CASA

Annual Report 2017

Centre for Advanced Structural Analysis

Basic Contents, Facts & Figures

sfi Centre for Research-based Innovation

SINTEF

NTNU

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COVER
CASA's research on safety glass is highly interesting for the planning of the new government building complex in Oslo. Cover photo: Julie Gloppe Solem and Team Urbis / Statsbygg.

PHOTOS
All photos this section Lena Knutli except cover, pp. 11, 21, 22, and 24.

GRAPHIC DESIGN
NTNU Grafisk senter

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SUMMARY

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.

The integrated approach to structural problems involves all aspects necessary to make computational mechanics successful. This adds up to a unique platform for the research in CASA.

The SIMLab Tool Box is a collection of software products that enables the transfer of technology from the SIMLab centre to CASA. This provides a foundation for further developments and seamless implementation at the user partners. CASA is much broader in scope than the previous centre. It 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.

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 Materials and Chemistry is the research partner. The industrial partners in 2017 were Audi AG, Benteler Aluminium Systems Norway AS, BMW Group, DNV GL AS, Gassco AS, Honda R&D Americas Inc., Hydro Aluminium AS, Hydro Extruded Solutions (formerly Sapa AB), Ministry of Local Government and Modernisation, Norwegian Defence Estates Agency, Norwegian National Security Authority, Norwegian Public Roads Administration, Renault, Statoil Petroleum AS, and Toyota Motor Europe. Gassco announced their withdrawal in 2017, effective from 31 December. Norwegian consultancy Multiconsult decided to join SFI CASA from 1 January 2018.

SFI CASA's board comprises representatives from all the partners. A director heads the daily operation, assisted by a core team and programme heads. A Scientific Advisory Board of international experts has been appointed to provide scientific and strategic advice. In addition, CASA has established an Industrial Reference Group to oversee and facilitate industrial implementation of the results generated in the Centre.

Generic research

The Centre will develop validated computational tools for innovation with and for the partners working in the oil and gas industry, in transportation and with 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 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 questions and programmes

Three core research questions form the basis for the research in the Centre:

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

2. How can we apply knowledge of material, geometry and joining technology to obtain optimal behaviour of hybrid structures for given load situations?

3. How can we describe the interaction between the load and the deformable structure under extreme loading scenarios?

Motivated by these questions, the Centre has defined five basic research programmes to increase the prediction accuracy of numerical simulations: Lower Scale, Metallic Materials, Polymeric Materials, Structural Joints, and Structures. Each programme has annual work plans with contributions from PhD candidates, post docs and scientists from the partners. The Methods and Tools and the Industrial Implementation activities serve as links between the basic research and the industrial need for the technology developed and are gathered in the SIMLab Tool Box for implementation at the industrial partners.

Meetings, seminars, and conferences

The Centre organized several technical meetings and seminars linked to the different research programmes and seminars throughout 2017. 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 was convened on 12 May and 14 November. Finally, the Board had a seminar and Board meeting on 15-16 November in Munich, Germany.

CASA hosted the DYMAT 23rd Technical Meeting from 12 to 14 September. More than 100 researchers from 16 countries attended the conference. One of the Centre's academic goals is to organize two international conferences. This was the first of the two.

SFI SIMLab

Some of the PhD projects in SFI SIMLab were not finished at its closure in 2014. They continue in SFI CASA as parallel projects as the topics are closely related. Three PhD candidates from SFI SIMLab and one PhD candidate on a concurrent project defended their theses in 2017:

Vegard Aune: Behaviour and modelling of flexible structures subjected to blast loading

Erik Grimsmo: Behaviour of steel connections under quasi-static and impact loading - An experimental and numerical study

Lars Edvard Dæhli: Numerical studies on ductile failure of aluminium alloys

Joakim Johnsen: Thermomechanical behaviour of semi-crystalline polymers: experiments, modelling and simulation

International cooperation

International cooperation and leading-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. SFI CASA has cooperated with the following universities, research laboratories and companies in 2017:

Ecole Normale Supérieure de Cachan/Laboratorie de Mécanique et Technologie (ENS/LMT), France; University of Toyama, Japan; Tokyo Institute of Technology, Japan; IMPETUS Afea AB, Sweden; Joint Research Centre, Institute for the Protection and Security of the Citizen, Italy; Indian Institute of Technology (IIT) Delhi, India; Warsaw University of Technology, Poland; University of Manchester, UK; University of Montreal, Canada; Laboratory of Thermomechanical Metallurgy, EPFL, Switzerland.

In addition the Centre has six international partners (Audi, BMW, Honda, Renault, SAPA AB and Toyota).

Visibility

CASA's media strategy aims at popular science presentations of its research activities. It is also an aim to make female researchers particularly visible in order to recruit female researchers and contribute to a more even gender balance in this research field. The popularized part of this report exemplifies how the strategies are carried out and contains articles from CASA's monthly newsletter.

Besides popular science presentations, visibility in the research community is of great importance. In 2017 CASA published 25 articles in peer-reviewed journals and gave 17 conference presentations.

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. In order to facilitate the use of validated numerical simulations by the user partners and to meet their technology roadmaps and business plans for process and product development, a multi- and interdisciplinary research approach based on multiscale testing, modelling and analysis in an industrial context is required. This represents a major research initiative that 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

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.

Lower Scale: This programme 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 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 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 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.

Research methodology and scope

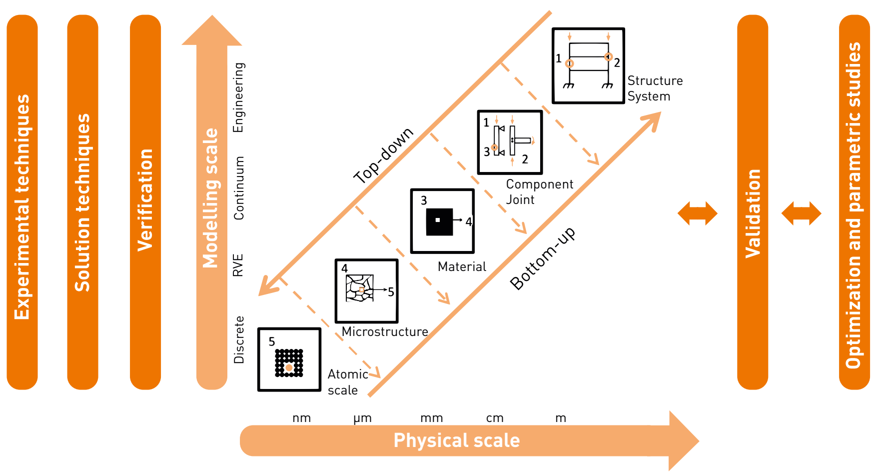


Figure 1: Research methodology.

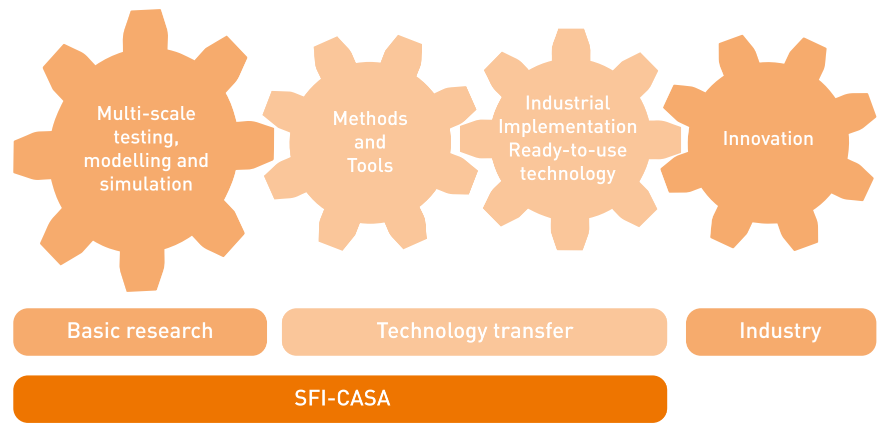
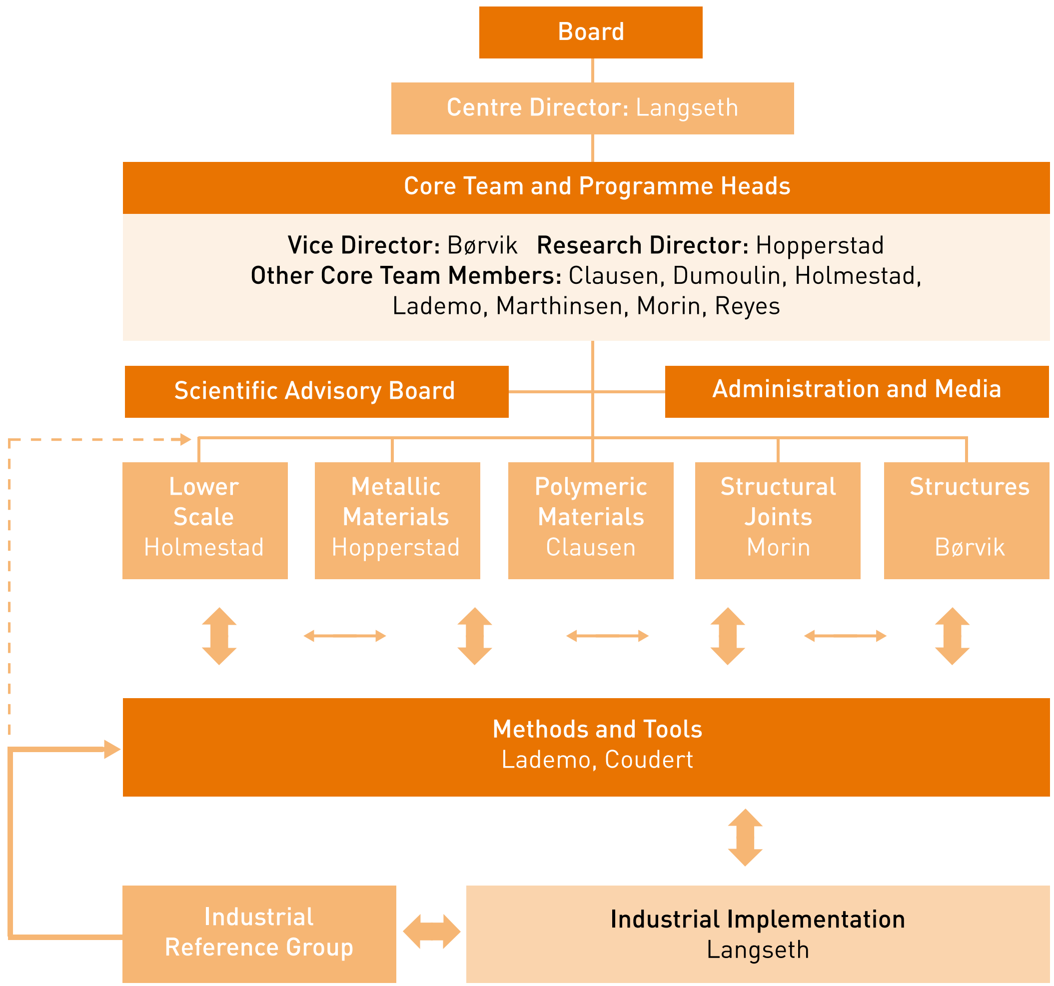


Figure 2: Structure of research, technology transfer and industrial implementation.

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.

RESEARCH ORGANIZATION



The overall management structure of the Centre consists of a board comprising members from the consortium participants, Figure 3. 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 industrial implementation is supported by an Industrial Reference Group. 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.

Figure 3 : Structure of the organization in 2017.

Core team. *From left: David Morin, Odd Sture Hopperstad, Tore Børvik, Magnus Langseth, Knut Marthinsen, Randi Holmestad, Stéphane Dumoulin, Arild Holm Clausen, Aase Reyes and Odd-Geir Lademo.*

The Board

Olav Bolland, NTNU (Chair)
Anders Artelius, Benteler Aluminium Systems Norway AS
Ketil Bonesmo, Norwegian National Security Authority
Ole Daaland, Sapa AB/Hydro Extruded Solutions
Håkon Hilmar Ferkingstad, Gassco AS
Ana Fernandez, Renault
Agnes Marie Horn, DNV GL AS
Håvar Ilstad, Statoil Petroleum AS
Octavian Knoll, BMW Group
Andreas Koukal, Audi AG
Helge Langberg, Norwegian Defence Estates Agency
Satoru Miyagano, Toyota Motor Europe
Brian O'Hara, Honda R&D Americas Inc.
Rudie Spooren, SINTEF
Knut Syvertsen, Ministry of Local Government and Modernisation
Hans Erik Vatne, Hydro Aluminium
Gina Ytteborg, Norwegian Public Roads Administration

Scientific Advisory Board

Professor Ahmed Benallal, LMT-Cachan, France
Professor Em. David Embury, McMaster University, Canada
Professor Jonas Faleskog, Royal Institute of Technology, Sweden
Professor Norman Fleck, University of Cambridge, UK
Professor Stefan Hiermaier, Ernst Mach Institute, Germany
Professor John Hutchinson, Harvard University, USA

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 Materials and Chemistry
Stéphane Dumoulin, Research Scientist, SINTEF Materials and Chemistry
Randi Holmestad, Professor, Dept. of Physics, NTNU
Odd Sture Hopperstad, Professor, Dept. of Structural Engineering, NTNU
Odd-Geir Lademo*, Research Manager, SINTEF Materials and Chemistry
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)*

Administrative and key personnel

Trond Auestad, Senior Engineer, Dept. of Structural Engineering, NTNU
Vegard Aune, Associate Professor, Dept. of Structural Engineering, NTNU
Torodd Berstad, Researcher, Dept. of Structural Engineering, NTNU
Albert H. Collett, Communication Officer, Dept. of Structural Engineering, NTNU
Egil Fagerholt, Researcher, Dept. of Structural Engineering, NTNU
Peter Karlsaune, Project Coordinator, Dept. of Structural Engineering, NTNU
Laila Irene Larsen, Accountant, Dept. of Structural Engineering, NTNU
Ida Westermann, Dept. of Materials Science and Engineering, NTNU
Tore Wisth, Staff Engineer, Dept. of Structural Engineering, NTNU

Partners

Host institution
NTNU

Research partner
SINTEF Materials and Chemistry

Industrial partners
Audi AG
Benteler Aluminium Systems Norway AS
BMW Group
DNV GL AS
Gassco AS
Honda R&D Americas Inc.
Hydro Aluminium AS
Ministry of Local Government and Modernisation
Norwegian Defence Estates Agency
Norwegian National Security Authority
Norwegian Public Roads Administration
Renault
Sapa AB, Hydro Extruded Solutions from autumn 2017.
Statoil Petroleum AS
Toyota Motor Europe

The board seminar in Munich in November. *From left Odd-Geir Lademo and Térence Coudert, SINTEF, Jakub Galazka, Toyota, Knut Syvertsen, Ministry of Local Government and Modernisation, Yann Claude Ngueveu, Toyota, Liv Jorunn Jensen, Research Council of Norway, Ana Fernandez, Renault, Rudie Spooren, SINTEF, Agnes Marie Horn, DNV GL, Arild Holm Clausen, NTNU, Olav Bolland, NTNU, Chair, Hans Erik Vatne, Hydro, Håvar Ilstad, Statoil, Octavian Knoll, BMW, Helge Langberg, Norwegian Defence Estates Agency, Lars André Moen, Hydro, Odd Sture Hopperstad, NTNU, Cato Dørum, Norwegian Public Roads Administration, Lukas Schulenberg, Audi, Sven Samuelsen, Research Council of Norway, Magnus Langseth, NTNU, Director, Andreas Koukal, Audi, David Morin, NTNU, Eric DeHoff, Honda, Tore Børvik, NTNU, Randi Holmestad, NTNU Arjan Strating, Audi, Brian O´Hara, Honda, and Peter Karlsaune, NTNU. Photo: Albert H. Collett*

COOPERATION WITHIN THE CENTRE

The annual work plans for 2017 were based on the project description in the SFI CASA application, the work done in 2016, and discussions with the industrial partners. In-depth discussions took place in the technical meetings in the research programmes throughout 2017. The aim was to make work plans for 2018 and the following years.

SFI CASA's Industrial Reference Group (IRG) was established in 2016. Two IRG meetings were organized in 2017, on 12 May and 14 November in Ingolstadt, Germany and Munich, Germany, respectively. 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.

Scientists from NTNU and SINTEF and PhD candidates at NTNU have been the main contributors to the research work, while the industrial partners have participated on the basis of their defined contributions in kind. DNV GL AS, the 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.

The Core Team has a meeting every week, led by the Centre Director. Every two weeks the 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 Hotel Europa in Munich, Germany, on 14-16 November.

The Board of SFI CASA comprises one member from each of the 17 partners in the Centre. NTNU's representative is Chairman of the Board. The Board had two meetings in 2017: a telephone meeting on 27 June and a face-to-face meeting in Munich, Germany, on 14-16 November.

INTERNATIONAL COOPERATION AND LEADING-EDGE RESEARCH

International cooperation is one of the success criteria for an SFI centre. Six 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 has had cooperation with the following research institutions and companies in 2017:

LMT Cachan, France; University of Toyama, Japan; Tokyo Institute of Technology, Japan; IMPETUS Afea AB, Sweden; Joint Research Centre, Institute for the Protection and Security of the Citizen, Italy; Indian Institute of Technology (IIT) Delhi, India; Warsaw University of Technology, Poland; University of Manchester, UK; University of Cambridge, UK; University of Montreal, Canada; Laboratory of Thermomechanical Metallurgy, EPFL, Switzerland;

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 held its first meeting in 2016 and a second meeting and seminar is planned for September 2018.

The Centre hosted the DYMAT 23rd Technical Meeting from 12 to 14 September 2017. The conference topic was Dynamic Fracture of Ductile Materials. The conference gathered a total of 115 scientists from 16 countries on three continents. The DYMAT association is a non-profit organization bringing together engineers and scientists within the field of impact research with particular focus on the dynamic behaviour of materials, modelling, simulation, and application. Professor Magnus Langseth is a member of the DYMAT Governing Board.

Engaged participants at DYMAT. Top: David Embury and Francois Moussy, middle: Sandra Guerard and Nadia Bahlouli, bottom: Wayne Chen and Krishnaswamy Ravi-Chandar.

The DYMAT Technical Meeting in September gathered 115 scientists from 16 countries on 3 continents.

RESEARCH PROGRAMMES

Lower Scale

Head of Programme: Randi Holmestad

This programme concentrates on the lower length scales of materials, from atomic up to the micrometre scale. It provides experimental and calculated input to the multiscale framework from the lower scale. This will provide constitutive models for microstructure evolution, strength and work hardening for metallic materials, such as aluminium and steels. In addition, it gives a foundation for the development of physical-based models for crystal plasticity, continuum plasticity, damage and fracture.

The overall goal is to connect and coordinate the atomistic- and microscale framework connecting the models and the experiments at the different scales. The results will increase our basic understanding of mechanical properties and deformation of metal structures in a multiscale framework (from the nanoscale to the complete structure). This will enable research on improved models and will be used in both model developments and validations.

Four PhD students have been working in the Lower Scale programme in 2017:

- **Emil Christiansen** (Department of Physics). His PhD work is focused on micro- and nanostructure characterization of deformed aluminium alloys using transmission electron microscopy (TEM). The objective is to investigate the underlying physical mechanisms of ductile fractures in age hardening aluminium alloys. Thus this PhD research is concerned with the interaction between dislocations and precipitation free zones (PFZs) and the evolvement of a microstructure as a function of strain. In 2017, he studied how the microstructure in the PFZ of an AA6060 alloy changes as a function of deformation. His results will provide input to the different models used to describe deformation response and will be used to verify and develop numerical models in related SFI CASA projects.
- **Christian Oen Paulsen** (Department of Materials Science and Engineering). His PhD work combines experimental work and modelling activities to describe the correlation between microstructure and mechanical properties in multiphase steels. In 2017, he has completed a low temperature study of super duplex stainless steel containing intermetallic phases by in situ stretching in scanning electron microscopy (SEM). This gives input data for mathematical models for understanding and describing the performance of heterogeneous materials based on microstructure information. The experimental tests are combined with digital image correlation (DIC) to obtain detailed information about local deformation.
- **Jonas Frafjord** (Department of Physics). His PhD work will couple atomistic simulations, e.g. density functional theory, and mesoscale methods, e.g. dislocation dynamics. The goal is to provide fundamental understanding of mechanical properties and use this to improve and calibrate models at a continuum scale. He will study the effect of solute atoms and hardening precipitates, and how these affect initial yielding and hardening under different conditions. In 2017, Jonas has concentrated on how solute-dislocation interactions affect the yield stress. He has developed a method that from first principle can predict the influence of hydrostatic pressure on solute strengthening of various alloying elements (such as Mg, Si, Fe and Mn) in aluminium.
- **Jianbin Xu** (Department of Materials Science and Engineering). His PhD work studies the Portevin–Le Chatelier (PLC) effect, which describes the serrated yielding some materials exhibit as they undergo plastic deformation, resulting in early shear failure and thus reduced formability. The effect is associated with dynamic strain aging or interactions between solute atoms and matrix dislocations in strained metallic alloys. In 2017, Jianbin has studied the existing modelling approaches for work hardening and flow stress to describe solid solution strengthening and the PLC effect in aluminium alloys. In 2017, he has completed experimental characterization and tests which will enable work on validation and further improvement of existing models.

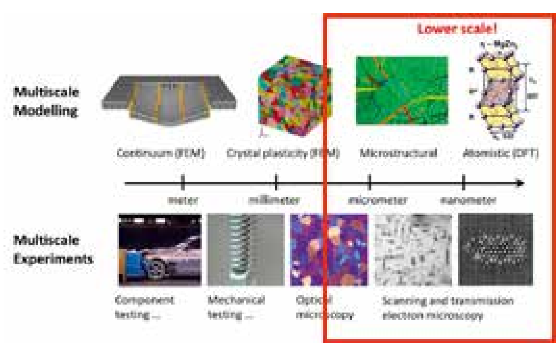


Figure 4: In a multiscale framework the Lower Scale programme covers the micrometre and nanometre scales for modelling and experiments.

Metallic Materials

Head of Programme: Odd Sture Hopperstad

Constitutive models describe the stress and internal variables (representing in an average sense the microstructural rearrangements of the material) as functions of the strain, strain rate and temperature. In large-scale simulations of structures, the framework of continuum thermo-mechanics is typically adopted to formulate the constitutive models, while thermo-mechanical testing is used to identify the model parameters. Advanced constitutive models, including plastic anisotropy, non-linear isotropic and kinematic hardening, strain-rate and temperature dependence, damage evolution and failure, tend to have a large number of model parameters.

In close collaboration with the Lower Scale programme, the Metallic Materials programme applies multi-scale methods to develop validated constitutive models for large-scale simulations of metal structures. Thus the need for calibration of the constitutive models against thermo-mechanical tests is reduced and the prediction accuracy of the models is increased with respect to properties that are not always easily measured by testing. Qualitative and quantitative descriptions at different length scales are closely accompanied by well-designed experiments at the relevant length scales for the phenomena of interest (from the nano-scale to the complete structure). This provides a basis to achieve improved understanding, model development and model validation. The quantum, atomistic and nano scales are covered by the Lower Scale programme, while the Metallic Materials deals with crystal plasticity and continuum plasticity at the micro, meso and macro scales.

The main themes of the research activities in 2017 have been:

- Micromechanical modelling of ductile fracture in aluminium alloys (PhD Lars Edvard Bryhni Dæhli)
- Ductile fracture of aluminium alloys at low stress triaxiality: an experimental and numerical study (PhD Bjørn Håkon Frodal)
- Micromechanical modelling and simulation of steel materials (PhD Sondre Bergo)
- Crystal plasticity finite element methods (Principal investigator S. Dumoulin)
- Microstructure based finite element methods (Principal investigator A. Saai)

In addition to researchers at SINTEF Materials & Chemistry and professors at NTNU, three PhD candidates are linked to the activities within the research programme, namely Lars Edvard Bryhni Dæhli, Bjørn Håkon Frodal and Sondre Bergo.

Lars Edvard Bryhni Dæhli defended his PhD thesis in 2017. As an example of his research activities, one out of his four journal papers is briefly presented. The aim of this study was to investigate void growth in strongly anisotropic FCC materials, like aluminium alloys, and to establish a heuristic extension of a porous plasticity model, namely the Gurson model, to account for plastic anisotropy. To this end, unit cell simulations of fictitious FCC materials with strong texture were conducted. The simulations revealed a pronounced dependence of the void growth and the void shape evolution on the plastic anisotropy, see Figure 5. The anisotropic porous plasticity model was found to capture the main trends seen in the unit cell simulations, see Figure 6, and is considered to be applicable in large-scale simulations of ductile damage and fracture of anisotropic aluminium alloys.

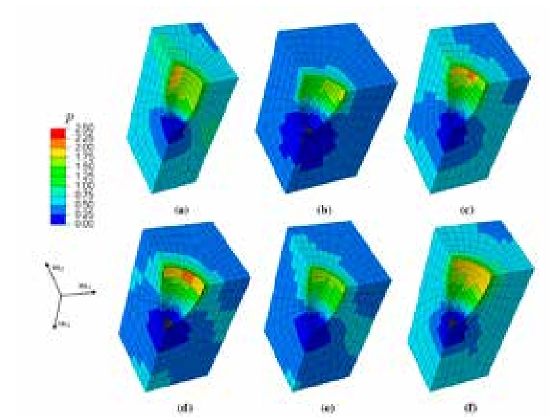


Figure 5: Examples of comparable deformed configurations of the voided unit cell with fringes of matrix accumulated plastic strain for six strong, generic FCC textures: (a) brass, (b) copper, (c) cube, (d) Goss, (e) S, and (f) random.

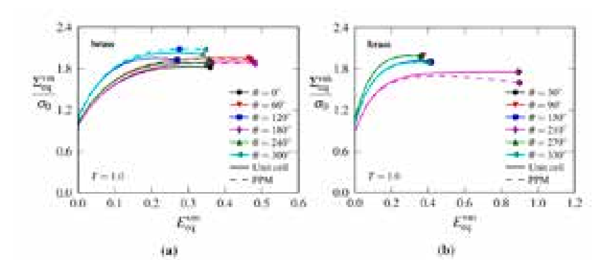


Figure 6: Comparison of equivalent stress-strain curves from the unit cell simulations (solid lines) and the anisotropic porous plasticity model (dashed lines) for brass texture at stress triaxiality equal to unity: (a) generalized axisymmetric states, and (b) generalized shear states.

Polymeric Materials

Head of Programme: Arild Holm Clausen

Polymers comprise a wide range of natural and synthetic materials. The demand for polymers has increased considerably during the last few decades. Applications include safety-related parts in cars, coatings, thermal insulation in offshore components, seals and inter-glass layers in laminated windows. The finite element method has only recently become a relevant tool in the design process of parts made of polymers. Therefore, constitutive models for such materials are less mature than for metals. The prediction of fracture is also a topic of interest for research and industry. Knowledge about the physical mechanisms governing the thermo-mechanical behaviour is of utmost importance for successful development of material models.

The main objective of the Polymeric Materials research programme is to develop and improve material models representing the thermo-mechanical response up to fracture for polymers. 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. Actual materials include commodity thermoplastics (like PE and PP, commonly reinforced with small mineral and/or rubber particles), fibre-reinforced thermoplastics, elastomers and foams made of polymers.

Four PhD candidates have been affiliated with the programme in 2017. Petter Holmstrøm will finish his thesis on the behaviour and modelling of fibre-reinforced thermoplastics in 2018. He has been supplied with materials through Audi. Daniel Morton, working with polymeric foams, has also received materials from Audi. After establishing an experimental database, he will explore the capabilities of available material models and thereafter propose improvements. Unfortunately, the PhD project of Jon Eide Pettersen was terminated in July 2017 when he decided to move from Trondheim. Nevertheless, he completed a comprehensive experimental campaign where significant process effects were revealed, see Figure 7. Another important observation is that the surface finish of tensile test samples has a major influence on the failure strain. Finally, Sindre Olufsen returned to CASA in September 2017 after one year off. He is researching failure in ductile thermoplastics, and has realized that computer tomography (CT) is an important tool when analysing the deformation mechanisms to capture in material models.

The interaction with the industrial partners engaged in the Polymeric Materials programme is maintained through annual technical meetings. One such meeting was arranged in Munich in November 2017, and gathered Audi, Benteler, BMW, DNV GL, Honda, Renault, Statoil and Toyota. The partners address their research needs at these meetings, and provide valuable advice for future research activities. Moreover, there has been cooperation with BMW, Statoil and Toyota through MSc theses.

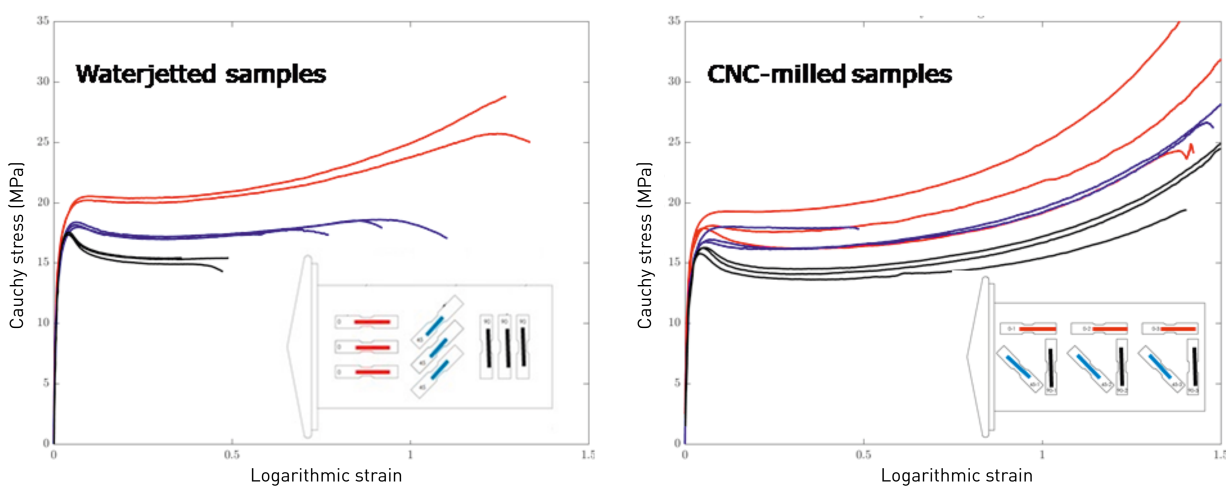


Figure 7: True stress-strain curves revealing anisotropy, process effects and importance of surface finish during machining.

Structural Joints

Head of Programme: David Morin

The need for multi-material structures in the automotive, offshore and physical infrastructure security industries is becoming increasingly important to meet the requirements regarding performance and weight reduction of their products. Often, the behaviour of a structure is strongly linked to its connections and capacities to sustain and transfer the applied load to its different members. In this perspective, the design of multi-material structures has to be carried out taking into account how the connections will behave and fail in the numerical simulations used by the designers. Today, large shell elements are used for computational efficiency which hampers an accurate representation of the connections and their failure modes due to poor discretization of these complex problems.

The aim of this research programme is to provide macroscopic models for multi-material connections which are based on a fundamental understanding of the structural joints. These models should be industry-friendly in terms of computational time as well as calibration cost. Here the multi-material connections involve aluminium, steel and fibre reinforced polymers. This objective will be addressed by using a multiscale testing and modelling strategy. This strategy involves testing at different scales from the material within the connector, through single connector tests, to the final component level. Each of these testing levels is important to gain fundamental understanding about the connections we are studying. In terms of numerical modelling, mesoscopic models where the connections are represented by solid elements will be employed to increase knowledge of the behaviour and failure of structural joints. However, macroscopic models are the final outcome of the programme.

In 2017, PhD projects were running on flow drill screw connections (Johan Kolstø Sønstabø), self-piercing rivets combined with structural adhesive (Matthias Reil) and structural bonding (John Fredrick Berntsen). In addition to this PhD work, a postdoc project was running on the effect of the pre-hole on the strength of flow drill screw connections as well as a SINTEF project on welding of dissimilar aluminium alloys.

A validation strategy is formulated to support the development of macroscopic models of joints. In this context, a new test rig has been developed to study the behaviour of connections at unit level under quasi-static conditions, i.e. when one screw and rivet are used. Furthermore, a new component tests for both flow drill screw connections and self-piercing rivets is prosed and tested. The component tests are designed to enable both quasi-static and dynamic loading. The resulting aluminium component test for flow drill screw connections as well as the validation of a numerical model for large scale analyses is shown in Figure 9.

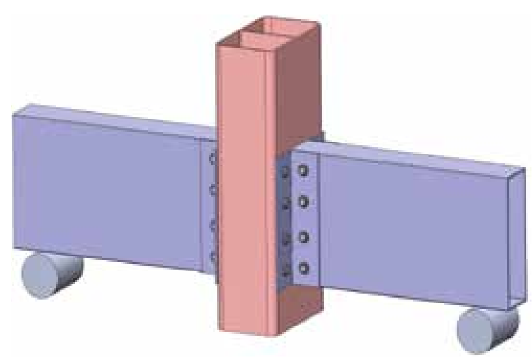


Figure 8: Component designed by PhD candidate Johan Kolstø Sønstabø to evaluate the accuracy of the macroscopic models developed for FDS connections under both quasi-static and dynamic loading conditions.

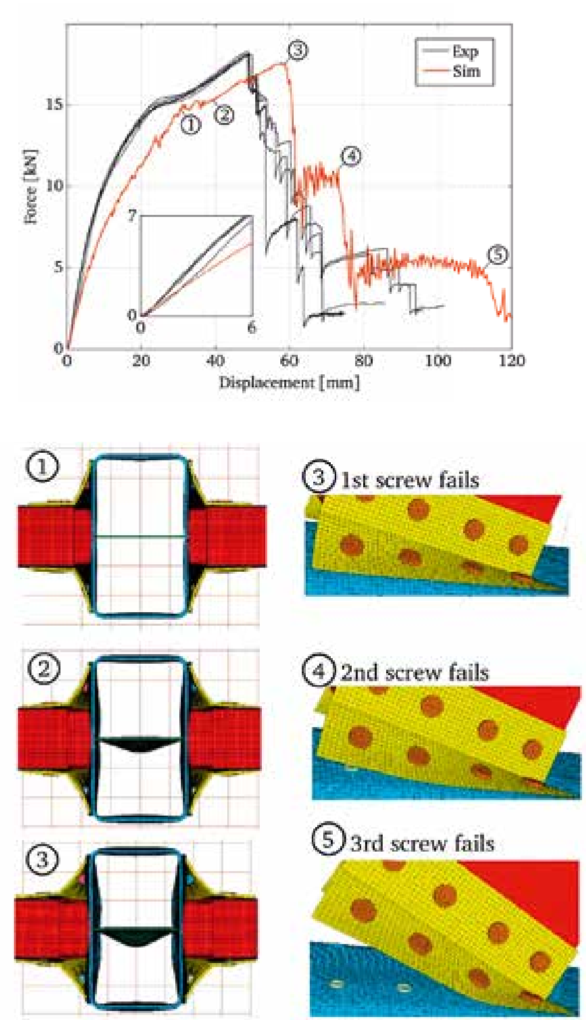


Figure 9: Quasi-static tests and numerical analyses of flow drill screw connections in an aluminium structure

Structures

Head of Programme: Tore Børvik

Design against accidental loads, such as explosions, impacts and collisions, has become increasingly important for a number of engineering and industrial applications. To meet the challenges posed by such complex loading conditions, product development and structural analysis are often carried out in virtual environments using the finite element method (FEM) to achieve safer and more cost-effective designs. The long-term goal of this research programme is to improve the survivability of people and vital infrastructure to a given threat. It is important to realize that the protective structure is the last layer of defence against a threat when all other protective measures have failed. It is thus of utmost importance that such structures are designed and validated on a sound theoretical and experimental basis. This requires accurate, efficient and robust constitutive models and solution techniques that are used in a multiscale modelling context. Further, new designs need to be validated through high-precision experimental tests involving advanced instrumentation such as three-dimensional digital image correlation for full-field displacement and strain measurements. Although much information can be obtained from laboratory tests, relying on this approach would be too costly and inefficient. By using computer-aided design, together with a strategy for material selection, optimization and well-selected validation tests, this can significantly lower the cost and enhance the overall quality and efficiency of the required protection.

The main objective of this research programme is to develop and evaluate new computational tools and establish validated modelling guidelines for computer-aided design of safer and more cost-effective protective structures. Another objective is to replace phenomenological models with physically based 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. This will be carried out in close collaboration with the other research programmes at CASA.

The main research activities in 2017 have been:

- *Modelling of structural impact*
  (Jens Kristian Holmen's postdoc project)
- *Modelling of structures subjected to blast loading*
  (Vegard Aune's PhD project)
- *Fragmentation of window glasses exposed to blast loading*
  (Karoline Osnes' PhD project)
- *Impact against coated and uncoated offshore steel pipes*
  (Ole Vestrum's PhD project)
- *Sacrificial claddings exposed to blast loading*
  (Kristoffer Aune Brekken's PhD project)

The two first projects are activities from SFI SIMLab, which are continued in SFI CASA as postdoc projects. Jens Kristian Holmen defended his PhD thesis in September 2016, while Vegard Aune defend his PhD thesis in May 2017. Both Holmen and Aune were employed as postdocs in SFI CASA in 2017. Osnes' PhD project was started in August 2015. Vestrum started his PhD project in January 2016, while Brekken started his PhD project in August 2017. In addition, a concurrent research activity on blast-loaded concrete plates conducted by postdoc Martin Kristoffersen (financed by the "Ferry-free coastal route E39" research project which is hosted by the Norwegian Public Roads Administration) has been linked to the research in Structures. Examples from Jens Kristian Holmen's postdoc project and Karoline Osnes' PhD project are shown in Figure 10 and Figure 11, respectively.

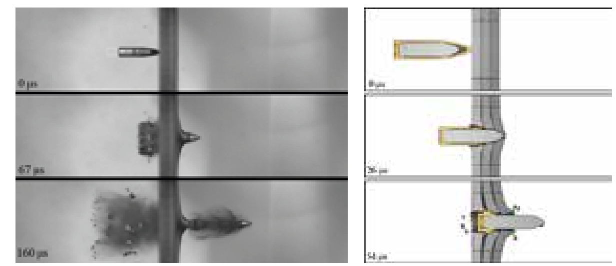


Figure 10: Comparison between high-speed camera images (left) and simulations (right) using the IMPETUS Afea Solver from a ballistic test where a layered and case hardened steel plate is perforated by an armour-piercing bullet.

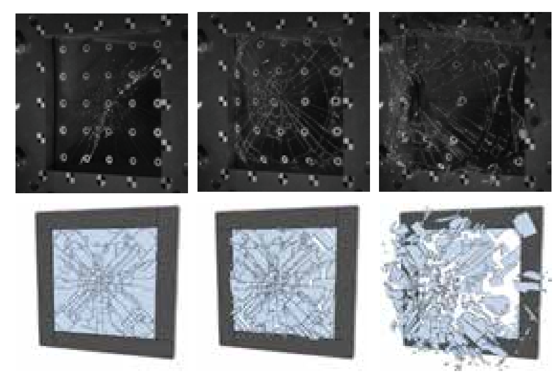


Figure 11: Comparison between high-speed camera images (top) and simulations (bottom) using the IMPETUS Afea Solver from a blast-load experiment in SIMLab's shock tube on annealed float glass.

Methods and Tools

Heads of Programme:
Odd-Geir Lademo and
Térence Coudert

The M&T programme represents the main instrument to link the Basic research in the Centre to the Industrial implementation at the industrial partners. The SIMLab Toolbox is a synthesis of the research results. It supports and guides the user to the necessary steps to build a reliable finite element model for advanced structural analysis, such as selecting the suitable material model, processing experimental data, calibrating and optimizing the material model parameters.

The main activities during 2017 were (i) to improve the existing SIMLab Toolbox, (ii) to develop and introduce new tools for multiscale modelling in close collaboration with the Metallic Materials programme, and (iii) to disseminate the use of the SIMLab Toolbox for master's and PhD candidates.

Components of the SIMLab Model Library have been released for the partners: SMM for Metals and SPM for Polymers. Other developments have been carried out for the SCMM (Crystal Mechanics), the SPPM (Porous Plasticity), and the localization module. The model calibration toolbox (e.g. MatPrePost) provides identification procedures for the SMM and the SPM. In 2017, a new procedure to identify the thermal sensitivity parameters of the SMM has been developed. At the same time, a modern design and a new graphical user interface has been considered for MatPrePost version 3.0. The main motivation for this updated version is easy-to-use and easy-to-develop software. A beta version will be released in 2018. A methodology has been developed to build a material card library from the scientific publications produced by SIMLab staff.

Several tools are needed at different scales to assist the research in the various programmes. An FE analysis using the Crystal Mechanics model needs a simple tool to generate representative volume elements (RVE). The team has selected open source software DREAM.3D and developed plugins that fit the needs of the Centre. DREAM.3D is a modular software package that allows users to reconstruct, instantiate, quantify, mesh, handle and visualize multidimensional, multimodal data. It was originally designed to analyse microstructure data coming from sources such as EBSD observations, and may generate equivalent material structures from statistics that are synthetic or extracted from real data. Two more filters have been added to the filters developed in 2016 (i) to create a «Rubik's Cube» RVE (a grain in the RVE is represented by a cube made of one or several elements) (ii) to generate smooth grain boundaries. The latter needs further development and verification before being operational.

In close collaboration with the Metallic Materials programme, the team has set up a workflow to compute a yield surface atlas. The steps of the workflow are: (i) to generate a texture (e.g. Brass 50%), (ii) to generate a RVE (e.g. «Rubik's cube») using DREAM.3D and extract associated texture, (iii) to run FE simulations with SCMM to generate a discrete yield surface, and (iv) to calibrate a yield function, e.g. Yld2014-18p, for the SMM.

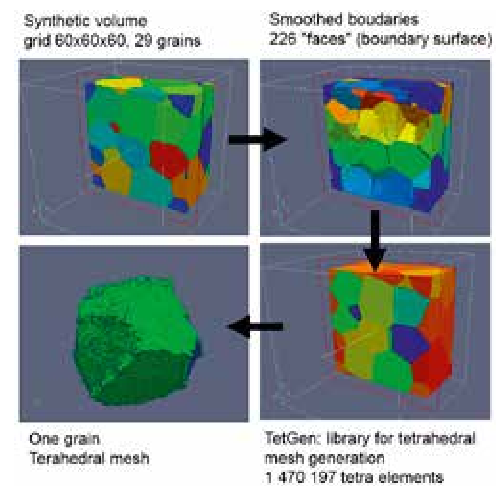


Figure 12: DREAM.3D: Generate smooth grain boundaries.

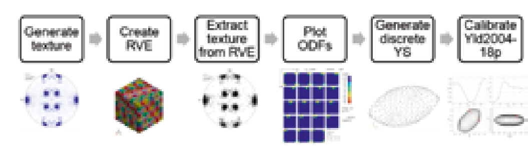


Figure 13: Workflow to generate a yield surface atlas.

Industrial Implementation

Head of Programme: Magnus Langseth

Figure 14 illustrates the important interlink between *Basic research, Technology transfer* and Industry. Here the *Industrial implementation* programme will be the link between the *Methods & Tools* programme and the industrial use of the research and technology developed at the Centre for Innovation.

In order to strengthen the industrial implementation of the research and cooperation between the partners, an industrial reference group (IRG) has been established where there is one expert from each partner. The defined mandate for the group states that a report is to be presented to the SFI CASA Board once a year about how the implementation is carried out and how research and commercial cooperation is initiated between the industrial partners. The survey carried out in 2016 about implementation showed that the partners define implementation as both short- and long-term activities, see Figure 15. On a short-term perspective, a key issue is the training of the partners to use the tools that are developed, whereas for long-term activities they expect that the technology will be implemented into their daily processes.

The key issue discussed during the two IRG meetings in 2017 has been the implementation of SFI CASA material models into commercial solvers like LS-DYNA, ABAQUS and PAMCRASH. Based on meetings with the code owners, a new metallic material model for shell elements will be implemented in 2018.

To support implementation and show the capability of the models developed, a building group or demonstrator activity has been discussed, Figure 16. The activity is part of a validation strategy, which includes testing and modelling at Unit level, at Benchmark level, at Component level and at Building group level. Activities beyond the Building group level are handled by the partners as it is linked to a specific process or product. The validation strategy shown in Figure 16 also ensures pre-competitive research in the Centre.

The validation strategy is also used to train the partners as illustrated as the short-term activity in Figure 15. A very successful seminar was organized in Munich in June on the behaviour and modelling of aluminium and structural joints. Another issue of importance for the IRG is recruitment and how actions can be taken by the Centre to recruit good master's and PhD students. Here the master's topics proposed by the partners are very important. Some of the topics launched include a research period at the partners during the students' work on their master's theses. Another instrument for implementation and exchange of information between the Centre and the partners is periods of research for PhD students at the partners. In 2018, Statoil and BMW will host one student each for three months.

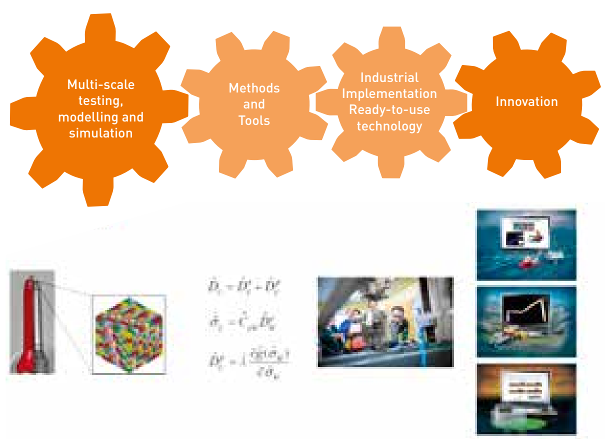


Figure 14: From research to innovation

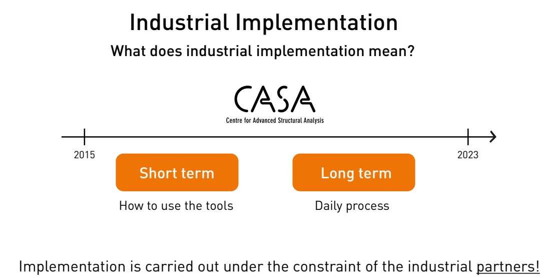


Figure 15: Implementation at partners

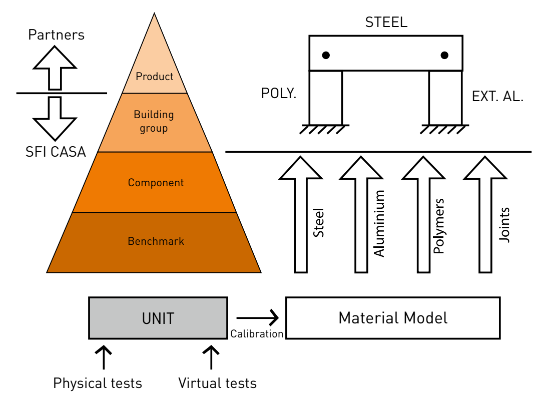
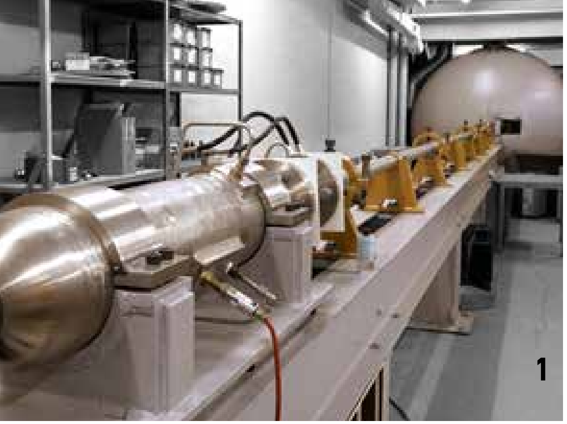
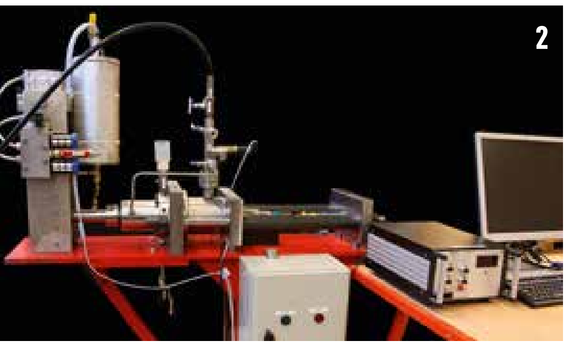


Figure 16: Validation strategy and building groups

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. Please go to our website to read more about the Centre's laboratories: www.ntnu.edu/casa

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.

Hydro-pneumatic machine (HPM) (2)
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) (3)
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 that is connected to a hydraulic/pneumatic actuator system. The 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.

Self-piercing riveting machine (4)
In this machine self-piercing riveting can be carried out of sheets under industrial conditions.

Sheet metal forming machine (BUP) (5)
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.

Split-Hopkinson tension bar (SHTB) (6)
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.

Stretch bending rig (7)
The stretch-bending rig applies a combined bending and axial tensile/compressive loading to the test component. The length of the specimens is 1-2 m, and they are bent around an exchangeable die with a defined curvature. The 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.

Droptower impact system (8)
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 from 2-70 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.

Split-Hopkinson pressure bar (SHPB) (9)
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.

Shock tube facility (10)
The SIMLab Shock Tube Facility consists of a long tube and a tank. 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 x 0.3 m. Threaded holes in the tube floor enable mounting of test specimens in the test section, and windows in the test section and the dump tank allow high-speed cameras to investigate the structural response during an experiment.

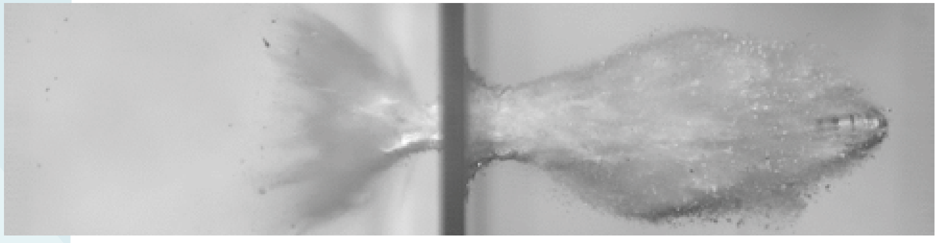
Scanning electron microscope (SEM) laboratory (11)
SFI CASA has access to a SEM lab with the following equipment: Zeiss SUPRA 55VP (LVFESEM, 2006), Hitachi S-4300SE (FESEM, 2002), Zeiss, Ultra 55LE, FESEM (2007), Jeol 840 (1989). 3 SEMs are equipped with EDS and EBSD. The laboratory have in-situ sub-stage 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.

Cameras
SFI CASA has a FLIR SC7500 infrared camera that can convert infrared radiation to a visual image that depicts thermal variations across an object or scene. Thus it can be used to measure the surface temperature of a specimen under inelastic deformations. With a resolution of 320x256 pixels the maximum frame rate is 380 per second, while at a resolution of 48x4 pixels the maximum frame rate is 31 800 per second (FPS).

During impact testing of materials and structures, the events are recorded using high-speed cameras. The research group has a Kirana-05M camera with a maximum frame rate of 5 000 000 FPS, allowing detailed studies of crack propagation. In addition the research group has 4 more high speed cameras and several cameras for Digital Image Correlation measurements.

The picture below shows a test where the Phantom V1610 high-speed camera has been used. A 7 mm laminated safety glass is hit by a 7.62 calibre lead bullet at a speed of 800 m/s. The camera is set to a frame rate of 60 000 FPS and exposure time 0.452 μs.

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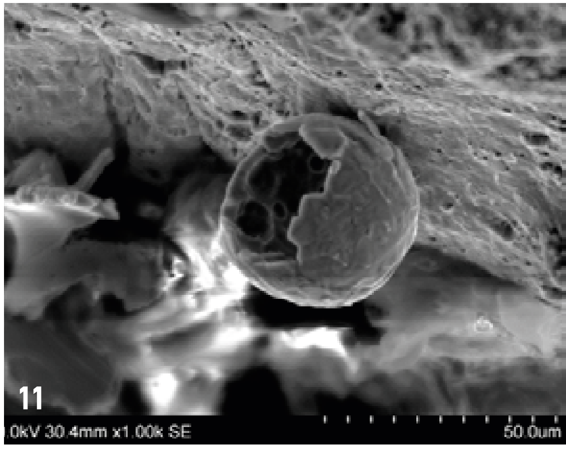

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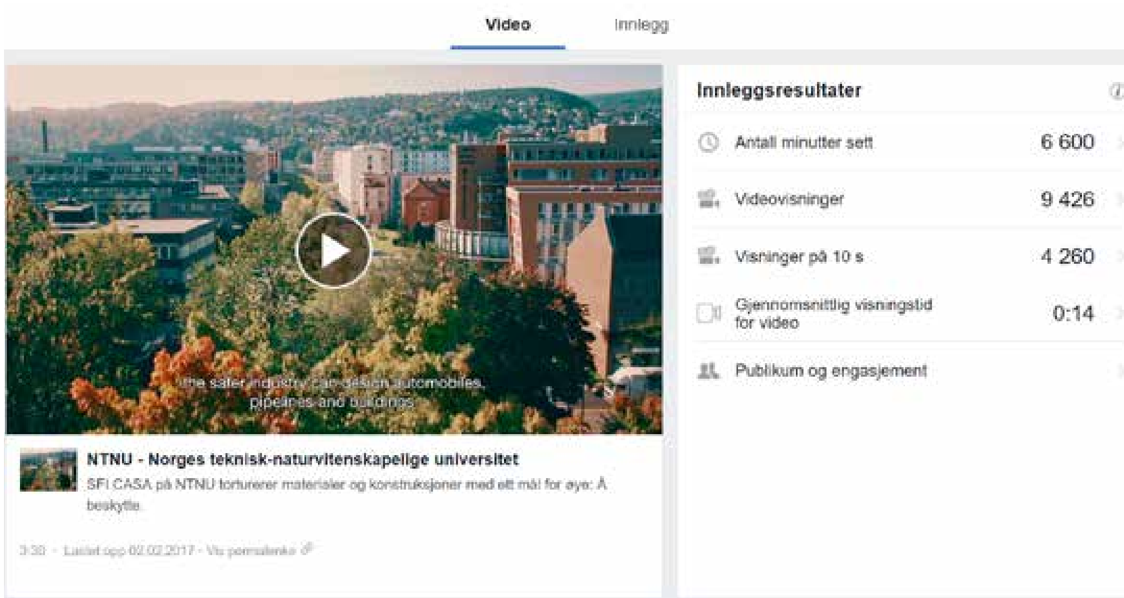
Photos 1, 2, 4, 5, 6 and 7: Melinda Gaal
Photos 3 and 8 – 10 and 12: Ole Morten Melgård



As the statistics show, the presentation video had many views on NTNU's Facebook page. YouTube and other distribution channels add to that.

Media strategy

CASA has a media strategy for popular science presentations of its research activities in magazines, newspapers, on television, radio and the web. It is also an aim to make female researchers particularly visible in order to recruit women and contribute to a more even gender balance in this research field. The popularized part of this report is an example of how these strategies are carried out. The articles have also been published in our monthly newsletter and on the blog www.ntnutechzone.no.

SFI CASA newsletter

As part of the media strategy SFI CASA has a monthly newsletter. The newsletter is sent out to partners, contacts and other people in SFI CASA's social and professional network and to professionally interested parts of the media. The newsletter presents both research news and in-depth interviews with key personnel working with SFI CASA. The newsletter is published here: http://sfi-casa.no/ and anyone can subscribe.

Presentation video

Towards the end of 2015, the core team expressed a wish for a video that could present SFI CASA. Shortly after, a staff brainstorm defined the goals. The video premiered in January 2017. Since then it has won wide acclaim and distribution.

Several of the partners have found it useful for a variety of purposes. One is to show colleagues and others how their own organizations may benefit from generic research as a foundation for innovation. Another is to illustrate how they contribute to research that benefits society as a whole.

The staff at CASA has used the video extensively. They have shown it to hundreds of NTNU employees and students, to executives from many of the partners, to a large meeting of Norwegian police leaders, to the Minister of Trade and Industry, to a member of Parliament - leading to a white paper recommendation for more research on civil infrastructure security, to visitors from abroad, and in many more contexts.

NTNU's rectorate chose an abridged version as NTNU's contribution to a video series from the 51 European technological universities in the CESAER partnership.

Social media

The video has caught on in social media. After a month, it had passed 9 000 views on NTNU's Facebook page. More than 2 000 have seen it on YouTube.

The increasing importance of social media is also well illustrated in the distribution of stories from the SFI CASA Newsletter. The newsletter has close to 300 subscribers who are notified by email every time new stories are posted. As an example, around 60 of them opened the Master Educator article about Professor Arild Holm Clausen. These 60 include most of the board members and other key recipients that are very important to reach. However, the article reached many more. It was last year's most read article on the blog www.ntnutechzone.no with contributions from three faculties, where it had 2 000 readers. It did not stop there: the Facebook posting of the same article had more than 25 000 views.

CASA in traditional media

The research website Gemini and other media reported the work of PhD candidate Karoline Osnes on safety glass. Osnes performs tests in SIMLab's shock tube. These reveal that glass is an unpredictable friend. One sample may turn out to be twice as strong as another seemingly identical sample. Osnes is working to develop numerical models that manage to predict the behaviour of laminated glass.
Karoline Osnes also got publicity for her participation in "Researcher's Grand Prix", organized by the Research Council of Norway. The annual event is set up to stimulate good, popularized presentations of research.

Several media, including national broadcaster NRK, brought results from SIMLab's shock tube related to submerged, floating tunnels. The tests found that concrete is tougher than assumed.
"We carried out the first tests with five centimetre thick, unreinforced concrete plates. We subjected them to a seven bar shock wave. To our surprise, very little happened," said researcher Martin Kristoffersen.

A local newspaper Hammerfestingen interviewed researcher Marius Andersen about his thesis on thermoplastics at large deformations. The work is of particular interest to the automotive industry. After defending his PhD, Andersen went on to work for a concurrent project AluMast about the possible use of aluminium in power pylons. His topic has been the structural response of thin-walled aluminium tubes subjected to axial loading.

Awards

Professor Arild Holm Clausen was awarded Best Educator by the students in mechanical engineering at NTNU.

SFI CASA Post doc Miguel Costas was awarded the Extraordinary PhD award by the University of A Coruna for his PhD thesis *Crashworthiness analysis and design optimization of hybrid impact energy absorbers*. This is an annual prize given to the best PhD thesis within the field of Civil Engineering.

Skills development

Assistant Professor Erling Østby from DNV GL gave CASA researchers a course entitled *A Fracture Mechanics Short Course* on 31 May and 1 June.
Researchers from Simula Research Laboratory visited SFI CASA on 30-31 January and gave a course on the programming language Python.

Arild Holm Clausen receives this year's prize for best educator from Maria Dyrseth, representative of the mechanical engineering students. Photo: Olav Bolland, Dean of the Faculty of Engineering.

Invited and guest lectures

- PhD candidate Erik Grimsmo gave an invited lecture entitled *Behaviour of steel structural joints exposed to impact loading* at the Norwegian National Security Authority's annual Security conference on 28-29 March in Oslo, Norway.
- PhD candidate Karoline Osnes gave an invited lecture at the Norwegian National Security Authority's annual Security conference on 28-29 March in Oslo, Norway. The lecture title was *Laminated glass exposed to blast loading – behaviour and modelling.*
- Professor Magnus Langseth gave a presentation of SFI CASA's innovation strategy at the Research Council of Norway's annual forum for the Centres of Research Based innovation on 27 April in Oslo, Norway.
- SFI CASA's communication officer Albert Collett presented SFI CASA's communication strategy at the Research Council of Norway's annual forum for the Centres of Research Based innovation on 27 April in Oslo, Norway.

Guest lectures at SFI CASA

- Francois Moussy gave a guest lecture with the title *How are car manufacturers decreasing the weight of their cars?* on 11 September.
- Associate professor Josef Kiendl held a lecture on 5 April titled *Isogeometric Methods in Structural Mechanics.*
- Professor Ahmed Benallal from LMT-Cachan stayed at the research group SIMLab from 13 March to 7 April. On 5 April he gave a lecture with the title *On the roles of thermal effects and thermomechanical couplings in strain localization and fracture: bifurcation versus imperfection analyses.*
- Folco Casadei from Joint Research Centre, Ispra, Italy, gave a talk with the title *Treatment of Contact and of Fluid-Structure Interaction in the Explicit Code EUROPLEXUS* on 3 May.
- Professor Ted Krauthammer from the Center for Infrastructure Protection and Physical Security, University of Florida, USA, gave a presentation at SFI CASA on 21 June. The presentation title was *Energy Flow Considerations for Protective Structures.*

Research visits abroad by SFI CASA staff

- Professors Magnus Langseth, Tore Børvik and Odd Sture Hopperstad stayed at LMT-Cachan, France, from 13 to 16 February 2017.
- PhD candidate Emil Christiansen visited the Faculty of Materials Science and Engineering at Warsaw University of Technology, Poland from 1 March to 1 April 2017.
- PhD candidate Christian Oen Paulsen stayed at the School of Materials at University of Manchester from 1 to 29 May.
- Post doc Vegard Aune visited the Directorate for Space, Security and Migration Safety and Security of Buildings, Joint Research Centre in Ispra, Italy from 12 June to 14 July 2017.
- Professor Odd Sture Hopperstad visited LMT-Cachan, France in the period 9-13 October 2017.

Research visits at SFI CASA

- Professor Ahmed Benallal from LMT-Cachan, France, visited the research group from 13 March to 7 April and from 11 to 15 September.
- Folco Casadei from Joint Research Centre, Ispra, Italy visited SFI CASA from 1 to 6 May.
- Emeritus Professor David Embury from McMaster University, Canada, visited CASA from 29 May to 2 June and from 11 to 15 September.
- Professor John Hutchinson from Harvard University, USA, visited CASA from 11 to 15 September.
- MSc student Lei Liu from TU Eindhoven, the Netherlands, did a 5 month internship at SFI CASA from August to December 2017.

Concurrent projects

Some of the concurrent projects run with technology developed at the Centre:

Fundamental studies of materials´ behaviour in future cold climate applications (SMACC) (2013-2017): NTNU and SINTEF were involved in this joint industry project with SINTEF as project host. SIMLab was involved in the project with a PhD candidate working on the behaviour and modelling of thermoplastics at low temperatures.

Joint research project with Honda R&D Americas (2013-2017): The objective of the project was to model the behaviour and failure of flow drilling screws submitted to crash loadings. One PhD candidate worked on this project.

Alumast (2015-2018): NTNU was one of several partners in a consortium working on aluminium power pylons. One post doc at SIMLab worked on 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 from LMT-Cachan 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 a postdoctoral research fellow who is working with submerged floating tunnels subjected to internal blast loading.

FlexLinerLife (2017-2020): 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.

PERSONNEL

PhD candidates and post docs. *From left: Jianbin Xu, Lars Edvard Dæhli, Emil Christiansen, Henrik Granum, Miguel Costas, Karoline Osnes, Vegard Aune, Ole Vestrum, Susanne Thomesen, Joakim Johnsen, Marius Andersen, John Fredrick Berntsen, Asle Joachim Tomstad, Bjørn Håkon Frodal, Einar Schwenke, Martin Kristoffersen, Jonas Frafjord, Johan Kolstø Sønstabø, and Sondre Bergo.*

PhD candidates and post docs

PhD candidates and post docs with funding from SFI CASA

Name	Position	Start	End	Programme	Nationality	Gender
John Fredrick Berntsen*	PhD	2015	2019	Structural Joints	Norwegian	M
Emil Christiansen*	PhD	2015	2019	Lower Scale	Norwegian	M
Bjørn Håkon Frodal*	PhD	2015	2019	Metallic Materials	Norwegian	M
Sindre Olufsen*	PhD	2015	2019	Polymeric Materials	Norwegian	M
Karoline Osnes*	PhD	2015	2019	Structures	Norwegian	F
Christian Oen Paulsen**	PhD	2015	2019	Lower Scale	Norwegian	M
Sondre Bergo**	PhD	2016	2020	Metallic Materials	Norwegian	M
Jonas Frafjord*	PhD	2016	2020	Lower Scale	Norwegian	M
Daniel Morton**	PhD	2016	2020	Polymeric Materials	Norwegian	M
Jon Eide Pettersen*	PhD	2016	2020***	Polymeric Materials	Norwegian	M
Matthias Reil**	PhD	2016	2019	Structural Joints	German	M
Ole Vestrum**	PhD	2016	2020	Structures	Norwegian	M
Jianbin Xu**	PhD	2016	2020	Lower Scale	Chinese	M
Kristoffer Aune Brekken**	PhD	2017	2021	Structures	Norwegian	M
Jens Kristian Holmen	Post doc	2016	2020	Structures	Norwegian	M
Miguel Costas	Post doc	2017	2020	Structural Joints	Spanish	M
Vegard Aune	Post doc	2017	2018	Structures	Norwegian	M
Joakim Johnsen	Post doc	2017	2019	Polymeric materials	Norwegian	M

** Salary and operational costs from the Centre.*
***Operational costs from the Centre. Salary from other sources.*
****The PhD project was terminated autumn 2017*

PhD candidates with funding from SFI SIMLab. The topics are highly relevant for SFI CASA

Name	Position	Start	End	Programme	Nationality	Gender
Vegard Aune*	PhD	2012	2017	Structures	Norwegian	M
Lars Edvard Dæhli**	PhD	2013	2017	Metallic Materials	Norwegian	M
Erik Løhre Grimsmo***	PhD	2013	2017	Structural Joints	Norwegian	M
Petter Henrik Holmstrøm	PhD	2013	2018	Polymeric Materials	Norwegian	M

**Thesis defended in 2017 and then employed as post doc at SFI CASA.*
***Thesis defended in 2017 and is employed as post doc at FractAl (a concurrent project).*
****Thesis defended in 2017.*

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

Name	Position	Start	End	Project***	Nationality	Gender
Joakim Johnsen*	PhD	2014	2017	SMACC	Norwegian	M
Mikhail Khadyko	Post doc	2015	2018	FractAl	Russian	M
Martin Kristoffersen	Post doc	2015	2018	E39	Norwegian	M
Johan Kolstø Sønstabø**	PhD	2013	2017	Honda	Norwegian	M
Marius Andersen	Post doc	2016	2018	Aluminium Power Pylons	Norwegian	M
Henrik Granum	PhD	2016	2020	FractAl	Norwegian	M
Susanne Thomesen	PhD	2016	2019	FractAl	Norwegian	F
Asle Joachim Tomstad	PhD	2017	2021	FractAl	Norwegian	M
Lars Edvard Dæhli	Post doc	2017	2021	FractAl	Norwegian	M

**Thesis defended in 2017 and then employed as post doc at SFI CASA*
***Thesis submitted in 2017. Thesis defended in 2018.*
****See concurrent projects.*

The SFI CASA staff all lined up.

Recruitment

One new PhD candidate started at SFI CASA in 2017 and one started on a concurrent project. Both were former MSc students at NTNU. Three post docs were employed by SFI CASA; one with a PhD degree from University of A Coruña, Spain, two with a PhD from the SIMLab research group. Another former PhD student at the research group was employed as post doc on a concurrent project. The Centre's ambition is to attract Norwegian candidates and improve the gender balance. However, only one female candidate has been employed at SFI CASA so far, illustrating the uneven gender balance in the research field. A recruitment seminar for MSc students was organized in April 2017. Of the 24 attending students only 4 were female. More direct recruitment measures are planned for 2018. In 2017 SFI CASA played an active role in NTNU's student recruitment. The Centre has given guided tours for a total of 100 upper secondary school students during 2017. In addition, four guided tours were given to different groups of professionals from industry and public agencies.

MSc students

The following MSc students (19 male and 5 female) were associated with the Centre in 2017

STUDENT	TOPIC
N. Amundsen and A. Lynum	Knekking av hule aluminiumssøyler med og uten sveis
S. Berdal and L.E. Bjørgo	Impact behaviour of foam-based protective structures
O. S. Bratsberg and M. Kolsaker	Window glasses exposed to blast loading
D. Gulbrandsen	Stålplater utsatt for støtlast i kaldt klima
P. Gunathasan	Ballistisk oppførsel av stålplater ved lave temperaturer
S. Hammersvik and E.B. Kulsrud	Impact against coated steel pipes
G.M. Hellum	Ductile-brittle transition in offshore steel
E.T. Kittilsen and E. Swanberg	Behaviour and modelling of cast aluminium rims
E.K. Kjus and E. Solhjem	Modelling, simulation and optimization of crash components in aluminium
M. Nordhaug	Identification of Material Properties of an Aluminium Alloy
E.E. Pettersen	Simulation and behaviour of dual-phase steels
E. Schwenke	Cold impact performance of polypropylene
J.M. Stensjøen and S.T. Thorgeirsson	An Experimental and Numerical Investigation of the Blast Response of Pre-damaged Aluminium Plates
B. Storheim	Mechanical behaviour of a mineral filled elastomer modified polypropylene compound
E. Tjønn	Modelling and simulation of hyper velocity impact against debris shields for spacecraft protection
A.J. Tomstad	Modelling and simulation of ductile fracture in aluminium alloys
R.S. Engebretsen	Modelling of PA in inner liner in flexible pipes

PUBLICATIONS & ANNUAL ACCOUNTS

The following lists journal publications and conference contributions generated in 2017

CASA publications

1. V. Aune, G. Valsamos, F. Casadei, M. Larcher, M. Langseth, T. Børvik. Numerical study on the structural response of blast-loaded thin aluminium and steel plates. International Journal of Impact Engineering 99 (2017) 131–144.
2. V. Aune, G. Valsamos, F. Casadei, M. Larcher, M. Langseth, T. Børvik. Use of damage-based mesh adaptivity to predict ductile failure in blast-loaded aluminium plates. Procedia Engineering 197 (2017) 3-12.
3. V. Aune, G. Valsamos, F. Casadei, M. Langseth, T. Børvik. On the dynamic response of blast-loaded steel plates with and without pre-formed holes. International Journal of Impact Engineering 108 (2017) 27–46.
4. M. Costas, D. Morin, M. Langseth, J. Diaz, L. Romera. Static crushing of aluminium tubes filled with PET foam and a GFRP skeleton. Numerical modelling and multiobjective optimization. International Journal of Mechanical Sciences 131-132 (2017) 205-217.
5. L.E.B. Dæhli, J. Faleskog, T. Børvik, O.S. Hopperstad. Unit cell simulations and porous plasticity modelling for strongly anisotropic FCC metals. European Journal of Mechanics A/ Solids. Volume 65 (2017) 360-383.
6. L.E.B. Dæhli, D. Morin, T. Børvik, O.S. Hopperstad. Influence of yield surface curvature on the macroscopic yielding and ductile failure of isotropic porous plastic materials. Journal of the Mechanics and Physics of Solids 107 (2017) 253-283
7. B.H. Frodal, K.O. Pedersen, T. Børvik, O.S. Hopperstad. Influence of pre-compression on the ductility of AA6xxx aluminium alloys. International Journal of Fracture 206 (2017) 131-149.
8. E.L. Grimsmo, L.E. Bryhni Dæhli, O.S. Hopperstad, A. Aalberg, M. Langseth, A.H. Clausen. Comparison of damage models in numerical simulations of fillet welds under quasi-static and impact loading. Procedia Engineering 197 (2017) 79–88.
9. E.L. Grimsmo, L.E.B. Dæhli, O.S. Hopperstad, A. Aalberg, M. Langseth, A.H. Clausen. Numerical study of fillet welds subjected to quasi-static and impact loading. International Journal of Mechanical Sciences 131-132 (2017) 1092-1105.
10. E.L. Grimsmo, A.H. Clausen, A. Aalberg, M. Langseth. Fillet welds subjected to impact loading – an experimental study. International Journal of Impact Engineering 108 (2017) 101-113.
11. E.L. Grimsmo, A. Aalberg, M. Langseth, Arild H. Clausen. How placement of nut determines failure mode of bolt-and-nut assemblies. Steel Construction 10 (2017).
12. G. Gruben, D. Morin, M. Langseth, O.S. Hopperstad. Strain localization and ductile fracture in advanced high-strength steel sheets. European Journal of Mechanics A/Solids 61 (2017) 315-329.
13. G. Gruben, D. Morin, M. Langseth, O.S. Hopperstad. Ductile fracture of steel sheets under dynamic membrane loading. Procedia Engineering 197 (2017) 185–195.
14. G. Gruben, S. Sølvernes, T. Berstad, D. Morin, O. S. Hopperstad, M. Langseth: Low-velocity impact behaviour and failure of stiffened steel plates. Marine Structures 54 (2017) 73–91.
15. J.K. Holmen, L. Olovsson, T. Børvik. Discrete modeling of low-velocity penetration in sand. Computers and Geotechnics 86 (2017) 21–32.
16. J.K. Holmen, O.S. Hopperstad, T. Børvik. Influence of yield-surface shape in simulation of ballistic impact. International Journal of Impact Engineering 108 (2017) 136-146.
17. J. K. Holmen, J.K. Solberg, O.S. Hopperstad, T. Børvik. Ballistic impact of layered and case-hardened steel plates. International Journal of Impact Engineering 110 (2017) 4-14.
18. J.K. Holmen, B.H. Frodal, O.S. Hopperstad, T. Børvik. Strength differential effect in age hardened aluminum alloys. International Journal of Plasticity 99 (2017) 144-161.
19. J.K. Holmen, T. Børvik, O.S. Hopperstad. Experiments and simulations of empty and sand-filled aluminium alloy panels subjected to ballistic impact. Engineering Structures 130 (2017) 216–228.
20. A. Ilseng, B.H. Skallerud, A.H. Clausen. Volume growth during uniaxial tension of particle-filled elastomers at various temperatures –Experiments and modelling. Journal of the Mechanics and Physics of Solids 107 (2017) 33-48.
21. A. Ilseng, B.H. Skallerud, A.H. Clausen. An experimental and numerical study on the volume change of particle-filled elastomers in various loading modes. Mechanics of Materials 106 (44-57) 2017.
22. 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 (2017) 204141961774132.
23. D. Morin, B.L. Kaarstad, B. Skajaa, O.S. Hopperstad, M. Langseth. Testing and modelling of stiffened aluminium panels subjected to quasi-static and low velocity impact loading. International Journal of Impact Engineering 110 (2017) 97-111.
24. M.S. Remøe, K. Marthinsen, I. Westermann, K.O. Pedersen, J. Røyset, C.D. Marioara. The effect of alloying elements on the ductility of Al-Mg-Si alloys. Materials Science & Engineering: A 693 (2017) 60-72.
25. D. Vysochinskiy, T. Coudert, O.S. Hopperstad, O.-G. Lademo, A. Reyes. Experimental study on the formability of AA6016 sheets pre-strained by rolling. International Journal of Material Forming (2017) 1-17.

Publications on projects closely related to SFI CASA

1. J. Johnsen, F. Grytten, O.S. Hopperstad, A.H. Clausen. Influence of strain rate and temperature on the mechanical behaviour of rubber-modified polypropylene and cross-linked polyethylene. Mechanics of Materials 114 (2017) 40–56.
2. J. Qin, B. Holmedal, O.S. Hopperstad. Modelling of strain-path transients in commercially pure aluminium. Materials Science Forum 877 (2017) 662-667.

Conference contributions

1. V. Aune, G. Valsamos, F. Casadei, M. Larcher, M. Langseth, T. Børvik. Numerical simulations of blast-loaded plates using combined fluid and structure mesh adaptivity. 30th Nordic Seminar on Computational Mechanics, Copenhagen, Denmark 25-27 October 2017.
2. V. Aune, G. Valsamos, F. Casadei, M. Larcher, M. Langseth, T. Børvik. Use of damage-based mesh adaptivity to predict ductile failure in blast-loaded aluminium plates. DYMAT 23rd Technical Meeting on Dynamic fracture of ductile materials, Trondheim, Norway, 12-14 September 2017.
3. E. Christiansen, W. Chrominski, C.D. Marioara, O.S. Hopperstad, R. Holmestad. Precipitate Free Zones in Deformed Al-Mg-Si Alloys. SCANDEM2017, Reykjavik, Iceland, 5-9 June 2017.
4. L.E.B. Dæhli, D. Morin, T. Børvik, O.S. Hopperstad. Strain localization analyses of generic FCC textures using imperfection band analyses. 14th International Conference on Fracture, Rhodes, Greece, 18-23 June 2017.
5. L.E. Grimsmo, L.E.B. Dæhli, O.S. Hopperstad, A. Aalberg, M. Langseth, A.H.C Clausen. Comparison of Damage Models in Numerical Simulations of Fillet Welds under Quasi-static and Impact Loading. DYMAT 23rd Technical Meeting on Dynamic fracture of ductile materials, Trondheim, Norway, 12-14 September 2017.

6. E.L. Grimsmo, A. Aalberg, M. Langseth, A.H. Clausen. How placement of nut determines failure mode of bolt-and-nut assemblies. The 8th European Conference on Steel and Composite Structures, Copenhagen, Denmark, 13-15 September 2017.
7. E.L. Grimsmo, L.E.B. Dæhli, A. Aalberg, M. Langseth, A.H. Clausen. FE simulations of fillet welds subjected to impact loading. Mek'IT 17 - 9th National Conference on Computational Mechanics, Trondheim, Norway, 11-12 May 2017.
8. G. Gruben, D. Morin, M. Langseth, O.S. Hopperstad. Ductile Fracture of Steel Sheets under Dynamic Membrane Loading. DYMAT 23rd Technical Meeting on Dynamic fracture of ductile materials, Trondheim, Norway, 12-14 September 2017.
9. R. Holmestad, S. Wenner, E.A. Mørtsell, E. Christiansen, J.K. Sunde, C.D. Marioara, J. Friis, S.J. Andersen. Precipitates in age hardenable Al alloys studied by (S)TEM techniques. 13th Light Metals International Workshop by Japan Institute of Light Metals, Toyama, Japan, 12-13 October 2017.
10. O.S. Hopperstad, D. Morin, A. Benallal. Simulation of anisotropic tensile failure in high-strength aluminium alloy by localization theory. COMPLAS 2017, XIV Conference on Computational Plasticity. Fundamentals and applications, Barcelona, Spain, 5-7 September 2017.
11. J. Johnsen, F. Grytten, O.S. Hopperstad, A.H. Clausen. Numerical simulation of cross-linked polyethylene at different ambient temperatures and strain rates. Mek'IT 17 - 9th National Conference on Computational Mechanics, Trondheim, Norway, 11-12 May 2017.
12. M. Kristoffersen, T. Børvik, M. Langseth, H. Ilstad, E. Levold. Transverse Deformation of Pressurised Pipes With Different Axial Loads. 36th International Conference on Ocean, Offshore and Arctic Engineering OMAE 2017, Trondheim, Norway, 25-30 June 2017.
13. K. Marthinsen. A first-principles study on impurity segregation towards grain boundaries and stacking faults in aluminium. 12th International Conference on the Physical Properties and Application of Advanced Materials, Kosice, Slovakia, 6-9 August 2017.
14. D. Morin, O.S. Hopperstad, A. Benallal. Qualitative aspects of ductile failure by strain localization. COMPLAS 2017, XIV Conference on Computational Plasticity. Fundamentals and applications, Barcelona, Spain, 5-7 September 2017.
15. O. Vestrum, M. Kristoffersen, M. Langseth, T. Børvik, M.A. Polanco-Loria, H. Ilstad. Quasi-Static and Dynamic Deformation of Polymer Coated Pipes. 36th International Conference on Ocean, Offshore and Arctic Engineering OMAE 2017, Trondheim, Norway, 25-30 June 2017.
16. D. Zhao, O.M. Løvvik, Knut Marthinsen, Y.Li. Atomistic simulations in Aluminium alloy development. 13th Light Metals International Workshop by Japan Institute of Light Metals, Toyama, Japan, 12-13 October 2017.
17. D. Zhao, O.M. Løvvik, K. Marthinsen, Y.Li. A first-principles study on impurity segregation towards grain boundaries and stacking faults in aluminium. 12th International Conference on the Physical Properties and Application of Advanced Materials, Kosice, Slovakia, 6-9 August 2017.

Keynote and invited lectures

1. Professor Randi Holmestad gave a plenary talk entitled Precipitates in *age hardenable aluminium alloys studied by advanced TEM* at the XVI International conference on Electron Microscopy in Jachranka, Poland on 11 September 2017.
2. Professor Odd Sture Hopperstad gave a keynote lecture on *Modelling and simulation of ductile fracture in metals using strain localization theory* at the DYMAT 23rd Technical Meeting on 12 September 2017 in Trondheim, Norway.
3. Professor Knut Marthinsen gave an invited lecture with the title *Evolution of deformation texture during flat profile aluminium extrusions* at the 18th International Conference on Textures of Materials (ICOTOM-18) in St. George, Utah, USA on 8 November 2017.

Annual accounts

SFI CASA FUNDING 2017 (ALL FIGURES IN 1000 NOK)

Item	Host NTNU	Research partner SINTEF	Public partners	Industrial partners	RCN grant	Total funding
Research programmes	7488	1100	3192	5542	11245	28567
Equipment			298	858		1156
Administration	1000		1710	2900		5610
Total budget	8488	1100	5200	9300	11245	35333

SFI CASA COST 2017 (ALL FIGURES IN 1000 NOK)

Item	Host NTNU	Research partner SINTEF	Public partners	Industrial partners	Total cost
Research programmes	19867	5100	700	2900	28567
Equipment	1156				1156
Administration	5410	200			5610
Total budget	26433	5300	700	2900	35333

CASA

Annual Report 2017

Centre for Advanced Structural Analysis

Stories & Profiles

sfi Centre for Research-based Innovation

SINTEF

NTNU

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 new 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.

COVER

Associate Professor Ida Westermann studies an aluminium sample. It has just reached the point of fracture in a fatigue test.

PHOTOS THIS SECTION

Cover and pp. 4-8, 12-15 and 18: Lena Knutli.
Pp. 11, 16 and 20: Albert H. Collett.

GRAPHIC DESIGN

NTNU Grafisk senter

...and what is this?

This is the popularized part of the annual report. This is a glimpse of what CASA is all about for those of us who don't deal with kinematic hardening or finite element methods on a daily basis. The aim is the same as in the rest of this report: to explain what goes on in CASA and why it is important to society. The articles here come in two categories: stories and profiles.

THE MASTER EDUCATOR

* What qualities make students honour the same professor again and again for being the best educator? Meet Arild Holm Clausen: orderly and structured, engaging, always well prepared. Fills an auditorium at 8 a.m. on a Friday morning.

* Thanks to fresh funds, CASA is now able to step up its work on civil infrastructure security. Vegard Aune's first day as Associate Professor in the field was 1 December 2017. One of the many topics on his agenda is exploring the potential of the shock tube he helped build.

* Associate Professor Ida Westermann is a metallurgist. She knows how to bake aluminium. Her PhD candidate Christian Oen Paulsen knows how to spit gold. He spits it on steel. It improves the contrast and resolution one hundred times so he can study it in more detail.

* A lot of the research at SFI CASA ends up in the SIMLab Toolbox. This Toolbox helps the partners to take advantage of scientific breakthroughs in their own innovative processes. Partner feedback is invaluable to make it ever more useful.

PROFESSORS DON'T WELD

* A generation ago, professors were gods. Still, they were helpless in the lab. They didn't know how to weld, machine or mill. They needed expert help. They still do. Only nowadays, they communicate with the lab staff in a totally different manner.

* Sixty-five per cent of the world's offshore pipelines are designed and installed to DNV GL's technical standards. Developing and updating these standards is a long story. SFI CASA is part of it.

* Ahmed Benallal is our man in France. For 20 years, the SIMLab research group and their colleagues at LMT-Cachan have collaborated closely. For many reasons. Benallal is one of them.

* Then there is a story you shouldn't read. If you have seen previous annual reports from SFI CASA, you know the rules.

* As a reward to those of you who don't read the "Don't Read This" article, this year's annual report also carries a bonus story. It deals with explosions in submerged tunnels. Enjoy!

Contents

The MASTER Educator

What qualities make students honour the same professor again and again for being the best educator? Meet Arild Holm Clausen.

Humanity is a fascinating conglomerate. Hardly a day passes at SFI CASA without Director Magnus Langseth's laughter echoing through the corridors. Professor Holm Clausen is another kind of guy. Probably just as happy, just more low-key.

"EXCEPTIONALLY STRUCTURED"

Bear in mind: low-key is not the same as vague. In Professor Holm Clausen's case, rather the opposite. The students put it like this:

"He goes through the curriculum in an exceptionally orderly and structured manner. He is incredibly engaging, always well prepared. A full auditorium at 8.15 every Friday morning is a good indication that he gets it right.

He is very knowledgeable in his field, yet humble and interested in his students. He possesses a unique ability to meet us at our own level and he takes time to help us with our preparation work although it is not his primary task."

These viewpoints are from two different occasions when he was voted best educator and speak for themselves. What does the professor say? "I always liked teaching." Simple as that.

REGENT

The good chemistry with the students was further illustrated in 2013, when he was appointed regent of the Civil Engineering Students Association "Hennes Majestet Aarhønen" – "Her Majesty the Grey Hen" at its centenary celebration. The name Aarhønen stems from an incident in 1913 when a grey hen crashed through a window and landed in a lecture hall in NTNU's main building. Professor Holm Clausen remains regent, a position with some influence: he chairs the committee that deals with the association's financial reserves, currently amounting to more than NOK 1 000 000. He also has the authority to fire the board if the members do something really stupid.

MILITARY SERVICE

Like several of his colleagues, Arild Holm Clausen came to the SIMLab research group with a little help from the army and SIMLab "Godfather" Arnfinn Jenssen. Magnus Langseth recruited him along with present professor colleague Tore Børvik to take his military service at SIMLab in 1992.

After dealing with marine structures for his master's degree, he joined SIMLab's grand old man Per Kristian Larsen as an assistant in the course on steel structures during his PhD years. "I was unsure about the direction of my career after my doctoral defence in 1999," he confesses. Luckily, for SIMLab and his students, he decided to continue. In 2003, he became associate professor and from 2007, full professor.

VIRGIN TERRITORY

No one becomes a professor for being a good educator alone. High quality research is another prerequisite.

In Norwegian, the term potato is used for someone who enjoys and is good at a great variety of tasks. Arild Holm Clausen thrives as a professorial potato.

"I enjoy knowing something about many different topics. Polymers and steels have diametrically opposite properties. I like working with both materials," he says.

At present, he heads SFI CASA's Polymer Programme, which was virgin territory at SIMLab. It started very carefully in 2005 with initial interest from SFI SIMLab partners Statoil and Plastal. They asked about the modelling of polymers in numerical simulations.

"At that time we knew next to nothing about the material. Magnus Langseth challenged me to look into it," Holm Clausen remembers.

CLOSE COLLABORATION

He started with the supervision of just one PhD candidate in 2007 and a second from 2008. With time, the number of PhD candidates within the field has increased, and so has partner interest. Renault's François Moussy came in early, then Dominic Seibert from Audi and Ernesto Mottola from Toyota. Today, Lars Greve from VW/Audi and Statoil's Mario Polanco-Loria are among the more active partner representatives. Most of the partners follow the programme closely.

As in his teaching, Arild Holm Clausen's structured approach is clearly visible. Since 2011, he has organized annual technical meetings with the partners.

"We work closely with the partners. Many of them are very competent and we have had numerous valuable discussions. They have also been very patient. They know that research takes time," he says.

From the outset, material models were sought after. Luckily, SFI CASA has the modelling expert Odd Sture Hopperstad on board. Lately, there has been increased interest in the joining of dissimilar materials, possibly involving polymers of some kind. Nobody knows what the future holds.

CASA STEPS UP

Civil Infrastructure Security

Thanks to fresh funds from the Ministry of Justice and Public Security and from NTNU, SFI CASA is able to step up its work on civil infrastructure security. Vegard Aune's first day as Associate Professor in the field was 1 December 2017.

The new position is made possible by a grant of NOK eight million from the ministry, spread over a five-year period. After five years, NTNU takes over responsibility for the position. In addition, NTNU has granted fresh funds to employ a PhD candidate who will cooperate closely with Aune.

"LACK OF AWARENESS"

On 2 January 2018, Thor Kleppen Sættem, State Secretary for the Minister of Justice and Public Security, visited CASA to mark the establishment of the new professorship. Sættem met NTNU's Rector, the Dean of the Faculty of Engineering, the Director of CASA and other staff. Preparations for future talks on how to prioritize the research were started. Sættem was also given a guided tour of CASA's research facilities. During the meeting, the State Secretary directed attention towards the lack of awareness concerning civil infrastructure security in Norwegian municipalities. This is particularly the case when it comes to the planning of public buildings and open spaces. Awareness needs to be raised for a number of reasons, including terror, accidents and more extreme weather conditions. Mr Sættem indicated that stricter infrastructure security measures may be included in relevant laws and regulations.

POLITICAL PRIORITY

To develop cooperation with business and research environments in the field of civil infrastructure security is part of the ministry's strategy. A particular priority is to look for potential partnerships with chosen players in education and research. In doing so, the ministry wants to cooperate with relevant governmental agencies. The aim is to build competence.

The ministry considers that the grant will improve CASA's ability in further education and research as an effective measure in this context. It also underlines that the contribution will add value to the support already given by the Norwegian National Security Authority.

CONTENT IS KING

So, how will the money be spent? No-one is closer to answer that than the newly employed associate professor. Still, he is quick to point out that it is very early days. Indeed, his first task will be to discuss the matter with the ministry, his colleagues in CASA and with the partners in the centre.

"Education will certainly be an important part of my job. We need more experts on the behaviour of materials and structures subjected to blast loadings. I will also have an opportunity to continue the research I started in my PhD work and I will build further on the international network we are part of."

MR SHOCK TUBE

Associate Professor Aune is by no means new to CASA. His name will forever be linked to the acquisition of CASA's most important test facility for many years: the shock tube. SIMLab's research group benefactor for decades, R&D Director Arnfinn Jenssen in the Norwegian Defence Estates Agency, had stressed the need for a shock tube for 20 years when the decision was finally taken to dedicate a PhD thesis to the project. Vegard Aune got the job.

At the outset, ambitions were limited. CASA even considered buying a mass-produced steel pipe that would only serve for the work on Aune's thesis. Thanks in part to a substantial contribution from the Norwegian National Security Authority, the result was quite different and cost ten times as much as the original budget: a 20 metre long custom-made pipe with innumerable possibilities for recording and measuring blast loads. Since the inauguration three years ago, it has proven an invaluable tool. Aluminium, steel, glass and concrete plates have been subjected to series of blast loads. This has led to important new knowledge ranging from the effects of an explosion inside a submerged tunnel on the new E39 highway to the unpredictable behaviour of laminated glass. The latter is of particular interest in the preparation for the huge, new government administration building complex in central Oslo.

FURTHER POTENTIAL

This is also one of the research areas where the added funds from the ministry will provide extra momentum. The shock tube contains many possibilities that haven't been explored so far. One of them is to put models of buildings and other structures in the middle of the tube. This makes it possible to study the behaviour of shock waves when they meet the model and capture the effect of the shock waves in confined spaces.

"Why is it necessary to do this research in Norway? Aren't there shock tubes abroad?"

"Yes, there are" says Aune. "The Ernst-Mach-Institut in Germany and others have them up to road tunnel size. However, hands-on experience with the equipment gives invaluable insight. We now have a custom-built shock tube on our own premises, built specifically to meet our needs. This is a great asset for our students and significantly improves our ability to build competence on the effects of blast loadings."

It may be added that CASA's Scientific Advisory Board has pointed out that the centre's unique in-house lab facilities are a major factor in making CASA world leading in its research field.

NO SHIFT

"The automotive industry has a very strong position in CASA with five of the world's leading manufacturers as partners. Would it be correct to say that your new position somewhat shifts the balance within the centre?"

"I don't see it that way. The research we do is generic. A typical illustration is the considerable interest from the automotive industry in our research on laminated glass. This research was initially motivated by the desire to protect people inside buildings."

Enthusiastic encounter between (from right) Associate Professor Vegard Aune, State Secretary Thor Kleppen Sættem and Department Director John Arne Gisnås.

Baking Aluminium, Spitting Gold

Associate Professor Ida Westermann has a bun in the oven.
Don't worry. She knows how to bake. Even aluminium.

More baking in a moment. First a bit of maltreatment. In the picture, Westermann studies an aluminium sample. It has just reached the point of fracture in a fatigue test.

METALLURGIST

Ida Westermann is a metallurgist. Fatigue is part of her ball game. She looks for the connection between processing and deformation. In the process, she is trying to find out what happens to microstructures and properties. She wants to know what comes out at the other end.

For her PhD thesis, she "baked" aluminium bumpers. Strength will increase with time up to a certain level. After that it sinks. The same is valid for temperature. To be able to control the process, it is important to know what happens inside the material. The process is called artificial ageing. In an interview for SFI SIMLab's annual report back in 2011, Westermann described it like this:

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

In her thesis, she tried to find the mathematical relationship between microstructure and strength of aluminium based on experimental investigations.

EARLY START

Westermann fell in love with aluminium at the age of 18. Raised in the Danish village of Bredebro, she was invited to spend two weeks at the nearby plant of aluminium firm Hydro. After two weeks of learning about extruding and plastic forming, she was invited to visit NTNU in Trondheim and the Hydro plants in Sunndalsøra and Raufoss. By then she was hooked: her future was in metal.

After defending her PhD thesis in 2011, she has given birth to two children. At the time of writing, a third bun was in the oven. Along the way, she worked three years for SINTEF, collaborating closely with CASA professors Odd Sture Hopperstad and Tore Børvik on several projects.

In 2014, Westermann returned to NTNU and her present position as Associate Professor with special emphasis on steel. Which brings us to the gold spitting.

HOW TO SPIT GOLD

Confession: Ida Westermann doesn't actually spit gold. Her PhD candidate Christian Oen Paulsen does the spitting. Still, she went along with him earlier this year to the University of Manchester, where he learnt the technique.

The professional term is gold sputtering. It is central in Oen Paulsen's project on micromechanical modelling of steel. Westermann explains:

"Oen Paulsen carries out in situ scanning electron microscopy investigations. He uses digital image correlation in his quest for local deformations. Sputtering a layer of gold on the steel surface improves contrast and resolution one hundred times, so the gold particles enable studies at a much smaller scale than would otherwise be possible. The challenge of the technique is to get the gold layer to form particles. This is unproblematic with stainless steel (and aluminium), where water vapour may be used. In other cases, this process will cause corrosion."

In short: this is another example of how CASA and affiliated researchers look for better methods to improve the analysis of materials and structures. In this case the critical aspect is to understand deformation of steels; the different phases, how properties are influenced towards fracture and how to avoid it.

Westermann's other PhD candidate, Siri Marthe Arbo, studies solid joining techniques between steel and aluminium. This is of particular interest to the automotive industry.

AMBITIOUS

Ida Westermann doesn't hesitate long when asked how others would describe her:

"Ambitious, I guess, and dedicated. A team player. I am also very much a family person," she says.

This seems to include a very good adaption to Norwegian lifestyle. Alongside former co-PhD candidate, now husband Gaute Gruben, a SINTEF researcher working closely with CASA himself, she is well underway building the family's cabin in the mountains. Counting from February 2018, it will be the refuge of three children, two parents and two dogs; a bracco italiano and a dachshund.

2027

In 2011, Ida Westermann hoped to continue her research as part of Trondheim's academic environment. Her hope has been fulfilled.

"Why did you want to be a researcher?"

"Because of the freedom. I can use my creativity. Nobody decides my interests. I also very much enjoy the contact with the students."

"And now? Where do you see yourself in ten years?"

"In the same environment, I hope, as a full professor."

PS

At the time of the interview, Ida Westermann did indeed have a bun in the oven. Not anymore. On 23 January 2018 she gave birth to a girl.

Contributing to the SIMLAB Toolbox

"All kinds of contributions are welcome to make the SIMLab Toolbox better and more useful," Térence Coudert writes in this article. Coudert is co-head of SFI CASA's Methods and Tools Programme.

All kinds of contributions are welcome to make the SIMLab Toolbox better and more useful. This can take any form: user case reports, documentation, issue reports or entirely new software modules (new «tools»). Contributing to the toolbox project can be a rewarding way to learn, teach, and build experience in different skills. Here are some ways that you can get involved and help the SIMLab toolbox team to improve the product.

REPORT AN ISSUE

One of the easiest and most effective ways you can help improve the toolbox is to report issues. The only thing you need to do is to send an email to simlab-toolbox@sintef.no. Write a short summary of the issue in the email subject and describe your problems and/or your ideas in the email body. An issue could be, for example:

- a «bug»: if you have a problem which impairs or prevents the functions of the product;
- a new feature: you are thinking about a new feature of a product;
- an improvement: an enhancement to an existing feature.

Please do not forget to specify the component (a tool in the toolbox) in the description of the issue (for example MatPrePost, SIMLab Metal Model, etc.). Please keep in mind that reporting an issue (or a bug) that you have encountered is nice but it is better when the developer can reproduce this problem. When sending an issue, you could attach some files in addition to the description of the issue. These files will change from software to software but here is a short summary of what can or should be attached at the same time as the issue:

- MatPrePost: upload the MatPrePost project file as well as the experimental data. The developer will have to reproduce your problem and needs the same data as you.
- SIMLab Model Library: the best way to track a bug with the SML is to re-run the same input file. Please indicate which FE solver you have used (e.g. ABAQUS or LS-DYNA), the computation mode (mpp or smp), single or double precision, and the error file you got. If you are not able to provide the input file and/or material card (due to confidentiality), you should provide a similar material card with different parameters. The same holds for the input file. Sometimes bugs in the SML are related to missing options in the input file.

WHAT HAPPENS WHEN AN ISSUE IS REPORTED?

The email is received by the issue tracker hosted at code.sintef.no, then the server notifies the project manager. He or she then contacts the main developer responsible for the related component if the issue is a bug. The new feature requests are discussed by the entire team in a regular meeting. A plan is then defined to solve the issue and more description is added to the issue and, if necessary, new issues are created (e.g. a task for the developer). The developer writes a new «unit test», a small program that can automatically reproduce the issue/bug. Then the developer changes the source code of the software until the unit test succeeds. The new code is committed to the «version control system», it is then registered and available for the other developer. The continuous integration server is notified that the code has changed, builds the component software and runs all unit tests to validate the software features. If a test fails, the developer has broken one feature of the software and needs to solve this new issue. When all tests are passed, the new executable or new libraries can be distributed to the issue reporter and the new patch/feature will be available in the next software release. The SIMLab Toolbox executables are available in the SFI CASA Sharepoint portal https://spfarm.ntnu.no/sites/project/103.

CONTRIBUTE TO THE KNOWLEDGE BASE AND/OR WIKI

The toolbox development is supported by professional development software hosted on code.sintef.no. These tools help the team with workflows, task management, change management, and issue tracking. When users engaged in the project have an issue, they submit a «ticket» via an email to the system and then contribute to a knowledge base. However, an issue tracker is not a user support forum. It is a list of pending technical tasks, along with information relevant for those tasks, and information about progress on those tasks including which ones might be worked on in the short term. So, why not use a collaborative tool where everyone can view and contribute to the information within it to grow a knowledge base on the SFI CASA Methods and Tools.

Confluence (https://www.atlassian.com/software/confluence), already included in the code.sintef.no server, is a great knowledge base solution. It combines professional web publishing features with the ease-of-use and flexibility of a wiki. The users are assigned to categories that best suit their field of expertise, meaning that articles are only written by those who are best informed. Confluence's users can post questions on an article, and experts can answer them. It's a tool for sharing information; the users have the opportunity to expand their knowledge, and the experts have the opportunity to share it.

Key software developers Afaf Saai, left, Térence Coudert and Stéphane Dumoulin continually upgrade the SIMLab Toolbox.

Professors DON'T Weld

When Tore Wisth started at NTNU, professors were gods. The thing is, gods are helpless in the lab. They don't know how to weld or machine or mill. They need expert help.

Expert help comes in many shapes and forms. Here is one: Has the knob on your kettle lid fallen off and can't be found? Do you need some machining done for your stretch test? A novel design for a rig? A smile? Someone you can trust? Freshly made coffee when you come to work? Then Tore Wisth is your man. Just ask. He'll fix it. Just like you wanted. Without delay. In the case of coffee, he has made it already.

BACK TO THE EIGHTIES

Think back to the eighties. February 1980, to be exact. Tore Wisth came to NTNU after five years with a steel construction company. He was a trained welder and sheet metal worker. He was employed as a university technician and met a new world: "It wasn't possible to speak directly to a professor. We had to address the secretary. Then it was "Mister Professor" here and "Mister Professor" there. We were asked to make a machine part, but didn't know what it was for. We just got the drawings. I am sure we made a lot of useless stuff."

GAS GUN

"When did it change?"

"Gradually, of course, but one point was when the lab was reorganized and we got a new administrator. Another important change was when I helped Professor Tore Børvik set up our gas gun. We didn't make the gun ourselves, but we collaborated closely on building the foundation. I felt like a colleague on an equal footing," Wisth says.

The example is illustrative. Professor Børvik explains:

"I think that we all do a better job when we know the purpose and the context. In fact, I had a heated discussion with a foreign colleague around the time Tore Wisth mentions. The foreign colleague saw no need to explain the purpose of each assignment to the lab engineers. I totally disagreed and still do."

Now, this is important, not only to Tore Wisth. It is an attitude that many have pointed to as one of the reasons for the world leading position of the SIMLab research group: everyone is involved in achieving ever better research.

A DAY IN TORE WISTH'S LIFE

"How is your typical day?"

"I start at seven. The first thing I do is to make coffee and go through the mail. Before long, a student will come to see me. There isn't a day passing without at least one of them turning up. They may need a sample or help setting up a test rig. From time to time, we discover that a set-up that looks fine in theory doesn't work out in practice. Then we have to modify it. In most cases, we arrive at a feasible solution without having to ask for external help.

That solved, a professor might call and ask me to come to his or her office to discuss a new challenge.

Apart from that, I organize my own schedule. I make samples, I collect the prices for things we need, and I place orders. We buy quite a lot of what we need in the lab from outside suppliers. I prepare the specifications."

"Do you enjoy your work?"

"Thoroughly. It is a true privilege to be able to make an effort when you want to. Especially when you want to all the time, like I do."

ALWAYS YESTERDAY

"What are professors and students like?"

"Like most other people, I guess. Very nice, mostly. I enjoy working with them. A common trait is that they all want test samples first. I don't think I have ever heard that they don't need things in a hurry. With time, they learn that they cannot all have their samples tomorrow. Sometimes it takes three weeks.

Then, people vary with origin. Some students and candidates tend to be afraid to ask. They are not trained to do so."

"Do you have trouble communicating?"

"No. One thing puzzles me. Many of our foreign researchers speak Norwegian very well. Yet I experience over and over again that their Norwegian colleagues speak English to them. I don't understand that. They need to practice! I speak Norwegian to them and without exception they are happy about it."

A COTTAGE BY THE SEA

All things come to an end. This year Tore Wisth can retire if he wants to. He hasn't quite decided yet. When the time comes, he can head for the family cottage. It is located by the sea in a fjord southwest of Trondheim. Fishing is a favourite pastime. And enjoying the result.

"Fillet of angler fish with cream sauce is a delicacy," he says. Agreed.

JOY, DNV GL Style

Sixty-five per cent of the world's offshore pipelines are designed and installed to DNV GL's technical standards. Developing and updating these standards is a long story. SFI CASA is part of it.

DNV GL joined CASA for many reasons. The SIMLab Toolbox was one of them. The toolbox contains the accumulated results of many years of testing, modelling, simulation and verification, all made available for industry. Among the tools is the material model. It describes the behaviour of materials and structures.

"We deal with complex questions where the exact coupling of materials and structures is essential. One example is our close cooperation with Statoil on offshore pipelines, where SIMLab's material model was extremely valuable. It is a perfect illustration of our CASA membership. To be able to learn more and at the same time meet customer expectations in this way is pure joy," says principal specialist Agnes Marie Horn. She represents DNV GL on CASA's board.

"CASA is an important arena for us. The appointment of Erling Østby from DNV GL as Professor II in CASA means that there is knowledge transfer and interaction with the students," Horn continues.

WORLD LEADER

The Statoil example points to one of DNV GL's key business areas. It is the world's largest technical assurance and advisory company to the renewable industry sector as well as the oil and gas industry. This is illustrated by DNV GL's dominant position in offshore pipeline standards.

"Our technical standards are by no means given once and for all. We are constantly challenged by our customers – and we welcome that. They want to know: "What is really the critical condition?" On the one hand, we generally belong to a world of conservative estimates. On the other, while oil companies and other clients want to ensure robust and safe operation they don't want to pay for superfluous safety. This means that we have to increase our understanding continually. It is not sufficient to know when materials and structures fail. We need to know why. This is where SIMLab's material model and other tools are vital to use," says Horn.

LONG HISTORY

DNV GL's history goes more than 150 years back and started with the classification of merchant vessels. Today, it is the world's largest classification society for ships and offshore mobile units.

The core of the business still is quality assurance and risk management, with a portfolio ranging from electrification to food, from healthcare to software. DNV GL is one of Norway's most international companies, with some 13 000 employees spread in 350 offices in more than 100 countries.

DEDICATED TO RESEARCH

DNV GL is owned by the Norwegian foundation Det Norske Veritas and has a clearly stated dedication towards research. Every year, five per cent of its revenue is set aside for the purpose.

The dedication is visible in in-house research with support from the labs in Oslo, Ohio, Singapore and elsewhere, but also as in-kind and financial contributions to research partners like SFI CASA. DNV GL takes part in half a dozen SFIs under the Centre for Research-based Innovation scheme of the Research Council of Norway and operates its own technology excellence network.

"What characterizes CASA is the openness. We meet partners at the forefront of their respective industries and can learn from them. The automotive industry is a good example. This is unique. It helps us with our own strategy of always being innovative and in the forefront when we work in our own labs. The strong partners in this SFI were one of the convincing arguments for joining CASA in the first place. Another argument, of course, was the excellent track record of the SIMLab research group," Horn says.

CHALLENGES AHEAD

There are challenges ahead. Always. In DNV GL's case, age is one. Example: what happens to polymer coatings in arctic waters after 30 or 40 years of use? This is a typical area where digital solutions are needed and part of the motivation behind the establishment of the DNV GL Digital Solution.

"At present, we have some way to go to obtain a good understanding of material responses after several decades of environmental exposure. Because of this and the extreme conditions in many of the environments where our clients operate, we need to be conservative in our estimates.

"That said, very much is happening in the world of materials. With the help of big data through CASA and all our other research efforts, we keep on moving towards the vision of being able to simulate almost anything," Horn continues.

"DNV GL has digitalization as a key company strategy. However, to move from words to solutions we need concrete building blocks. Considering materials, we see CASA and the SIMLab Toolbox as potentially important pieces of the puzzle we must solve. Collecting knowledge and ways to use information about materials in a structured and versatile way will be an important success factor in reaching our ambition to provide our customers with step-changing digital solutions," says Horn.

FRUITFUL MEETINGS

Agnes Marie Horn has NTNU roots. After graduating at the university, she moved to France, before working for several years for Aker in Oslo and Exxon in the US prior to joining DNV GL 12 years ago.

In her new position as CASA board member, she is back at the NTNU department she graduated from.

"I really enjoy the meetings in CASA. They are always very rewarding," she concludes.


DNV·GL

Our MAN in France

For 20 years, the SIMLab research group at NTNU and their colleagues at LMT-Cachan in Paris have collaborated closely. For many reasons. Ahmed Benallal is one of them.

Basic facts first: Ahmed Benallal heads SFI CASA's Scientific Advisory Board: a group of six world-leading scientists from as many countries. He was also a member of the SAB in CASA's predecessor, SFI SIMLab. He is a key member of the research team in SIMLab's latest achievement: Toppforsk project FractAl. All with good reason.

ANALYTICAL

CASA Director Magnus Langseth puts it like this:
"Ahmed's main research field is complementary to the research we carry out at SIMLab: behaviour and modelling of materials. His analytical work linked to localization is recognized. His expertise and international research position combined with a unique network in France and abroad made it easy for me to engage Ahmed as the chairman of the Scientific Advisory Board."

SOCIABLE AND LIVELY

Professor Odd Sture Hopperstad heads the FractAl Toppforsk Project. His description of his long-time collaborator goes along the same lines:
"Ahmed's research is within constitutive equations for plasticity, viscoplasticity and damage, material instabilities and localization, and ductile fracture. Thus, his research interests are well calibrated with those of the SIMLab team. In addition to being an excellent scientist, he is sociable and lively, and he has an incredible network around the world. Another important quality: he has a genuine interest in wine (mostly Burgundy and Piemonte), like some of the SIMLab researchers."

ALGERIAN CHILDHOOD

Benallal grew up in Ain Sefra in the interior of Algeria. He came to Paris as a young student and quickly found his way to where he is still working.
The mid-70s was an era when the French chose nuclear energy for their main power supply. This created a need for research on materials and energy. The lab at LMT-Cachan was established in 1975. Benallal arrived in 1978 and took his PhD soon after.
In 1995 the supervisor for his PhD, Jean Lemaitre, received a phone call from Magnus Langseth at NTNU. Lemaitre headed the Mechanical Materials Group at the university. The two soon found common ground.

MORE THAN VISITS

Collaboration was established already the same year, much to Ahmed Benallal's satisfaction:
"I like this kind of work – collaboration – not just visits," he says.
Before long, he had Arild Holm Clausen and Odd-Geir Lademo working with him in Paris. Today, Holm Clausen heads SFI CASA's Polymeric Materials Programme, while Lademo heads the Methods and Tools Programme. LMT-Cachan has also received master's students from NTNU.

COMPLEMENTARY

"The fact is, we have found more and more common ground as the years have passed," Benallal states:
"At the same time, we complement each other. For instance, we don't work with impact. Our lab is also very different from SIMLab's."
"How would you describe SIMLab?"
"SIMLab has a very efficient way of doing research and they are really among the best I know. The management and the staff are very good. It is fantastic for PhD students. Now that they have reached cruising speed, SIMLab is indeed a very attractive place to work. They also have enough means to do the job. However, there is a limit to how much they can achieve."
"Small is beautiful, but..."
"Exactly. It explains the efficiency, and this attracts smart people, but they must take care to avoid overload."

"WE DON'T CREATE CARS"

"CASA is a Centre for Research-based Innovation, an SFI. From time to time one can hear voices saying that industry doesn't receive research results that are prepared enough to enable innovation. Do you understand these voices?"
"No. The SFI scheme is perfect for industry and SIMLab is doing the job. It is industry that does not take their part of the responsibility. We hear this story in France, too, and have done so for a long time. The message from politicians and others is that research results are not calibrated. Really, this is up to industry. This is their challenge. We are researchers. We are not going to create cars for them."

Don't READ this

Did you read any of the «Don't Read This» articles in the previous annual reports? Then you know that they weren't about CASA. Nor is this year's version. So stay away, OK?

Not OK? Still reading? Then what follows is at your own risk. For instance, you risk learning that aluminium could replace steel in electricity pylons. Test pylon Alma was duly christened, champagne bottle and all, by Statnett's R&D Director Sonja Berlijn on 24 October. Alma had half the weight of her steel competitors. She was made from fifteen different profiles. Eight of them were brand new. NTNU helped find the best.

POTENTIAL NEW INDUSTRY

Alma is not the first aluminium pylon produced in Norway. Hydro erected a series of them close to their production plant in Årdal 45 years ago, but stopped at that.

This time AluMast project owner Statnett is serious. Håkon Borgen, Executive Vice President for Technology and Development, puts it like this: "If we can get aluminium pylons at the same cost as steel, we will go for it. We will halve helicopter transport and reduce the need for assembly onsite. This will greatly improve working conditions."

Statnett's vision is to develop a pylon that can be erected without the need for workers climbing above ground level. As owners of 33 000 pylons, Statnett represents a significant potential for a new industry. A pylon has a service life of 70 years or more. Still, hundreds need to be replaced every year. New power lines mean that more pylons are needed. Many of them require helicopter transport.

WHEN DOES SHE BUCKLE?

Researcher Marius Andersen has been NTNU's man on the project. After defending his PhD at SFI SIMLab, he was engaged by the AluMast project to work with the behaviour and modelling of aluminium columns. He has paid special attention to the structural response of thin-walled aluminium tubes subjected to axial loading. The aim: to avoid buckling and collapse. In his work, Andersen has taken advantage of the numerical simulation methods and experimental techniques available at SIMLab.

His work was one of the factors that helped choose the fifteen best profiles to give Alma her optimal properties. As sometimes happens, a successful research result is the scrapping of the solution you have investigated. In Marius Andersen's case, his careful work on tubes showed that they were not the best choice for large parts of the structure. One important reason was the need for bolted joints. He found that half-moon shaped tubes were preferable.

PERFECT PASTA

All the profiles were produced at Hydal in Raufoss, Norway's largest pasta factory. Aluminium pasta, that is. The professional term for the production process when aluminium bars are heated to optimal temperature and formed into any imaginable form, is extrusion. The profiles were made from the alloy 6082; this is the same alloy as the pylons produced 45 years ago.

Eight of Alma's profiles had never been produced before. That says a great deal about the amount of research and development that has been required for the project. It also illustrates the pasta qualities of aluminium: only imagination limits the shapes and forms. In this context, the aim was for Alma to withstand any thinkable combination of stretching, compression, torsion, bending, vibration and temperature, while still keeping her sleek figure.

DIED YOUNG

Alma died young. However, she experienced a lot on a way. First, the profiles underwent wind tests. After the christening, vibrations tests were waiting at Kapp Aluminium. After that, Alma was dismantled and sent to Seville in Spain for further tests. In the final one, she was brought to collapse.

The aim was to find out how much Alma could take. She should be able to tackle all the conditions she would experience in real life. At the same time, she mustn't be too strong. If she was, it meant she could be made even lighter.

IPN

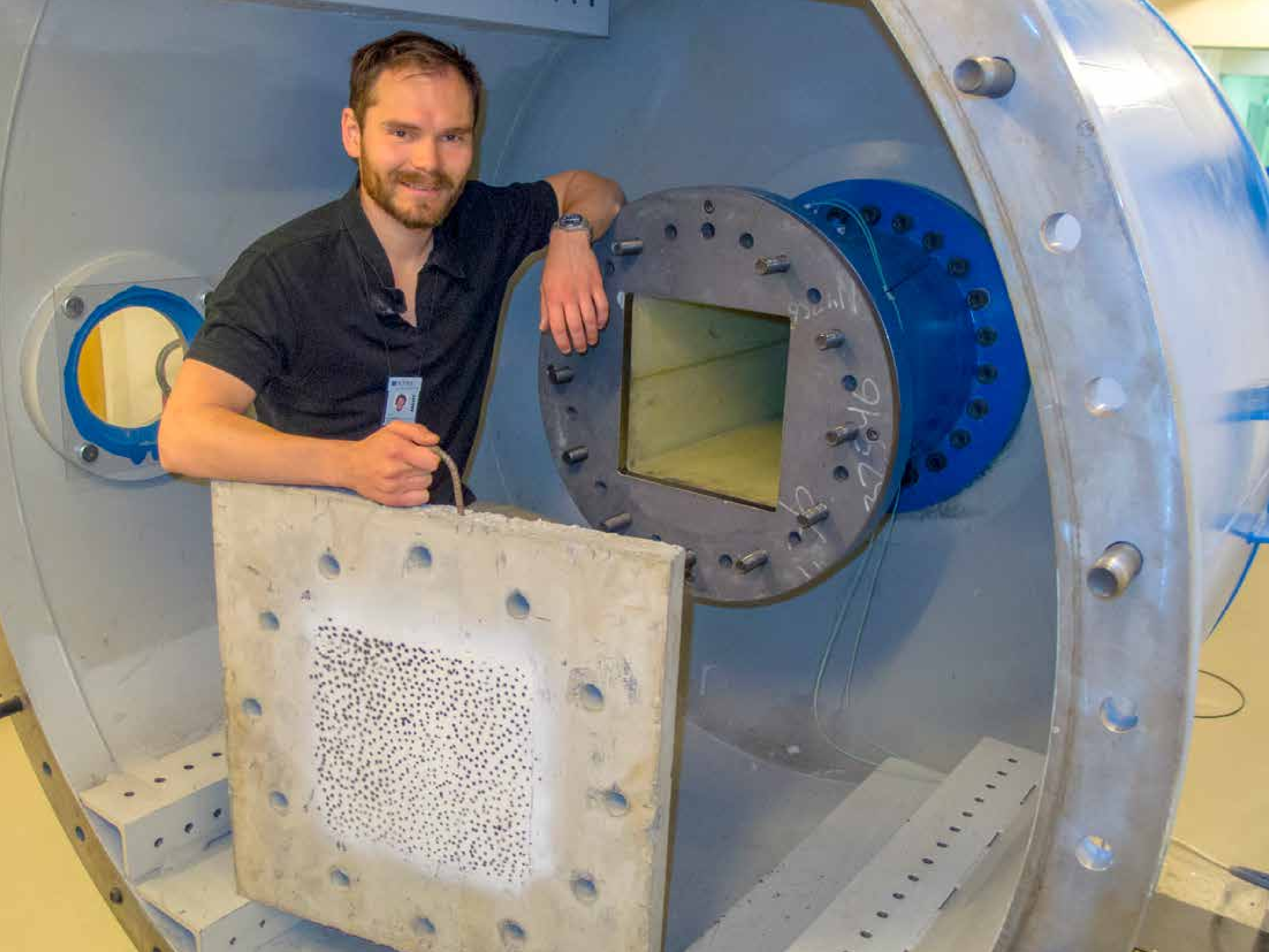
The AluMast project, that produced Alma, is an IPN project. IPN is a funding scheme administered by the Research Council of Norway, directed towards innovation building projects for industry. The aim is to help industry through research.

AluMast comprises the whole chain typical for an IPN project, starting with the basic research performed by Marius Andersen and others. SFI CASA partners SINTEF and Hydro are also AluMast partners. SINTEF's Raufoss Manufacturing branch has played an important role in pushing the project forward, while Hydro has supplied the aluminium and its expertise.

Statnett is the customer at the other end of the chain. Their wish has been to obtain an aluminium pylon that is suited for the highest voltage levels and the Nordic climate and topography.

At the christening ceremony, all partners stressed how useful it has been for the project that all parts of the chain have collaborated. It has been financed by in-kind contributions from the partners. In addition, the Research Council has granted ten million NOK. Statnett and Innovation Norway have invested two million NOK each.

If everything goes well, the first aluminium pylons will be installed in northern Norway in a few years.



Submerged tunnel will withstand EXPLOSIONS

A submerged, floating tunnel in the Sognefjord on Norway's west coast will withstand powerful explosions. Tests in SIMLab's shock tube at NTNU found that concrete was tougher than assumed.

"We carried out the first tests with five centimetre thick, unreinforced concrete plates. We subjected them to a seven bar shock wave. We chose this pressure because it was stated in the guidelines of the Norwegian Public Roads Administration. To our surprise, very little happened," says Martin Kristoffersen.

He is one of the many researchers who work on establishing the basis for the decision about building a ferry-free coastal highway, the new E39, along the west coast of Norway from Kristiansand to Trondheim. According to Kristoffersen, there is increasing probability that we will soon see the world's first submerged, tubular bridge.

VERY GOOD MARGIN

The NTNU researcher has one year left of the three-year project he is engaged in. The task is to find out what happens when a submerged, tubular bridge is subjected to an internal explosion.

The preliminary findings will soon be presented in a peer-reviewed journal. They are based on a large number of tests with varying shock waves in the shock tube. The conclusion so far is that a submerged, tubular bridge will withstand the most plausible explosion scenarios by a good margin, including tanker truck incidents like the recent one in the Oslofjord tunnel.

It should be noted that there is a considerable difference between the five centimetre thick plate in the first test and the final dimensions. The tunnel wall under consideration will be between 80 and 100 centimetres, which is 15 to 20 times as thick, and it will be reinforced. Even the bomb Anders Behring Breivik detonated in a van next to the main government administration building in Oslo in 2011 which had an explosive force equivalent to 700 kilos of TNT would have been insufficient to rupture the tunnel wall.

REPEATABLE LOADS

Since NTNU's NOK six million shock tube was in place in 2014, steel, aluminium and glass have been subjected to strong shock waves. Now the same has been done with concrete.

"Why?"

"It has been a win-win situation. On the one hand, we have been able to test the shock tube on new materials. On the other, the tube is unique when it comes to performing repeatable loads under controlled circumstances. This has proven very useful as we want to learn how concrete tackles strain," Kristoffersen says.

The shock tube is a solid construction. In the pressure chamber at one end, it is possible to build a pressure of 170 bar. That equals the pressure at 1.7 kilometres below sea level. In practice, most tests are carried out at much lower pressure. Kristoffersen actually holds the record so far, with 80 bar. When the shock wave hit the test plate in the other end of the 20-metre long tube, the pressure was 30 bar. That was more than the five centimetre thick concrete plate could take.

WORLD-LEADING

It is far from coincidental that the tests are carried out in the lab linked to the SIMLab research group at NTNU. SIMLab is a world leader in research into the behaviour of materials and structures subjected to sudden strain.

Nor is it coincidental that in 2015, SIMLab was granted its second SFI – Centre for Research-based Innovation – with substantial financial support from the Research Council of Norway. The new SFI carries the name CASA, Centre for Advanced Structural Analysis. The 16 partners include five of the world's leading car manufacturers, the Norwegian Defence Estates Agency, the Norwegian National Security Agency and the Norwegian Public Roads Administration (NPRA).

"To be able to do the job in this environment is crucially important because of the access to the lab, but above all because the research group has relevant experience. It is important to know what tests to perform and what results to look for," Martin Kristoffersen underlines.

GROUNDBREAKING

Kristoffersen defended his PhD at SIMLab. He still works there; now as a postdoc financed by the large E39 highway project of the NPRA.

When a submerged tubular bridge is being considered in the Sognefjord, it is because the fjord is 3.7 kilometres wide at the crossing point: this is nearly twice the length of the world's longest suspension bridge. A tunnel under the fjord is unfeasible: it is 1300 metres deep. Thus the need for groundbreaking research: submerged, tubular bridges of this kind simply do not exist today.

The solution is also being considered for two other fjord crossings on the new E39: in the Sulafjord, as part of the Hafast connection, and in the Digernes strait, in combination with the underwater tunnel in the Bømlafjord.

CONCRETE TUBES NEXT

In addition to the tests in the shock wave, Kristoffersen has shot at the concrete plates with a rifle in SIMLab's lab. These tests are relevant because an explosion is more than a shock wave: it also involves physical objects being hurled out at great speed.

As mentioned, both the NPRA and the Norwegian Defence Estates Agency (NDEA) are partners in SFI CASA. This greatly simplifies the execution of Kristoffersen's remaining tests:

"NDEA provides testing grounds, staff and explosives so we can carry out the next phase. What we will do now is subject concrete tubes of varying dimensions to blast loads."

MORE LIKELY

"You have worked with this for two years now. Has a submerged, tubular bridge become more or less likely during this time?"

"I think it has become more likely. When we started, this solution was under consideration for five fjord crossings. Now we may be down to three. At the same time, it is more likely at these three locations than it was at the outset, partly because we know better what will result in a safe solution. However, I think that other factors will decide whether a submerged, tubular bridge will be chosen or not. Such a process involves a great variety of considerations.