara, A. Van Helvoort. Phase and orientation mapping in Al alloys using SPED. CAMRIC-FORUM4, 4th Forum of Centre of Advanced Materials Research and International Collaboration, Toyama, Japan, 31 October – 1 November 2018
11. J. Johnsen, A.H. Clausen, F. Grytten, A. Benallal, O.S. Hopperstad. Modelling of the thermo-mechanical behaviour of cross-linked low density polyethylene. 31st Nordic Seminar on Computational Mechanics (NSCM-31), Umeå, Sweden, 25-26 October 2018.
12. M. Kristoffersen, K. Hauge, G. Valsamos, T. Børvik. Blast Loading of Concrete Pipes Using Spherical Centrically Placed C-4 Charges. DYMAT 2018, 12th International Conference on the Mechanical and Physical Behaviour of Materials Under Dynamic Loading, Arcachon, France, 9-14 September 2018.
13. M. Kristoffersen, A. Minoretti, T. Børvik. Submerged floating tunnels subjected to internal blast loading. 7th Transport Research Arena (TRA2018), Vienna, Austria, 16-19 April 2018.
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21. M. Reil, O. Knoll, D. Morin, M. Langseth. Behavior and modeling of adhesively bonded self-piercing riveting connections between steel and aluminium. Joining in Car Body Engineering 2018, Automotive Circle Conference, Bad Nauheim, Germany, 10-12 April 2018.
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*Funding from CASA and concurrent project FractAl

**Conference contributions on projects closely related to SFI CASA**

1. S. Thomesen, O.S. Hopperstad, T. Børvik. On the Material Characterization of an Aluminium Alloy Using Different Specimens and Identification Methods. ICEM 2018 - 18th International Conference on Experimental Mechanics, Brussels, Belgium, 1-6 June 2018.

## Annual accounts

**SFI CASA FUNDING 2018 (ALL FIGURES IN 1000 NOK)**

| Item | Host NTNU | Research partner SINTEF | Public partners | Industrial partners | RCN grant | Total funding |
|---|---|---|---|---|---|---|
| Research programmes | 6711 | 1100 | 2199 | 7037 | 10089 | 27136 |
| Equipment | | | 69 | 108 | 551 | 728 |
| Administration | 1000 | | 1882 | 3705 | 1694 | 8281 |
| Total budget | 7711 | 1100 | 4150 | 10850 | 12334 | 36145 |

**SFI CASA COSTS 2018 (ALL FIGURES IN 1000 NOK)**

| Item | Host NTNU | Research partner SINTEF | Public partners | Industrial partners | Total cost |
|---|---|---|---|---|---|
| Research programmes | 18986 | 4550 | 700 | 2900 | 27136 |
| Equipment | 728 | | | | 728 |
| Administration | 7731 | 550 | | | 8281 |
| Total budget | 27445 | 5100 | 700 | 2900 | 36145 |

# What is an SFI, what is SIMLab, what is CASA...

**SFI is a funding scheme**

SFI, Centre for Research-based Innovation, is a funding scheme administered by the Research Council of Norway (RCN).

The main objective for the SFIs is to increase the capability of business to innovate by focusing on long-term research. The idea is to forge close alliances between research-intensive enterprises and prominent research groups.

The host institution for an SFI can be a university, a university college, a research institute or an enterprise with a strong research activity.

The partners (enterprises, public organisations and other research institutions) must contribute to the centre in the form of funding, facilities, competence and their own efforts throughout the life cycle of the centre.

The life cycle is eight years. On the average, each centre receives roughly 12 MNOK per year from RCN. The host institution and partners must contribute with at least the same amount.

**SIMLab is a research group**

Structural Impact Laboratory, SIMLab, is a research group at the Department of Structural Engineering, NTNU. From 2007 to 2014, SIMLab hosted an SFI with the same name, SFI SIMLab. This double use of the name sometimes causes confusion, but now you know:

SFI SIMLab is history; the SIMLab research group is alive and kicking. All the more comforting, since the group carries with it all the expertise that brought SFI SIMLab to a world-leading position in the design of crashworthy and protective structures.

**CASA is an SFI**

CASA, Centre for Advanced Structural Analysis, is the name of the second SFI hosted by the SIMLab research group. It was officially established on 1 July 2015.

The vision of SFI CASA is to establish a world-leading centre for multi-scale testing, modelling and simulation of materials and structures for industrial applications.

In doing so, CASA goes further down in scale to nano level and wider in scope than SFI SIMLab did. New materials such as glass are included.


*Work with the annual report 2018 in progress. From her position in the lift, photographer Lena Knutli does her very best to get the attention of PhD candidates and post docs. (Photo: Sølvi W. Normannsen)*

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