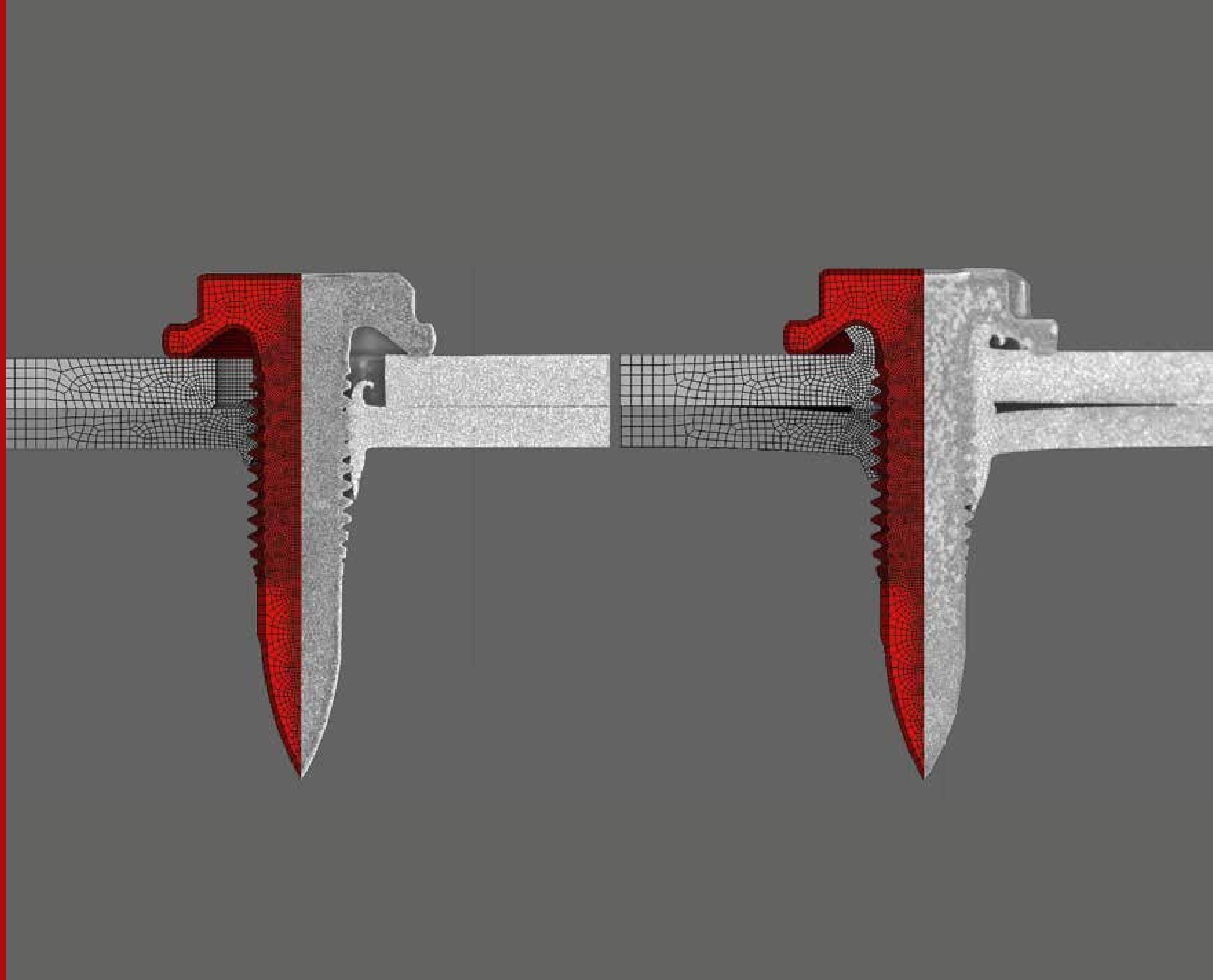
CASA

Annual Report 2020

Centre for Advanced Structural Analysis



sfi Centre for Research-based Innovation

SINTEF

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Multiconsult

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HONDA

BENTELER Automotive

NORWEGIAN NATIONAL SECURITY AUTHORITY

FORSVARSBYGG

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Audi

Hydro

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COVER:
Made by Researcher Miguel Costas for an activity on testing of flow drill screw connections with and without clearance holes. The activity ran in collaboration with Toyota Motor Europe.

GRAPHIC DESIGN:
NTNU Grafisk senter

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p. 2, 14-15: Shutterstock
p. 20-21: Aluminium profiles, Hydro
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p. 47: Sølvi W. Normannsen

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SUMMARY AND FUTURE PROSPECTS

Preparing for the Post-CASA Period

CASA is well underway and is in the second half of the Centre's allocated duration. We have been preparing for a life outside the SFI scheme for a long time.

«I want to preserve what we have built up. I want the group to continue to do cutting-edge research and interact with industry». These were my words in early January 2020. CASA was half-way in its SFI period, and we did a time-to-sum-up-and-to-adapt-for-the-future interview on our newspage sfi-casa.no.

Some relevant questions were asked: «What happens when the SFI chapter closes?», «How do we secure the continuation?» «How do we prevent the loss of knowhow and crumbling of expertise when the financing period is over in 2023?», «What should the Centre do to keep its world-leading position?».

At this moment, these questions still swirl the air. However, I can assure you that we have not rested on our laurels, we are preparing for the post-SFI CASA period.

We have continued to follow up on our initiative towards the Norwegian Ministry of Justice and Public Security throughout the year. In May 2019 we applied to establish a research programme organized as a national centre at the Department of Structural Engineering at NTNU. The research is on societal security and primary focus is on object security.

Professor Tore Børvik is in charge of the SIMLab-group´s application to the Norwegian Centres of Excellence scheme (SFF). The scheme´s primary objective is to conduct targeted, focused, long-term research of high international calibre. Our project is «Centre for Extreme Mechanics» - CEMech. The ground-breaking aspect? To establish a fully integrated physical and numerical laboratory for advanced experimental, theoretical and numerical studies of extreme mechanics. CEMech will introduce multi-scale simulations in the design of protective structures. It will pave the way for an entirely new way of designing materials for engineering structures subjected to extreme loading conditions.
The final decision on which grant applications will be invited to advance to Phase 2 of the application process will be announced in June 2021. It is a pinhole. With 161 applicants - a record high. 11 new SFF centres will be announced in summer 2022.

We have also started to work on the possibility of a future new SFI application, where we bring our knowledge and research fields into new research areas.

CASA is lucky to have a very active Industrial Reference Group (IRG) that secures continuous and close cooperation between scientists and partners. Chairman of the IRG is Mr Arjan Strating. He is R&D Engineer in Audi Neckarlsum and helps us keep the strong interaction with the partners. In an interview on sfi-casa.no, he found it quite an achievement for a research group to deliver knowledge, methods and tools that non-scientists can use in their daily work.

Now, with less than three years to go, it is time to focus on harvesting. In close cooperation with Mr Strating, we have mapped the ongoing activities. The scheme displays the various stages and the route of each project from basic research to implementation and ready-to-use technology. It has become a useful tool, that enables our partners to follow the various projects, and see which stage they are in at any given time.
From a research perspective, I think we can safely conclude that CASA is a success. The number of articles with outstanding research results, published in reputable international journals, confirms this. This is a much-needed sign of quality for our international partners. Simultaneously, ready-to-use technology is the deliverable that will define the success story for industry.

«Return of investment, so to say», as Mr Strating puts it.

Every day, we strive to make the partner´s investments pay.
More and more of CASA´s models are being used in commercial software, such as the leading simulation tools LS-DYNA, PAM-CRASH and ABAQUS. We are proud to see that several of our partners implement our glass and Through Thickness Regularisation models. The Virtual Laboratory for aluminium offers simulations that replace costly, time-consuming and environmentally harmful physical tests of automotive and other structures. Now, we take it one step further, by including steel.

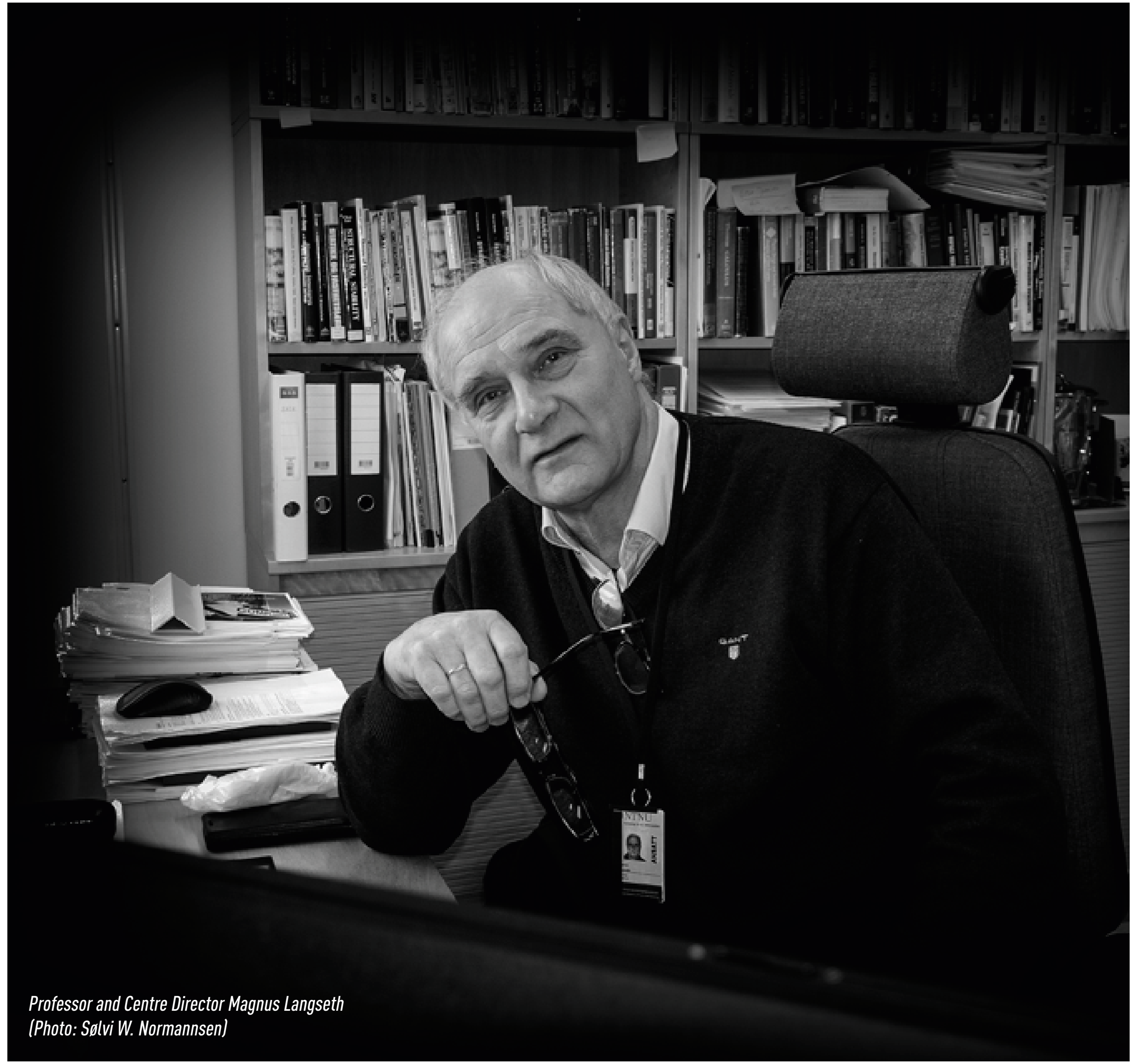
During the pandemic, we have organized several open online seminars and technical meetings. All our doctoral dissertations in 2020 have been streamed. The irony of the close-down is that we have become more open and available to more people at the partners than ever before. Their feedback is excellent.

By the end of the year, we had a virtual Site Visit from the Research Council of Norway (RCN). The summary states that SFI CASA is well on track and works purposefully and structured. Further, it says that the Centre is unique internationally, and has interdisciplinary research cooperation. RCN notes that collaboration with the partners seems to be excellent and trusting.
We get credit for the IRG which works well, and for the development of tools for monitoring results. The concluding remarks say that «SFI CASA has taken advice from the mid-term evaluation consciously and wisely. The challenges of the pandemic have been handled well, and no significant delays or postponements are expected. The Centre is well on its way to looking at alternative routes after 2023».

Thanks to an external grant from our long-time partner Hydro, we will now employ a new associate professor at the Department of Structural Engineering. Thus, we strengthen education and research within the field of aluminium structures. Particular emphasis is on structural design as well as impact and crashworthiness.

This is good news that also points forward and confirms that we are on the offensive to meet the post-CASA period.

Magnus Langseth
Centre Director



Professor and Centre Director Magnus Langseth (Photo: Sølvi W. Normannsen)

ABOUT CASA AND 2020 IN BRIEF

History
The activities in SFI CASA are based on the research platform generated in the SFI SIMLab centre from 2007-2014. They preserve and develop further the knowledge and infrastructure generated by an investment of NOK 225 million to facilitate innovation and value creation in important business areas for Norwegian society. CASA is much broader in scope than the previous centre as it 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 Industry is the research partner. In addition to NTNU and SINTEF, the consortium includes 14 industrial partners. SFI CASA's board comprises one representative from each partner. A director heads the daily operation, assisted by a core team and programme heads. CASA's Industrial Reference Group monitors and facilitates industrial implementation of the results generated in the Centre. Our Scientific Advisory Board of 8 international experts provide scientific and strategic advice.

Research plan
The Centre's research is organized in five basic research programmes: Lower Scale, Metallic Materials, Polymeric Materials, Structural Joints, and Structures. The programmes Methods and Tools and Industrial Implementation focus on the transfer of knowledge and technology from the research programmes to the industrial partners.

Meetings, seminars, and conferences
The Centre organized several online technical meetings and seminars linked to the different research programmes throughout 2020. 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 generated on the basis of discussions at the technical meetings. The Industrial Reference Group had Teams meetings in May and November. The Board have had 2 meetings on Teams, on 27 May and 2 November.

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. The Centre cooperates with several research institutions and companies worldwide. In addition, the Centre has five international partners (Audi, BMW, Honda, Renault, and Toyota).

Visibility
SFI CASA has a media strategy for popular scientific presentations of its research. CASA also aims to contribute to a knowledge-based, open public debate. When it comes to visibility and publicity on different media platforms, 2020 has been a good year. It is also our aim to make female researchers and profiles particularly visible to recruit women and contribute to a more even gender balance in this research field. We continued this work in 2020. We are happy to report that 2 new female scientists, Professor Patricia Verleysen from Ghent University in Belgium and Professor Stefanie Reese, RWTH Aachen University in Germany, are appointed new members of SFI CASA´s Scientific Advisory Board. Visibility in the research community is also important. The CASA researchers published 26 journal articles and they gave 5 conference presentations. In addition, the research group published 5 journal articles and gave 1 conference presentations related to concurrent projects.

PhD defences
6 PhD candidates defended their theses in 2020:
Ole Vestrum, Sondre Bergo, Henrik Granum (concurrent project FractAl), John Fredrick Berntsen, Sindre Nordmark Olufsen and Jonas Frafjord.

Vision

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

Thus, CASA´s main objective 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.

Just before Covid-19 led to the lock-down of campus at NTNU, MSc student Erla Gudding completed some quasi-static bending tests on steel beams. Here with senior engineer Bjørn Strickert Schjølberg. (Photo: Sølvi W. Normannsen)

GOALS AND RESEARCH QUESTIONS

Industrial goals:

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

Academic goals:

- To graduate at least 20 PhD candidates and employ 5-10 post docs at the Centre.
- To graduate 100-200 MSc students.
- To attract 5-10 non-Norwegian professors/scientists to the Centre.
- To publish 100-150 papers in international peer-reviewed journals in addition to conference papers.
- To arrange two international conferences.

Media goals:

- To make the Centre and the activities as visible as possible.
- To participate in the public debate by writing articles and debate posts.
- To be active in facilitating popular science presentations for different media on various platforms.
- To make female researchers particularly visible, in order to help improve the gender balance in our field of research.

Research questions:

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 materials, 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 under quasi-static and impact loading conditions.

RESEARCH PROGRAMMES

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. Head of the programme is Professor Randi Holmestad.

Metallic Materials:

This programme 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 steel. In many critical structural applications, material properties beyond standard testing conditions are required; hence, there will be given special attention to high and low temperatures, high pressures (from blast waves or water depths) and elevated rates of strain (including shock loading). Head of the programme is Professor Odd Sture Hopperstad

Polymeric Materials:

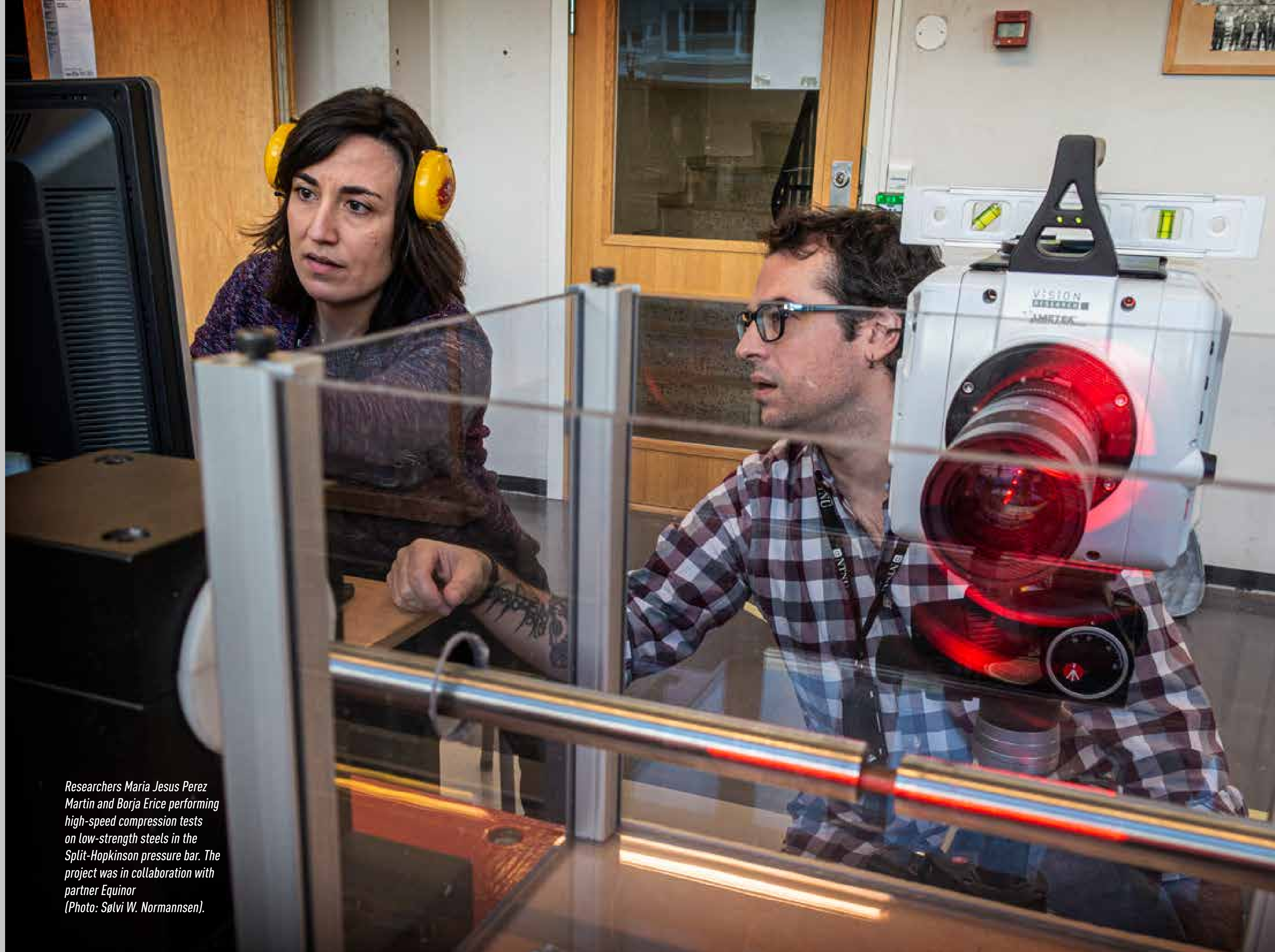
This research programme will develop and improve material models representing the thermo-mechanical response up to fracture for polymers, i.e., thermoplastics with or without fibre-reinforcement and elastomers. The models will be developed for application in an industrial context. Particular attention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

Structural Joints:

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

Structures:

This research programme will develop advanced computational tools and establish validated modelling guidelines for computer-aided design of safer and more cost-effective structures. Another objective is 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 move away from traditional fortification installations and focus on innovative lightweight and hybrid structures to meet the future needs of the user partners. Materials of interest are those typically used in protective structures, such as steel, aluminium, polymers, glass, foams, ceramics and concrete. Head of the programme is Professor Tore Børvik.



Researchers Maria Jesus Perez Martin and Borja Erice performing high-speed compression tests on low-strength steels in the Split-Hopkinson pressure bar. The project was in collaboration with partner Equinor (Photo: Sølvi W. Normannsen).

RESEARCH METHODOLOGY

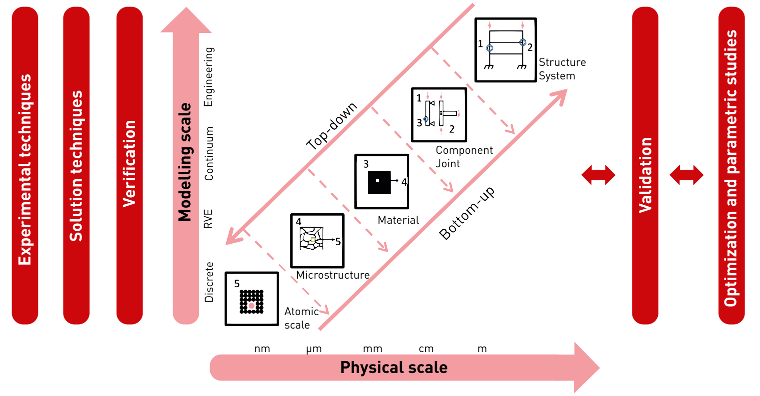


Figure 1: Research methodology.

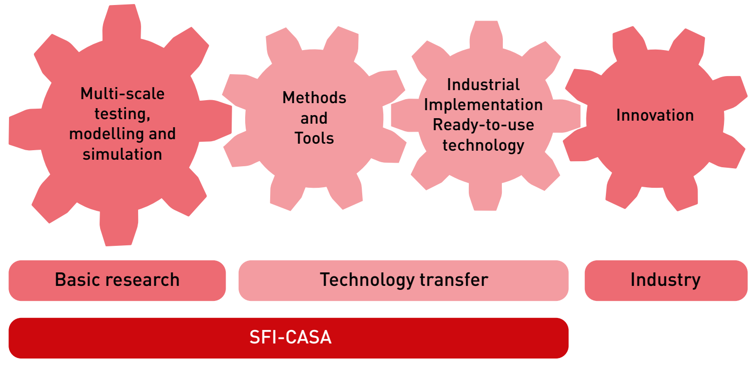


Figure 2: Structure of research, technology transfer and industrial implementation.

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 is 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.

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

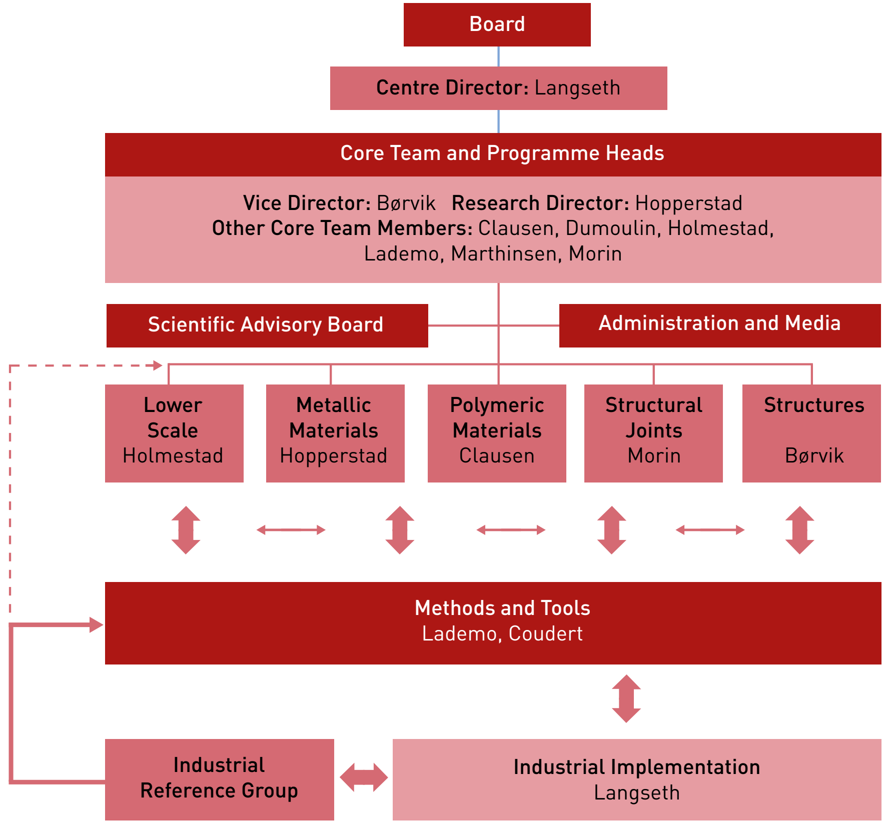


Figure 3: Structure of the organization in 2020.

RESEARCH ORGANIZATION

CASA CORE TEAM

Magnus Langseth

Arild Holm Clausen

Tore Børvik

Randi Holmestad

Odd Sture Hopperstad

Knut Marthinsen

David Morin

Stéphane Dumoulin

Odd-Geir Lademo

Scientific Advisory BOARD


Ahmed Benallal


John Hutchinson


Patricia Verleysen


Jonas Faleskog


David Embury


Stefanie Reese


Norman Fleck


Stefan Hiermaier

The Board

Anders Artelius, Benteler Automotive Raufoss AS
Olav Bolland, NTNU (Chair)
Jørn Brunsell, Norwegian Defence Estates Agency
Ole Daaland, Hydro Aluminium AS
Sebastian Kreissl, BMW Group
Bjørn Tore Hellesøy, Norwegian National Security Authority
Agnes Marie Horn, DNV GL AS
Rolf Jullum, Ministry of Local Government and Modernisation
Andreas Koukal, Audi AG
Nicolas Neumann, Multiconsult Norge AS
Hiroaki Imai, Toyota Motor Europe
Eric DeHoff, Honda R&D Americas, LLC.
Håvar Ilstad, Equinor Energy AS
Rudie Spooren, SINTEF Industry
Pablo Wilson, Renault
Hanne Hermanrud, Norwegian Public Roads Administration

Scientific Advisory Board

Professor Ahmed Benallal, LMT/ENS Paris-Saclay, France
Professor Em. David Embury, McMaster University, Canada
Professor Jonas Faleskog, Royal Institute of Technology, Sweden
Professor Norman Fleck, University of Cambridge, UK
Professor Stefan Hiermaier, Ernst Mach Institute, Germany
Professor John Hutchinson, Harvard University, USA
Professor Stefanie Reese, Aachen University, Germany
Professor Patricia Verleysen, Ghent University, Belgium

Centre Director

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

Core team and programme heads

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

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

Scientific staff

Vegard Aune, Associate Professor, Dept. Of Structural Engineering, NTNU
Torodd Berstad, Researcher, Dept. of Structural Engineering, NTNU
Miguel Costas, Researcher, Dept. of Structural Engineering, NTNU
Virgile Delhaye, Senior Research Scientist, SINTEF Industry
Cato Dørum, Norwegian Public Roads Administration*
Borja Erice, Researcher, Dept. of Structural Engineering, NTNU
Egil Fagerholt, Researcher, Dept. of Structural Engineering, NTNU*
Petter Holmstrøm, Researcher, Dept. of Structural Engineering, NTNU
Martin Kristoffersen, Researcher, Dept. of Structural Engineering, NTNU
Calin Marioara, Senior Research Scientist, SINTEF Industry
Ole Runar Myhr, Hydro Aluminium AS*
Aase Gavina Reyes, Professor, Oslo Metropolitan University *
Inga Gudem Ringdalen, Research Scientist, SINTEF Industry
Afaf Saai, Research Scientist, SINTEF Industry
Ida Westermann, Ass. Professor, Dept. of Materials Science and Engineering, NTNU
Erling Østby, DNV GL*

*20% position at NTNU

Other Key Personnel

Trond Auestad, Senior Engineer, Dept. of Structural Engineering, NTNU
Peter Karlsaune, Project Coordinator, Dept. of Structural Engineering, NTNU
Sølvi W. Normannsen, Communication Officer, Dept. of Structural Engineering, NTNU
Linda Katalin Veres, Accountant, Dept. of Structural Engineering, NTNU
Tore Wisth, Senior Engineer, Dept. of Structural Engineering, NTNU

Partners in 2020

Host institution

NTNU

Research partner

SINTEF Industry

Industrial partners

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

COOPERATION WITHIN THE CENTRE

The research done in CASA is based on annual work plans based on the project description in the SFI CASA application, previous work, and discussions with the industrial partners. In-depth discussions took place in online technical meetings in the research programmes throughout 2020. The aim was to ensure that the technical content was according to the defined plans and to prepare the work plans for the coming years.

SFI CASA's Industrial Reference Group (IRG) was established in 2016. In 2020, the IRG met online on 6 May and 25 November. Each industrial partner has one member in the IRG. IRG's mandate is to give advice on how implementation should be facilitated and to evaluate the implementation work at each partner.

The research in the Centre is mainly carried out by NTNU (PhD candidates, post docs, scientists and professors) and SINTEF (scientists) personnel. The main contribution from the partners is to guide the direction of the research to be carried out and to be active in the implementation of the technology. SINTEF, DNV GL, Norwegian Public Roads Administration and Hydro Aluminium AS are sponsoring one Adjunct Professor position each at the Department of Structural Engineering, NTNU. This ensures a link between the industry and the PhD and MSc students at SFI CASA.

Furthermore, the Core Team has weekly meetings, led by the Centre Director. A number of technical meetings and lectures have been given online through 2020 (see next page).

The Centre Board met online on 27 May and 2 November.

A Boost with Zoom: The Virtual Meetings Reached More People

CASA's researchers reached out to many more people when our technical meetings and seminars became just a click away.

Whether we love them or hate them, Zoom, Teams and Skype have come to stay. In 2020, virtual meetings became the new normal. And as time passed, more and more of us saw that the downsides were far outweighed by their benefits.

NEW AND BETTER WAYS OF COMMUNICATING

«Covid-19 led to a ban on travelling and thus prevented us from in-person meetings, but in fact, we now reach out towards many more people at our individual partners. The online solutions made us more flexible and opened up new and better ways of communicating with our partners», says SFI CASA's director Magnus Langseth.

The Centre organized a series of online dialogue meetings with partners and open seminars on ongoing work. There were technical meetings on glass, polymers, structural joints and protective structures. Other topics at these events were modelling and simulation of aluminium castings, as well as modelling of steel and aluminium. We had a series of 5 CASA seminars, where our PhD candidates presented their topics. And of course, we had all of our six doctoral defences streamed online.

THREE TO FOUR TIMES MORE PARTICIPANTS

These events gathered three to four times more participants than the physical sessions would have.

«It is brilliant that so many join the sessions. Our research becomes more available», says Professor Arild Holm Clausen.

He has the impression that participants tend to be a little more disciplined when attending online meetings. The transition to virtual meetings means fewer questions and less discussion after the presentations.

«So, there are definitely some downsides. But as none of us were allowed to travel anywhere, the online meetings worked perfectly OK», Clausen says.

MORE THAN A T-SHIRT

In September, researcher Miguel Costas presented the lecture with the somewhat cryptic title «*MAT_258: more than a T-shirt?». He took the lead role in front of the camera with Associate Professor David Morin as an assistant. They both wore white T-shirts printed «*MAT_258». The explanation is that material models in LS-DYNA are named *MAT_number. Costas & company got number 258, and there was definitely more to this presentation than the cool T-shirts.

The topic was the TTR model and specific challenges related to the simulation of ductile failure in metals. Miguel Costas has mixed feelings about online meetings. He sees the advantages for those who listen comfortably from their offices. Also, it is the apparent fact that the Centre can reach out to people who would not be able to participate in person.

«In this way, the partners get first-hand information about the development and what we strive for daily and can provide direct immediate feedback».

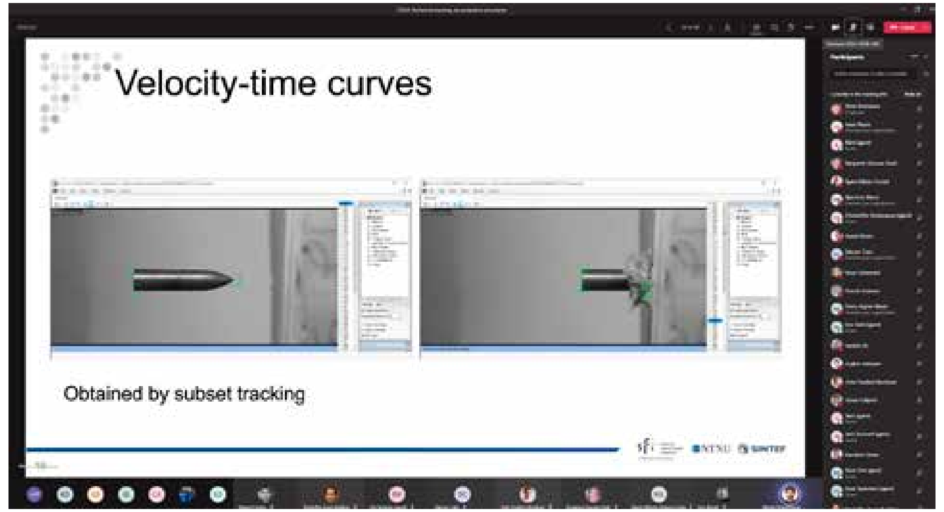
REAL AND TANGIBLE DISADVANTAGES

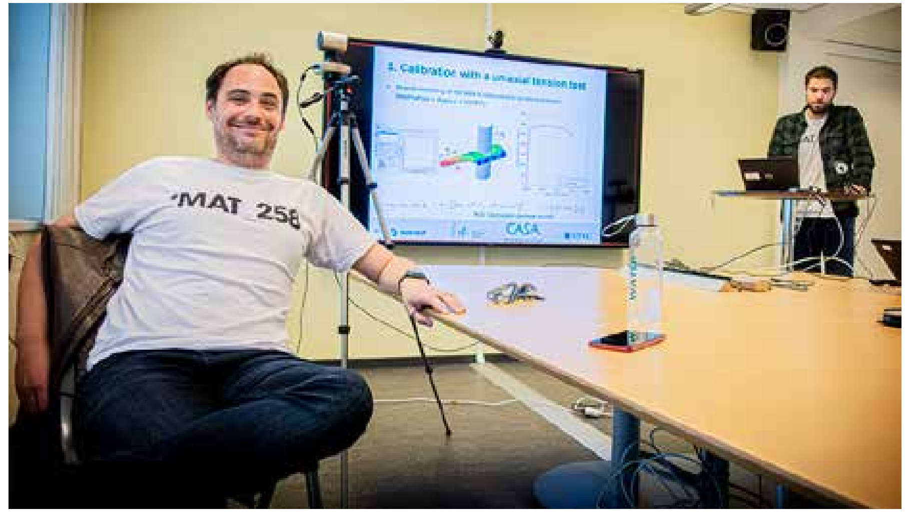
However, he thinks there are real and tangible disadvantages.

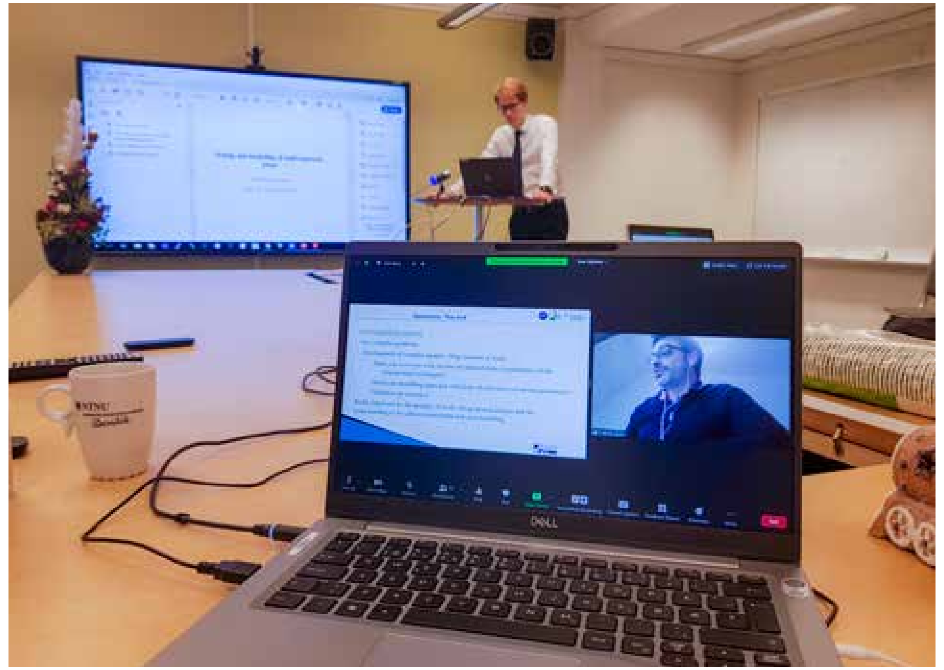
«I don't like talking to a camera in a semi-empty room, and not being able to move from a static position. Honestly, I don't think anyone does», the researcher says.

And the T-shirt thing? It was Miguel Costas thinking it would be nice having the outfits as an internal joke. So, he made some for the close collaborators and authors of the paper «A through-thickness damage regularisation scheme for shell elements subjected to severe bending and membrane deformations».

«People definitely ask about them at the conferences and recognize us when they see us again. I guess that is good», he says.







Upper left:
Screenshot from Researcher Martin Kristoffersens´s presentation at a technical meeting 27 August. Topic: Ballistic perforation of concrete slabs impacted by ogive-nose steel projectiles.

Right:
*Associate Professor David Morin (sitting) and Researcher Miguel Costas during the *MAT_258 presentation.*
(Photo: Sølvi W. Normannsen)

Below left:
John Fredrick Berntsen´s digital doctoral dissertation on 3 December.
(Photo: Arild Holm Clausen)

Right:
Technical meeting 27 August. Professors Magnus Langseth and Tore Børvik during PhD candidate Kristoffer A. Brekkens presentation on protective structures.
(Photo: Sølvi W. Normannsen)

INTERNATIONAL COOPERATION AND LEADING-EDGE RESEARCH

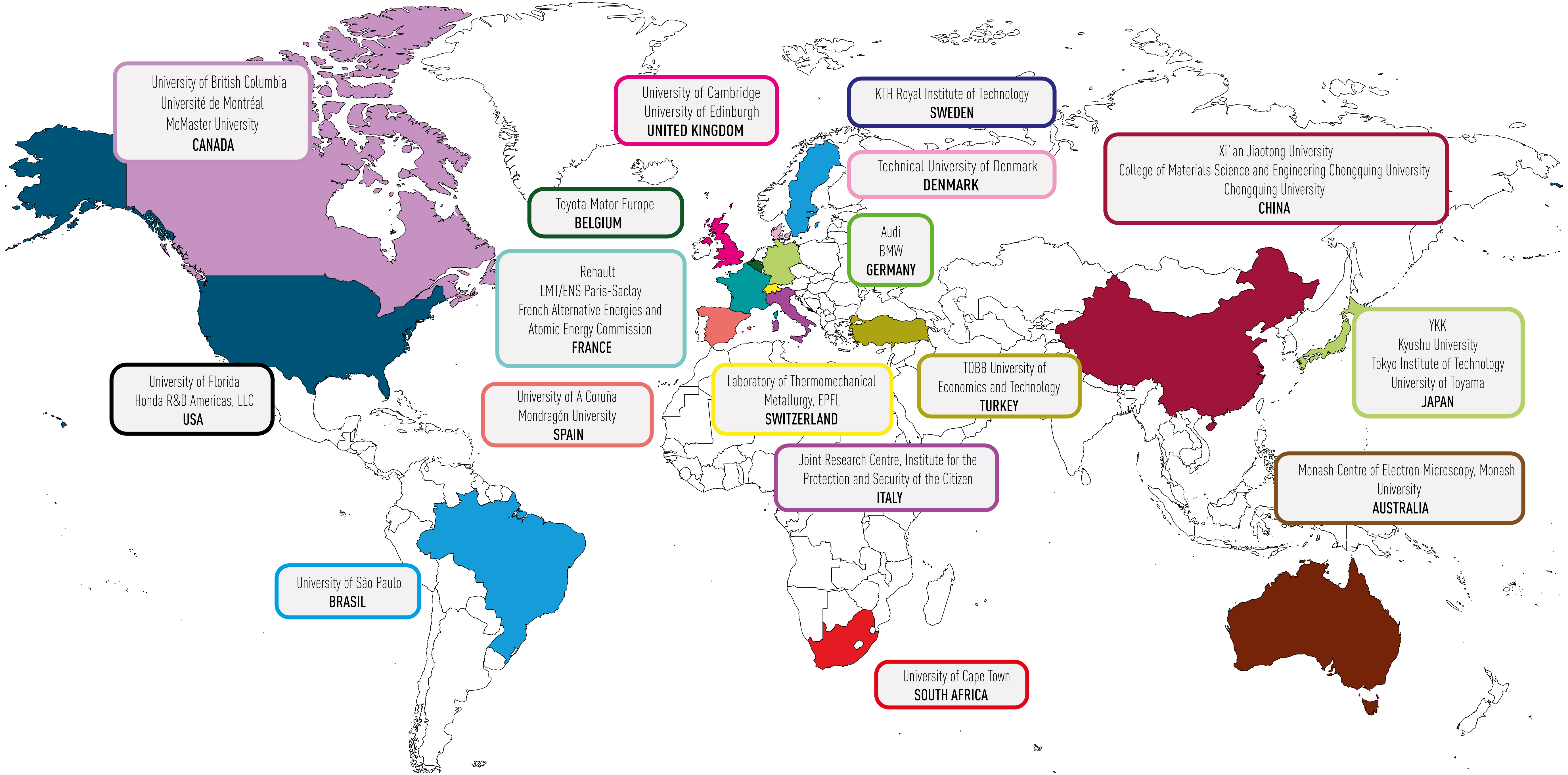
International cooperation is one of the success criteria for an SFI centre and SFI CASA has international collaboration in several ways. Among SFI CASA's partners there are five companies from outside Norway (Audi, BMW, Honda, Renault, and Toyota). SFI CASA also has strong interaction with universities, companies and research organizations abroad.

SFI CASA is a member of the European Automotive Research Partners Association, EARPA, an association of automotive R&D organizations. Four of the key researchers in SFI CASA are members of the DYMAT, a European association for the promotion of research into the dynamic behavior of materials and its applications. Professor Magnus Langseth has a seat in DYMAT's governing board.

The key researchers in SFI CASA all have an extensive international network. This is partly a result of the researcher's visibility in the academic environment through publications in peer-reviewed journals and presentations at international conferences. In addition, three of the Centre professors are editors in highly ranked international journals.

The cooperation with top international research groups ensures that the Centre transfers leading-edge technology to the partners and, at the same time, is able to define innovative research areas of importance to the partners.

SFI CASA aims at being world-leading. Reaching that goal requires advice from the best. A Scientific Advisory Board (SAB) of international experts has been appointed.



SELECTED CONCURRENT PROJECT

Toppforsk Project FractAl:

A New Way to Design Aluminium Structures

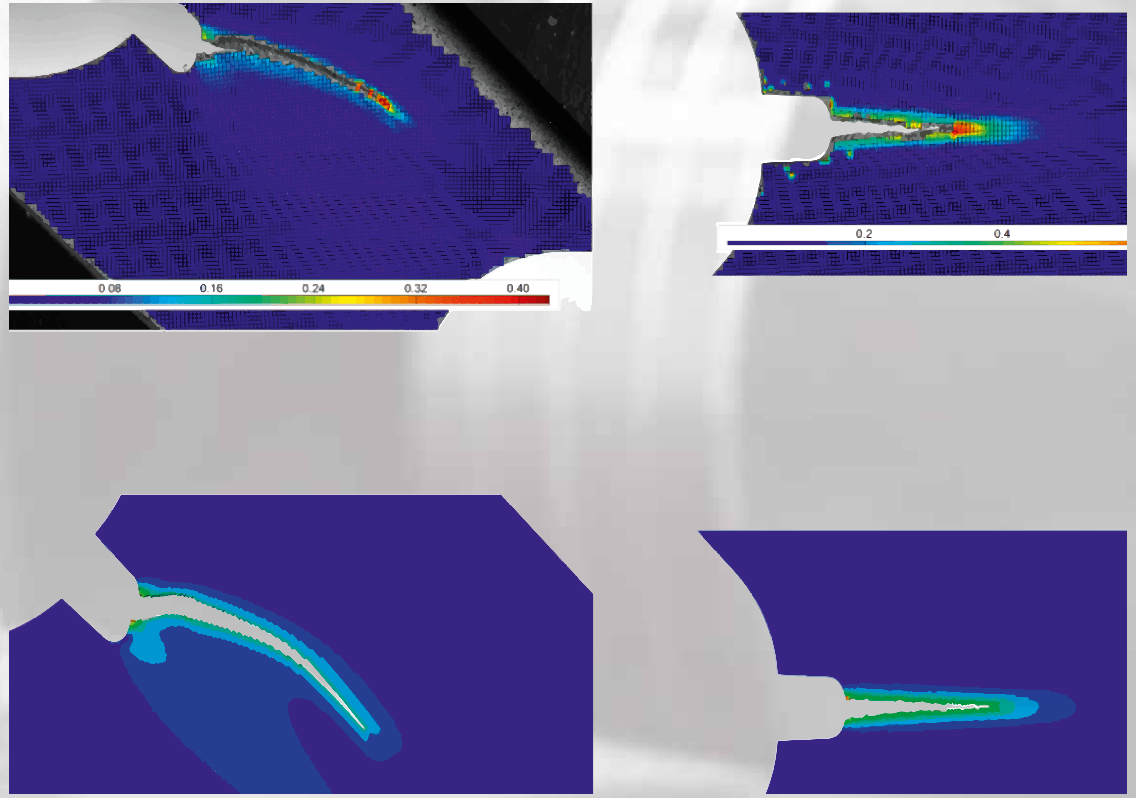


Figure 1: *Crack propagation in Arcan tests of aluminium alloy AA6016: experiments and finite element simulations using high-exponent isotropic metal plasticity combined with Modified Mohr-Coulomb fracture model calibrated by means of localization analyses.*

Toppforsk funding is a targeted initiative for providing substantial, long-term support to research groups that have the potential to reach the top of their field internationally.

When launching the programme in 2016, Norwegian Prime Minister Erna Solberg pointed out that the project is a crucial step in cultivating more world-leading academic groups in Norway. Funding is allocated to projects that have received the highest score after review by panels of international referees.

The Toppforsk project FractAl started in August 2016 and lasts for five years. It is a concurrent project to SFI CASA, and the activities coordinate closely with the activities in the Centre.

THE ESSENTIAL FACTORS

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

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

A FRAMEWORK FOR TAILORING ALLOYS

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

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

THE CORE TEAM, PHD-CANDIDATES AND POSTDOCS:

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

Currently, three PhD candidates and two postdocs are working with the core team. Professors Jonas Faleskog from KTH in Stockholm and Ahmed Benallal from ENS Paris-Saclay in Paris also take part in the project. Mikhail Khadyko was Researcher in FractAl until autumn 2018 when he was employed as an Associate Professor at UiT The Arctic University of Norway in Narvik. Susanne Thomesen defended her PhD thesis within the FractAl project in autumn 2019. She is now working as a postdoc in CASA. Henrik Granum defended his PhD thesis within the FractAl project in autumn 2020. He will begin working for the CASA spin-off, Enodo, in January 2021. Here, he will join others to work on a joint project with SIMLab and Equinor.

MEET THE NEW

DOCTORS

>>>

OLE VESTRUM

Defence: 26 March 2020

Due to Covid-19 Vestrum was among the first candidates to defend their theses at NTNU by virtual means

Thesis: «Impact on porous polymer coated pipelines»

Supervisors: Professors Tore Børvik and Magnus Langseth

Towards a Greater Understanding of IMPACT at Extreme Water Depths

A surprising side effect of polymeric coating on steel pipelines is that they also work as bumpers at extreme water depths.

Dr Ole Vestrum has found a new way to model how steel pipelines react when hit by mooring lines, falling anchors or fishing trawls. The primary task of polymeric coating is to insulate and protect the pipelines from corrosion. But sometimes, there are unexpected benefits such as the bumper-effect of the polymer coating.

«When pipelines are subjected to sudden impact, we can clearly see that the porous polymeric coating absorbs the impact energy very effectively. Thus, the coating makes a considerable contribution to protecting pipelines», says Ole Vestrum.

Despite these exciting qualities, the positive contribution of the coating is often neglected in pipeline design evaluations.

Why so?

Simply because the polymer coating has some extremely sophisticated features that make it too hard to assess. Until now.

A NEW MODEL FOR POROUS POLYMER COATING

In 2016, Vestrum embarked on the task of documenting the effectiveness of polymer coating as an energy absorber. His work established a new method to describe how the coating contributes to the behaviour of the pipeline when subjected to sudden impact.

Such pipelines are often installed at extreme depths. Oil and natural gas flow through them for thousands of miles every day, all year round. The polymer coating protects and insulates, keeps the oil smoothly flowing despite the icy cold surrounding water.

There are several potential damage risks for pipelines deep down in the dark sea including falling mooring lines and anchors, or fishing trawls that plough the seafloor. This can cause pull-overs and twisting of pipelines, as well as hooking, buckling or vibrations.

Ole Vestrum´s primary focus has been loading caused by maritime activities. Commercial fisheries and the petroleum industry often operate in areas of common interest. Subsea installations tend to attract fish, and the petroleum industry is not allowed to hinder fishing activities.

EXTREMELY COMPLEX FEATURES

«The consequences of sudden impacts may range from damage to the external coatings to displacement of the pipeline or even fracturing of the inner steel hull which may result in leakage», Vestrum explains.

For the petroleum industry, lowering the risk by bypassing regions with high fishing activity comes with a substantial expense. The longer the pipelines, the higher the cost. When incidents occur in deep water, it is often difficult to get a clear view of precisely what has happened. Full-scale component experiments can replicate different scenarios. However, this involves time, resources and a lot of money.

Numerical models present a cost-effective alternative to physical tests. But, including the mechanical contribution made by coatings in such models means another challenge: determining the complex features of the porous polymer.

RESEMBLES A SWISS CHEESE

Polymers are more complex and sensitive to loading rates and variation in temperatures than steel or aluminium. Consequently, design evaluations have omitted the pipeline coating and only assessed the steel section of the pipelines.

Vestrum says that much of the secret of the complex behaviour of polymer coating is its pore structure.

«It looks like Swiss cheese, full of holes and voids. In fact, the porosity across the coating can vary from zero to 30 per cent. In other words: You cannot treat a polymeric coated component as a single-material component», he adds.

HAIRY CALCULATIONS

Vestrum started his work with an extensive series of quasi-static indentation and dynamic impact tests in NTNU's kicking machine. He tested full-scale pipeline samples in cooperation with Equinor.

Then he scanned several specimens with X-rays, which is an excellent way to study pore structures. Operating on the micro-scale means studying units measuring down to one-millionth of a metre. As each of the specimen processes 8 billion data points, it takes some hairy calculations.

With help from postdoc Lars Edvard Dæhli in SIMLab´s FractAl project, Vestrum was able to describe the behaviour of the polymer coatings on the microstructure level. «The results showed a surprisingly strong correlation between the porosity and the behaviour of the material», Ole Vestrum states.

ORIGINAL AND EXCEPTIONAL WORK

The new modelling approach is a groundbreaking tool in the simulation of realistic scenarios. It makes it possible to build a model of pipelines without having to do large-scale and costly mechanical tests.

Besides, the beauty of this generic modelling approach is that it will hopefully work for other materials and properties too. For instance, simulating thermal insulation, which is the primary purpose of the coating. In deep water, features like this are nearly impossible to test in full-scale component experiments.

His supervisor, Professor Tore Børvik, finds Vestrum´s work both innovative and exceptional. «He contributes both to scientific theory and to our field of expertise. And, at the same time, his work can save the industry and society large sums of money», Børvik says.

The Hunt for the ACCURATE Point of Fracture

Sondre Bergo loves equations. That passion helps him to get closer to the goal of predicting the exact moment when a fracture occurs in ductile metals.

Materials that crack, fail and cause structures to collapse are every engineer's nightmare. An essential part of engineering applications is to make reliable predictions and assessments to prevent such failure.

Sondre Bergo aims to improve the accuracy, and thus the reliability of these applications. His PhD work reveals some of the underlying physical phenomena that lead to undesired material failure. It is all about accurately determining when fractures in ductile metallic alloys occur and how they subsequently develop.

EQUATIONS THAT INCREASE PHYSICAL SECURITY

His work is focused on the theory and numerical methods used in the data simulations. «The overall goal is a more efficient and accurate design of structures that are designed to be able to plastically deform on a permanent basis. Everyone has their strengths and weaknesses. I think my strength lies in solving numerical problems», Bergo says.

The whiteboard in his office is filled with rows of voluminous equations. To most of us, it looks like an impenetrable mass of letters, numbers and symbols giving zero meaning. But the intricate formulas have magic in them. They are the basis of the numerical models used to reduce the scope of physical tests. Thus, they contribute to save time and money for industry, reduced waste, an improved environment, and better protective solutions that benefit all of us.

TAKING ADVANTAGE OF DUCTILITY

His research is based on steel. However, an important fact is that the fracture assumptions are valid for other alloys too, as long as they have a predominantly ductile response before a fracture occurs.

Ductility is a mechanical property that enables alloys to be permanently deformed or pressed into another shape without immediately breaking. A sandwich wrapped in aluminium foil is a brilliant example of taking advantage of this property. The foil shaped around the food achieves an extremely deformed shape without breaking.

Ductility is essential when it comes to protection and safety considerations in structural projects. According to Bergo, structural engineering assessments have traditionally selected a conservative design approach. The home ground for industry has been the elastic domain, where materials return to their original form after being subjected to deformations. A bridge that is constructed for heavily loaded trucks is designed to hardly deform at all. Another example is how tall buildings sway like trees in strong winds but return to their original undeformed state as soon as the wind drops.

Since fractures and failures are seldom meant to occur, industry has been less concerned with calculating fracture criteria or performing simulations in the plastic domain.

DEFORMATION THAT PROTECTS

«However, some, like the defence and the automotive industries will benefit from accurate simulations on materials that deform permanently. In fact, there are situations where such deformations should not be ruled out», Bergo says.

That is because the ductile deformation serves as protection. Examples include incidents in offshore and marine activities, car crashes, or attacks on military or civil structures. In the event of a crash, a blast or another sudden extreme load, the ductility allows the structures to deform to some extent without rupturing. The aluminium crash box behind the bumper beams in your car is there to protect you. The box absorbs the kinetic energy from the speeding vehicle by deforming and reduces the g-forces experienced by the car and its passengers. While elastic deformations return the energy as the structure regains its original geometry; ductile deformations absorb the energy as the original geometry is never restored.

«This means that extreme loading can be stopped early by letting specific components deform and thus take the most of the impact. In fact, the first cars were hazardous as they were much stiffer than now and bounced back from whatever object they hit to a much larger extent».

HUNTING THE EXACT POINT OF FRACTURE

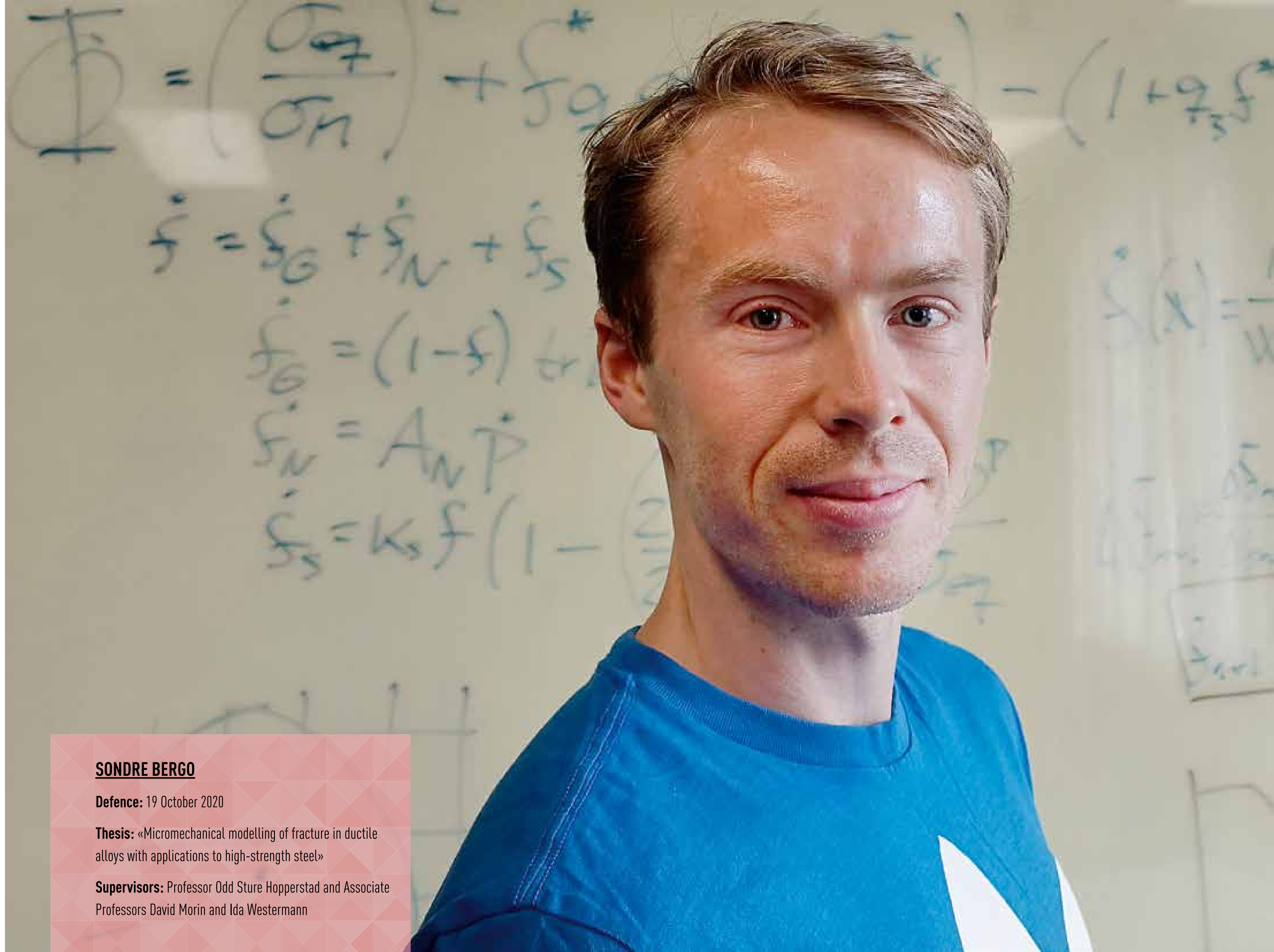
Today, some industries perform quite expensive and extensive testing to determine the properties and behaviour of a material under various loads.

«Predictive and reliable numerical models are essential to reduce the scope of tests. Instead of crashing hundreds of full-sized Lambhorginis into a wall to see what happens, it is possible to deform small specimens with a size in the millimetre range. By recording the material's behaviour, the test results can rather be used to simulate and thus replace, most of the full-scale experiments», Bergo explains.

Several industries realize this and require increasingly accurate models for ductile failure. More precise predictions pave the way for efficient design and optimization processes. As a result, there is less experimental testing, less use of unnecessary materials and savings in terms of time and money.

Bergo hopes that his work is useful for everyone who is focused on ductile fracture. «As Isaac Newton said: «If I have seen further it is by standing on the shoulders of Giants».

«By producing research in new directions, further work can start from a level of greater understanding. I am certainly no giant in the field of micromechanical modelling, but I hope I have made a slight contribution».



SONDRE BERGO

Defence: 19 October 2020

Thesis: «Micromechanical modelling of fracture in ductile alloys with applications to high-strength steel»

Supervisors: Professor Odd Sture Hopperstad and Associate Professors David Morin and Ida Westermann

HENRIK GRANUM

Defence: 26 November 2020

Thesis: «Multiscale modelling and simulation of ductile fracture in aluminium alloys».

Supervisors: Professors Odd Sture Hopperstad and Tore Børvik

A New Building Block for the VIRTUAL Laboratory

What happens inside a material before it breaks and fails? How do deformations and cracks occur, and how do they propagate?

Some people's urge to study almost unimaginable details can save lives and improve the quality of life for the rest of us. Henrik Granum is one of them. He works with microstructure-based modelling of ductile fracture in aluminium alloys. Ductility is a measure of the ability of a material to undergo significant deformations such as bending or stretching before fracturing and failure. Thanks to his PhD work, he added a new building block to the virtual laboratory under construction at SFI CASA. This will be a powerful tool for simulating and predicting such fracture.

SAVING TIME, MONEY AND THE ENVIRONMENT

Granum is one of five PhD candidates in FractAl, a top research project working in parallel with CASA. FractAl's ultimate goal is to develop «a multiscale modelling framework for ductile fracture in aluminium alloys». It will allow industrial designers and engineers to reduce the number of experiments needed to simulate ductile fracture. Also, it can speed up design processes significantly. More trustworthy numerical simulations represent a vast potential for industry to save time and cost, as well as help the environment.

COMBINING LIGHTWEIGHT, STRENGTH & PROTECTIVE PROPERTIES

Aluminium is a remarkable material that is used for almost anything from drink cans and food foil to window frames, cars and aeroplanes. In recent years the global demand has been fuelled by the automotive industry, continually aiming to reduce the weight of vehicles without sacrificing crashworthiness.

To design lightweight structures, it is often necessary to use high strength aluminium alloys where the material is utilized to the brink of failure. However, increased strength often comes at the expense of the ductility. Which again may enhance the risk of structural failure.

Therefore, to simulate aluminium structures subjected to different load situations, it is vital to have good models describing the properties of the alloys. This is where Granum's work comes in.

THE JOY OF EXPERIMENTS

His PhD work was comprised of an extensive base of experiments. He has been crashing aluminium profiles and subjecting aluminium plates to blast loads. This is all to validate and refine the modelling framework under construction. And he has enjoyed it.

«Regardless of the type, it is always a thrill to investigate if a crack has initiated and propagated. The experiments often throw in a surprise, and then the exciting part begins where I try to simulate the behaviour of the material», adds the fresh doctor in engineering.

ON THE SHELVES OF FAME

His numerous experiments secured him a place in the SIMLab Shock Tube Facility's Shelves of Fame. Here, on both sides of the 20-metre-long blue painted steel pipe used for blast experiments, the remains of tortured materials are on display. Broken glass plates and fragments, concrete slabs with holes and cracks, cracked steel and deformed aluminium plates are stacked along the walls.

One of the maltreated aluminium plates has Granum's signature on the back. It is one of the heat-treated plates in a study investigating the structural response of blast-loaded plates with different pre-cut slits. Before subjecting the blast load, the slits were cut into the plate to mimic the effect of perforation by fragments. This kind of impact is assumed to be the most detrimental among the different blast events.

FROM NANO-LEVEL TO TAILOR-MADE

The multiscale modelling framework Granum has worked with consisted of five modules. These cover the nano-, micro- and mesoscale. SIMLab and CASA researchers with unique expertise are associated with the specific modules. The NaMo model was developed by Ole Runar Myhr, a senior scientist in Hydro and Adjunct Professor at the Department of Structural Engineering at NTNU. The model calculates how alloying elements such as magnesium and silicon, are combined into tiny particles during heat treatment. It is the size and density of these particles that decide how alloys behave during a car crash, for instance. The model can predict the density and size of these tiny particles. Hydro has called the model potentially «the world's smallest lifesaver». Further, SFI CASA's Bjørn Håkon Frodal's PhD thesis work made a significant contribution to the Crystal Plasticity model. Researcher Lars Edvard Dæhli is an expert on Unit Cell Modelling. At the same time, localization analyses are the favourite topic of Associate Professor David Morin.

A FRAMEWORK WITH A VAST POTENTIAL

Henrik Granum has worked on the continuum modelling part, performing Finite Element simulations. He says he needed the work of these other colleagues. «I tried to obtain an overview of the most essential parts and understand how they affect the continuum modelling part. Then I joined the contributions together and investigated the ability of the model to reproduce exactly when fracture initiates and propagates».

Since the modules are developed by the researchers in the project, they are continuously refined when experiments and simulations reveal a weakness or inability in one of them.

Dr Granum is convinced that the multiscale framework has vast potential in the future. «Being part of this project feels like this contribution might make a substantial difference», he says.

Creates Virtual Versions of **ADHESIVES**

The weakest adhesive John Fredrick Berntsen has studied in his doctoral work is strong enough to lift a 1500 kilo car with a bonded area of only 3x3 centimetres.

The strongest adhesive would do the same job with only 2x2 centimetres.
«Rough estimates, and in ideal conditions, obviously. But these are not your standard glue from the kindergarten», Dr Berntsen, now a postdoc at SFI CASA, says.
However, the main task of the adhesives he studied in his doctoral research is not to lift cars off the ground. Their job is to connect the range of fundamentally different materials found in modern car bodies. They improve crash performance, too. Plus, superglues possess several other beneficial properties. That explains why they are being used more and more in the design of modern cars.

FROM EQUATIONS TO SIMULATIONS

According to Berntsen, there is a general lack of understanding of both the performance and modelling of adhesives. That explains why he concentrated on figuring out how the sticky substances behave when exposed to extreme loading until failure.
He has performed numerous material tests to investigate the strength and ductility of a variety of adhesives and bonded combinations. Based on observations and measurements, he uses mathematical equations to describe their behaviour. Then he writes the equations into the computer code used to generate virtual versions of the adhesive.
«In turn, these can be used to predict how the adhesive behaves, for instance in a full crash simulation», Berntsen explains.

GOOD NEWS FOR THE INDUSTRY

According to his supervisor, Associate Professor David Morin, the main interest is to include the effect of adhesives in a large-scale analysis, without using too much calculation time. Morin says that Berntsen's studies have promising results and his work is in line with the goals of CASA, namely, to deliver techniques that are useful for industry.

To support the work on reliable large-scale analysis, Berntsen has proposed a «partial virtual lab». This introduces a partial virtual calibration procedure with considerable potential to reduce the costs and time linked to calibration.
«Based on the work presented in my thesis, the procedure for large-scale models of an adhesive in various configurations could be reduced to just a few hours. That is, given the use of an already calibrated lower-scale model», Berntsen explains.
David Morin states that this work certainly contributes to the needs of the automotive industry. It could also have application in other business sectors – such as physical security».

ADHESIVES WITH ATTRACTIVE PROPERTIES

So, what are the driving forces behind Berntsen's research? One answer is that the trends in lightweight designs in the automotive industry are pushing towards more optimized structures. Which again, leads to structures with greater complexity and numerous multi-material joints.
Traditionally, steel car frames extensively used spot welding as the primary joining technique. Adhesives have become a vital component in the joints as they are much more flexible than typical fasteners such as spot welds.
New generations of car bodies require new joining techniques – and this is where the beauty of adhesives comes in. Not only can they join fundamentally different materials, they also increase the overall stiffness of the vehicles and improve crash performance.
Adhesives are also beneficial concerning noise and vibration. A further advantage is that they act as corrosion barriers.

THE FLEXIBLE BETAFORCE AND THE STIFF SIKAPOWER

Two selected adhesives play the main characters in Berntsen's monograph. The first is the «semi-structural two-component adhesive Betaforce 2816». Despite the flexibility of this adhesive and its wide applicability to a variety of materials, so far it has not received much attention in scientific studies.
The second, «SikaPower 498», is a structurally hardened epoxy adhesive which has received much more attention and figures in many studies. Sikapower is known for its high stiffness and strength and is often referred to as a crash-stable adhesive.
Berntsen found significant differences between the two adhesives, which he concludes will entail different modelling approaches for each of them.

REPLACE THE EXPENSIVE AND TIME-CONSUMING TESTS

«Since the performance of the joints could have a significant impact on the overall behaviour of a component, it is critical to have sufficiently accurate modelling strategies for adhesives», Berntsen says.

Besides, there is a cost aspect. It would be very beneficial to replace the expensive and time-consuming tests with virtual experiments.
His work contributes here on different levels.
«For the semi-structural adhesives, I think the contribution would be part of presenting an experimental regime sufficient for characterizing and determining which phenomena govern mechanical behaviour. Additionally, my work demonstrates how to model these phenomena with an acceptable degree of accuracy on the lower scale. This is considerably different from how adhesives are typically modelled».
As an MSc student, John Fredrick Berntsen spent half a year as an intern with Toyota in Brussels. He reveals that he still has a genuine interest in working with the automotive industry in the future. In fact, he already does. As a post-doc, he works on industrial implementation with David Morin who is CASA's extended arm towards the Centre´s automotive partners.

JOHN FREDRICK BERNTSEN

Defence: 3 December 2020

Thesis: «Testing and modelling of multi-material joints»

Supervisors: Associate professor David Morin, Professors Magnus Langseth and Arild Holm Clausen

SINDRE NORDMARK OLUFSEN

Defence: 17 December 2020

Thesis: «Experimental and numerical study of dilation in mineral filled PVC»

Supervisors: Professors Odd Sture Hopperstad and Arild Holm Clausen

A Polymer Guy with a PASSION for Python

Sindre Nordmark Olufsen's efforts to understand the deep interior of polymers can improve the safety of everything from cars to planes, and perhaps even heart valves.

He appears to be one of those young, unassuming scientists that prefer to listen and observe rather than talk loudly and often himself. He is always wearing some cool T-shirt, only occasionally popping out of his office to top up his coffee-mug before disappearing into his cave again.

A LITTLE OFF THE BEATEN PATH

But, if you talk to Sindre Olufsen privately, the modest impression fades quickly. The 32-year old has strong opinions and has confidence in his own skills. Obviously, he also dares to go a little off the beaten path in academia. In fact, a great deal of his PhD work is based on techniques never used in CASA until now.

«I guess I am a bit of an atypical scientist. I mostly enjoy the early phase of research, that is, getting an overview and figuring out how to approach a problem. I like to quickly test possible approaches and have this childish joy of creating and trying new things. To prototype, to test and make demos to see if things work – that is what I really enjoy», he says.

POLYMERS PUT UNDER STRESS AND STRAIN

The aim of his PhD work was to gain an understanding of how the failure behaviour of polymers is affected by stress triaxiality and the strain rate. It all started with a grand, experimental study that confirmed earlier observations.

«The polymer we looked at changed its volume during deformation, a phenomenon caused by nucleation and the growth of tiny voids inside the material. In fact, several of the test cases showed void volume fractions reaching 30 per cent, making the material resemble a foam more than a solid block of plastic. But how these voids were distributed within the specimen, was one of several questions that were impossible to answer at the time».

To see what is going on inside a piece of plastic while it is deforming is an extremely challenging task. Sindre Olufsen found a way around this:

USING X-RAYS

«X-ray computed tomography (XCT) is a technique which allows sections within a tensile specimen to be imaged by using an X-ray beam. However, acquiring a single scan takes in the order of 1 hour, so we had to pre-deform a set of tensile specimens and scan each of them in their unloaded state. This approach allowed us to see how the voids were distributed inside the tensile specimen. We saw that the distribution of voids is inhomogeneous and that it changed during deformation».

He has published a research paper «X-ray computed tomography investigation of mineral-filled PVC under monotonic loading» together with his supervisors Professor Arild Holm Clausen and Professor Odd Sture Hopperstad, and Professor Dag Werner Breiby (Department of Physics, NTNU).

A NOVEL METHOD TO MEASURE HOW VOIDS GROW

However, the XCT study came with a significant limitation: a very limited number of deformed specimens were scanned. This translates to watching a few snapshots of a movie and trying to figure out the plot. Thus crucial details are likely to be missed. To keep a detailed and rather long story short: Olufsen found a way around this too and developed a novel method to measure how voids grow and spread inside a polymer during deformation.

«The novelty of this method is that we can do these experiments using readily available equipment, making this kind of measurement available to a broad audience and our industrial partners», says Olufsen.

CONTRIBUTING TO THE OPEN-SOURCE COMMUNITY

His doctoral work is referred to as original, creative and groundbreaking. That goes for the originality in the work itself, as well for the publication of two pieces of software developed during his thesis work. This is the digital image correlation toolkit (µDIC) and the code which allowed him to do the in situ XCT measurements (AXITOM).

The source code is open, making it accessible to a broad user group, and anyone is free to inspect, modify, and improve the code.

At GitHub, the world's largest community of developers to discover, share, and build better software, Sindre Olufsen presents himself as «PolymerGuy, Mechanical engineer and happy coder».

TRANSPARENCY THAT PAYS OFF

So, no doubt. Locked up, complicated and closed-source tools with what Olufsen calls «fascinating price-tags» are not among his favourite things.

«During work on a PhD thesis, we all write large amounts of code or software. In most cases, it's put in a drawer and forgotten after we are done using it. This is sad, because others may benefit from using our tools. By sharing the software, we can also increase the transparency and credibility of our work», Olufsen says.

Also, he finds sharing code developed during research an ethical principle, simply because the codes are paid for from the public purse and should be accessible and free for anyone.

COMPOSITES, HEART VALVES, 3D-PRINTING TECHNIQUES

So, at the end of the day, who benefits from his PhD studies on polymers?

The answer might be, most of us.

We encounter plastics every day in the form of packaging, building/construction, transportation vehicles, medical equipment, scientific instruments, institutional products, furniture and furnishings and electronics. When we know how the material reacts to different loading conditions, we can make improved components and reduce material usage.

The open-source tools of Sindre Olufsen have already spread to several research groups worldwide.

The µDIC toolkit has been used for analysing damage propagation in composite materials and lately, for measuring the deformation of heart valves.

The Art of Modelling Aluminium ATOMS

Because he can simulate how atoms behave when aluminium is deformed, Jonas Frafjord knows better than most that the devil is in the details.

«Imagine bending an aluminium spoon», says Jonas Frafjord.

«The deformation that you observe is a combination of millions of small defects at the atomic level. They have the form of lines, and as a response to the stress exerted by bending the metal, they become rearranged. When they move, they cause tiny structural changes in the interior of the metal».

TOWARDS DIGITAL DESIGN OF TAILOR-MADE ALLOYS

Aluminium is a favourite among engineers and architects and is one of the most commonly used materials in the global construction industry. When structures deform, the damage always starts in the microstructures and the smallest of the building blocks. The tiny defects Frafjord describes are called dislocations. They are extremely interesting for materials scientists as they actually govern plastic deformation.

As a PhD candidate in the Lower Scale programme of SFI CASA, Frafjord has gained insight into how crystals, grains, particles, atoms and electrons move and interact with each other. He transfers this behaviour into computer simulations, and thus paves the way for the digital design of tailor-made alloys.

A KEY TO STRONGER METALS

«Knowing how the different parts of the system interact, behave and respond to external pressure is important. It is the key to making better, stronger alloys with the desired properties for their particular purpose», Frafjord says.

Returning to the spoon. Looking through a microscope, one can see that the metal consists of many tiny grains. They rotate, and deform as the utensil is bending, due to the movement of the dislocation. Inside the grains are particles, which consist of atoms with their nuclei and electrons.

THE IMPORTANCE OF SOLUTES

Solute elements like magnesium, copper, or silicon are added to make aluminium alloys stronger. They impede the dislocation motion and make the material harder to bend. Their different properties affect the dislocation, too. Without them, aluminium would be soft and useless as a structural material. Frafjord explains:

«Imagine a dislocation as a line of associated strain that is travelling through the vast sea of aluminium atoms. Suddenly, one part of the line feels repulsion from a magnesium atom that causes an obstruction in the travelling direction. The combined interaction of many such solute atoms is strong enough to hinder the dislocation from moving further, and the deformation is temporarily halted».

EXTREMELY CHALLENGING TASKS

Their numerous counts and long-range effects make dislocations challenging to incorporate in higher scale models. A crucial task for the Lower Scale is «To develop a credible multiscale framework for advanced structural analysis down to the atomistic scale».

Frafjord´s supervisor is Professor Randi Holmestad. She admits that her PhD candidate was given some extremely challenging tasks when he entered the world of atomistic modelling of dislocation interactions back in 2016. Innumerable questions swirled around: How do the solute atoms behave in the presence a dislocation? What happens when the metal is put under pressure or strain? Can we prove the response by atomistic calculations?

BRIDGING THE GAP

Jonas Frafjord´s doctoral work aims to bridge the simulations at the nanoscale to simulations at the continuum scale. The latter is where engineers, architects and industrial designers operate.

The gap in these scales is a challenge in terms of length and time. All the atomistic scale studies have been designed to be coupled with phenomena on a larger scale.

«This has been achieved by calculating interaction energies at an atomic scale. Then these parameters are used to describe the effect at the continuum scale», Frafjord explains.

183 YEARS TO CALCULATE 1 NANOSECOND

The computational requirements of atomistic calculations are exceptionally demanding. The following description by Frafjord gives an idea of exactly how demanding they are:

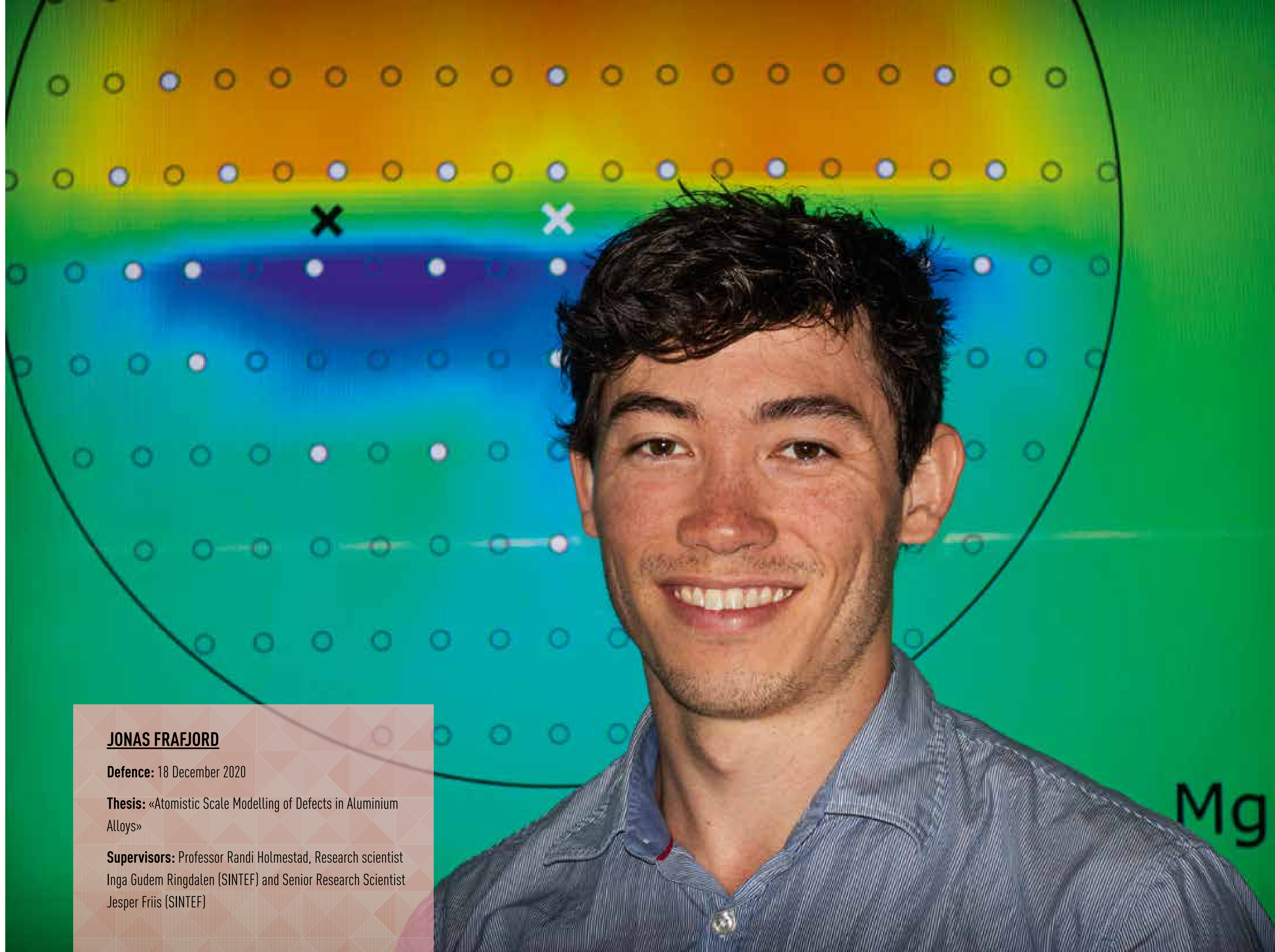
«Consider a 10 cm long strand of hair made out of aluminium. In this aluminium piece, there would be a billion trillion aluminium atoms. Each atom is affected by the others. Thus, for each time step, one would have to perform 12 calculations for each atom just to get the interactions with the nearest neighbour. The fastest computer in the world would use 183 years to calculate 1 nanosecond of evolution. Not to mention the amount of data such a simulation would create».

«HOPEFULLY, ANOTHER STEP IN THE RIGHT DIRECTION».

Jonas Frafjord says that, hopefully, new students could use his work as a doorway to the atomistic modelling of aluminium alloys. Besides, «the aluminium industry will gain a better understanding of the nuts and bolts that their continuum models rely on».

From an environmental perspective, society will benefit from increased use of tailor-made digital alloy design.

«To get there, we must define a strong fundamental multiscale framework. Hopefully, my work is another step in the right direction».



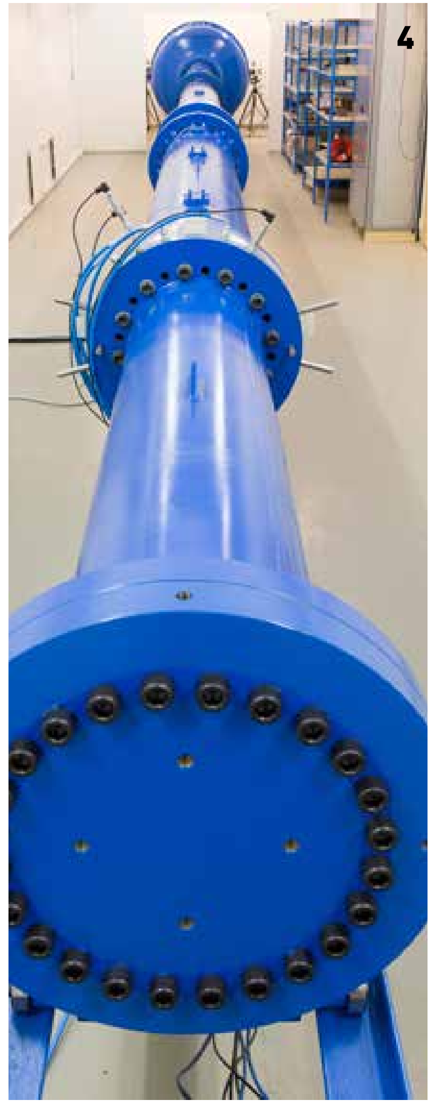
JONAS FRAFJORD

Defence: 18 December 2020

Thesis: «Atomistic Scale Modelling of Defects in Aluminium Alloys»

Supervisors: Professor Randi Holmestad, Research scientist Inga Gudem Ringdalen (SINTEF) and Senior Research Scientist Jesper Friis (SINTEF)

TEST FACILITIES



SFI CASA has access to test facilities in several laboratories at NTNU and SINTEF. Here is a list of the most important testing equipment.

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

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

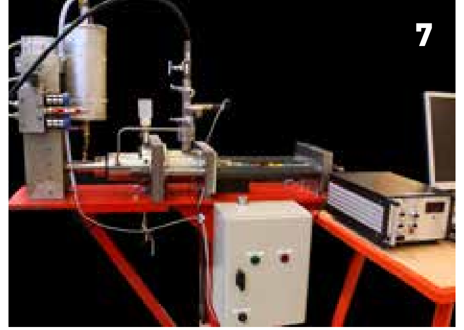
Droptower impact system (3)
In this machine impact testing of materials and small components can be done at high and low temperatures. The mass of the projectile ranges from 2-70 kg and gives an impact velocity in the range 0.8-24 m/s. All tests can be carried out with an instrumented nose which gives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

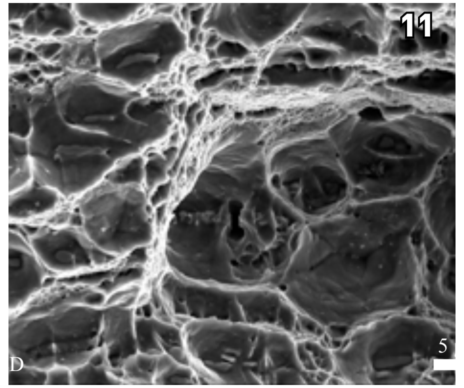
Shock tube facility (4)
The tube is 18.2 m long and is divided into six sections and ends in a 5.1 m^3 dump tank. The tube starts with a circular internal cross-section with a diameter of 0.34 m before it is transformed to a square cross-section of 0.3 m x 0.3 m. Threaded holes in the tube floor enable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

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

Stretch bending rig (6)
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.

Hydro-pneumatic machine (HPM) (7)
The hydro-pneumatic machine (HPM) is a device for tensile material testing. It operates in the strain–rate range between 1 and 100 s^{-1}.





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

Split-Hopkinson tension bar (SHTB) (9)
The split-Hopkinson tension bar is a device for material testing at strain rates in the range between 100 and 1500 s^{-1}. Data is recorded with strain gauges and high-speed cameras. An induction heater facilitates tests at elevated temperatures.

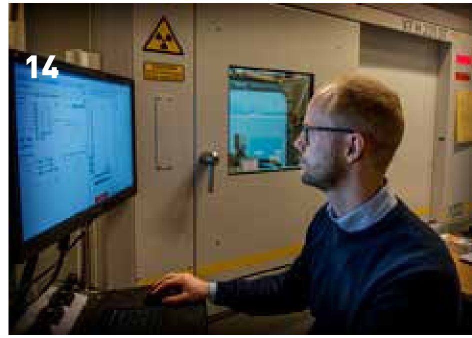
Cameras (10)
Impact testing of materials and structures are recorded using high-speed cameras. The Kirana-05M camera has a maximum frame rate of 5 000 000 per second (FPS) allowing detailed studies of crack propagation. In addition, the research group has four more high-speed cameras and several cameras for Digital Image Correlation measurements.

Scanning electron microscope (SEM) laboratory (11)
SFI CASA has access to a SEM lab with the following equipment: Zeiss SUPRA 55VP (LVFESEM, 2006), Hitachi S-4300SE (FESEM, 2002), Zeiss, Ultra 55LE, FESEM (2007), Jeol 840 (1989). Three SEMs are equipped with EDS and EBSD. The laboratory has in situ sub-stage systems for EBSD tensile and thermo-mechanical experiments (heating and cooling down to -60 °C).

Transmission electron microscope (TEM) laboratory (12)
SFI CASA cooperates with the TEM Gemini Centre at NTNU, providing SFI CASA access to five 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.
The laboratory includes a Merlin direct electron detector for electron diffraction experiments. The MDED allows cutting edge diffraction experiments for advanced and accurate defect analysis, phase mapping, magnetic and electrical field mapping, and orientation mapping at very high spatial resolution (nanometer scale) or with very high frame rates (21000 FPS).

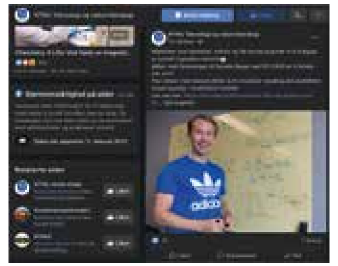
Sheet metal forming machine (BUP) (13)
This multi-purpose hydraulic sheet metal forming machine is designed to test the formability of sheet metals. The machine has a 600 kN load capacity, a maximum clamping force of 50 kN, a maximum test stroke of 120 mm and a maximum test speed of 750 mm/min.

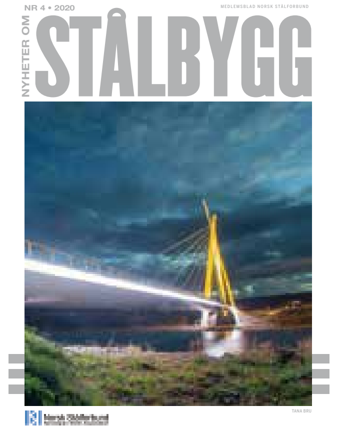
Computer tomography (CT) scanner (14)
The internal structure of materials and components can be studied in a non-destructive manner by X-ray computed tomography. The Nikon XT H 225 ST µ-CT scanner is capable of resolving structures with a size down to ten micro-metres revealing the otherwise hidden 3D-microstructure of specimens and materials. A Deben CT5000 tensile test apparatus allows for in situ imaging of samples subjected to tensile and compressive loading.



Photos:
1,2,6,7,9 13: Melinda Gaal.
3,4,5,8: Ole Morten Melgård.
10, 12, 14: Sølvi W. Normannsen
11: Bjørn Håkon Frodal

VISIBILITY





Media strategy

SFI CASA has a media strategy for popular scientific presentations of its research. We aim to contribute to a knowledge-based, open public debate. It is also our aim to make female researchers and profiles particularly visible to recruit females and contribute to a more even gender balance in this research field. We continued this work the previous year.

Newsletters

We use the website sfi-casa.no as an essential tool to make the Centre visible. It works as a platform for sharing news and spreading content to mainstream and social media. In all, we published more than 30 posts on the site. Among these were the full versions of the articles on the 6 PhD candidates published in this annual report. The content includes research news, stories and in-depth interviews with key personnel working with or connected to SFI CASA. Throughout the year, 11 newsletters were distributed to partners, contacts and other people in our social and professional network.

In 2019 we introduced a Technical Newsletter (TN) intended solely for the partners in the Centre. This year, we distributed 9 TNs, up from 5 in 2019.

Social media

The excellent collaboration with NTNU's communication division continued in 2020. Content posted on our blog is often shared via the university´s news page «NTNU News» and the Facebook page NTNU Science and Technology. When we post videos, we use NTNU SIMLab´s YouTube channel. So far, we have preferred to tweet via NTNU´s official account @NTNU, which has close to 38 000 followers.

CASA in the Media

We have had a great deal of publicity in 2020, despite the circumstances around Covid-19.

January: The local newspaper Stangeavisa published a 2-page story on SFI CASA´s postdoc Emil Christiansen.

March/April: Ole Vestrum´s PhD thesis on «Impact on porous polymer coated pipelines» caught a great deal of public interest. The research magazine Gemini published an article on his extensive work, and so did regional papers Østlandsposten and Adresseavisen. Vestrum defended his thesis on 26 March 2020, just 2 weeks after the national lockdown due to Covid-19. Thus, he also was one of the first PhD candidates at NTNU to perform a public, digital defence on Zoom.

May: When a shiny new car model is rolling off the factory floor, it is also a compact example of research with high utility value. During winter, vendors in car-dealer Møller Bil visited CASA. They got a presentation on how our scientists contribute to ever safer vehicles. In May, the retailer´s customer newspaper brought a story about the visit.

September: The national newspaper Khrono covers the Norwegian university and research sector. They interviewed two former PhD candidates at SFI CASA when publishing a story on a new report. It states that researchers with a doctorate are happy with their everyday work and the relevance of their education.

October: Centre Director Magnus Langseth published a chronicle in the newspaper The Norwegian Business Daily (Dagens Næringsliv (DN)). The title was «Innovation Demands Bring Greater Tension Between NTNU and SINTEF». The article triggered a further debate in DN and also editorial coverage in other newspapers.

NTNU is involved in an innovation project with Equinor, Baker Hughes and spinoff-company Enodo AS. As the latter is run by former graduates at CASA, the Centre also got some publicity in the local paper Drammens Tidende.

December: An article on the work in Ådne Lund's MSc thesis, which was connected with the post.doc project of Panagiotis Manoleas, was published in the industry magazine Stålbygg. Topic: welded T-joints between rectangular hollow sections. Magnus Langseth starred in a podcast broadcasted by Technoport Trondheim. Technoport works to advance science-based, technological innovation. This is one of Langseth´s favourite topics, and he was happy to discuss innovation and how to bridge the gap between science and industry with the CEO of Technoport. Postdoc Sindre Nordmark Olufsen was interviewed by the newspaper Rana Blad.

Lab visits at CASA

- Representatives from Hydro Aluminium Rolled Products and Extrusion Europe came to visit CASA's laboratories on 6 January
- Representatives from Norwegian Car vendor Møller Bil visited the lab on 14 January
- Politicians from the municipal council of Trondheim visited the labs on 23 January, hosted by the Rector of NTNU and NTNU's Pro-Rector for research.

Guests from industrial partners

- Oda Toreskås and Sumita Dey, Norwegian Defence Estates Agency, 8-9 January 2020.
- Tormod Grue, Norwegian Defence Estates Agency, 14 January 2020.

PhD defences in 2020

- 26 March, Ole Vestrum, Impact on porous polymer coated pipelines
- 19 October, Sondre Bergo, Micromechanical modelling of fracture in ductile alloys with applications to high-strength steel
- 26 November, Henrik Granum, Multiscale modelling and simulation of failure in aluminium alloys*
- 3 December, John Fredrick Berntsen, Testing and modelling of multi-material joints
- 17 December, Sindre Olufsen, Experimental and numerical study of dilation in mineral filled PVC
- 18 December, Jonas Frafjord, Atomistic Scale Modelling of Defects in Aluminium Alloys

*Doctoral work funded by concurrent project FractAl.

Research visits by SFI CASA staff

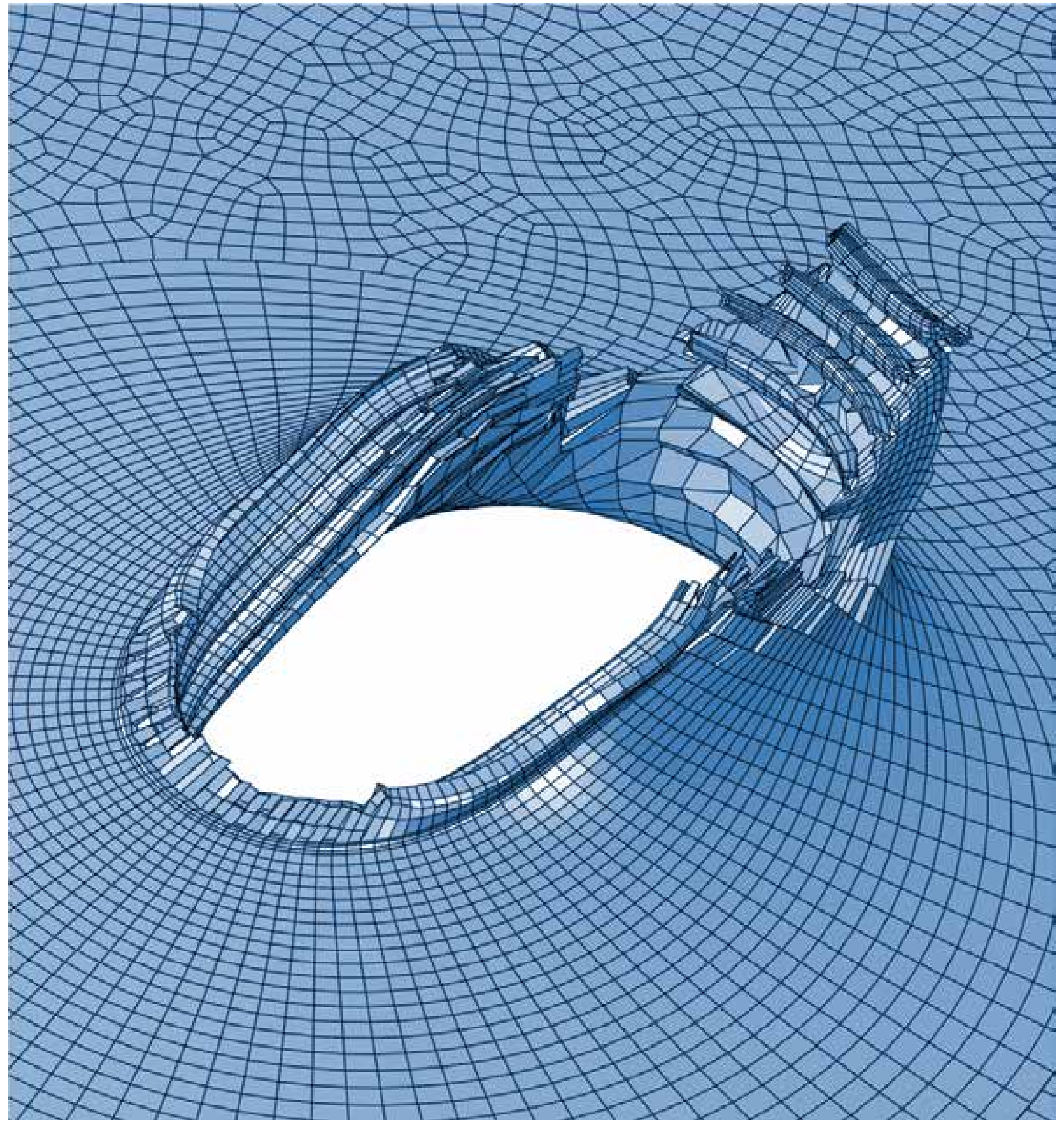
- Professor Randi Holmestad visited Monash Centre of Electron Microscopy, Monash University, Melbourne, Victoria, Australia from 16 to 24 February.
- Professor Knut Marthinsen stayed at the University of British Columbia (UBS), Vancouver, Canada from January to March.

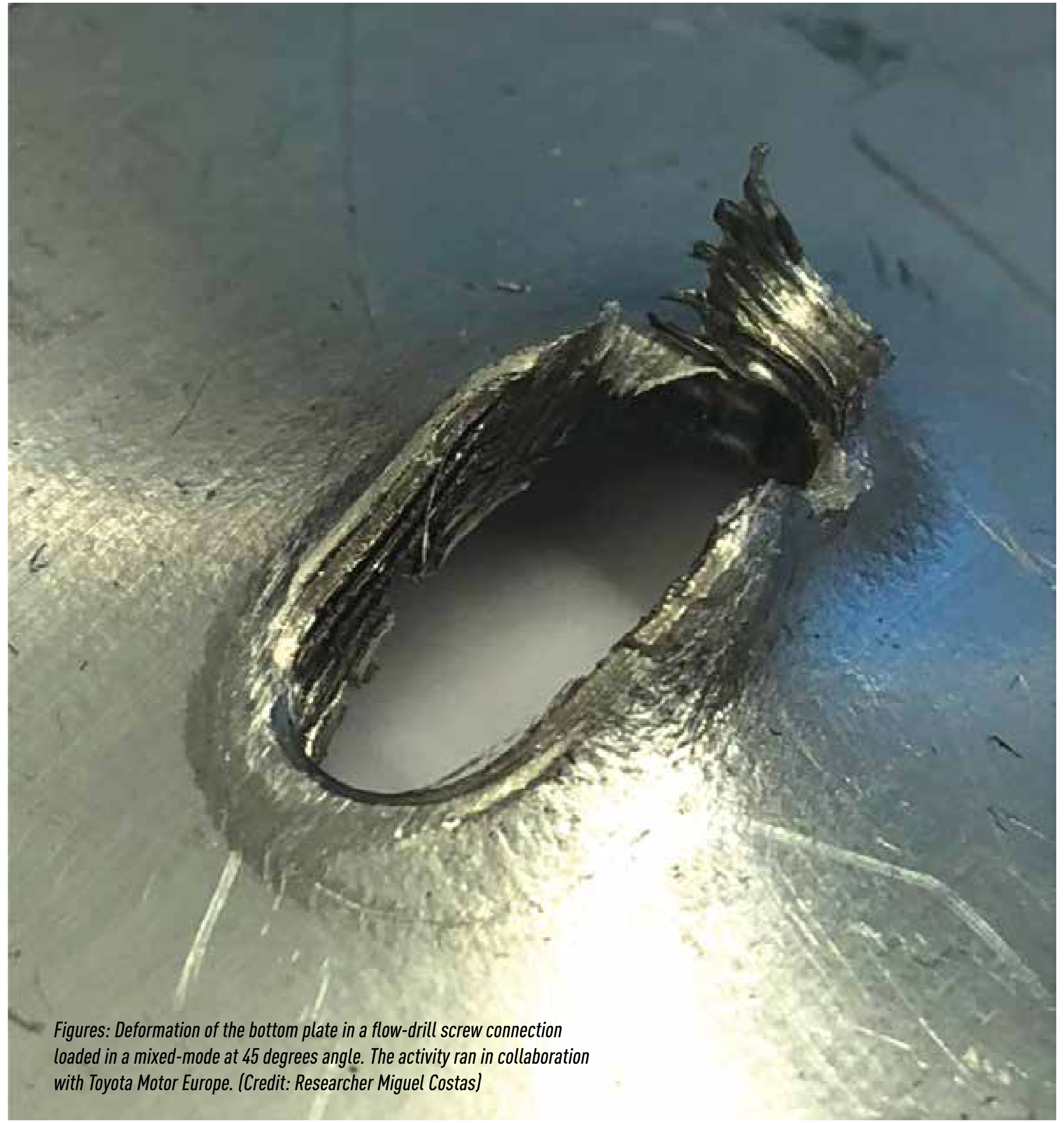
Research visits at SFI CASA

- PhD candidate Kinga Somlo, DTU, Denmark.2 December 2019-27 March 2020.

Visiting MSc students

- Maisie Anne Edwards-Mowforth, University of Edinburgh, UK, January-June 2020





Figures: Deformation of the bottom plate in a flow-drill screw connection loaded in a mixed-mode at 45 degrees angle. The activity ran in collaboration with Toyota Motor Europe. (Credit: Researcher Miguel Costas)

Selected concurrent projects

KPN project SLaDE on fundamental investigations of violent wave actions and impact response (2019-2021): The objective of the SLaDE project is to improve safety at sea, for which impact loads from steep and energetic waves represent a critical part of the structural design. This requires a better understanding of the mutual interaction between the impacting wave and the response of the structure. The project employs one post doc at the SIMLab research group.

Aluminium alloys with mechanical properties and electrical conductivity at elevated temperatures, AMPERE (2015-2020): The focus of this competence enhancement project is to study the properties of aluminium alloys at elevated temperatures. Professors Randi Holmestad and Knut Marthinsen are involved in this project.

Fundamentals of Intergranular Corrosion in Aluminium Alloy, FICAL (2015-2020): The objective of this competence enhancement project is to establish new fundamental understanding of the mechanisms of intergranular corrosion (IgC) susceptibility. Professors Randi Holmestad and Knut Marthinsen are involved in this project.

Rational Alloy Design, ALLDESIGN (2018-2022): NTNU project on digital materials design of aluminium-based alloys. PhD student Marcos Fernandez at CASA is involved in the project.

Microstructure based modelling of ductile fracture in aluminium alloys, FractAl (2015-2020): This FRIPRO Toppforsk project is run by professors Odd Sture Hopperstad, Tore Børvik and Ole Runar Myhr from NTNU's Structural Impact Laboratory along with partners Ahmed Benallal LMT/ENS Paris-Saclay, France and Jonas Faleskog from the Royal Institute of Technology in Sweden. The FractAl project employs one researcher, two post docs and four PhD candidates.

KPN project SumAl (2019-2024), Solute cluster manipulation for optimized properties in Al-Mg-Si based Al alloys. Professors Randi Holmestad and Knut Marthinsen are involved in this KPN project, working with the understanding of early stage clustering and ordering of solute atoms in aluminium alloys. SFI CASA partners Benteler, Hydro and SINTEF are also involved in the project.

The Norwegian Ministry of Justice and Public Security funds a professorship for Vegard Aune on physical security at the SIMLab research group (2018-2022). NTNU funds one PhD candidate in connection to the professorship. The overall goal of the project is to strengthen education and research in Norway on civil engineering structures and critical infrastructure prone to extreme loading events.

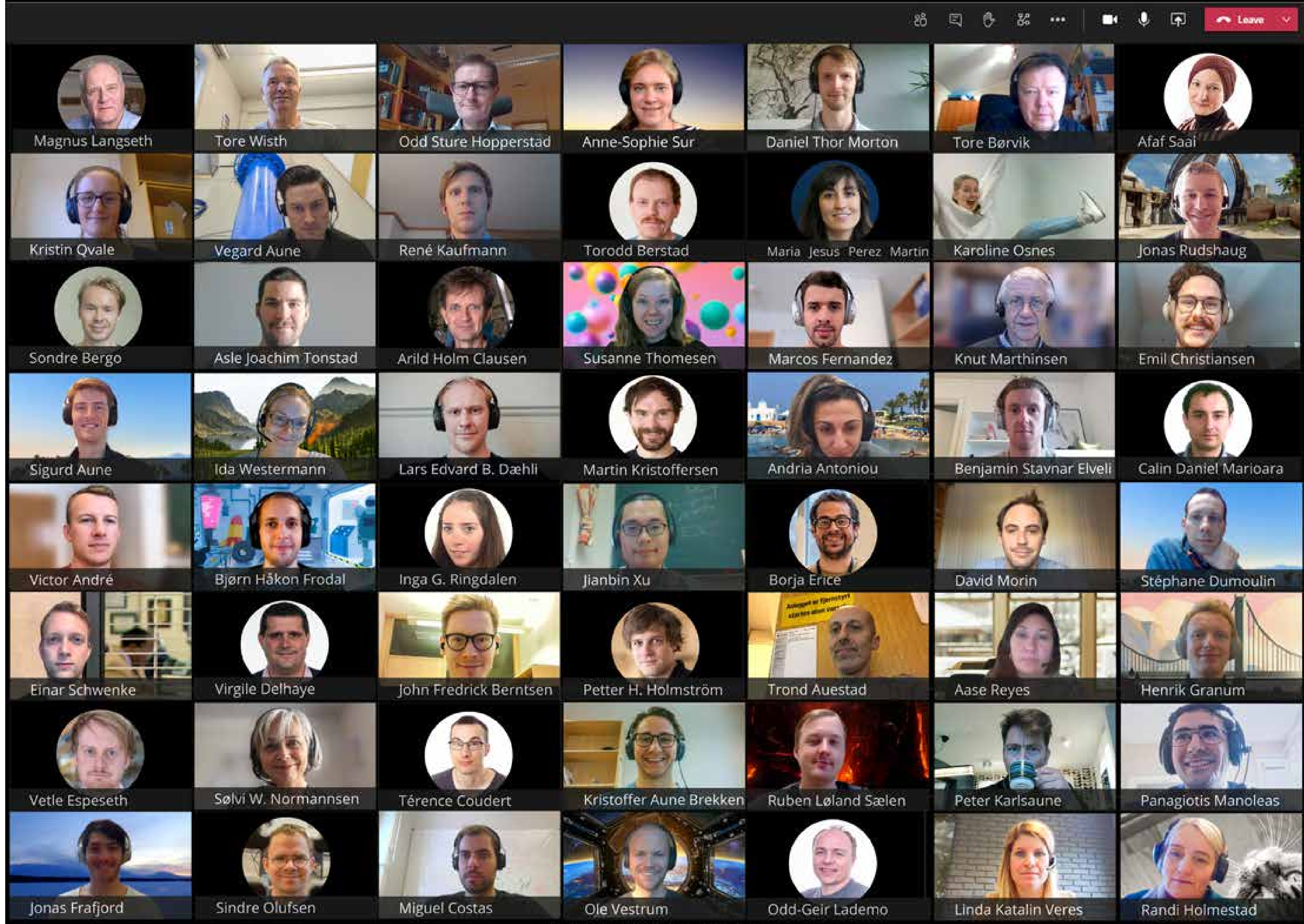
PERSONNEL

PhD candidates and post docs

PHD CANDIDATES AND POST DOCS WITH FUNDING FROM SFI CASA

Name	Topic	Position	Start	Planned exam/end	Programme	Nationality	Gender
John Fredrick Berntsen*	Testing and Modelling of Multi-Material Joints	PhD	2015	Defended in 2020	Structural Joints	Norwegian	M
Sindre Olufsen*	Modelling of Ductile Failure in Polymers	PhD	2015	Defended in 2020	Polymeric Materials	Norwegian	M
Sondre Bergo**	Localization of Plastic Deformations in Construction Steel	PhD	2016	Defended in 2020	Metallic Materials	Norwegian	M
Jonas Frafjord*	Multiscale Modelling of Deformation in Aluminium Alloys	PhD	2016	Defended in 2020	Lower Scale	Norwegian	M
Daniel Morton**	Modelling of tahe Mechanical Behaviour of Polymer Foams	PhD	2016	2021	Polymeric Materials	Norwegian	M
Ole Vestrum**	Optimisation of Protective Structures	PhD	2016	Defended in 2020	Structures	Norwegian	M
Jianbin Xu**	Work Hardening and Portevin-Le Chatelier (Plc) Effect	PhD	2016	2021	Lower Scale	Chinese	M
Kristoffer Aune Brekken**	Modelling and Optimization of Sacrificial Claddings	PhD	2017	2021	Structures	Norwegian	M
Einar Schwenke**	Modelling of Viscoelasticity in Polymers	PhD	2018	2022	Polymeric Materials	Norwegian	M
Benjamin Stavnar Elveli**	Behaviour and Modelling of Steel Plates Subjected to Combined Blast And Impact Loading	PhD	2018	2022	Structures	Norwegian	M
Marcos Fernandez**	Modelling of Aluminium Components Under Large Deformations	PhD	2018	2021	Structural Joints	Spanish	M
Victor André*	Modelling of Multilayered Joints	PhD	2019	2022	Structural Joints	German	M
Ruben Løland Sælen**	Modelling of Polymers	PhD	2019	2023	Polymeric Materials	Norwegian	M
Jonas Rudshaug**	Modelling of Glass	PhD	2019	2023	Structures	Norwegian	M
Sigurd Aune*	Modelling of Welded Aluminium Joints	PhD	2020	2024	Structural Joints	Norwegian	M
Maria Jesus Perez*	Impact of Steel at Low Temp/Ductile Fracture of High-Strength Steel	Post doc	2018	2020	Metallic Materials	Spanish	F
Panagiotis Manoleas**	Steel Joints	Post doc	2018	2020	Metallic Materials	Greek	M
Susanne Thomesen*	Cast Aluminium	Post doc	2019	2023	Metallic Materials	Norwegian	F
Karoline Osnes*	Behaviour and Modelling of Glass	Post doc	2019	2021	Structures	Norwegian	F
Emil Christiansen*	Nanoscale Characterization of Aluminium	Post doc	2019	2021	Lower Scale	Norwegian	M
Sunita Mishra**	Blast Loading	Post doc	2019	2020	Structures	Indian	F
Andria Antoniou*	Blast Loading	Post doc	2020	2022	Structures	Cypriot	F
Sindre Olufsen*	Modelling of Ductile Failure in Polymers	Post doc	2020	2022	Polymeric Materials	Norwegian	M
John Fredrick Berntsen*	Industrial Implementation	Post doc	2020	2022	Structural Joints	Norwegian	M

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



SFI CASA FAMILY 2020






PHD CANDIDATES AND POST DOCS ON CONCURRENT PROJECTS. THE TOPICS ARE HIGHLY RELEVANT FOR SFI CASA

Name	Topic	Position	Start	Planned exam/end	Programme	Nationality	Gender
Henrik Granum	Multiscale Modelling and Simulation of Failure in Aluminium Structures	PhD	2016	Defended in 2020	FractAl	Norwegian	M
Asle Joachim Tomstad	Quasi-Static and Dynamic Ductile Fracture of Aluminium Alloys Under Low Triaxiality	PhD	2017	2021	FractAl	Norwegian	M
Kristin Qvale	Microstructure-Based Modelling and Simulation of Ductile Fracture in Aluminium Alloys	PhD	2018	2021	FractAl	Norwegian	F
Vetle Espeseth	Microstructure-Based Modelling and Simulations of Plasticity and Fracture in Aluminium Alloys	PhD	2018	2022	FractAl	Norwegian	M
Anne Sophie Sur	Running Ductile Fracture in Pressurised Steel Pipelines	PhD	2020	2023	FME NCCS	German	F
Lars Edvard Dæhli	Micromechanical Modelling of Ductile Failure in Aluminium Alloys	Post doc	2017	2021	FractAl	Norwegian	M
Bjørn Håkon Frodal	Modelling of Aluminium	Post doc	2019	2021	FractAl	Norwegian	M
Rene Kaufmann	Impact Response	Post doc	2019	2021	SLADE	German	M

Recruitment

One new PhD candidate and three new Post docs started at SFI CASA in 2020. Sigurd Aune is a former MSc student at NTNU and started his doctoral work at CASA in August. Andria Antoniou earned her doctoral degree at University Grenoble Alpes, France and started at CASA in March 2020. Sindre Olufsen and John Fredrick Berntsen defended their theses at CASA in 2020 and continue as Post docs at CASA until 2022.

Due to coronavirus restrictions, only one MSc student and one PhD candidate visited the Centre in 2020. A number of guided tours scheduled to take place in March and April were cancelled.

Above from left: *MSc student Ådne Lund with supervisor Researcher Panagiotis Manoleas on videolink from Sweden. Middle: MSc students Magnus Pjaaka Torp (left) and Håkon Frydenberg with supervisor Professor Tore Børvik. (Photos: Sølvi W. Normannsen).*
Right: MSc student Erla Gudding testing steel beams in the Kicking machine (Photo: Arild Holm Clausen).
Below left: *MSc student Jørgen Sørbøl with his supervisor Associate Professor Vegard Aune in the Shocktube. Middle: MSc student Oddvar H. Johannesen. Right: MSc student Sondre Tjessem testing aluminium rims. (Photos: Sølvi W. Normannsen)*

MSc students
The following MSc students were associated with the Centre in 2020

Name	Sex M/F	Topic
Alexander Tangen	M	Modelling of Heat-Affected Zones in Aluminium Structures
Anja Murud Gahre	F	Dynamic Response of Steel Plates Subjected to Combined Blast and Impact Loading
Ragnhild Hembre Haug	F	Dynamic Response of Steel Plates Subjected to Combined Blast and Impact Loading
Bjørn Gjertsen	M	Testing and Modelling of Thick Aluminium Castings Under Impact Loadings
Sondre Tjessem	M	Testing and Modelling of Thick Aluminium Castings Under Impact Loadings
Erla Christine Gudding	F	High Plastic Utilization of Welded Beam Section
Håkon Frydenberg	M	Impact on Polymer-Coated Pipelines
Magnus Pjaaka Torp	M	Impact on Polymer-Coated Pipelines
Håkon Johannessen	M	Experimental and Numerical Study on the Static and Dynamic Behaviour of Notched Square Hollow Sections Made of Three Different Types of S355
Oddvar H. Johannessen	M	Experimental and Numerical Study on the Static and Dynamic Behaviour of Notched Square Hollow Sections Made of Three Different Types of S355
Jostein Lima	M	Modelling and Simulation of Yielding, Work-Hardening and Fracture of Advanced High-Strength Steels
Sigurd Aune	M	Modelling and Simulation of Yielding, Work-Hardening and Fracture of Advanced High-Strength Steels
Jørgen Sørbøl	M	Performance of Perforated Aluminium Plates Subjected to Blast Loading
Lars Otto Lofthus Ose	M	Modelling of Laminated Glass
Steinar Liebe Harneshaug	M	Modelling of Laminated Glass
Magnus Leirvik Knoph	M	Plated Aluminium Structures Exposed to Extreme Pressure Loads
Odin Celius	M	Plated Aluminium Structures Exposed to Extreme Pressure Loads
Ådne Lund	M	An Experimental and Numerical Study of Welded T-Joints Between Rectangular Hollow Sections

PUBLICATIONS & ANNUAL ACCOUNTS

The following lists journal publications and conference contributions generated in 2020.

Journal articles 2020

1. B.C. Abrahamsen, H.S. Alsos, V. Aune, E. Fagerholt, O.M. Faltinsen, Ø. Hellan. Hydroplastic response of a square plate due to impact on calm water. Physics of Fluids 2020; Volume 32(8) 082103.
2. S. Bergo, D. Morin, T. Børvik, O.S. Hopperstad. Micromechanics-based identification of a ductile fracture model for three structural steels. Engineering Fracture Mechanics 2020; Volume 224, 106803.
3. K.A. Brekken, Aa.G. Reyes, T. Berstad, M. Langseth, T. Børvik. Sandwich panels with polymeric foam cores exposed to blast loading: An experimental and numerical investigation. Applied Sciences 2020; Volume 10(24), 1-36.
4. E. Christiansen, C.D. Marioara, I.G. Ringdalen, R. Bjørge, B. Holmedal, O.S. Hopperstad, R. Holmestad. Detailed investigation of the shearing mechanism of β» precipitates in Al-Mg-Si alloys. MATEC Web of Conferences 2020; Volume 326, 01005.
5. E. Christiansen, I.G. Ringdalen, R. Bjørge, C.D. Marioara, R. Holmestad. Multislice image simulations of sheared needle-like precipitates in an Al-Mg-Si alloy. Journal of Microscopy 2020; Volume 279, issue 3, 265-273.
6. M. Costas, D. Morin, M. de Lucio, M. Langseth. Testing and simulation of additively manufactured AlSi10Mg components under quasi-static loading. European Journal of Mechanics. A, Solids 2020; Volume 81. 103966.
7. B. Erice, M.J. Perez-Martin, M. Kristoffersen, D. Morin, T. Børvik, O.S. Hopperstad. Fracture mechanisms in largely strained solids due to surface instabilities. International Journal of Solids and Structures 2020; Volume 199, 190-202.
8. J. Frafjord, S. Dumoulin, S. Wenner, I.G. Ringdalen, R. Holmestad, J. Friis. Fully resolved strain field of the β'' precipitate calculated by density functional theory. Computational Materials Science 2020; Volume 187, 110054.
9. J. Frafjord, I.G. Ringdalen, O.S. Hopperstad, R. Holmestad, J. Friis. First principle calculations of pressure dependent yielding in solute strengthened aluminium alloys. Computational materials science 2020; Volume 184, 109902.
10. B.H. Frodal, E. Christiansen, O.R. Myhr, O.S. Hopperstad. The role of quench rate on the plastic flow and fracture of three aluminium alloys with different grain structure and texture. International Journal of Engineering Science 2020; Volume 150, 103257.
11. B.H. Frodal, D. Morin, T. Børvik O.S. Hopperstad. On the effect of plastic anisotropy, strength and work hardening on the tensile ductility of aluminium alloys. International Journal of Solids and Structures 2020; Volume 188-189, 118-132.
12. M. Gazizov, D.C. Marioara, J. Friis, S. Wenner, R. Holmestad, R. Kaibyshev. Unique hybrid precipitate structures forming in an Al–Cu–Mg–Si alloy. Journal of Alloys and Compounds 2020; Volume 826, 153977.
13. P. Holmström, O.S. Hopperstad, A.H. Clausen. Anisotropic behavior of short glass-fibre reinforced polyamide-6. Composites Part C: Open Access 2 (2020), 100019.
14. M. Kristoffersen, M. Costas, T. Koenis, V. Brøtan, C.O. Paulsen, T. Børvik. On the ballistic perforation resistance of additive manufactured AlSi10Mg aluminium plates. International Journal of Impact Engineering 137 (2020) 103476.
15. M. Lißner, E. Alabort, B. Erice, H. Cui, BRK. Blackman, N. Petrinic. On the dynamic response of adhesively bonded structures. International Journal of Impact Engineering 2020; Volume 138, 103479.
16. Lißner, B. Erice, E. Alabort, D. Thomson, H. Cui, C. Kaboglu, BRK. Blackman, M. Gude, N. Petrinic. Multi-material adhesively bonded structures: Characterisation and modelling of their rate-dependent performance. Composites Part B: Engineering 2020; Volume 195, 108077.
17. D.T. Morton, Aa.G.R. Reyes, A.H. Clausen, O.S. Hopperstad. Mechanical response of low density expanded polypropylene foams in compression and tension at different loading rates and temperatures. Materials Today Comunications 2020; Volume 23, 100917.
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19. S.N. Olufsen, M.E. Andersen, E. Fagerholt. µDIC: An open-source toolkit for digital image correlation. SoftwareX 2020; Volume 11, 100391.
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22. K. Osnes, O.S. Hopperstad, T. Børvik. Rate dependent fracture of monolithic and laminated glass: Experiments and simulations. Engineering structures 2020; Volume 212, 110516.
23. C.O. Paulsen, T. Børvik, I. Westermann. Effect of the gold remodeling preparation method on the microstructure and mechanical behavior of steel. SN Applied Sciences 2020; Volume 2 (1751).
24. J. Paz, M. Costas, J. Delgado, L.E. Romera, J. Diaz. Energy Absorption of Aluminium Extrusions Filled with Cellular Materials Under Axial Crushing: Study of the Interaction Effect. Applied Sciences 2020; Volume 10(23) 8510.
25. D. Thomson, G. Quino, H. Cui, A. Pellegrino, B. Erice, N. Petrinic. Strain-rate and off-axis loading effects on the fibre compression strength of CFRP laminates: Experiments and constitutive modelling. Composites Science And Technology 2020; Volume 195, 1-11.
26. O. Vestrum, L.E. Dæhli, O.S. Hopperstad, T. Børvik. Constitutive modeling of a graded porous polymer based on X-ray computed tomography. Materials and Design 188 (2020) 108449.

Conference contributions

1. E. Christiansen, C.D. Marioara, I.G. Ringdalen, R. Bjørge, B. Holmedal, O.S. Hopperstad, R. Holmestad. Detailed investigation of the shearing mechanism of β» precipitates in Al-Mg-Si alloys. 17th International Conference on Aluminium Alloys; 2020-10-26 - 2020-10-29
2. J.K Holmen, J. Johnsen, D. Morin, T. Børvik, M. Langseth. Application of *MAT_258 for bending and crushing of extruded aluminum profiles using shell elements. 16th International LS-DYNA ® Users Conference; 2020-06-10 - 2020-06-11.
3. J. Johnsen, J.K. Holmen, G. Gruben, D. Morin, M. Langseth. Calibration and Application of GISSMO and *MAT_258 for Simulations Using Large Shell Elements. 16th International LS-DYNA ® Users Conference; 2020-06-10 - 2020-06-11
4. J. Xu, K. Marthinsen, B. Holmedal, O.S. Hopperstad. Experimental characterization and modelling of the PLC effect in an AlMg-alloy. 6th Forum of Center for Advanced Materials Research and International Collaboration; 2020-09-28 - 2020-10-08
5. J. Xu, K. Marthinsen, B. Holmedal, O.S. Hopperstad, T. Manik. Experimental and modeling study of Portevin Le-Chatelier effect in an AA5182 alloy. The 17th International Conference on Aluminum Alloys ICAA17; 2020-10-26 - 2021-07-29

Invited lectures

1. A.H. Clausen. Stålkonstruksjonsforskning ved Institutt for konstruksjonsteknikk, NTNU. Nettverkssamling konstruksjonsteknikk, Multiconsult. 5 February 2020, Oslo, Norway.
2. E. Fagerholt, R. Kaufmann. Experimental methods and measurement techniques at high strain-rates. DYMAT Winter school 9-14 February 2020, Les Houches, France.
3. R. Holmestad. SPED and HAADF- STEM used to aid aluminium alloy developments. 26th Australian Conference on Microscopy and Microanalysis (ACMM). 16-20 February 2020, Toyama, Japan (online).
4. R. Holmestad. TEM used to study microstructure and precipitates for understanding 6xxx alloys. Global Engineering Lectures. 6 February 2020, Canberra, Australia.

PhD theses

1. Bergo, Sondre. Micromechanical modelling of fracture in ductile alloys with applications to high-strength steel. ISBN 978-82-326-4974-7
2. Berntsen, John Fredrick. Testing and modelling of multi-material joints. ISBN 978-82-326-5082-8
3. Frafjord, Jonas. Atomistic Scale Modelling of Defects in Aluminium Alloys. ISBN 978-82-326-5148-1
4. Granum, Henrik. Multi-scale modelling and simulation of ductile failure in aluminium structures. ISBN 978-82-326-5094-1
5. Olufsen, Sindre Nordmark. Experimental and numerical study of dilation in mineral filled PVC. ISBN 978-82-326-5122-1
6. Vestrum, Ole. Impact on porous polymer coated pipelines. ISBN 978-82-326-4562-6

Publications on concurrent projects

Journal articles

1. O. Cazacu, N. Chandola, B. Revil-Baudard, B.H. Frodal, T. Børvik, O.S. Hopperstad. Modeling the effect of notch geometry on the deformation of a strongly anisotropic aluminum alloy. European Journal of Mechanics. A, Solids 2020; Volum 82.
2. L.E.B. Dæhli, D. Morin, T. Børvik, A. Benallal, O.S. Hopperstad. A Numerical Study on Ductile Failure of Porous Ductile Solids With Rate-Dependent Matrix Behavior. Journal of applied mechanics 2020; Volume 87 (3).
3. Granum H, Morin D, Børvik T, Hopperstad OS. Calibration of the modified Mohr-Coulomb fracture model by use of localization analyses for three tempers of a n AA6016 aluminium alloy. International Journal of Mechanical Sciences 2020;192:106122.
4. O.R. Myhr, T. Børvik, C.D. Marioara, S. Wenner, O.S. Hopperstad. Nanoscale modelling of combined isotropic and kinematic hardening of 6000 series aluminium alloys. Mechanics of materials (Print) 2020; Volume 151.
5. S. Thomesen, O.S. Hopperstad, O.R. Myhr, T. Børvik. Influence of stress state on plastic flow and ductile fracture of three 6000-series aluminium alloys. Materials Science & Engineering: A 2020; Volume 783.

Conference contributions

1. A.J. Tomstad, S. Thomesen, T. Børvik, O.S. Hopperstad. Ductile failure of isotropic and anisotropic 6000-series aluminium alloys: effect of constituent particles. 17th International Conference on Aluminium Alloys; 2020-10-26 - 2020-10-29

A Polymer pipeline sample. *PhD candidate Ole Vestrum performed an extensive series of quasi-static indentation and dynamic impact tests of samples like this in his doctoral work. He also tested full-scale pipeline samples in cooperation with CASA-partner Equinor.*

Annual accounts

SFI CASA FUNDING 2020 (ALL FIGURES IN 1000 NOK)

Item	Host NTNU	Research partner SINTEF	Public partners	Industrial partners	RCN grant	Total funding
Research programmes	7388	1100	2711	7776	11725	30700
Equipment				867	1412	2279
Administration	1000		1439	2057	10	4506
Total budget	8388	1100	4150	10700	13147	37485

SFI CASA COSTS 2020 (ALL FIGURES IN 1000 NOK)

Item	Host NTNU	Research partner SINTEF	Public partners	Industrial partners	Total cost
Research programmes	22964	5100	700	2900	31664
Equipment	877				877
Administration	4944				4944
Total budget	5100	5100	700	2900	37485

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.

OUR VISION:

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

CASA

Centre for Advanced Structural Analysis