CASA

Annual Report 2022

Centre for Advanced Structural Analysis

Norwegian Centre for Research-based Innovation

SINTEF

NTNU

NORWEGIAN NATIONAL SECURITY AUTHORITY

Norwegian Ministry of Local Government and Regional Development

Statens vegvesen

Audi

BMW

RENAULT

HONDA

DNV

Multiconsult

BENTELER Automotive

equinor

FORSVARSBYGG

Hydro

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COVER:
PhD Candidate Kristoffer Aune Brekken investigates the behaviour of sandwich panels subjected to extreme loadings such as blast and ballistic impact. Here he is preparing a test in the SIMLab shock tube facility (Photo: Sølvi W. Normannsen).

GRAPHIC DESIGN:
Sølvi W. Normannsen/NTNU Grafisk senter

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Research Scientist Anette Brocks Hagen at SINTEF is an expert in a technique called nanoindentation. She is a part of the team in SFI CASA´s Lower Scale programme. (Photo: Sølvi W. Normannsen).

THE FINAL SUMMARY

RESEARCH FOR A SAFER SOCIETY

A world-leading center. Business-sector relevant research of the highest international quality. Effective bridgebuilding over the technology gap. A collaboration built on mutual trust between scientists and industrial partners.

These are some of the concluding remarks of SFI CASA's Scientific Advisory Board (SAB) in the final report on the Centre. Seven months before the doors close, the SAB states there is a strong indication that CASA´s industrial partners are satisfied. Clear evidence shows that these partners, who are among the world's largest players in their fields, are willing to support further collaboration.

DESTROY TO PROTECT

Violent crash and tough impact tests. Blast loading and shock waves. Projectiles fired at glass, steel, and concrete. Destructive experiments have been SFI CASA's hallmark over the years and the destruction has had a purpose: to protect people and vital infrastructure.

The scientists use the experiments to develop and validate numerical models. Construction engineers and industrial designers use the models to simulate how materials, buildings, cars, and other structures behave under extreme loading.

The Centre's partners come from the private and public sector within transportation, energy, and physical security. The beauty of CASA's generic technology is that, although for different applications, all partners can benefit from it. This technology, new virtual tools, drastically reduces the time – and money – spent on testing prototypes. Crash tests on a computer can reduce the number of physical tests needed, leading to less waste, and contributing to the green shift. Improved accuracy makes them more reliable and safer to use.

ONE THOUSANDTH THE WIDTH OF A STRAND OF HAIR

In many ways, the SAB report marks the close of SFI CASA´s eight-year long journey. To understand how the group progressed to this stage, praised by the world's foremost experts, we must take a quick look in the rearview mirror.

The vision for SFI CASA was to establish a world-leading centre for multi-scale testing, modelling and simulations of materials and structures for industrial applications. The predecessor, SFI SIMLab (2007-2015), was surpassed in breadth of scope and depth of scale in numerical models. Materials were studied at the scale of one thousandth the width of a strand of hair. This is the size of the smallest building blocks in aluminium and steel, the favourite construction materials of many engineers and architects.

MODELS THAT SUPPLY COMMERCIAL SOLVERS

Several of the first CASA PhD students studied and modelled how the atoms in different aluminium alloys behave under large deformations. The models make it possible to optimise for superior material properties all the way down to the nano level and adjust the chemical composition and treatment accordingly. Hydro uses the technology to develop ideal aluminium alloys for different customers.

Two of the largest simulation programs in the world, LS-DYNA and PAMCRASH, have included models generated by CASA. Among these, a through-thickness damage regularisation scheme for shell elements subjected to severe bending and membrane deformations. CASA's glass model has also become mainstream in the design and production processes of leading car manufacturers. The Centre has succeeded in improving the tools used by industry worldwide.

A VIRTUAL LAB AND GROUNDBREAKING RESEARCH

To list the achievements of SFI CASA is a lengthy task, but here are just a few: The Virtual Laboratory established for aluminium and steel enables the replacement of full-scale physical impact tests with simulations. CASA´s research on optimal pipeline solutions has saved companies such as Equinor large sums of money. In collaboration with the Norwegian Defence Estates Agency (NDEA), the Centre has developed material models that allow NDEA to run simulations of projectiles penetrating concrete. Groundbreaking work has transformed knowledge on glass, adhesive bonded connections, hybrid connections between aluminium and steel, and polymer foams used in car bumpers. In the course of its eight-year programme, CASA will have produced 24 PhDs and 160 masters' degrees. The Ministry of Justice and Public Security has financed a professorship in civil infrastructure security. An external grant from Hydro sponsors a professorship in the design and modelling of aluminium structures at the Centre. The startup company Enodo AS is a genuine and commercially viable spinoff from CASA.

RESEARCH-BASED INNOVATION – AT THE PARTNERS

The Scientific Advisory Board evaluated the Centre for the third and last time in November 2022. The members support the view that innovation is best effectuated by the industrial partners based on the research output of CASA. However, they leave no doubt that the Centre has worked profitably to bridge the gap between science and industry.

The SAB highlights that the Centre has:

- achieved its objectives in educating many researchers.
- conducted long-term, business sector relevant research of high international quality.
- conducted work well-aligned with the partners' interests.
- recruited PhD students of high quality.
- managed to attract national students.

THE SCIENTIFIC ADVISORY BOARD´S FINAL REPORT

The Scientific Advisory Board (SAB) of the SFI Centre for Advanced Structural Analysis (CASA) met in Trondheim on November 8th and 9th. During the first day, it has participated to the presentations made by the members of the Centre on the activities carried out on the second term (2019-2022). The morning of the second day was devoted to a general discussion between the members of the SAB and an assessment of the results that have been obtained.

The general conclusions reached are given below:

1. CASA has achieved its objectives in conducting long-term, business sector relevant research of high international quality. CASA is world-leading, with significant papers in leading journals. There is a focus on high quality and on relevant research on a set of identified problems. CASA has met its objectives in terms of educating a large number of researchers (Masters, PhDs) who have conducted work well-aligned with the partners' interests. The quality of the PhD students is high, and the Board was impressed by the clarity of their presentations. The Board also notes that CASA has managed to attract national students.

2. An effective working relationship exists with industrial partners, and trust has been established through continued collaborations. Frequent meetings have paid off. There is clear evidence that the industrial partners are keen to continue the collaboration, to commit internal employees to engage with CASA and to provide partial financial support to ensure that this is the case. CASA continues to be responsive to the needs of the partners, and to align with the objectives of the program. The mix of experiment, theoretical and numerical approaches is optimal for their objectives.

3. There is a good balance between basic research and industrial implementation, and the technology gap is being bridged in an effective way. These efforts take time and resource, and CASA has managed to keep a focus on relevant fundamental problems.

4. The CASA view of Innovation has the support of the SAB: innovation is best done by the industrial partners, based upon the research output of CASA. It is not the role of CASA to design and innovate new products. The CASA activity is unique in going from process modelling to the performance of a component. Appropriate modifications have been made to existing models as necessary. The toolbox and toolkit are suitable platforms for synthesis of models and data from processing to performance and failure. Maintenance will continue to be a challenge.

5. CASA has an established international network. The fact that the senior researchers of CASA are also journal editors means that they engaged in the international scientific community. Recent hires of faculty have been from abroad.

6. The leadership team is very strong and effective, and a younger group of researchers now exists. It is applauded that a full-time communications officer has been engaged to ensure effective communication of results and continued challenges to societal needs.

7. CASA continues to work on relevant problems in a responsive manner. The Board took note of the following examples:

   i. There has been significant progress in applying ductile fracture concepts to design in sectors such as automotive, security and energy.
   ii. A wide range of projects in polymers have reached a high level of maturity.
   iii. There has been a successful activity in multiscale problems down to the nanoscale.
   iv. Recently CASA has worked on joints, steels, and additive manufacture.
   v. There has been significant progress in understanding the stochastic nature of castings and the failure of glass.

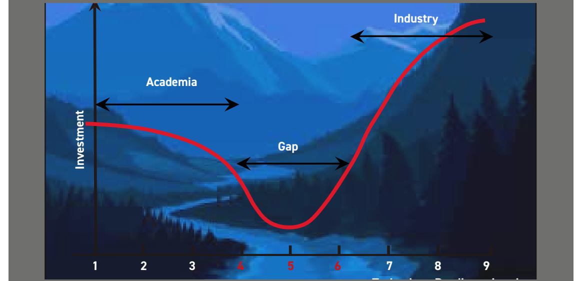
6. The Board suggests a number of possible new research areas that may require additional competences:

   i. Resilience engineering of critical infrastructures, such as energy supply systems and transportation in the face of extreme events such as climate change.
   ii. Failure mechanisms such as fatigue in components and in joints
   iii. CASA has much data at its fingertips. A mechanism is needed to ensure that the data survives. There is an opportunity to manage the data and to explore new ways of exploiting it, for example by machining learning and other techniques in artificial intelligence. The current approach of assessing the relevance of neural networks to upscale is encouraged.
   iv. Mechanical behaviour including crashworthiness of batteries, of fuel cell systems, and of recycled materials in automobiles.
   v. Sustainable (recyclable) production of automotive parts that can be disassembled or repaired. Controlled tearing to separate parts: tear-off mechanisms.
   vi. Expansion of efforts in additive manufacture.

On behalf of the members of the SAB
November 12th, 2022
Ahmed Benallal
Chairman of the SAB

The participating members of the SFI CASA´s Scientific Advisory Board in Trondheim. Sitting in front from left are Professor Stefan Hiermaier, Ernst Mach Institut, Germany, Professor Norman A. Fleck, Cambridge University, United Kingdom, Professor Ahmed Benallal, CNRS, ENS Paris-Saclay, France. Standing in the back from left are Professor Jonas Faleskog, KTH, Sweden, Professor Patricia Verleysen, Gent University, Belgium, Professor Stefanie Reese, Aachen University, Germany, and Professor John W. Hutchinson, Harvard University, USA (Photo: Ole Martin Wold).

ABOUT CASA AND 2022 IN BRIEF



Start the Hunt for Innovation in Technology's Valley of Death

«Our neighbours are crushing Norway in innovation. The gap between the business community's needs and what the universities deliver is growing. What can we do about it?»

This question was raised by Director Magnus Langseth in a chronicle in January.

The chronicle was published in the newspaper Khrono. Professor Langseth's concern is that despite all the possibilities and a flood of measures, there is too little research within the companies for the future and value creation in Norway. Many attempts become stranded in «technology's valley of death», the graveyard on the Technology Readiness Level (TRL) scale.

This scale from 1-9 shows the maturity of technology from basic research to commercialization. Academia invests in research and remains at levels 1-4, while the industry wants mature technology and production at levels 7-9. The innovative shipwrecks are in between.

In the chronicle, Mr. Langseth gave 9 specific suggestions to the Minister of Research and Higher Education, Ola Borten Moe.

«Plenty of actors and schemes plan to accelerate innovation in Norwegian academia. However, it is too slow. We have everything we need in Norway to accelerate innovation and transfer more research into profitable jobs and revolutionary technologies. We have world-leading research environments, a strong business community, and a wealthy state», wrote Mr. Langseth. He urged responsible politicians to take action to build bridges over technology's valley of death.

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 the 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 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 13 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. The research done in these programmes is based on annual work plans generated on the basis of discussions between the partners.

Meetings, seminars, and conferences

The Centre organized several online seminars and lectures through 2022 to spread knowledge about the research done in the research programmes. CASA's Industrial Reference Group is important to help transfer technology and know-how to the partner's organizations. The Industrial Reference Group met on 30 March and 9 November. In addition, the partners working with physical security met on 22 December. The Board has had 2 meetings in 2022, an online meeting on 1 June and a face-to-face meeting in Trondheim on 9 November. CASA hosted the 3rd International Conference on Impact Loading of Structures and Materials in Trondheim on 13-17 June. The conference attracted more than 100 scientists from around the globe. With this conference, CASA fulfilled its goal to host two international conferences.

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 four international partners (Audi, BMW, Honda, and Renault).

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. In that respect, the Centre director has been visible in 2022. 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.

Visibility in the research community is also important. The CASA researchers published 16 journal articles and they gave 15 conference presentations. In addition, concurrent projects hosted by the research group published 8 journal articles and gave 5 conference presentations.

PhD defences

2 PhD candidates defended their theses in 2022: Marcos Fernandez and Benjamin Stavnar Elveli. In addition, Kristin Qvale and Asle Joachim Tomstad defended their PhD theses, funded by the research group's concurrent project FractAl.

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 environmentallyfriendly structures and products through multiscale testing, modelling and simulation.

PhD student Debora Obkircher is affiliated with SFI CASA, working on bolted connections in steel structures. (Photo: Sølvi W. Normannsen).

GOALS AND RESEARCH QUESTIONS

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.

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 postdocs, 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 postdocs 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 implement a strategy for popular science presentations of the research activities in magazines, newspapers, on television, radio and the web.
- To establish a media strategy where female researchers are made particularly visible in order to recruit female PhDs and Postdocs and contribute to a more even gender balance in this research field.

Into the Secrets of the Soft Zones

As a part of the team in SFI CASA´s Lower Scale programme, SINTEF Research scientist Anette Brocks Hagen´s work task is to determine the nanomechanical properties of Al-Mg-Si alloys (aluminium, magnesium, silicon). These alloys are increasingly used as car bodies substituting heavier metals. Using high-sensitive equipment at lower scales, Hagen hunts for the weak spots and tracks initial failures in the metal´s building blocks.

We are talking about tiny things, like sizes down to one thousandth the width of a strand of hair. CASA'S Lower scale-people aim to understand the atomic and micrometre scale behaviour. The overall goal is to give aluminium producers materials of higher quality.

Hagen is an expert in a technique called nanoindentation. This is a variety of indentation hardness tests applied to small volumes.

«Nanoindentation helps us obtain insights into the alloys that we, to our knowledge, have not been able to see before. Currently, this is the only method to determine the accurate hardness distribution deep down in the interior of materials».

Material failure of any bulk material starts with a local formation and accumulation of defects. Eventually, this leads to fracture by an advancing crack, depending on the material system. To predict the alternation of the material and eventually, the lifetime of the components, it is essential to have in-depth knowledge of all the microstructural aspects.

RESEARCH METHODOLOGY

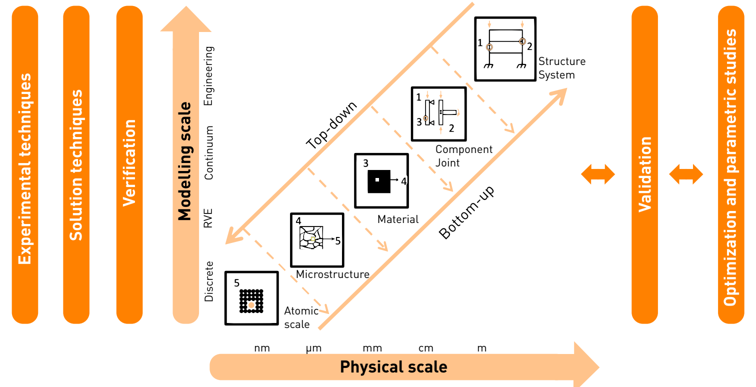


Figure 1: Research methodology.

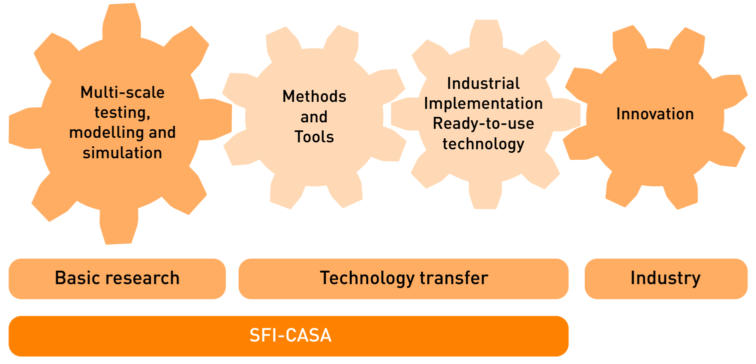


Figure 2: Structure of research, technology transfer and industrial implementation.

The activities in CASA 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.

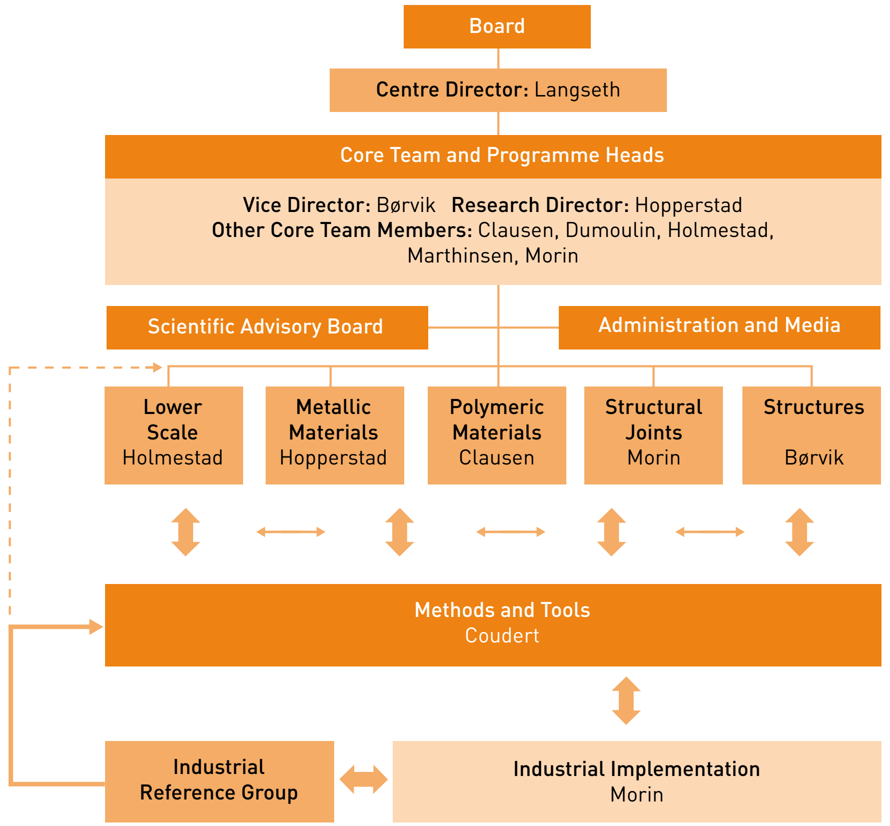


Figure 3: Structure of the organization in 2022

RESEARCH ORGANIZATION

CASA CORE TEAM

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)
Ole Daaland, Hydro Aluminium AS
Eric DeHoff, Honda R&D Americas, LLC.
Cato Dørum, Norwegian Public Roads Administration
Anders Haavik-Nilsen, Norwegian Defence Estates Agency
Agnes Marie Horn, DNV AS
Håvar Ilstad, Equinor Energy AS
Rolf Skåre-Jullum, Ministry of Local Government and Regional Development
Sebastian Kreissl, BMW Group
Christopher McCabe, Norwegian National Security Authority
Philippe Michel, Renault
Nicolas Neumann, Multiconsult Norge AS
Rudie Spooren, SINTEF Industry
Christian Teichmann, Audi AG

Scientific Advisory Board

Professor Ahmed Benallal, LMPS, Université Paris-Saclay, ENS Paris-Saclay, CNRS, 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
Knut Marthinsen, Professor, Dept. of Materials Science and Engineering, NTNU
David Morin, Associate Professor, Dept. of Structural Engineering, NTNU

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Torodd Berstad, Researcher, Dept. of Structural Engineering, NTNU
Miguel Costas, Associate Professor, Dept. of Structural Engineering, NTNU
Virgile Delhaye, Senior Research Scientist, SINTEF Industry
Lars Edvard Dæhli, Researcher, Dept. of Structural Engineering, NTNU
Egil Fagerholt, Researcher, Dept. of Structural Engineering, NTNU*
Anette Brocks Hagen, Research Scientist, SINTEF Industry
Rene Kaufmann, Researcher, Dept. of Structural Engineering, NTNU
Martin Kristoffersen, Researcher, Dept. of Structural Engineering, NTNU
Calin Marioara, Senior Research Scientist, SINTEF Industry
Inga Gudem Ringdalen, Research Manager, SINTEF Industry
Afaf Saai, Senior Research Scientist, SINTEF Industry
Ida Westermann, Associate Professor, Dept. of Materials Science and Engineering, NTNU
Jianbin Xu, Researcher, Dept. of Structural Engineering, NTNU

*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 2022

Host institution

NTNU

Research partner

SINTEF Industry

Industrial partners

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

The Challenge of Welded Joints

Aluminum makes our modern lives work. Sigurd Aune's PhD work could help things work even better.

Ever heard of HAZ or heat-affected-zones? They occur during the welding of aluminium joints and can reduce the strength of the metal. Which in turn can lead to failure and fatal collapse of structures.

«The strength reduction that occurs during welding is one disadvantage of aluminium», says Aune.

He aims to create a simple and effective computer model that predicts the exact behaviour of the zones when welded joints are subjected to extreme loads. Ideally, products and parts should have the same maximum strength all over.

«What happens is that within a few seconds during welding, the area closest to the welding line is exposed to more than 500 degrees Celsius. Thus, the local heat causes a local strength reduction. This is a significant challenge», Aune explains.

Compared to the base material, the zone's strength reduction may be up to 20-40 percent. However, this depends on several factors, such as the welding technique and type, the weld line's length, the geometry, and chemical composition. Also, the HAZ will vary in size. Sigurd Aune's model should be accurate and easy to use for the average industrial designer and engineer. Also, the interaction between many materials and joining techniques must be incorporated. And finally: the model must not be too computationally demanding. «So, basically, we look for a simple solution to a very complex problem» he says.

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.

Metallic Materials:

This programme develops 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 is on aluminium alloys and steel. In many critical structural applications, material properties beyond standard testing conditions are required; hence, there is given special attention to high and low temperatures, high pressures (from blast waves or water depths) and elevated rates of strain (including shock loading).

Polymeric Materials:

This research programme develops 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 are developed for application in an industrial context. Particular attention is paid to validation and efficient identification of the parameters involved in the models.

Structural Joints:

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

Structures:

This research programme develops 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 is to 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.

ICILSM 2022

SFI CASA hosted The International Conference on Impact Loading of Structures and Materials, ICILSM 2022, from 14 to 17 June. The conference gathered more than 100 engineering experts from around the globe. 59 presentations were given, covering all sub-domains of impact engineering.

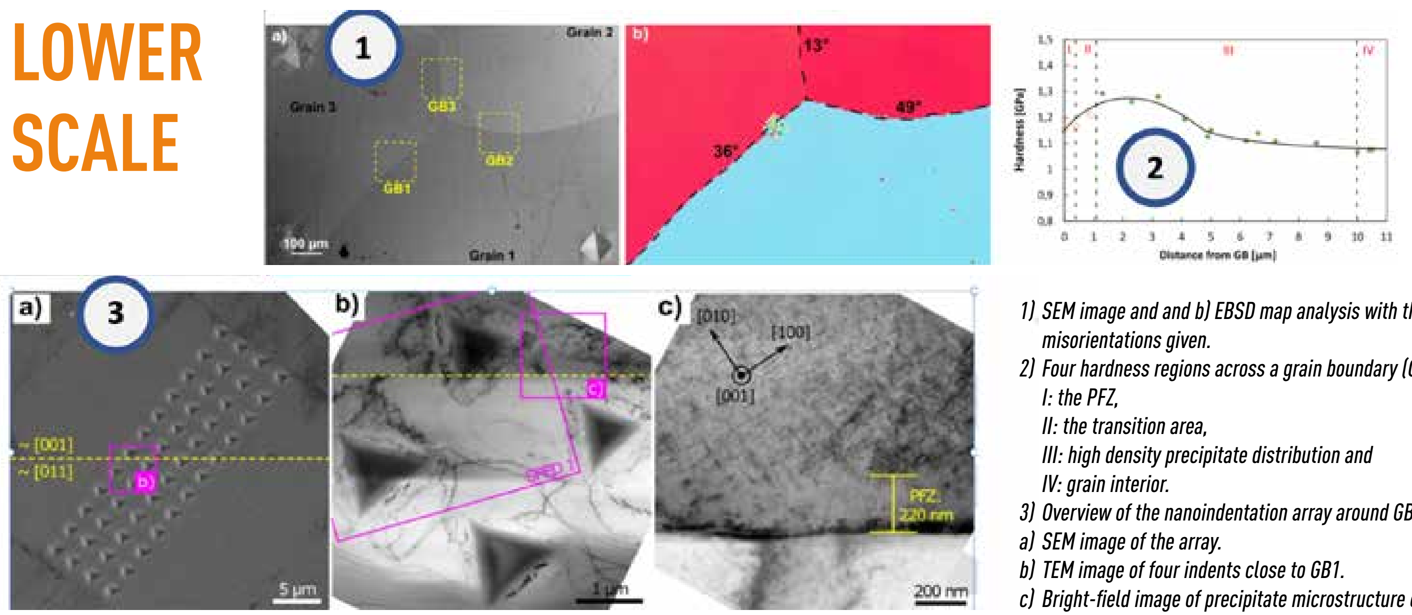
On the evening of the opening day, there was a Concert and welcome reception at the famous Nidaros Cathedral in Trondheim. The next morning, Professor Marcilio Alves entered the stage as the first of 11 reputable experts invited to lecture. Alves is a professor at The University of São Paulo. The topic of his lecture was «Impact Loading of Component and Structures». On day 2, 16 lectures were given during 2 parallel sessions. Professor Genevieve Langdon chaired the session on «Fracture of structures and materials under impact and blast loading». Langdon is a Blast and Impact Engineering professor at the University of Sheffield. The other session, «Dynamic material behaviour and failure» was led by Professor Patricia Verleysen. She is head of the DyMaLab group at Ghent University and a member of SFI CASA's Scientific Advisory Board. On the evening of 15 June, there was a social gathering with quizzes, games, and a barbecue at a charming farm situated outside Trondheim.

It was a typical early summer evening in mid-Norway, 12 degrees, cloudy, and with some rain. However, the mood was excellent.

During the last 2 days of the conference, there were 2 parallel sessions with 14 lectures. There were 9 plenum presentations. The final of all 11 invited lectures was a warm-up for the banquet on 17 June. Francois Moussy (Renault) held his famous presentation on the Dynamic Behaviour of Champagne Bubbles: from initiation to explosion.

The topic of PhD student Victor André´s work is modelling of multilayered joints. He is affiliated in the programme Structural Joints. In the background SFI CASA-senior engineer Trond Auestad. (Photo: Sølvi W. Normannsen)

LOWER SCALE



1. AB Hagen, S Wenner, R Bjørge, D Wan, CD Marioara, RHolmestad, IG Ringdalen, Local mechanical properties and precipitation inhomogeneity in large-grained Al-Mg-Si alloy, Mat. Science and Eng. A, (2022) 144222, https://doi.org/10.1016/j.msea.2022.144222

1) SEM image and and b) EBSD map analysis with the corresponding GB misorientations given.
2) Four hardness regions across a grain boundary (GB):
I: the PFZ,
II: the transition area,
III: high density precipitate distribution and
IV: grain interior.
3) Overview of the nanoindentation array around GB1.
a) SEM image of the array.
b) TEM image of four indents close to GB1.
c) Bright-field image of precipitate microstructure close to GB1.

This programme has concentrated on the lower length scales of materials, from the atomic up to the micrometre scale, and have provided experimental and modelling input to the multiscale framework from the lower scale.

The overall goal of Lower scale is to connect and coordinate the atom- and microscale framework linking the models and the experiments at the different scales. The results will provide a fundamental understanding of mechanical properties and deformation of metal structures in a multi-scale framework (from the nanoscale to the complete structure).

In large-scale simulations of structures, the framework of continuum thermo-mechanics is typically adopted to formulate the constitutive models, while thermo-mechanical testing is used to identify the model parameters. Advanced constitutive models, including plastic anisotropy, non-linear isotropic and kinematic hardening, strain-rate and temperature dependence, damage evolution and failure, tend to have many model parameters, some of which need to be taken from lower scale. In this programme, the microstructure – dislocations, grain boundaries, precipitates, and precipitate free zones – will be studied and modelled in detail. This will work as a basis for achieving improved models and will be used in both model developments and validations.

The knowledge and understanding gained in this programme will be used to further develop the foundation and starting point of the simulation chain (through-scale modelling) in the virtual laboratory. The main objective is to develop a physical and experimentally validated framework at the lowest scale. This includes providing understanding, development, and validation of constitutive models for solute strengthening, microstructure evolution and work hardening in metallic materials, restricted to aluminium and steels. Key approaches in these tasks are numerical simulations by use of ab initio models, physically based models for nano-/microstructure evolution and mechanical response, in addition to advanced electron microscopy experiments.
The activities in 2022 have been limited to a SINTEF study of local mechanical properties in precipitate free zones (PFZs) and close to grain boundaries in a large-grained Al-Mg-Si alloy [1]: In these relatively high strength 6xxx alloys, we find a soft PFZ close to grain boundaries that weakens them and promotes fracture, and thereby reduces the ductility of the material. Through combined nanoindentation hardness measurements and characterization of the microstructure adjacent to the PFZ region and in the grain interior, this study provides insights into the mechanical properties and underlying plasticity behavior. The nanoindentation hardness mapping revealed the soft zone, but also an increase in hardness a few micrometers from the grain boundary with respect to the grain interior. Transmission electron microscopy (TEM) confirmed that the hardness increase was caused by a locally higher density of precipitates. These findings have important implications for the mechanical properties of large-grained (> 100 µm) aluminium alloys. Figure 1 shows the results obtained. Four PhD students have been educated in Lower scale: Emil Christiansen 2019: «Nanoscale Characterisation of Deformed aluminium alloys». Christian Oen Paulsen 2019: «Experimental characterization of two-phase steels». Jonas Frafjord 2020: «Atomistic Scale Modelling of Defects in Aluminium Alloys» Jianbin Xu 2021: «An experimental and numerical study of the Portevin-Le Chatelier effect in an AlMg alloy».

METALLIC MATERIALS

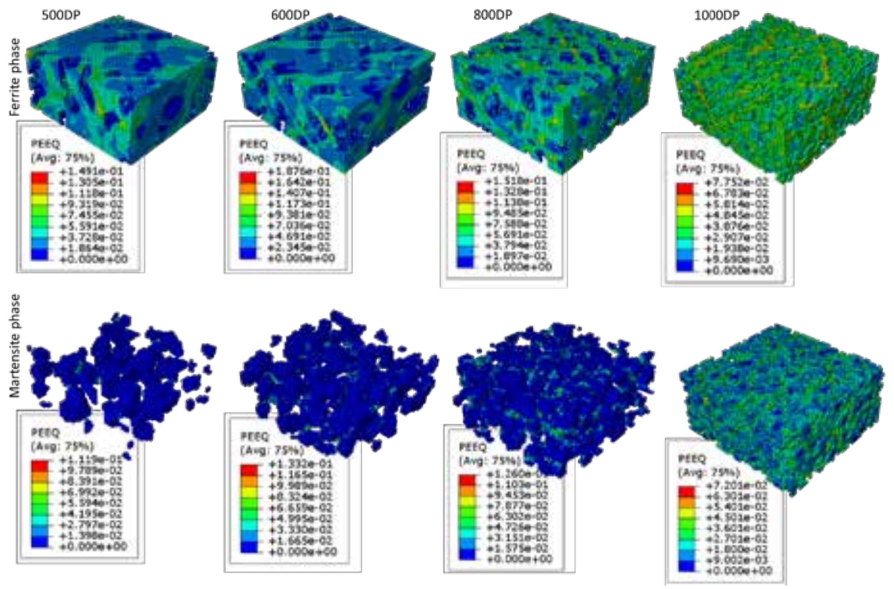


Figure: Micromechanics-based simulation of the distribution of equivalent plastic strain in the ferrite and martensite phases of four dual phase steels with increasing martensite content after prestraining to 3 % uniaxial strain and unloading.

In the Metallic Materials programme, we have developed constitutive models for plastic flow, damage, and failure of structural metals across the length scales, implemented the models in nonlinear finite element codes, validated them against experimental data, and applied them for a range of problems of relevance for our industrial partners.

The research has dealt with aluminium alloys (extrusions and castings) and steels (pipeline steels, dual-phase steels, and martensitic steels) and has combined experiments with mathematical modelling and numerical simulations. A main effort has been to establish a virtual laboratory for studies of the plastic flow and ductile fracture of these structural materials at various length scales. The research activities on aluminium alloys have been closely coordinated with those in the Toppforsk project FractAl (2016-2022) funded by the Research Council of Norway and NTNU and the Lower Scale programme of CASA.

The Metallic Materials program has included three PhD projects:

- Micromechanical modelling of ductile fracture in aluminium alloys (Bjørn Håkon Frodal, 2015-2019)
- Micromechanical modelling of fracture in ductile alloys with applications to high-strength steel (Sondre Bergo, 2016-2020)
- Machine learning and the upscaling problem of material mechanics (Håvard Næss, 2021-2025)

In addition, postdoctoral researchers and SINTEF scientists have been involved in the research in addition to the scientific staff at the Department of Structural Engineering. In addition, master students have been linked to the research activities in various degree.

Selected achievements are summarized below:

- In collaboration with the FractAl project, novel mathematical models for single crystal behaviour of aluminium alloys which couple plasticity with damage and fracture at the microscale have been developed. These models can be applied in studies of plastic anisotropy, tensile ductility, and bendability of aluminium materials.
- An extensive numerical framework for micromechanics-based modelling of ductile failure in structural metals has been developed in collaboration with the FractAl project and makes it possible to reduce the number of experiments necessary to calibrate the parameters of advanced fracture models used by the industrial partners.
- Stochastic models for fracture of aluminium castings have been developed which make it possible to calculate the probability of failure of a cast component. This modelling tool has been implemented at industrial partners of CASA.
- A through-thickness damage regularization scheme for shell elements subjected to severe bending and membrane deformations, coined the TTR model, has been developed and implemented as a standard model in the LS-DYNA and PAM-CRASH finite element codes. The TTR model is currently used by several of the industrial partners of CASA.

The research has led to 28 scientific papers in peer-reviewed international journals, and 5-10 papers are expected to be published in the wind-up period of the centre.

POLYMERIC MATERIALS

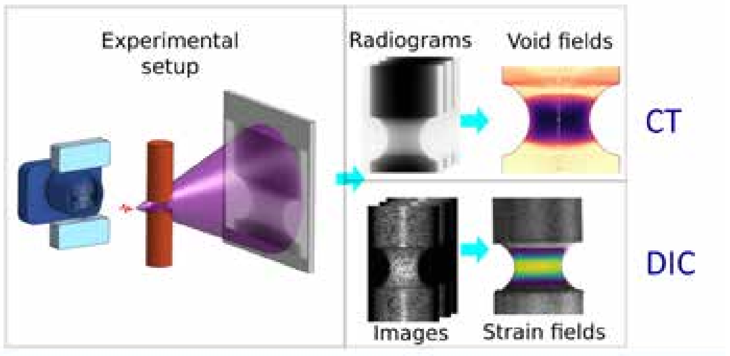
Polymers comprise a wide range of natural and synthetic materials. Applications include safety-related parts in cars, coatings, thermal insulation in offshore components, and various 3D-printed components. The finite element method has only rather recently become a relevant tool in the design process of parts made of polymers. Knowledge about the physical mechanisms governing the thermo-mechanical behaviour is of utmost importance for successful development of material models.

The main objective of the research programme Polymeric Materials has been to develop and improve material models representing the thermo-mechanical response up to fracture for polymers. The models are intended for application in an industrial context.

The research within Polymeric Materials has been carried out through five PhD and postdoc projects:

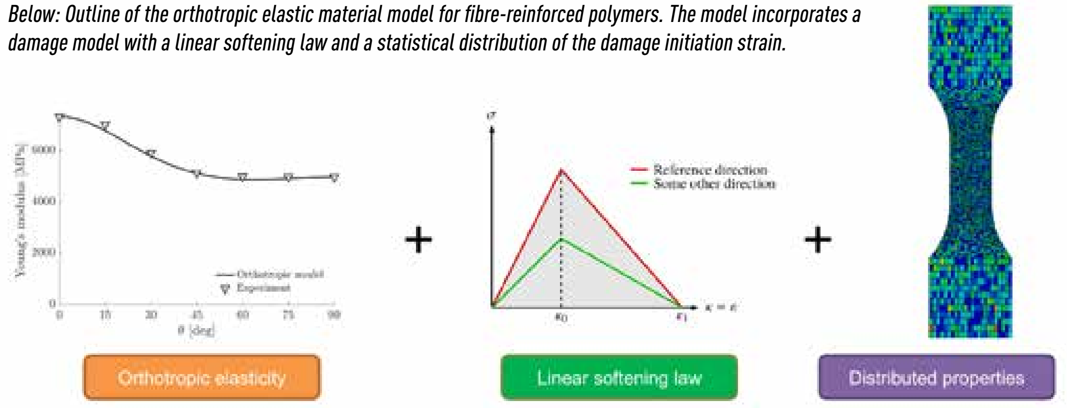
- Ductile failure in polymers (Sindre N. Olufsen, PhD and postdoc project, 2015 – 2022)
- Rate and temperature effects in polymers (Einar Schwenke, PhD project, 2018 – 2022)
- Polymer foams (Daniel Morton, PhD project, 2016 – 2021)
- Fibre-reinforced polymers (Petter Holmström, postdoc project, 2019 – 2020; continuation of PhD project at the previous centre SFI-SIMLab)
- Additively manufactured polymers (Ruben Løland Sælen, PhD project, 2019 – 2023)

The programme Polymeric Materials has had a close interaction with the industrial partners. In addition to suggesting several of the research projects and supplying materials, there has been exchange of people. Three of CASA's researchers (Holmström, Olufsen and Sælen) has spent 2-3 months at Equinor, while a planned stay at Audi (Schwenke) had to be cancelled due to the Covid pandemic. Further, three MSc students did their



Left: Schematic of an in situ tension test in an X-ray tomography setup. A digital camera facilitates determination of the surface strain field through digital image correlation (DIC), while the tomograms give information on the density and hence the void field.

Below: Outline of the orthotropic elastic material model for fibre-reinforced polymers. The model incorporates a damage model with a linear softening law and a statistical distribution of the damage initiation strain.



thesis in cooperation with Equinor, and the topic of the thesis of another three MSc students was proposed by the former CASA partner Toyota.

Selected achievements are summarized below:

- A technique for doing in situ tension tests in an X-ray apparatus. This combination of computer tomography and mechanical testing provides new insight into the underlying mechanisms for plastic deformation and failure.
- Experimental procedures for mechanical testing of polymeric materials at a wide spectre of rates and temperatures.
- Well-suited for fibre-reinforced polymers and other quasi-brittle materials, an orthotropic elastic material model with a stochastic damage criterion was developed and evaluated.
- Hyper-viscoelastic constitutive model suitable for additively manufactured polymers. The model also incorporates a stress-based fracture criterion with a stochastic critical stress.

Academic dissemination includes about 15 journal articles and around 10 conference contributions.

STRUCTURAL JOINTS

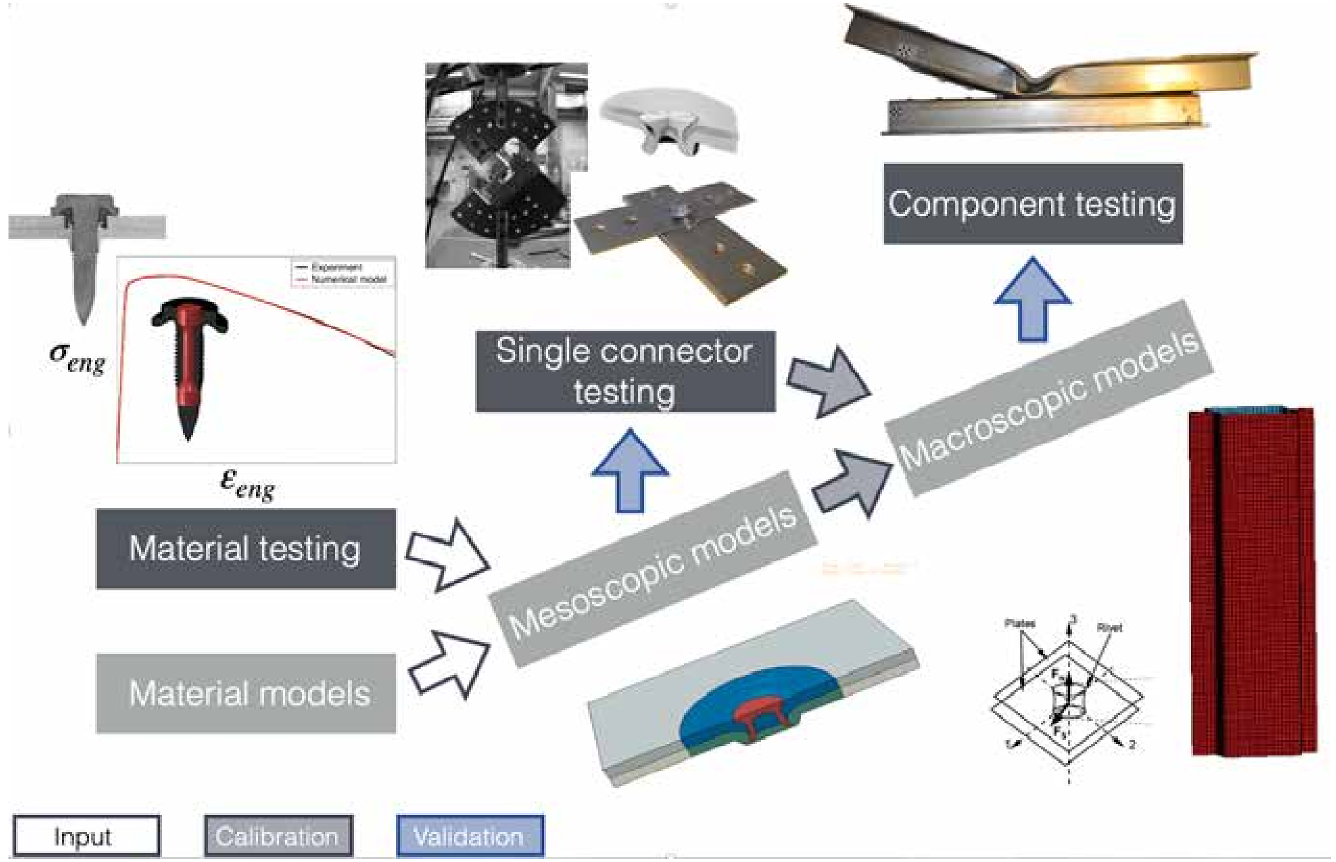
In the Structural Joints (SJ) research program, we are concerned with testing and modelling of connections subjected to quasi-static and dynamic loadings.

The program's primary goal is to develop numerical methods that can account for the strength and ductility of connections in a large-scale analysis setting. By this term, we mean that a successful model should be able to predict the correct overall response of a connection in terms of forces, displacements, and fracture without affecting the computational time of a structural analysis.

To reach that goal, as part of the SJ program, we have developed a multi-scale testing and analysis strategy illustrated in the figure. In this strategy, which is applied in nearly all PhD projects, we conduct experiments on different levels from material up to component.

In addition to testing, the modelling activities are divided into mesoscopic and macroscopic levels. While the macroscopic modelling activities are the project's main deliverable, the mesoscopic models are used to understand the mechanical behaviour of the studied connections more deeply and to provide data for calibration of the macroscopic models.

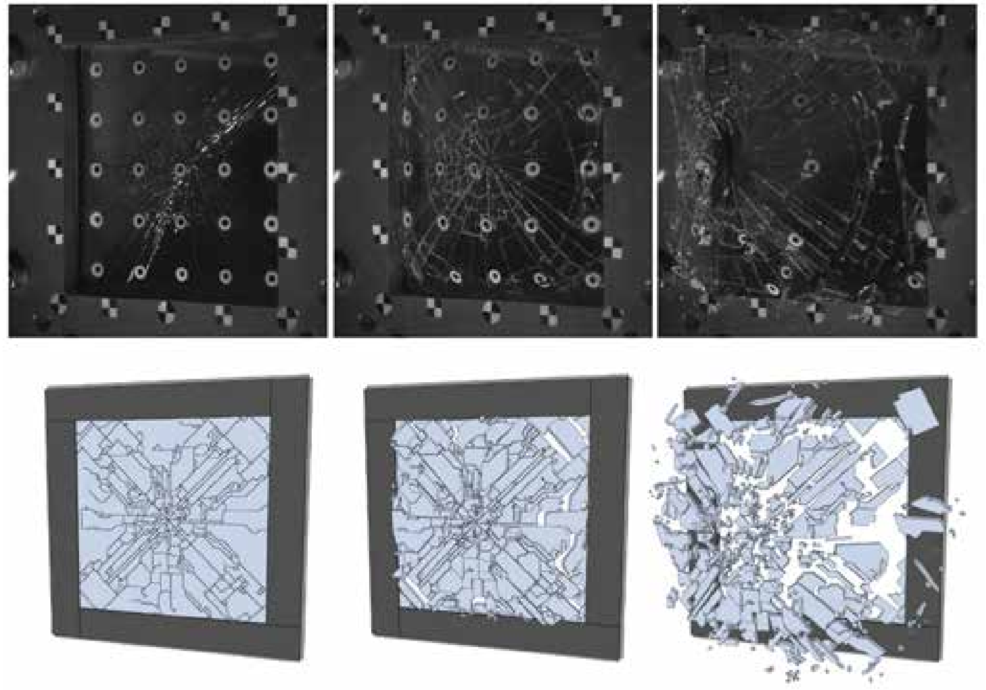
As part of the SJ program, 8 PhD theses have been carried out, 5 of them will be defended before the end of SFI-CASA. The 3 remaining theses will be defended during the windup period. In addition to the PhD students, 3 postdocs or researchers have been linked to the program on shorter-duration projects. Across these projects, we have investigated several joining techniques, such as self-piercing rivets, flow-drill screws, adhesive bonding, welding, and bolted connections. Academic dissemination includes about 21 journal articles and 16 conference contributions



PhD projects:

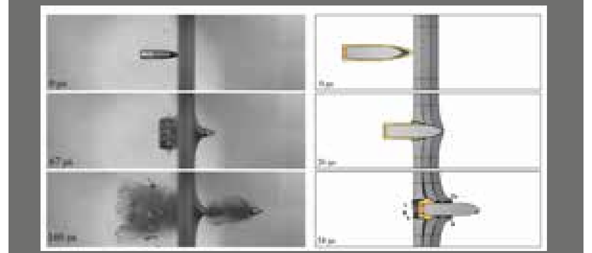
- Behaviour of steel connections under quasi-static and impact loading - An experimental and numerical study (Erik Løhre Grimsmo, 2013-2017)
- Behaviour and modelling of flow-drill screw connections (Johan Kolstø Sønstabø, 2013-2018)
- Testing and modelling of multi-material joints (John Fredrick Berntsen, 2015-2020)
- Connections between steel and aluminium using adhesive bonding combined with self-piercing riveting: Testing, modelling and analysis (Matthias Reil, 2016-2019)
- Behaviour and modelling of multi-layered connections in crash applications (Victor Andre, 2018-2022)
- Welded connections in aluminium structures (Sigurd Aune, 2020-2024)
- Adhesive bonded joints under crash loadings (Fanny Dameme, 2021-2024)
- Bolted connections in civil engineering structures (Deborah Obkircher, 2022-2026).

STRUCTURES



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

Design against accidental loads, such as explosions, impacts and collisions, has become increasingly important in many engineering and industrial applications. To meet the challenges posed by such extreme loading conditions, product development and structural analysis are often carried out in virtual environments using the finite element method (FEM) to achieve safer and more cost-effective designs. The long-term goal of this research programme is to improve the survivability of people and vital infrastructure to a given threat. It is thus of utmost importance that protective structures are designed and validated on a sound theoretical and experimental basis. To do so, accurate, efficient, and robust constitutive models and solution techniques used in a multi-scale modelling context are required. Further, new designs need to be validated through high-precision experimental tests involving advanced instrumentation such as three-dimensional digital image correlation for full-field displacement and strain measurements. Although much information can be obtained from laboratory tests, relying on such an approach would be too costly and inefficient. Computer-aided design, together with a strategy for material selection, optimization, and well-selected validation tests, can significantly lower the cost and enhance the overall quality and efficiency of the required protection. The main objective of this research programme has been to develop and evaluate new computational tools and establish validated modelling techniques for safer and more cost-effective protective structures. Another objective has been to replace phenomenological models with more physically based models in a top-down/bottom-up multi-scale modelling approach to reduce the number of mechanical tests as much as possible in the design phase. This part has been carried out in close collaboration with the other research programmes within CASA.

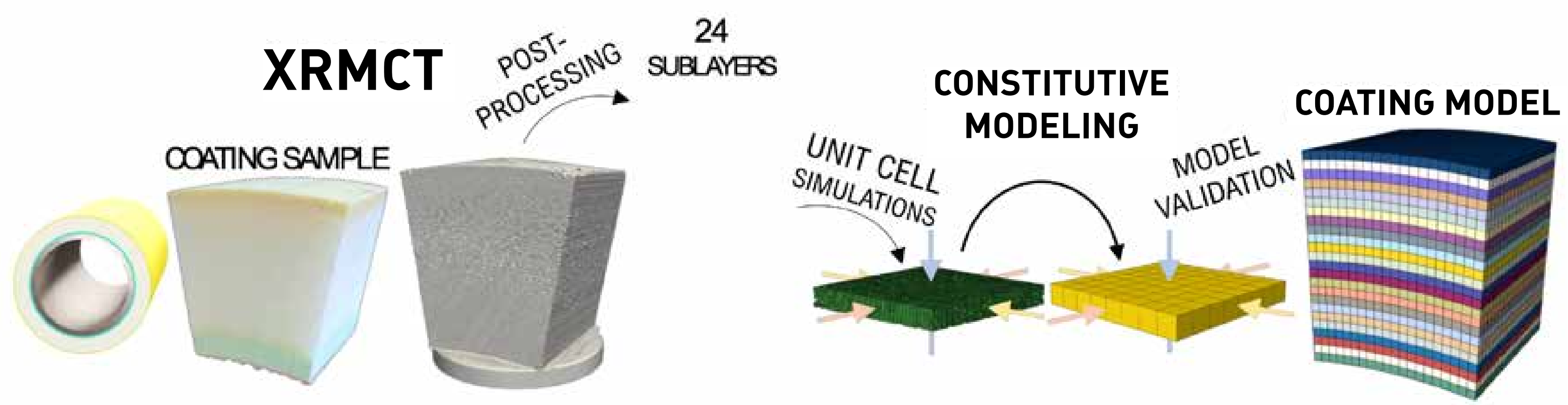


Comparison between high-speed camera images (left) and simulations (right) using the IMPETUS Afea Solver from a ballistic test where a layered and case-hardened steel plate is perforated by an armour-piercing bullet.

The Structures programme has included seven PhD projects:

- On the modelling of fragmentation of window glasses exposed to blast loading (Karoline Osnes, 2015-2019)
- Impact on porous polymer coated pipelines (Ole Vestrum, 2016-2020)
- Modelling and optimization of sacrificial claddings exposed to blast loading (Kristoffer A. Brekken, 2017-2023)
- Behaviour, modelling and simulation of thin steel plates subjected to combined blast and impact loading (Benjamin Stavnar Elveli, 2018-2022)
- Modelling of fracture and fragmentation of monolithic and laminated glass under extreme loadings (Jonas Rudshaug, 2019-2023)
- Hypervelocity impact (Rannveig M. Færgestad, 2021-2025)
- Modelling of concrete exposed to dynamic loading (Øystein E. K. Jacobsen, 2021-2025)

In addition to the PhD-candidates, master students, postdocs, and scientific staff at SIMLab has been involved in the various research activities.



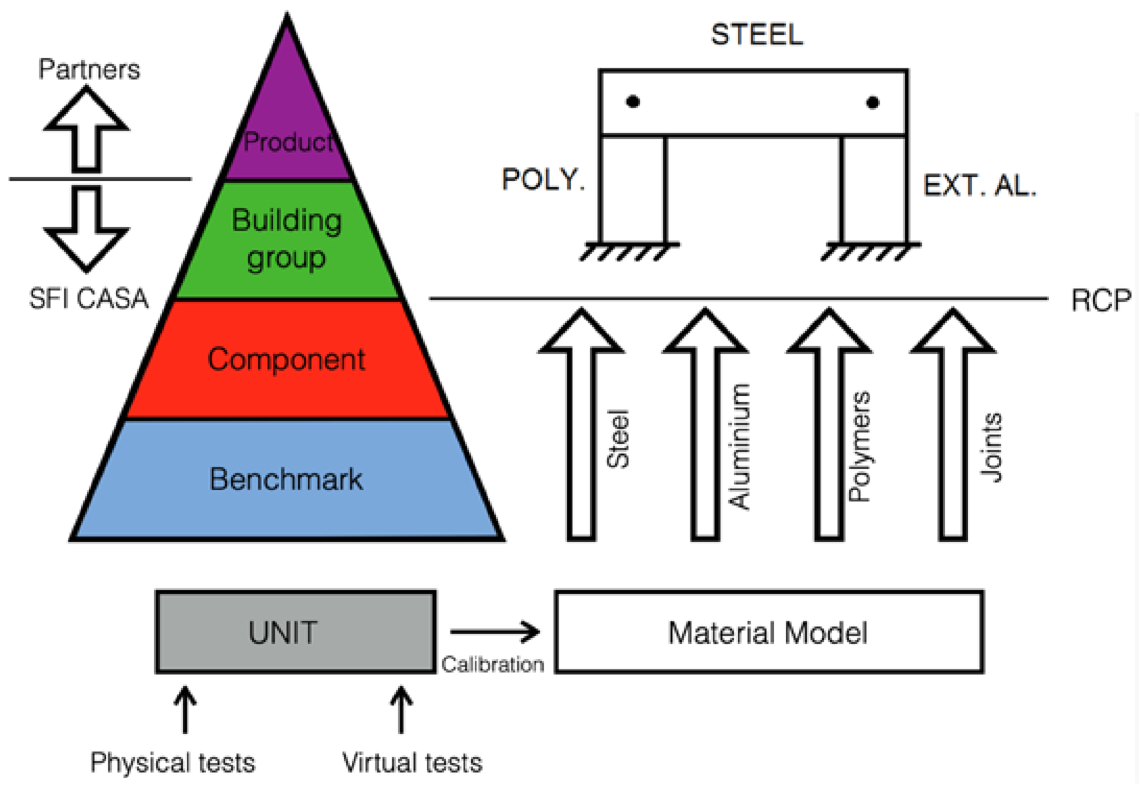
Constitutive modelling of a graded porous polymer used as pipeline coating based on X-ray computed tomography – overview of the various modelling steps.

Selected achievements are summarized below:

- **The strength prediction model for glass (SSPM) for estimating the probabilistic fracture strength of windows.** The probabilistic fracture strength of glass depends on several factors such as the geometry, the loading situation, and the boundary conditions. The SSPM can be used to estimate the probability distribution for laminated and monolithic glass.
- **A large experimental database, including numerous tests on monolithic and laminated glass.** The database contains of both quasi-static and dynamic tests, including low-velocity impact test, ballistic impact test, blast-load test, and bending tests, in addition to windscreen test.
- **Numerical studies on the post-fracture behaviour of monolithic and laminated glass using finite element simulations.** Several numerical techniques have been studied to recreate the post-fracture behaviour of monolithic and laminated glass under extreme loading. In addition, the strength prediction model has been implemented as a user material model in LS-DYNA.
- **Constitutive modelling of a graded porous polymer based on X-ray computed tomography.** A novel framework to model the graded porous polymer used as coating on pipelines has been established where XRMCT is used to characterize and model the macroscopic structure.
- **A fully coupled physical-virtual laboratory for studies on blast loading against deformable structures.** The main objective with this laboratory is to increase our understanding on the occurrence of fluid-structure interaction (FSI) effects during the dynamic response of plated structures exposed to blast loading.
- **Extension of the shock tube.** SIMLab's shock tube has been extended with a transparent section for detailed studies of deformable components subjected to air-blast loading.
- **Studies on the combined effect of fragment impact and blast loading on thin steel plates.** Experiments and numerical simulations have been used to identify scenarios where this type of combined loading may be crucial for the design.
- **Ballistic perforation resistance of concrete slabs.** The accuracy of the MHJC model in predicting the ballistic perforation resistance of concrete slabs has been proven. The extensive experimental database on both normal and low-carbon concrete slabs will serve to validate other constitutive models available in FE codes.
- **Additively manufactured protective structures.** We have tested and simulated additively manufactured steel and aluminium components under ballistic impact. We have seen that additively manufactured metals perform at least as good as their cast-produced equivalents.
- **Spacecraft protection.** Numerical modelling of hypervelocity impacts on aluminium Whipple shields for spacecraft protection, using a coupled FEM-DEM method, and comparing results to experimental data from literature and from conducted experimental campaigns.

The research has led to roughly 50 scientific articles in peer-reviewed international journals and almost 60 conference papers at various international conferences. It is also expected to be published more than 10 journal articles in the wind-up period of SFI CASA.

INDUSTRIAL IMPLEMENTATION

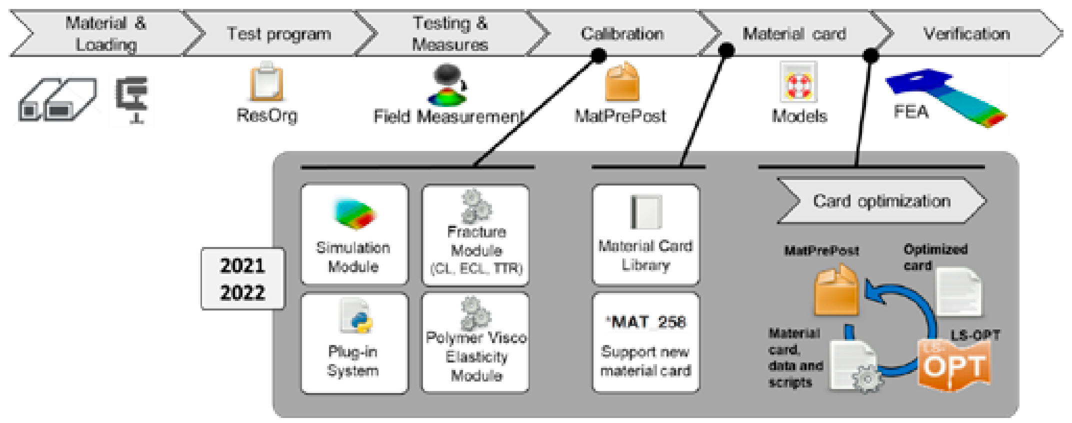


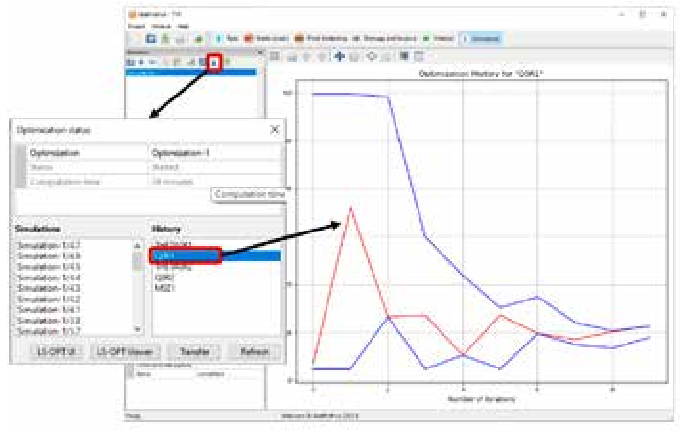
In the industrial implementation programme, we mainly deal with the transfer of technology from the Centre to the user partners. The activities in the programme started early in the SFI period, when we sent several surveys out to the user partners. One of the first activities carried out together with the Industrial Reference Group (IRG) was to define «Industrial Implementation». Two aspects were defined and used throughout the Centre´s period. In a short-term perspective, we defined «How to use the tools?» and in the long-term, we defined «transfer of technology for daily use».

Another significant activity in the Industrial Implementation programme, was to develop a validation strategy (illustrated in the Figure) since a critical aspect of numerical simulations is their actual accuracy when simulating structures subjected to impact loadings. To this end, we have developed a systematic approach for the validation of numerical models and applied this procedure to several materials (steel, aluminium, and polymers) and different joining techniques. The test data and their numerical counterparts, have formed the basis for training datasets. These datasets have further been used together with the user-partners to fulfill the «How to use the tools?» aspect of industrial implementation.

An essential part of the Industrial Implementation programme has been the IRG meetings held twice a year. Here, the CASA personnel and the user-partners could exchange ideas on several aspects linked to technology transfer. In addition to the progress made on the validation strategy, experiences from the user partners linked to "how to transfer technology?" using masters' students, PhD candidates and postdocs were discussed. These IRG meetings also acted as a forum where mature technologies were identified. These mature technologies were then transferred to commercial versions of the finite element solver in use at the user partners. This has been a crucial step to cover «transfer for daily-use» aspects of industrial implementation.

METHODS AND TOOLS





The Methods and Tools Programme provides a synthesis of the basic research carried out in the Centre in order to facilitate the Industrial Implementation at the industrial partners. M&T has developed tools and software and has established guidelines and recommended practices for reliable numerical structural analysis. Those tools support and guide the user to select the suitable material model, to process experimental data, and to calibrate and optimize the material model parameters.

The development of the SIMLab Model Library has been a key activity to select the ingredients of the material model used at the industrial partners. A simplified version of the SIMLab Metal Model (SMM) has been implemented as MAT_258 in LS-DYNA and MMAT in VPS/PAMCRASH. Some parts of the SIMLab Polymer Model (SPM) have been implemented in the MMAT polymer in VPS. Other developed models like the SIMLab Crystal Mechanics Model (SCMM) and SIMLab Porous Plasticity Model (SPPM) have been used in the different research programmes. A development framework has been established recently to support the current and future research in the Centre. This framework provides a set of user-material models which can be tailored to specific problems and can be combined with a generalized non-local modelling framework.

An experimental test program is the main input to calibrate the parameters of a material model. A library gathering test specimen drawings and main geometric parameters to consider before testing has been built. In addition, the software eCorr can be used to monitor the deformation of the specimen during testing using either the Digital Image Correlation technique (2D or 3D), digital target tracking, or optical edge tracing.

In close collaboration with the Metallic Materials programme, a workflow has been developed to generate a discrete yield surface atlas. It is a combination of a set of scripts, the DREAM.3D software and FE simulations using ABAQUS/LS-DYNA. In addition, PhD B.H. Frodal has developed an application to calculate the discrete yield surface of an FCC polycrystal using the full-constraint (FC) Taylor homogenization approach. In both above approaches, the discrete yield surface data can be used to calibrate the phenomenological Yld2004-18p yield surface.
A software, MatPrePost, has been designed and developed to provide identification procedures for various material model (e.g. SMM, SPM, MAT_258, MMAT). After processing the experimental test data, the user calibrates model parameters (like the thermal sensitivity parameters or the through thickness regularization, etc.) and transfer those parameters to a material card for ABAQUS, LS-DYNA or VPS/PAMCRASH. A procedure is available to optimize automatically a selected number of parameters in a material card (like to optimize the work hardening parameters to simulate the post-necking behaviour), using the software LS-OPT.

The SIMLab Toolbox App is the entry point of many tools developed in M&T. The user can access the tools with a Graphical User Interface: plan a test program, launch DIC software and visualize images, calibrate material model parameters, export calibrated material cards from a library, access theory manuals and tutorials, access other advanced tools (e.g. generating and representing texture, launch FC-Taylor App).

In addition, a post-processor tool for probabilistic failure in finite element analysis, the SIMLab Probabilistic Failure Modelling (SPFM), has been implemented based on the work done in the PhD thesis of O. Knoll at SFI SIMLab.

COOPERATION WITHIN THE CENTRE

Collaboration with partner the Norwegian Defence Estates Agency (NDEA). A part of PhD student Øystein Eirik Kvist Jacobsen´s doctoral work is comparing the carbon footprint of standard and low carbon concrete. Here, he and his supervisors, Professor Tore Børvik (left) and Dr Sumita Dey (right) study the results of a projectile penetration test in SIMLab´s ballistic lab. Dr Dey is a Senior Engineer and Researcher at NDEA. In the background Senior engineer Trond Auestad at SFI CASA. (Photo: Sølvi W. Normannsen)

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.

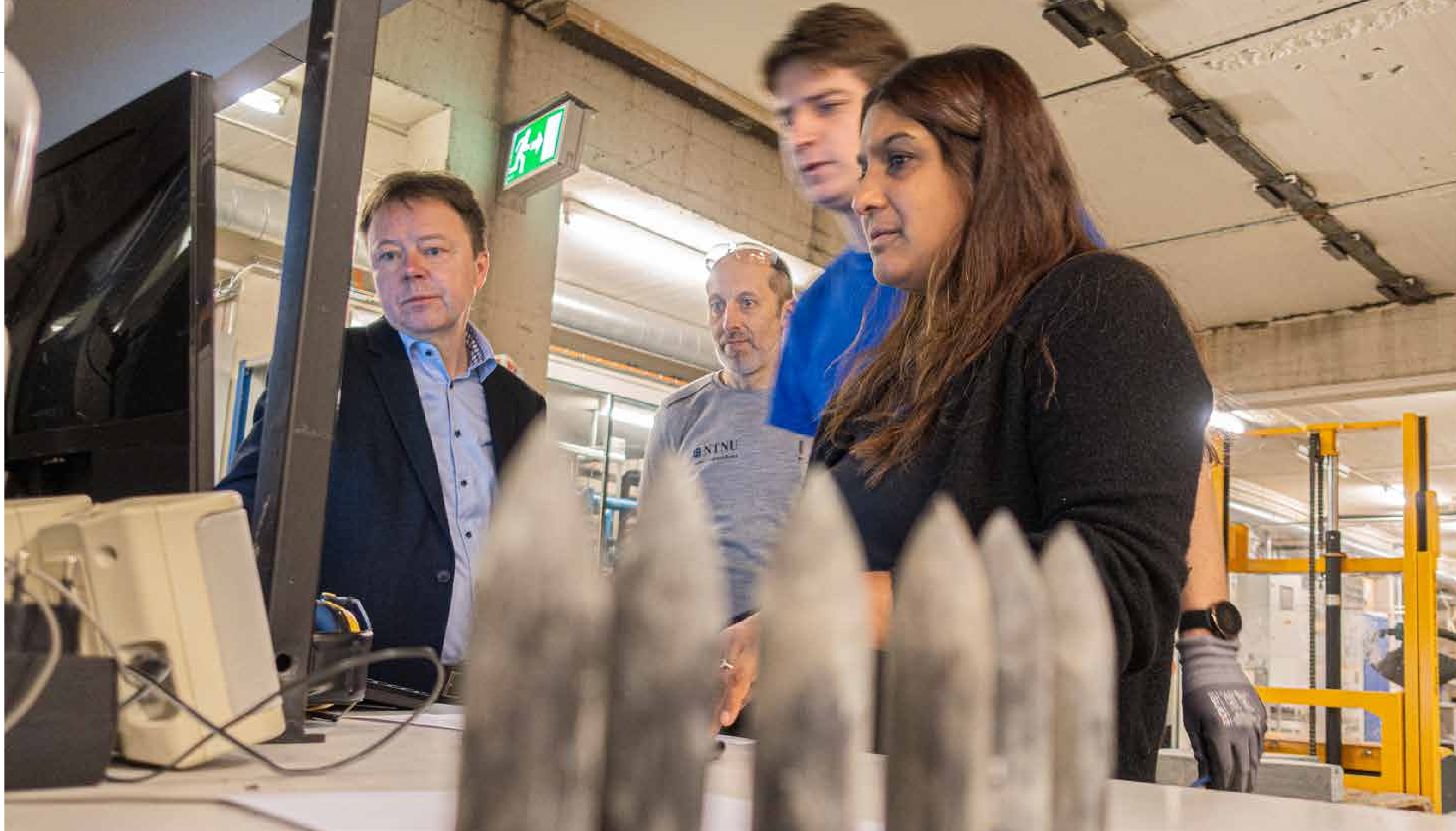
SFI CASA's Industrial Reference Group (IRG) was convened three times in 2022; in March, November, and December. Each industrial partner has one member in the IRG, whose mandate is to give advice on how implementation should be facilitated and to evaluate the implementation work at each partner. This work has been intensified now as the Centre is soon to be ended.

The research in the Centre is mainly carried out by NTNU (PhD candidates, postdocs, 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. Norwegian Public Roads Administration and Hydro Aluminium AS are sponsoring one Adjunct Professor position each at the Department of Structural Engineering, NTNU. This is to strengthen the link between the industry and the PhD and MSc students at SFI CASA.

Furthermore, the Core Team has bi-weekly meetings, led by the Centre Director. A number of seminars and talks have been held online through 2022.

The Centre Board met online on 1 June and face-to-face on 9 November.



Pipelines put to test. Senior engineer Tore Wist, Researcher Lars Edvard Dæhli (middle) and PhD student Øystein Eirik Kvist Jacobsen (right) put pipelines to quasi-static tests in SIMLab´s test facilities.
(Photo: Sølvi W. Normannsen)

A Master´s in Cracked Windscreens

Master´s student Einer Herrem´s great interest in cars has led him to destroy 21 windscreens. The aim is to model how the safety glass behaves under impact.

The laminated glass used in car windscreens has essential safety components, both for pedestrians and passengers. Fortunately, few of us have heard or seen what happens when they break. This MSc student has. During spring 2022, he pressed glass panes to their breaking point and heard the characteristic crackling sound of glass giving in 21 times. The topic of his thesis was «Modeling of laminated glass» and was part of the ongoing collaboration with CASA-partner BMW.

Typically, a windscreen consists of two glass panels laminated with a polymer. Polyvinyl Butyral (PVB) is the most used interlayer in such safety glass. Laminated glass reduces the risk of dangerous glass fragments. In a collision, the pieces will be stuck in the PVB foil after breaking. To optimize the windscreen against various loads, it is crucial to understand the behaviour of the glass, the polymer, and the component as a whole. Due to existing microcracks in the glass surface, there will be a large spread in the performance of a pane. This must be considered in connection with numerical calculations.

«We captured the crack propagation with high-speed cameras. «The tests have been very successful. They replicate what we see in the literature in some areas. We have also seen unexpected results», says Herrem. His work has added important input to SFI CASA´s glass models.

Members of the Norwegian Parliament Paid us a Visit

SFI CASA was one of the selected places to visit when the Standing Committee on Education and Research arrived at NTNU on 4 April 2022. Director Magnus Langseth presented the Centre´s activities and the initiative to establish a national center for physical security. The committee has 13 members who are responsible for all matters relating to education and research, including coordinating Norwegian research policy. During their visit to NTNU, they gained insight into research areas such as energy, aquaculture, digitalization, and cyber security.

Their hosts were Anne Borg, NTNU´s rector; Marit Reitan, pro-rector for education;Tor Grande, pro-rector for research; and Toril N. Hernes, pro-rector for innovation. Also, Olav Bolland, the dean of the Faculty of Engineering and chair of SFI CASA´s board, was present.

In his presentation, Professor Langseth reminded the audience that the project period for SFI CASA ends in mid-2023. The Centre has put a lot of effort into the possibility of establishing a new national centre for research within physical security.

This initiative will help educate more MSc and doctoral engineers who are trained to use the latest tools and think holistically about safety. The visit included the test facilities at the Department of Structural Engineering, next to the Pendulum Impactor. After the presentation, the politicians had a demonstration where an aluminium profile was subjected to a 40 kph crash test.

New Close-range Explosion Studies

During a few days of spring 2022, 30 blast loads were detonated inside one of the Norwegian Defence Agency's (NDEA) test facilities.

The aim of the destruction by CASA and its partner NDEA was to address the complexity of close-range detonations. Several studies show how near- and far-field blast events affect blast-loaded structures. «Thus, we know quite a bit about the loading and what happens when significant explosive charges detonate some distance from a critical infrastructure. Such incidents have been the main threat in historical explosive events, » says Associate Professor Vegard Aune.

Close-range detonations imply complex interactions between the blast overpressure and expanding detonation products such as fireballs. Today's computational tools enable advanced simulations.

«We must challenge the existing methods for near- and far-field events and see how they work for modelling the effects of blasts in small, confined spaces,» Aune says.

The actual loading environment is not yet fully understood. The core question is, «what is the load»? This is an essential element of uncertainty because it affects the behaviour of the material and its structure. We want to explore this to provide models which give reliable predictions».

Dr Ole Vestrum, a senior engineer and researcher at NDEA, says the purpose is to become better acquainted with studying and calculating explosion loads. «The work is part of NDEA's continuous research efforts to form the best possible basis for our advisory assignments,» Vestrum says.

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 four companies from outside Norway (Audi, BMW, Honda, and Renault). SFI CASA also has strong interaction with universities, companies, and research organizations abroad. In addition, several industrial partners have subsidiary companies abroad and offer services and goods to the international market.

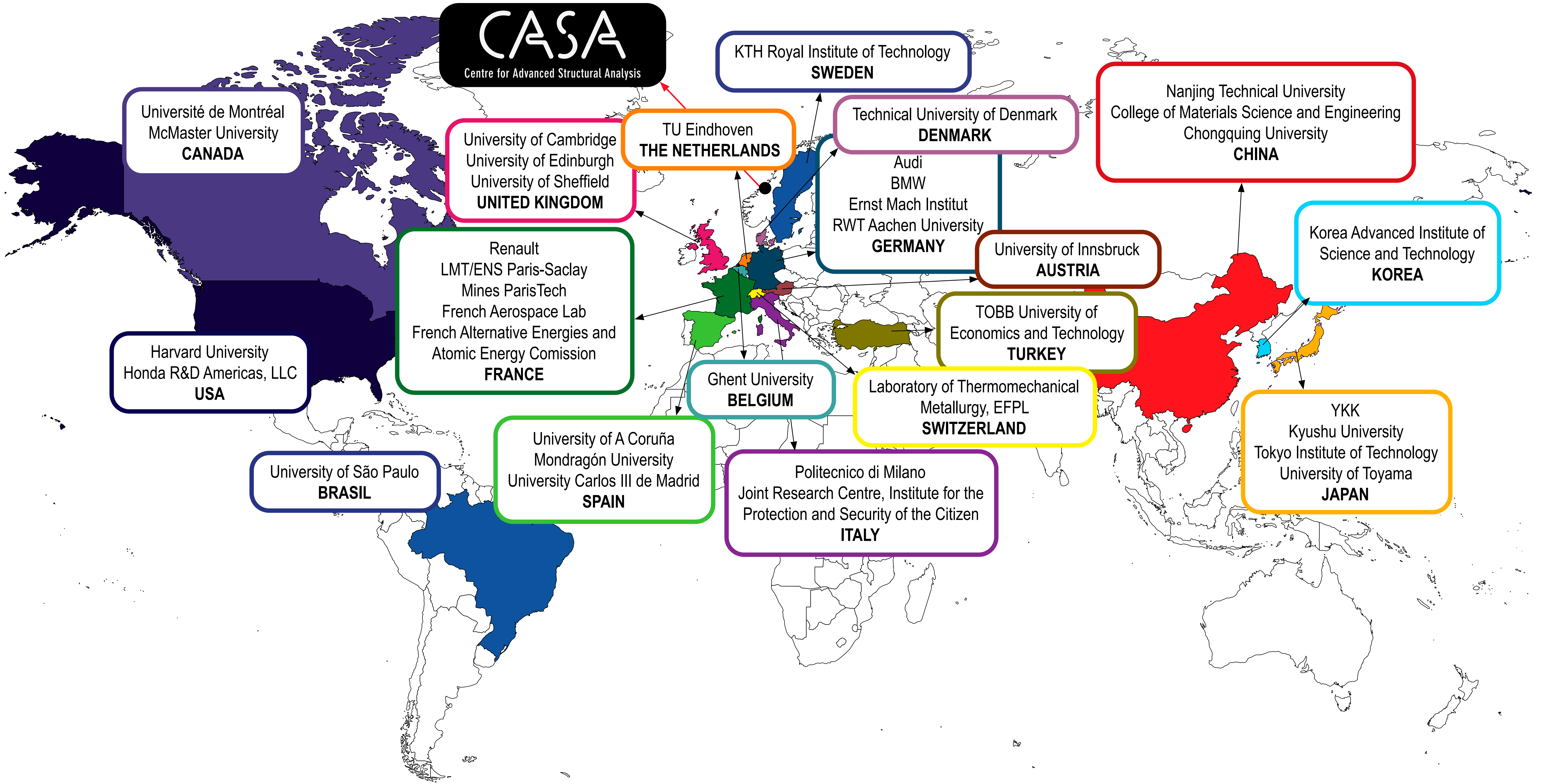
SFI CASA is a member of the European Automotive Research Partners Association, EARPA, an association of automotive R&D organizations. Four key researchers in SFI CASA are members of the DYMAT, a European association for the promotion of research into the dynamic behavior of materials and its applications.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

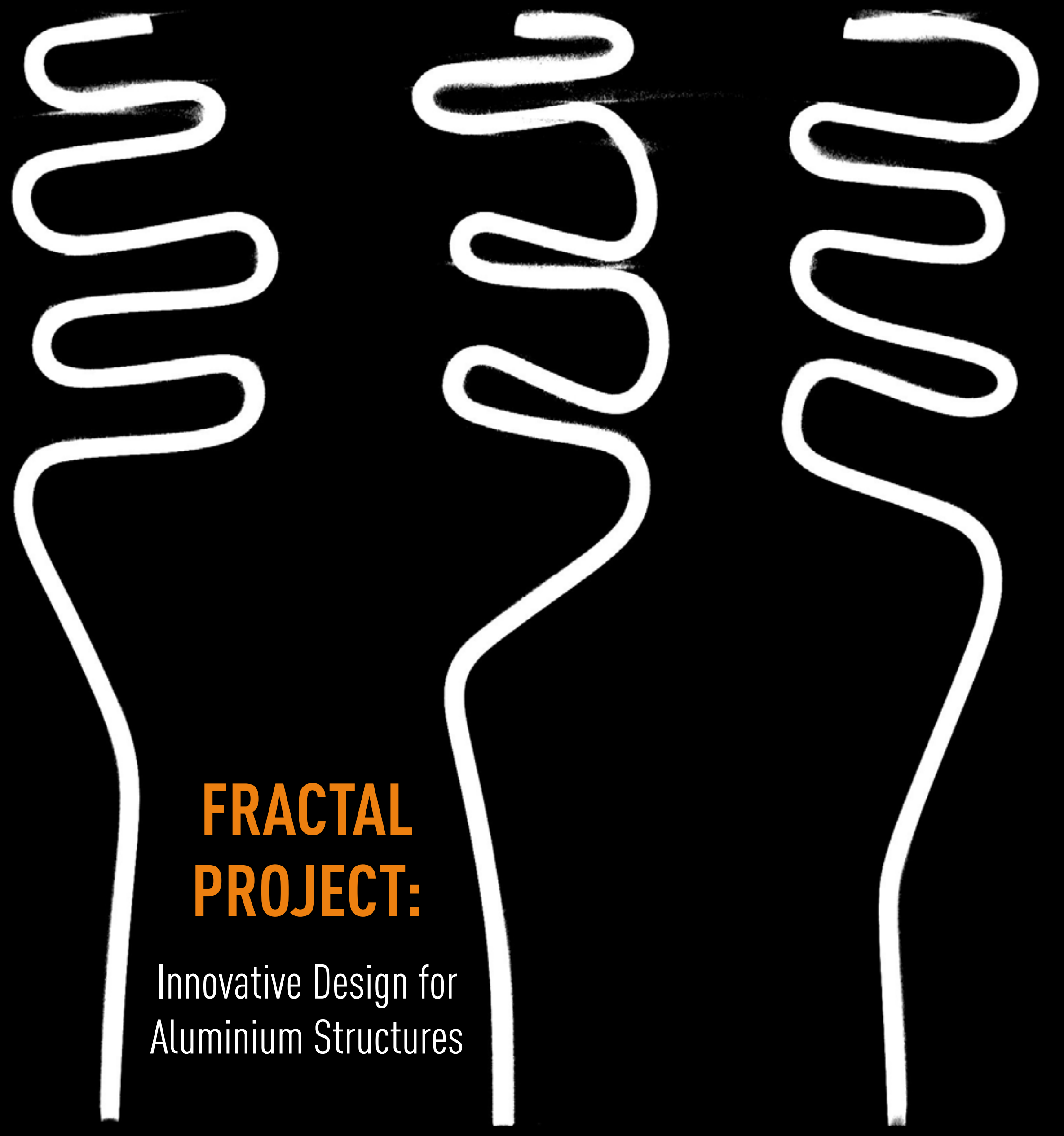
SFI CASA's key researchers all have an extensive international network. This is partly a result of the researcher's visibility in the academic society through publications in peer-reviewed journals and presentations at international conferences. In addition, three of the Centre professors are editors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

The cooperation with top international research groups ensures that the Centre transfers leading-edge technology to the partners. It also enables the group to find innovative research areas important to the partners.

SFI CASA aims at being world leading. Reaching that goal requires advice from the best. A Scientific Advisory Board (SAB) of international experts has been appointed. The advisory committee met in Trondheim in November 2022 to assess CASA's work and to give advice for future research.

The map shows the companies and research institutions that the group have cooperated with through 2022.





A slice of an X-ray CT scan of a crushed double-chamber aluminium crash box, showing progressive buckling of the profile walls. The experiment was part of Kristin Qvale's PhD work.

FRACTAL PROJECT:

Innovative Design for Aluminium Structures

When launching the programme in 2016, the then 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 only allocated to projects with the highest score from reviews by panels of international referees.-

The Toppforsk project FractAl started in August 2016 and ended in May 2022. It has been a concurrent project to SFI CASA, and the activities have been coordinated closely with the activities in the Centre. The project has dealt 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 full advantage of ductility. For aluminium alloys, increased strength often comes at the expense of the ductility of the material, meaning that 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 has been developed and validated. It has involved modelling and simulation at multiple scales as well as customized laboratory experiments. Besides building a basic understanding of ductile fracture in aluminium alloys, the modelling framework enables designers and engineers to select the most suitable aluminium alloy for a given structure with fewer time-consuming and costly mechanical tests. The framework can also be used to tailor alloys with ideal strength and ductility for a given structure. This could pave the way for an entirely new way to design aluminium structures.

The results obtained in FractAl have been implemented in the SIMLab Toolbox. They have thus been made available to the partners of CASA and others in the industry.

The core team of the project has consisted of professors Odd Sture Hopperstad (principal investigator), Tore Børvik, and Ole Runar Myhr at SIMLab, Department of Structural Engineering, NTNU. Associate professor David Morin at SIMLab has also been a significant contributor. Professors Ahmed Benallal and Jonas Faleskog have been international collaborators. Four PhD candidates have successfully earned their doctoral degrees in the project. Two postdoctoral researchers have been involved in the research.

SIGMALab Meets SIMLab

In the winter of 2022, Luca Lomazzi arrived from Politecnico di Milano to blast metal plates in the SIMLab Shock Tube Facility. His doctoral work uses artificial intelligence methods to predict how structural damage evolves in metals and structures exposed to severe blasts and assess the response. Well into his 2nd year of doctoral studies at the SIGMALab research group in Italy, he began searching for a test facility. He needed access to new experimental data and wanted to develop novel data-driven approaches to enhance numerical models.

The ball started rolling when he came across SIMLab's Associate professor Vegard Aune´s work. Eventually, the two of them teamed up with SIMLab's Associate professor David Morin, colloquially known as Mr. Machine Learning. During his stay, Lomazzi tested steel, aluminium, and titanium plates under blast loads. He worked in close collaboration and under the supervision of Vegard Aune.

«I will bring home loads of new experimental data. Plus, a new way of using Machine Learning. I think the stay at the SIMLab group will make up the most important part of my doctoral work,» Lomazzi said when he headed back to Italy in April.

At the ICILSM 2022 conference in Trondheim, the Ph.D. candidate presented a lecture titled «A Data-driven approach to account for fluid-structure interaction effects on blast loaded steel plates». The lecture extracted a joint conference paper with Lomazzi's supervisors, Professor Andrea Manes, Francesco Cadini, David Morin, and Vegard Aune.

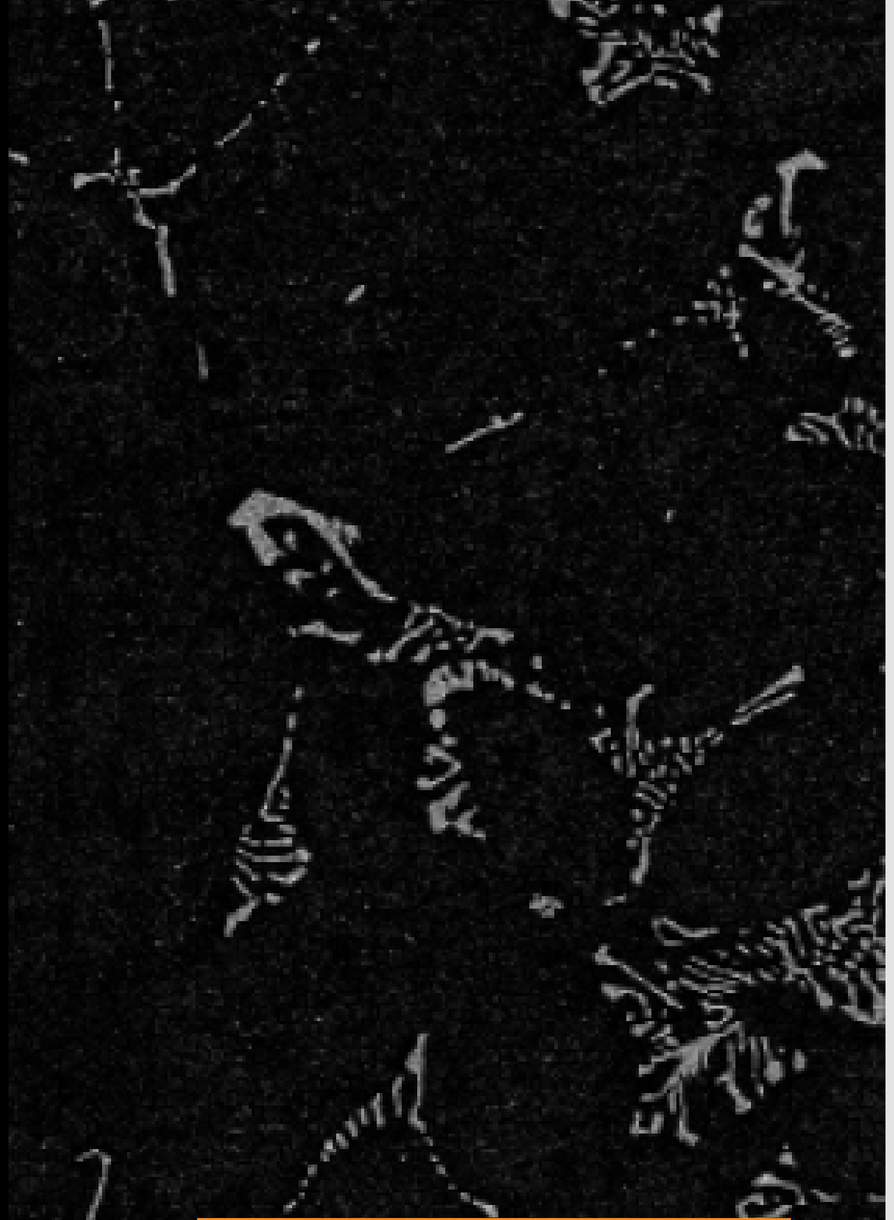
Honour and Glory to Rannveig Marie Færgestad

In spring 2022, SFI CASA´s PhD candidate Rannveig Marie Færgestad received the Norwegian Industrial Forum for Space Activities (NIFRO) prize for the best space-related master's thesis in 2021. Færgestad completed her MSc thesis at SFI CASA. The title was «Modeling and simulation of hypervelocity impact against debris shields for spacecraft protection.» NIFRO and Andøya Space hand out the NIFRO Award every year, and Færgestad was announced as the winner at the annual Space Conference's industry dinner in Oslo on 10 May.

In their justification, the Jury stated, "Space debris is a growing threat to current and future low-Earth spacecraft. There will be a need to meet this threat to ensure the future exploration of space. Here, protective shields can be a significant contributor».

Further, they recognize that Færgestad presents a valuable approach to modelling impact. «The candidate ensures that the spacecraft of international and Norwegian space players can withstand potential collisions and contribute to a sustainable future in low-Earth orbit.»

The Jury announced that the candidate had worked on a complex task with mathematical modelling, simulation, and the processing of results. Færgestad´s passion for space technology is getting more and more attention. In the autumn, she was honored with the "Young Spaceport Norway Award" at the Spaceport Norway 2022 Conference and Expo in Oslo, Norway. She got the prize for her master's and doctoral work at NTNU and for being particularly active in organizations that bring together students interested in space travel. She has both started and led the rocket association Propulse NTNU and the umbrella organization Space NTNU.



ASLE JOACHIM TOMSTAD

THESIS: «Ductile fracture of aluminium alloys in the low to moderate stress triaxiality range»

DEFENCE: 16 May 2022

SUPERVISORS: Professors Odd Sture Hopperstad and Tore Børvik.

A Tailormade Approach to ALUMINIUM Alloys

They are incomprehensibly small but significantly impact the safety of aluminium structures. Asle Joachim Tomstad pinpoints the importance of primary particles.

A modest, delicate work of art is hanging on the wall in SFI CASA's canteen at NTNU in Trondheim. An immediate association, at least for a non-expert in material science, might be that this is a photo of white petroglyphs carved and painted on a grey rock. Various shades of dark grey dominate the surface. Several smaller, uneven shapes and skeleton-like structures of a much lighter grey, almost white, are randomly scattered around the image surface.

It is none of this; rather, it is a Scanning Electron Microscope-image: It displays a tiny section of the inside of an iron-enriched aluminium alloy. The white, uneven shapes are primary particles, deposits of silicon and iron. These little fellows are the primary source of damage in the materials and play the leading role in Asle Joachim Tomstad's doctoral work.

FROM SODA CANS TO SPACE STATIONS

«What happens on the macroscopic scale evolves deep down in the microstructures. The important stuff happens on the lower scales. That's fascinating», Dr. Tomstad says.

Dr. Tomstad's primary objective has been investigating how these particles affect ductile fracture in the 6000 series of aluminium alloys. The high-strength materials typically consist of 90-96 percent aluminium. A mixture of alloying elements such as silicon or iron fills the rest. You'll find them in everything from soda cans to space stations. Any industry appreciates aluminum alloys, from automotive to aerospace, construction, and consumer goods. Unique features such as a high-strength-to-weight ratio, corrosion resistance, formability, and recyclability awaken the passion for the metal.

This promotes the need for reliable and efficient models to determine the strength and ductility of different alloys.

Ductility is a metal's ability to sustain deformation before failure and collapse. It is an essential factor in engineering and construction work.

Advanced damage and fracture models require extensive test programs. These include modelling and simulation at multiple scales and customized laboratory experiments. Asle Tomstad says that, hopefully, his work contributes to the ongoing joint efforts to provide the industry with more accurate models of fracture behaviour.

UNRAVELING THE FRACTURE MECHANISMS

Dr. Tomstad was part of the Toppforsk project FractAl (2016-2022), led by Professor Odd Sture Hopperstad. The project aimed to develop a multiscale modeling framework for predicting ductile fracture in the 6000- series aluminium alloys. The new framework enables industrial designers to select the most suitable material and tailor the perfect strength and ductility for a given structure. Such tailormade alloys may provide us with safer and more eco-friendly designs. Plus, time and money are saved.

The activities in FractAl were closely linked to SFI CASA and SIMLab, the latter also known as the research group that tortures materials. Tomstad has undoubtedly maltreated his share by subjecting samples to various loads, stress conditions, strains, and tension in different directions. All to unravel the mechanisms that lead to fracture and failure.

THE RULERS OF DUCTILITY

To get an idea of his work, we need a quick look into a few details, namely the relationship between the primary particles and the metal's ductility. As they consist of iron and silicon, the primary particles are rock-hard. When the material deforms under an external load, they crack. Then they form voids that, as the strain increases, will grow and eventually merge with other growing voids. When this happens, the material fractures and fails.

«It is well accepted that the primary particles are the main source of the voids. However, we do not know their exact effect on fracture», says Tomstad.

One feature that makes his work unique is the use of tailored alloys. Adding extra silicon and iron makes their particle content more than three times the content of an engineered alloy.

He has conducted tension tests to assess the particle's effects on ductile fracture at different stress states. In these tests, half of the alloys were tailormade. He strained the specimens in tension until they fractured. Afterward, he characterized the materials using scanning electron microscopy (SEM), optical microscopy, and X-ray diffraction.

A UNIQUE, TAILORMADE APPROACH

Asle Tomstad's approach enabled him to isolate and investigate the exact effect of the small yet significant primary particles.

«The experiments show that the tailormade alloys have a poorer ductility. The reason is their higher content of constituent particles. What's unique about my work is the approach. The tailormade alloys allow us to quantify the detrimental effect of said particles. In addition, important findings confirm that the clustering is harmful as it reduces the metal's ductility».

In all, he says that his work supplies a great deal of new information to ongoing discussions. «I think my PhD work contributes significantly to our field», Tomstad says.

Digital Design of Aluminium - from **PARTICLES** to Products

Marcos Fernandez's research brings us closer to the day when physical tests become history. His efforts also pave the way for safer cars, planes, ships, and other structures.

The backdrop of Fernandez's doctoral work is the rapidly growing use of aluminium, especially in the automotive industry. The global effort to reduce CO_2 and greenhouse gas emissions has fueled the demand. Carmakers embrace the many attractive features of extrusion-based products. They can be extruded as cross-sections, single- and multi-chamber, thin-walled profiles, and other complex designs. Also, the superb blend of light weight, stiffness, strength, and the ability to deform before fracture, makes them optimal in energy-dissipating structures.

EXTENDS AND REFINES THE VIRTUAL LABORATORY

Marcos Fernandez defended his thesis in June 2022. His aim has been to improve cutting-edge technology for large-scale modelling and simulation of aluminium components. He focused on extruded profiles designed to absorb energy. We find them in the wheel suspensions, bumper systems, engine cradles, crash boxes, and other parts of our cars.

His work extends and refines the Virtual Laboratory (VL) to design aluminium alloys. The VL has been developed in close collaboration between SFI CASA and the parallel project FractAl (2016-2022). The idea is to replace costly and time-consuming physical tests with virtual testing on a computer. Fernandez was also part of Rational Alloy Design (ALLDESIGN), an NTNU Digital Transformation project. The project aims to create a digital materials design platform for intermetallic alloy design.

MORE ROBUST AND FASTER SIMULATIONS

Dr Fernandez feels confident that his work will make a difference to industry.
«I do not know how big or small this difference will be. Nevertheless, I am sure it will make an impact».

Crash-testing of cars and components is expensive. It takes a lot of time and harms the environment. The VL enables more robust and faster simulations of greater variety. Also, as the producers run virtual tests before making the prototypes, products and components become safer.

You can think of the VL as a chain with four links, starting with nanostructure modelling. Then it goes up in scale to crystal plasticity and unit cell modelling. Then localization analysis is used to establish a failure criterion for the alloys.
Most scientists in this field prefer to delve into one of the links in the chain. Marcos Fernandez's modelling work covers all the scales from the nano-level to full-scale components.

ENSURING RELIABLE AND SAFE CRASHES

The ability of a component to absorb energy is obtained by different physical mechanisms deep down in the micro-structures of the metal. Even the most minor variations in the geometry, material properties, and loading conditions can affect the behaviour. Fernandez points out that engineers and industrial designers must consider these variations.

Some extruded aluminium profiles are designed to fold into an accordion shape during impact. This shape points to effective absorption of shock and force in an accident, thus ensuring a reliable and safe crash.

SMALL VARIATIONS - HUGE EFFECTS

«If the energy dissipates inappropriately because of a non-robust design, this can produce unexpected accelerations and intrusions inside the vehicle».

Dr Fernandez studied how various features, such as chemical composition, plasticity, and anisotropy, affect the materials and the behaviour of specific components. While plasticity is the ability of the material to undergo permanent deformation, anisotropic materials produce different properties in various directions.

Even though his doctoral work focuses on the automotive industry, the results are helpful in other sectors where aluminium is crucial. Examples are the aerospace industry, shipbuilding, and transportation. Regardless of the application, the aim is more accurate simulations and, thus, safer products.

Industry uses large-scale finite element models to understand the structural capacity and predict the response from components to final products. The robustness and accuracy of these models are imperative. Dr Fernandez hopes his work can help engineers and designers make proper, faster, cost-effective decisions. He also hopes to help improve the behaviour of these metallic components in terms of weight and crash performance.

ADDED VALUE TO THE VIRTUAL LABORATORY

Fernandez's approach is entirely numerical and based on experimental data from his fellow researchers at SIMLab and SFI CASA. When asked what he thinks makes his work stand out, he says:
«The most rewarding part has been seeing how variations in the chemical composition, plastic, and failure anisotropy in large-scale analyses can influence the structural response for the considered components. I believe this PhD research will help improve the state-of-the-art in large-scale modelling and simulation of energy-absorbing structures. Therefore, the Virtual Laboratory can make a difference. We have proved that it works and that it can work well».

MARCOS FERNANDEZ

THESIS: «On the use of a virtual laboratory for aluminium alloys: application to large-scale analyses of extruded profiles.».

DEFENCE: 21 June 2022

SUPERVISORS: Associate Professor David Morin and Professor Odd Sture Hopperstad

KRISTIN QVALE

THESIS: «Energy absorption and failure in aluminium alloys: An experimental and numerical study»

DEFENCE: 28 June 2022

SUPERVISORS: Professors Tore Børvik and Odd Sture Hopperstad

Bridging the GAP

Kristin Qvale is an expert in energy absorption and fracture in aluminium components, such as crash boxes in cars. The key to more knowledge lies in the microstructures. Any change here affects the behaviour of the whole component.

The essence of her work was to perform various studies on ductile fracture in 6000-series aluminium alloys. She looked at how certain changes in the microstructure affect the fracture behaviour at higher scales and how fracture affects the crash behaviour of aluminium components.

VIRTUAL DESIGN AND TAILORMADE ALLOYS

Kristin Qvale was the 4th of 5 PhD candidates to defend her thesis within the framework of the Toppforsk project FractAl (2016-2022). It is a concurrent project to SFI CASA, led by Professor Odd Sture Hopperstad. FractAl´s prime objective was to develop and validate a multi-scale framework for modelling plastic deformation and ductile fracture of age-hardening aluminium alloys.

The 5-year project was completed in May 2022. It focused on modelling 6000-series (Al-Mg-Si) aluminium alloys, and opens completely new possibilities in the design and use of aluminium. However, parts of the modelling framework can also be used for other structural metals. The goal? To reduce the need for expensive physical tests by partially replacing them with numerical simulations. «By introducing such a modelling procedure, we are working to develop crash components almost completely virtually. This means tailoring an alloy to optimize the behaviour of a component to failure», Kristin Qvale says.

BRIDGING THE GAP

Qvale's thesis spans the nanoscale to full-size components. If you imagine the FractAl framework as a somewhat intricate puzzle, her work will consist of pieces that fit in several places.

«I emphasise the macroscopic scales, with fracture included. Thus, I help build a bridge between the microstructure and the behaviour of the component».

The automotive industry is increasingly turning to aluminium alloys when designing crash components. Many alloys provide a good balance in the strength-to-weight ratio and ductility, which is the ability to change physical shape without breaking. Fracture of a crash component should be avoided so that it can perform optimally in a crash situation.

«Accurate numerical predictions of deformation and fracture can enable car developers to optimize and utilize the energy absorption capacity of a material to its full potential. In addition, this may reduce the need for expensive test programmes», according to Dr Qvale.

INVESTIGATING HOW CHANGES AFFECT FRACTURE

A crucial part of her work was to perform physical tests and numerical simulations of alloys. She did so by varying compositions and processing at various scales and stress states. Thus, she extends experimental behaviour knowledge in order to support validation and modelling activities.

Her validation tests represent a fracture mode that is relevant to typical aluminium structures. Additionally, she has performed component tests representing a specific application of aluminium alloys. For the latter, she also performed tensile tests to determine the mechanical properties of an alloy.

Her doctoral work is a sound contribution to the FractAl project's experimental database. The research focuses on the higher physical scales of the modelling framework. The experiments include various features, and the work forms a basis for further investigation.

CRASH BOXES SUBJECTED TO CRUSHING

The complete work consists of three studies. In Part 1, she investigated how changes in the constituent particle content affect one specific fracture behaviour in three different alloys. Part 2 focuses on the behaviour of double-chamber aluminium crash box-profiles subjected to quasi-static and dynamic axial crushing. In Part 3, she focused on how specific solid element simulations can predict the behaviour of the crash boxes in Part 2.

One of her crash boxes left a prominent mark on the cover of the SFI CASA annual report 2019. The motif, an X-ray CT scan of a crushed double-chamber crash box, created excitement as itresembled the famous, ghost-like Hattifnatteners from the Moomin valley books. Also, Qvale's simulations captured the folding patterns of a quasi-static crushing of an AA6063 profile with high accuracy.

GREENER, SAFER, MORE COST-EFFECTIVE SOLUTIONS?

Aluminium is intriguing because of its versatility. The metal is a favourite in many structural applications because of its stiffness and strength, lightweight properties, and corrosion resistance. At the same time, it is a material with high potential as an energy absorber through plastic deformation. Tuning the mechanical properties through aging treatments is also an exciting feature.

Kristin Qvale says that everything we learn about the behaviour of materials will contribute to the ability to design greener, safer, and more cost-effective products. Additionally, due to increasing computational power, detailed numerical simulations should be able to replace physical testing more and more.

«Although my simulations are computationally heavy, they show the huge potential for predicting the behaviour of components. With reliable numerical tools, effective design optimization should be possible».

Studying the SCARIEST Loads

During an explosion, the shock wave may be accompanied by fragments accelerating to an immense speed. This scary mix is a massive challenge for those working with blast-resistant designs.

During combined blast and impact loading, the projectile-like fragments will often hit before the blast wave arrives. This increases the level of significant damage. Buildings, cars or other structures near a detonation will be subject to more severe loading than that from a single load.

THE SCARIEST LOAD

«This is the scariest load there is. It works the same way as shrapnel bombs», says Benjamin Stavnar Elveli.

It was in 2018 that the busy skateboarder, surfer, climber, and snowboarder from Gjøvik in eastern Norway started his doctorate at SFI CASA. The topic was severe blast events and investigations of how combined fragment impact and blast load affect thin steel plates.

The basis of his PhD work is more than 80 small-scale blast experiments on target plates of three different steel types. He recreated the blast loads in computer simulations by combining physical blast tests with theory and mathematics. Understanding the physics of a load will enable future engineers to design more accurate, safer, and sustainable structures. This is science for a safer society.

FRAGMENTS BEFORE THE BLAST LOAD LEADS TO MORE DAMAGE

Whether accidental or intentional, explosions can cause massive damage. Fragments can originate from an explosive device, such as a ruptured casing or ball bearings. Or from gravel, rocks, or debris from surrounding structures.

Depending on the distance, the fragments can strike before, during, or after the blast wave arrives. If they hit before, they can create weak points in, for instance, thin-walled elements in a façade. Often, it is these weak points where a fracture starts. Scenarios like this have the highest damage potential, as the structure will already contain a defect before it has to withstand the blast wave.

DESCRIBING BALLISTIC IMPACT AND BLAST LOADING – AT THE SAME TIME

The pressure from a blast wave can last for several milliseconds and cause deformation over a large area. A fragment moves at high speed and causes concentrated damage. Modeling the combined effects means describing two very different, damaging loads within the same model. It is an understatement to call this a complex modelling task.

«You will often end up with a kind of trade-off. To capture the locally reduced fracture resistance during the explosion, you must decide how accurate the descriptions of the fragment impact must be. If you do not get full control of it, you could overestimate the capacity of a structure regarding blast loading», Elveli says.

Overestimating the strength of a component or structure may have fatal consequences. Structural engineers must deliver reliable designs. A large part of Elveli's work has been investigating how accurate the models must be to ensure safe and reliable structures.

FROM MASSIVE MILITARY TO LIGHTWEIGHT CIVILIAN

Historically, those working on blast-resistant design have focused on massive military concrete structures. However, new threats have emerged during the last few decades. The need to protect civilian facilities in urban areas has increased. As has the interest in blast-resistant, thin-walled structures.

One common approach is to assume the fragments strike before the arrival of the blast wave. Then the loading scenario must be split into two sequential loading events. Often, such studies use structures with pre-cut defects. These mimic flaws or weaknesses from fragments before the explosion. The downside of this simplified approach is that it avoids all uncertainties related to real fragment impact.

«For instance, manufactured defects lack the small cracks that lead to fracture under blast load», according to Elveli.

COMPARING FRACTURE STRENGTH

One original aspect of his doctoral work is the comparison of pre-cut plates with plates subjected to real ballistic impact to find if they behave differently. Both had holes with the same diameter. The pre-cut holes were «clean» around the edges. In contrast, the projectile inflicted holes had small petalling cracks and plastic deformation. When exposed to the blast loads, propagation started in these cracks.

«Idealized defects are easier to test and simulate. However, since they lack the deformations and damage occurring in real explosions, there is a risk of exaggerating the strength of the materials in these models».

EXTENSIVE, EXPENSIVE – AND HOPEFULLY USEFUL

Benjamin Elveli has put a massive effort into designing controlled and reliable small-scale experiments. He has performed 110 tests, 82 representing blast load physics. Cameras filming 37 000 frames per second have captured the combined loads.

He thinks people working with R&D in large companies and the military and civilian scientific community will benefit from his work. Also, the extensive dataset may be helpful for engineers working with finite element software. The complicated load cases enable tests of the various numerical methods in use today.

«It has become an expensive doctorate, so I hope the new knowledge will be useful to more people than me,» Dr Elveli jokes.

BENJAMIN STAVNAR ELVELI

THESIS: «Behaviour, modelling, and simulation of thin steel plates subjected to combined blast and impact loading»

DEFENCE: 14 December 2022

SUPERVISORS: Associate Professor Vegard Aune and Professor Tore Børvik

VISIBILITY

Media strategy

SFI CASA has a media strategy for popular scientific presentations of our research. We aim to contribute to a knowledge-based, open public debate. Making female researchers and profiles particularly visible is essential for us as we plan to recruit more females and thus contribute to an even gender balance in our research field.

Website

One essential tool to make SFI CASA visible is the website www.sfi-casa.no. This works as a platform for sharing and spreading content in social and mainstream media. Here, we publish research news, feature stories, videos, and in-depth interviews with key personnel working with or connected to the Centre. We have published a total of 22 posts on sfi-casa.no in 2022. The content was distributed in 8 newsletters to partners, contacts, and other subscribers in our social and professional network. We have distributed 3 technical newsletters for the partners.

Social media

The excellent collaboration with the communication divisions in the NTNU administration and the Faculty of Engineering continued in 2022. They help spread the content posted on sfi-casa.no via NTNU News, Norwegian SciTech News/Gemini, YouTube, Instagram, Twitter, and the Facebook page NTNU Science and Technology.

In addition, we shared content via CASA friends and individual staff members' private Twitter and LinkedIn profiles. This helped spread the word about the Centre and the activities of CASA staff and contacts to relevant and engaged readers.

CASA in the Media

Also, in 2022, CASA achieved its fair share of publicity. In January, Professor Magnus Langseth published an article in the newspaper Khrono. The topic was innovation, and the title was «Start the Hunt for Innovation in Technology's Valley of Death».

During spring, the Director was interviewed in the industry magazine «Aktuell Sikkerhet». This is a magazine for the physical security sector in Norway. The topic was the Centre's future after the wind-up period.

In May, a local newspaper wrote a story about PhD candidate Rannveig Marie Færgestad. She was awarded the Norwegian Industrial Forum for Space Activities (NIFRO) prize for the best space-related master's thesis.
Later that month, Professor Magnus Langseth was interviewed in TU, technological weekly magazine. The topic was physical security related to the new tunnel, Hammersborgtunnelen, under construction beneath the new government headquarters in Oslo.

Just before summer, PhD candidate Rannveig Færgestad talked about the challenges in space in a podcast from the TU magazine. On two occasions during summer, Færgestad was an invited expert in the Norwegian Broadcasting Corporation's «Dagens» programme. Here, she commented on current space-related topics.

In the autumn, the TU magazine brought the story of a new, 3-year contract signed by SFI CASA and car manufacturer Audi. The contract is part of Audi's PhD programme. The agreement means that Audi has decided to continue the collaboration beyond the termination of SFI CASA in June 2023.

PhD candidate Kristoffer Aune Brekken also starred in the TU magazine. It presented a story on Kristoffer's work on sandwich façade claddings. These claddings absorb so much force from an explosion that the internal load-bearing structures remain undamaged. In addition, the claddings can be used as thermal insulation - thereby increasing the wall thickness.

The center was present with an exhibition stand at the Defense Conference 2022 in Trondheim on 22 September

Invited and guest lectures

- Børvik, Tore. Additively Manufactured Protective Structures. International Conference on Impact Loading of Structures and Materials (ICILSM 2022); 14 June 2022.
- Hopperstad, Odd Sture. Modelling of failure in aluminium structures. International Conference on Impact Loading of Structures and Materials (ICILSM 2022); 14 June 2022.
- Langseth, Magnus. Aluminium beams subjected to impact loading: Effect of material properties, mass ratio and welding. DYMAT webinar 12 January 2022
- Morin, David. From Research to innovation in the automotive industry: Experience from SFI CASA. NTNU's seminar series Let's talk innovation; 28 April 2022.

Lab visits at CASA

- A delegation from the Norwegian Defence Research Establishment (FFI) visited CASA's labs on 5 May.

PhD defences in 2022

- 21 June, Marcos Fernandez, On the use of a virtual laboratory for aluminium alloys: application to large-scale analyses of extruded profiles
- 14 December, Benjamin Stavnar Elveli, Behaviour, modelling and simulation of thin steel plates subjected to combined blast and impact loading

Research visits at SFI CASA

- PhD student Ramón del Cuvillo Mezquita from the Universidad Carlos III de Madrid, Spain, visited CASA in the period October 2021-January 2022.
- PhD student Luca Lomazzi from Politecnico di Milano, Italy, stayed with CASA from February to April 2022
- Postdoc Minjoo Lee from Korea Advanced Institute of Science and Technology (KAIST) visited CASA for three months from February to April 2022
- PhD student Maisie Ann Edwards-Mowforth from the University of Edinburgh, UK, stayed with CASA from August to December 2022.

Concurrent projects

INTPART
Norwegian-Japanese Aluminium Alloy Research and Education Collaboration: The objective of this INTPART project is to develop world leading education and research in the aluminium field in collaboration between NTNU, University of Toyama, Tokyo Institute of Technology, Kyushu University, SINTEF, Hydro and Japanese aluminium industry.

Rational Alloy Design, ALLDESIGN (2018-2022): NTNU project on digital materials design of aluminium-based alloys. Professors David Morin, Randi Holmestad, and Knut Marthinsen supervise one PhD candidate each in the ALLDESIGN project.

Microstructure based modelling of ductile fracture in aluminium alloys, FractAl (2015-2022): This FRIPRO Toppforsk project has been run by professors Odd Sture Hopperstad, Tore Børvik and Ole Runar Myhr from NTNU's Structural Impact Laboratory along with international partners Ahmed Benallal LMT/ENS Paris-Saclay, France and Jonas Faleskog from the Royal Institute of Technology in Sweden.

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.

IPN STIP (2020-2023)
The goal of the project is to develop methodology to accurately evaluate the capacity of flexible pipes with a polyvinylidene difluoride (PVDF) pressure liner. The project is run by Enodo AS and employs one postdoc at the SIMLab research group.

IPN Expect (2021-2024)
This project is lead by Benteler Automotive Raufoss and addresses the rapidly growing market for battery tray protections systems for electric mobility and the BEV (Battery Electric Vehicle) market. The project employs one postdoc working on ductility of complex profiles for crash management performance, and simulation and optimization of crashworthiness of extruded aluminum profiles.

SFI PhysMet (2020-2028)
The Centre for Sustainable and Competitive Metallurgical and Manufacturing Industry is hosted by the Department of Materials Science and Engineering at NTNU. CASA professor Knut Marthinsen is the Centre Director.

SCIENTIFIC STAFF

Vegard Aune, Torodd Berstad, Lars Edvard Dæhli, Egil Fagerholt, Miguel Costas, Rene Kaufmann, Martin Kristoffersen, Calin Marioara, Afaf Saai, Inga Gudem Ringdalen, Virgile Delhaye, Anette Brocks Hagen, Ida Westermann, Jianbin Xu

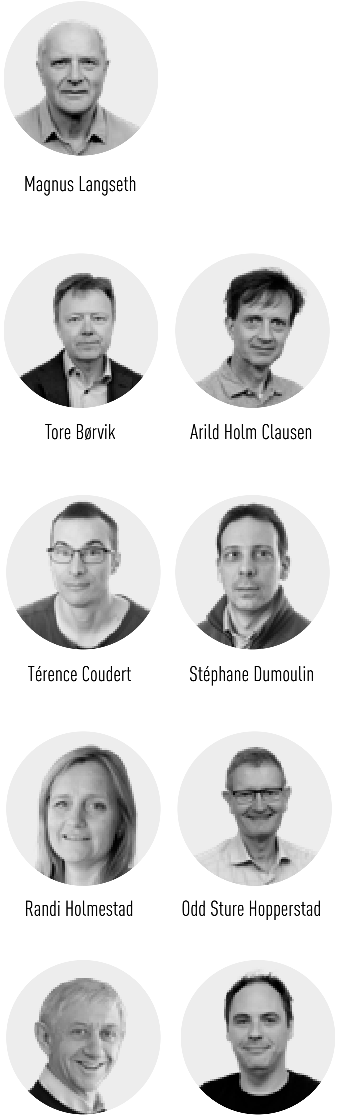
PHD AND POSTDOCS

Kristoffer Aune Brekken, Benjamin Stavnar Elveli, Marcos Fernandez, Victor André, Ruben Løland Sælen, Jonas Rudshaug, Sigurd Aune, Håvard Næss, Rannveig Marie Færgestad, Øystein Eirik Kvist Jacobsen, Debora Obkircher, Andria Antoniou, John Fredrick Berntsen, Asle Joachim Tomstad, Kristin Qvale, Vetle Espeseth, Anne-Sophie Sur, Daniele Cioni, Kinga Somlo, Jonas Hund, Einar Schwenke, Fanny Dameme

OTHER KEY PERSONELL

Trond Auestad, Peter Karlsaune, Linda Katalin Veres, Sølvi W. Normannsen, Tore Wisth

DIRECTOR CORE TEAM AND PROGRAMME HEADS



Magnus Langseth, Tore Børvik, Arild Holm Clausen, Térence Coudert, Stéphane Dumoulin, Randi Holmestad, Odd Sture Hopperstad, Knut Marthinsen, David Morin

PhD candidates and postdocs

PHD CANDIDATES AND POSTDOCS WITH FUNDING FROM SFI CASA

Name	Topic	Position	Start	Planned exam/end	Programme	Nationality	Gender
Kristoffer Aune Brekken**	Modelling and Optimization of Sacrificial Claddings	PhD	2017	2023	Structures	Norwegian	M
Einar Schwenke**	Modelling of viscoelasticity in Polymers	PhD	2018	2023	Polymeric Materials	Norwegian	M
Benjamin Stavnar Elveli**	Behaviour and modelling of steel plates subjected to combined blast and impact loading	PhD	2018	Defended in 2022	Structures	Norwegian	M
Marcos Fernandez**	Modelling of aluminium components under large deformations	PhD	2018	Defended in 2022	Structural Joints	Spanish	M
Victor André*	Modelling of multilayered joints	PhD	2019	2023	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
Håvard Næss*	Machine learning in material mechanics	PhD	2021	2025	Metallic Materials	Norwegian	M
Rannveig Marie Færgestad*	Modelling and simulation of hypervelocity impact against debris shields for spacecraft protection	PhD	2021	2025	Structures	Norwegian	F
Øystein Eirik Kvist Jacobsen*	Modelling of concrete at extreme loading	PhD	2021	2025	Structures	Norwegian	M
Debora Obkircher	Bolted connections in steel structures	PhD	2022	2026	Structural Joints	Italian	F
Fanny Dameme**	Dynamic loading and ageing of adhesives	PhD	2021	2024	Structural Joints	French	F
Andria Antoniou*	Blast loading	Postdoc	2020	2023	Structures	Cypriot	F
John Fredrick Berntsen*	Industrial implementation	Postdoc	2020	2023	Structural Joints	Norwegian	M
Marcos Fernandez	Industrial implementation	Postdoc	2022	2024	Industrial Implementation	Spanish	M
Sindre Olufsen*	Modelling of ductile failure in polymers	Postdoc	2020	August 2023	Polymeric Materials	Norwegian	M

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

Master´s in progress. Testing impact loading on beams of cross-laminated timber. From left: MSc student Lars Gruben, supervisor Professor Arild Holm Clausen, Associate Professor Haris Stamatopoulos (pointing), MSc student Sondre Skau Kentsrud, and Senior engineer Thomas Uhlving (Photo: Sølvi W. Normannsen).

Above from left: MSc student Cornelia R. Brantenberg, PhD student Luca Lomazzi, MSc students Anne Myran Larsen and Marie Bacher.
Below left: MSc student Einer Herrem and PhD student Jonas Rudshaug, MSc students Lars Gruben and Sondre S. Kentsrud (Photos: Vegard Aune and Sølvi W. Normannsen)

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

Name	Topic	Position	Start	Planned exam/end	Programme	Nationality	Gender
Asle Joachim Tomstad	Quasi-static and dynamic ductile fracture of aluminium alloys under low triaxiality	PhD	2017	Defended in 2022	FractAl	Norwegian	M
Kristin Qvale	Microstructure-based modelling and simulation of ductile fracture in aluminium alloys	PhD	2018	Defended in 2022	FractAl	Norwegian	F
Vetle Espeseth	Microstructure-based modelling and simulations of plasticity and fracture in aluminium alloys	PhD	2018	2023	FractAl	Norwegian	M
Anne-Sophie Sur	Running ductile fracture in pressurised steel pipelines	PhD	2020	2023	FME NCCS	German	F
Daniele Cioni	Impact modelling of Li-ion batteries	PhD	2022	2025		Italian	M
Kinga Somlo	Simulation and optimization of crashworthiness of extruded aluminum profiles	Postdoc	2021	2023	KPN Expect	Hungarian	F
Jonas Hund	Structural Integrity of PVDF pressure liners	Postdoc	2021	2023	IPN STIP	German	M

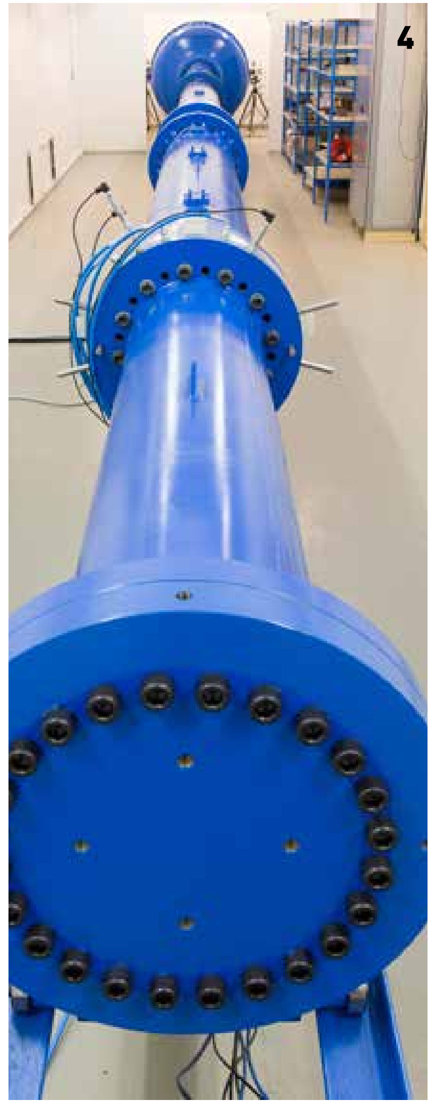
Recruitment

Former SIMLab Master's students Debora Obkircher and Daniele Cioni started as PhD students at the SIMLab research group in 2022. Debora Obkircher is affiliated with SFI CASA, working on bolted connections in steel structures, while Daniele Cioni will work with impact modelling of Li-ion batteries. In addition, visiting PhD student Maise Edwars-Mowforth started a one-year stay with the group in August. Former PhD student at CASA, Marcos Fernandez, started as a postdoc in 2022.

MSc students
The following MSc students were associated with the Centre in 2022

Name	Sex M/F	Topic
Marie Bacher	F	Thin steel plates subjected to confined, close-range blast loading
Anne Myran Larsen	F	Thin steel plates subjected to confined, close-range blast loading
Tiril Elea Narvestad	F	Additive manufactured protective structures
Cornelia Reinholdtsen Brantenberg	F	Additive manufactured protective structures
Ingebrigt Sæther	M	Modelling of running fracture in steel pipes for CO2 transport
Henrik Lorentz Burchardt	M	Modelling of running fracture in steel pipes for CO2 transport
Stian Gundersen Raniszewski	M	Mechanical testing and numerical simulation of car batteries subjected to extreme loads and deformations
Daniele Cioni	M	Mechanical testing and numerical simulation of car batteries subjected to extreme loads and deformations
Ludvig Reichborn-Bjørneklett	M	Modelling of tensile ductility using artificial neural networks
Sarah Stradel Garn Hansen	F	Design and modelling of vehicle security barriers
Yushi Li	F	Design and modelling of vehicle security barriers
Anders Aamodt Resell	M	Modelling of fluid-structure interaction with fixed grid methods: Opportunities and application to shock tube simulations
Einer Herrem	M	Modelling of laminated glass.
Simen August Ruste	M	Behaviour and modelling of welded aluminium joints
Jonas Tofte Røhne	M	Impact loading on beam of glulam timber
Matias Mortensen	M	Impact loading on beam of glulam timber
Sondre Skau Kentsrud	M	Impact loading on beam of cross-laminated timber
Lars Gruben	M	Impact loading on beam of cross-laminated timber
Ola Berge	M	Steel joints
Martin Melandsø	M	Dynamic material behaviour of wood

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 on sheets under industrial conditions..

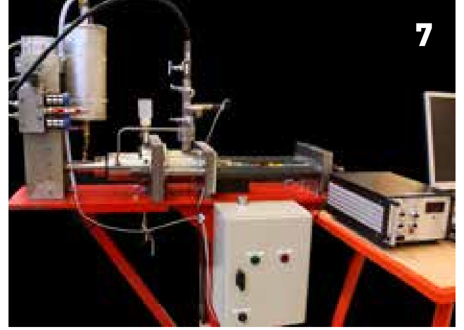
Droptower impact system (3)
In this machine impact testing of materials and small components can be done at high and low temperatures. The mass of the projectile ranges from 2 to 70 kg and gives an impact velocity in the range 0.8-24 m/s. All tests can be carried out with an instrumented nose which gives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

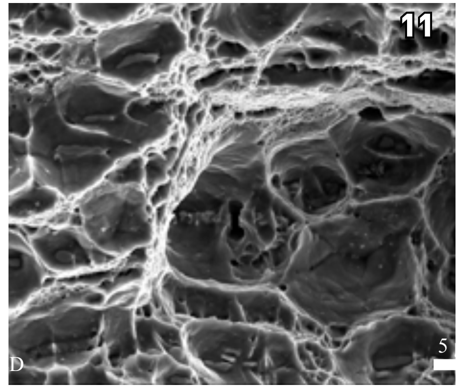
SIMLab Shock tube facility (SSTF) (4)
The tube is 18.2 m long and is divided into six sections and ends in a 5.1 m^3 dump tank. The tube starts with a circular internal cross-section with a diameter of 0.34 m before it is transformed to a square cross-section of 0.3 m x 0.3 m. Threaded holes in the tube 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 SSTF 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 400 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. A plexiglass chamber facilitates tests at low and elevated temperatures.

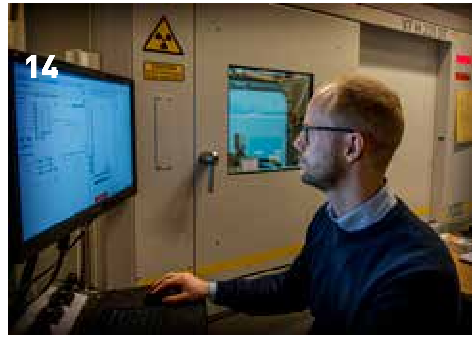
Cameras (10)
Impact testing of materials and structures are recorded using high-speed cameras. The Kirana-05M camera has a maximum frame rate of 5 000 000 per second (FPS) allowing detailed studies of crack propagation. In addition, the research group has four more high-speed cameras and several cameras 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. NORTEM II (project leader Randi Holmestad) got support from the INFRA program in the Research Council, so Department of Physics will during the next years get a new top level transmission electron microscope. 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
3,4,5,8,12: Ole Morten Melgård
10, 14: Sølvi W. Normannsen
11: Bjørn Håkon Frodal

PUBLICATIONS & ANNUAL ACCOUNTS

Vegard Aune Joins Exclusive Group

In 2022, Vegard Aune was appointed among 25 carefully selected participants in NTNU's Outstanding Academic Fellows Programme (OAFP). The scheme aims to accelerate the international career of the university's top talented young researchers. «This is a truly great and unique opportunity to concentrate on research over the next four years,» Dr. Aune said after the news broke.

Since 2014, NTNU has facilitated academic development and merit through the OAFP for more than 90 researchers. All those selected are already internationally outstanding in their field. One important contribution of the scheme is to qualify participants for excellence grants, such as the European Research Council (ERC) Grants.

Further, the participants must set aside all engagements and activities that do not support the development of ground-breaking research. «I see this as a parallel to top-level sport. You are supported in managing your time effectively and concentrating on the research. It is all about performing your best by prioritizing correctly and clearing space for what is important», Aune says.

Dr. Aune's selected mentor is Cambridge Professor Vikram S. Deshpande. Deshpande is the head of the Cambridge Solid Mechanics Group. The two are expected to work closely: together they must establish a career and research plan for publications, collaborations, grants, projects, and research stays. The plan must also detail concrete actions for Dr. Aune to prove himself as an independent international leader in his field.

The following lists journal articles, conference contributions and other publications published in 2022.

CASA articles

1. B.S. Elveli, T. Berstad, T. Børvik, V. Aune. Performance of thin blast-loaded steel plates after ballistic impact from small-arms projectiles. International Journal of Impact Engineering 2022; 173: 104437
2. B.S. Elveli, M. Iddberg, T. Børvik, V. Aune. On the strength-ductility trade-off in blast loaded thin-walled structures – An experimental study. Thin-Walled Structures 2022, 171:108787
3. B.S. Elveli, O. Vestrum, K.O. Hauge, T. Berstad, T. Børvik, V. Aune. Thin steel plates exposed to combined ballistic impact and partially confined airblast loading. Engineering Failure Analysis 2022, 144: 106943
4. J. Frafjord, J. Friis, R. Holmestad, I.G. Ringdalen. On the Atomic Structure of the β'' Precipitate by Density Functional Theory. Computational Materials Science 2023, Volume 217.
5. B.H. Frodal, S. Thomesen, T. Børvik, O.S. Hopperstad. On fracture anisotropy in textured aluminium alloys. International Journal of Solids and Structures 2022;244-245, 111563
6. A.B. Hagen, S. Wenner, R. Bjørge, W.D. Ruben, C.D. Marioara, R. Holmestad, I.G. Ringdalen. Local mechanical properties and precipitation inhomogeneity in large-grained Al-Mg-Si alloy. Journal of Materials Science and Engineering: A 2022, 144222
7. J.K. Holmen, S. Thomesen, M.J. Perez-Martin, O.S. Hopperstad, T. Børvik. Ballistic Impact of Structural Steels at Low Temperatures. Journal of Applied Mechanics 2022; 89(10), 101001
8. R. Kaufmann, S. Olufsen, E. Fagerholt, V. Aune. Reconstruction of surface pressures on flat plates impacted by blast waves using the Virtual Fields Method. International Journal of Impact Engineering 2022; 171: 104369.
9. M. Mokhtari, E. Kim, J. Amdahl. Pressure-dependent plasticity models with convex yield loci for explicit ice crushing simulations. Marine Structures 2022; 84, 103233
10. W. Nam, O.S. Hopperstad, J. Amdahl. Thermal analysis of marine structural steel EH36 subject to non-spreading cryogenic spills: Part III: structural response assessment. Ships and Offshore Structures (2022)
11. S.N. Olufsen, R. Kaufmann, E. Fagerholt, V. Aune. RECOLO: A Python package for the reconstruction of surface pressure loads from kinematic fields using the virtual fields method. Journal of Open Source Software (JOSS) 2022; 7, 71
12. K. Qvale, S. Thomesen, O.S. Hopperstad, T. Børvik. The effect of constituent particles on the tear resistance of three 6000-series aluminium alloys. Int J Fract 238 (2022) 165–183.
13. P.L. Reu, et al. DIC Challenge 2.0: Developing Images and Guidelines for Evaluating Accuracy and Resolution of 2D Analyses. Experimental Mechanics 2022, volume 62, pp. 639-654.
14. T. Warren, J. Johnsen, M. Kristoffersen, T. Børvik. Solution for the Dynamic Elastically Compressible Power-Law Strain Hardening Cylindrical Cavity-Expansion Problem. Journal of Dynamic Behavior of Materials 2022; 9, 65-78
15. J. Xu, B. Holmedal, O.S. Hopperstad, T. Manik, K. Marthinsen. Dynamic strain ageing in an AlMg alloy at different strain rates and temperatures: Experiments and constitutive modelling. International Journal of Plasticity 2022; 151, 103215
16. J. Xu, L. Liu, O.S. Hopperstad, B. Holmedal, T. Manik, K. Marthinsen. A simple method enabling efficient quantitative analysis of the Portevin–Le Chatelier band characteristics. Scripta Materialia 2022; 222, 115027

CASA conference contributions

1. A. Antoniou, M. Kristoffersen, T. Børvik. A constitutive model for concrete subjected to hard impact. 11th European Solid Mechanics Conference (ESMC2022), 4-8 July 2022
2. T. Børvik, M. Costas, M. Edwards-Mowforth, M. Kristoffersen. Additively Manufactured Protective Structures. ICILSM 2022, 13-17 June 2022
3. R. del Cuvillo, M. Costas, V. Aune, T. Børvik, J.A. Artero-Guerrero, J. Pernas-Sánches, J.L. Puente. Carbon fibre composite exposed to blast loading: A preliminary study. 3rd International Conference on Impact Loading of Structures and Materials - ICILSM 2022, 13-17 June 2022
4. M. Edwards-Mowforth, S. Thompson, M. Costas, M. Kristoffersen, T. Børvik, F. Teixeira-Dias. A numerical modelling and generative deep learning approach to the ballistic impact resistance of additive manufactured maraging steel plates. . 3rd International Conference on Impact Loading of Structures and Materials - ICILSM 2022, 13-17 June 2022
5. M. Edwards-Mowforth, S. Thompson, M. Costas, M. Kristoffersen, T. Børvik, F. Teixeira-Dias. A numerical modelling and deep learning approach to the ballistic impact resistance of additive manufactured maraging steel. Light-Weight Armour for Defence & Security LWAG 2022. 16-17 September 2022
6. B.S. Elveli, T. Børvik, V. Aune. Blast resistance of perforated steel plates. 3rd International Conference on Impact Loading of Structures and Materials - ICILSM 2022, 13-17 June 2022
7. R. Kaufmann, S.N. Olufsen, E. Fagerholt, V. Aune. Application of the Virtual Fields Method to Reconstruct Full-Field Surface Pressures During the Dynamic Response of Blast Loaded Steel Plates. 16th International Conference on Advances in Experimental Mechanics - BSSM2022, 6-9 September 2022
8. R. Kaufmann, S.N. Olufsen, E. Fagerholt, V. Aune. The Virtual Fields Method for Reconstruction of Impact and Blast Loading. 3rd International Conference on Impact Loading of Structures and Materials - ICILSM 2022, 13-17 June 2022
9. L. Lomazzi, A. Manes, F. Cadini, D. Morin, V. Aune. Data-driven approach to account for fluid-structure interaction effects on blast loaded steel plates. 3rd International Conference on Impact Loading of Structures and Materials - ICILSM 2022, 13-17 June 2022
10. D. Morin, M. Costas, M. Langseth. Modelling of fracture in aluminium extrusions in large scale analyses. Nordic LS-DYNA User's Conference 2022, 18-19 October 2022
11. D. Obkircher, M. Costas, T. Børvik, O.S. Hopperstad. Shape and size optimization of a complex extruded aluminium profile for protection of battery trays in electric vehicles. ECCOMAS Congress 2022, 5-9 June 2022
12. E. Schwenke, D. Morin, A.H. Clausen. Polymer testing with a pre-tensioned steel split-Hopkinson bar. 3rd International Conference on Impact Loading of Structures and Materials - ICILSM 2022, 13-17 June 2022
13. R.L. Sælen, O.S. Hopperstad, A.H. Clausen.Material modelling and mechanical behaviour of an SLA additively manufactured polymer. ECCOMAS Congress 2022, 5-9 June 2022.
14. J.K. Sønstabø, D. Morin, M. Langseth. Modelling of flow-drill screw connections in large-scale crash analyses. Nordic LS-Dyna User's Conference 2022, 18-19 October 2022
15. K.R.B. Tekseth, J. Rudshaug, M. Gholamimayani, B. Chattopadhyay, K.O. Schnell, M.N. Akram, T. Børvik, D.W. Breiby. Optical Metrology of Phase Objects by Computational Microscopy. Norsk Elektro-Optikk Møte, 7-9 September 2022

Book chapters

1. Kaufmann, Rene; Fagerholt, Egil; Aune, Vegard. Surface Pressure Reconstruction in Shock Tube Tests Using the Virtual Fields Method. I: Thermomechanics & Infrared Imaging, Inverse Problem Methodologies, Mechanics of Additive & Advanced Manufactured Materials, and Advancements in Optical Methods & Digital Image Correlation, Volume 4 Proceedings of the 2021 Annual Conference on Experimental and Applied Mechanics. Springer 2022 (ISBN 978-3-030-86745-4)
2. Kramer, Sharlotte L.B.; Tighe, Rachel. Thermomechanics & Infrared Imaging, Inverse Problem Methodologies, Mechanics of Additive & Advanced Manufactured Materials, and Advancements in Optical Methods & Digital Image Correlation, Volume 4 Proceedings of the 2021 Annual Conference on Experimental and Applied Mechanics. Springer 2022 (ISBN 978-3-030-86745-4)

Cracking the Codes of Crazing

Sometimes, polymer layers develop microvoids that can cause leakage. The underlying mechanism resembles crazing and is a mystery to the industry.

Now, the phenomenon is under investigation in the project STIP led by the company Enodo AS, a spinoff from SFI CASA. STIP is an abbreviation for «Structural integrity of PVDF pressure liners», and PVDF? Short for «polyvinylidene difluoride». This thermoplastic is a widely used engineering polymer, for instance, in pressure barriers in the oil and gas industry. Yet, PVDF is one of the polymers struggling with crazing that can lead to cracking and, eventually, leaking.

STIP involves some big energy industry players: Baker Hughes and Equinor. The project aims to enable engineers to predict if PVDF pressure barriers in flexible pipes are leakproof.

«We aim to understand why the polymer behaves this way and how to prevent this unwanted behavior», says Jonas Hund.

STIP winds up in 2023. Dr. Hund works with microstructural modeling of polymers and holds a postdoctoral position financed by the project. His main task is identifying the driving causes of craze formation and propagation. According to project manager Jens Kristian Holmen, the methodology in the making may bring benefits such as material savings and reduced risk of oil spillage on the continental shelf. Plus, minimizing the computational time while simultaneously describing the polymer's behavior with high accuracy. The latter will reduce costs for energy companies as well.

NTNU and Audi Signed a New, Long-term Research Agreement

The German car manufacturer Audi AG secures continued collaboration with NTNU and the SIMLab research group. A PhD scholarship is the first individual project to be launched.

Audi has been a collaborative partner with the SIMLab group for over 20 years. Mr. Arjan Strating R&D Engineer in Audi Neckarsulm, says Audi continues the collaboration because they are «pleased and confident with what SIMLAb does».

According to Mr. Strating, the new deal with NTNU is the first-ever of this kind that Audi has signed outside a non-German-speaking region. The agreement, in which NTNU is the formal contracting partner, states that the parties «aim to establish and expand a mutual exchange of experience and know-how and to bundle certain research activities». The document says that the two parties plan to work together within the framework of individual projects. This means that the research work will be determined case-by-case, according to Audi's needs and interests.

The parties expect mutual benefits: Audi wants to gain direct access to the scientific know-how of the university. On their side, NTNU considers that they participate in the worldwide trend towards greater practical relevance of science. «Based on the new PhD project under the Higher Education Framework Research Agreement, SIMLab will continue developing good models and simulation strategies to replace physical crash tests in the future», says CASA's director, Professor Magnus Langseth.

Concurrent projects

Journal articles

1. L.E.B. Dæhli, C. Tekoglu, D. Morin, T. Børvik, O.S. Hopperstad. Ductile failure predictions using micromechanically-based computational models. Journal of the Mechanics and Physics of Solids 2022, volume 164
2. V. Espeseth, T. Børvik, O.S. Hopperstad. Aluminium plates with geometrical defects subjected to low-velocity impact: Experiments and simulations. International Journal of Impact Engineering 2022, volume 167
3. B.H. Frodal, S. Thomesen, T. Børvik, O.S. Hopperstad. On fracture anisotropy in textured aluminium alloys. International Journal of Solids and Structures 2022, pp. 244-245.
4. J. Hund, H.M. Granum, S.N. Olufsen, P.H. Holmström, J. Johnsen, A.H. Clausen. Impact of stress triaxiality, strain rate, and temperature on the mechanical response and morphology of PVDF. Polymer Testing 2022; 114, 107717
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8. A.J. Tomstad, B.H. Frodal, T. Børvik, O.S. Hopperstad. Influence of particle content on the ductility of extruded non-recrystallized aluminium alloys subjected to shear loading. Materials Science & Engineering: A 2022, volume 850

Conference contributions

1. L.E.B. Dæhli, C. Tekoglu, D. Morin, T. Børvik, O.S. Hopperstad. Ductile failure predictions based on micromechanical models. 11th European Solid Mechanics Conference, 4-8 July 2022
2. V. Espeseth, T. Børvik, O.S Hopperstad. Low-velocity impact on aluminium plates with geometric defects. An experimental and numerical study. 3rd International Conference on Impact Loading of Structures and Materials, 13-17 June 2022
3. O.S. Hopperstad. Modelling of failure in aluminium structures. International Conference on Impact Loading of Structures and Materials (ICILSM 2022), 13-17 June 2022
4. O.S. Hopperstad. Modelling of plasticity and fracture across the scales – applications to aluminium alloys. 8th European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS Congress 2022), 5-9 June 2022
5. O.S. Hopperstad, S. Thomesen, B.H. Frodal, T. Børvik. Crystal plasticity modelling and simulation of plastic flow and fracture of aluminium alloys. ESMC 2022 – 11th European Solid Mechanics Conference, 4 July 2022

Annual accounts

SFI CASA FUNDING 2022 (ALL FIGURES IN 1000 NOK)

Item	Host NTNU	Research partner SINTEF	Public partners	Industrial partners	RCN grant	Total funding
Research programmes	7389	720	3322	7722	13386	32539
Equipment					466	466
Administration	1000		828	2078	1253	5159
Total budget	8389	720	4150	9800	15105	38164

SFI CASA COSTS 2022 (ALL FIGURES IN 1000 NOK)

Item	Host NTNU	Research partner SINTEF	Public partners	Industrial partners	Total cost
Research programmes	25169	4020	700	2650	32539
Equipment	466				466
Administration	5059	100			5159
Total budget	30694	4120	700	2650	38164

MSc Students Face Research Challenges

How can we minimize the risk of electric vehicle batteries catching fire? How to design maximum safe vehicle security barriers? And how can we utilize 3D-printed components in protective structures?

20 MSc students worked on 13 different topics during spring 2022. The subjects revolved around the behaviour and modelling of materials, components, and structures exposed to dynamic loads. SIMLab and CASA work at the intersection of mechanics, design, dimensioning, and material technology. Relevant materials are metals, polymers and glass, concrete, and composites. Applications are, for instance, protective structures, energy absorbers, junctions, and bridges. 3 MSc theses were connected to wood, as in glulam and cross-laminated timber. One MSc project focused on «Mechanical testing and numerical simulation of car batteries subjected to extreme loads and deformations».

Another topic in 2022 was modelling running fracture in steel pipes for CO2 transport. The backdrop is CO_2 capture and storage and systems for safe transportation through pipelines. Further, one student worked on «Modelling tensile ductility using artificial neural networks». The topic was part of a project aiming to investigate using Artificial Neural Networks to predict tensile ductility in 6000-series aluminium alloys. Two MSc students worked on additive-manufactured protective structures. The project implied numerical simulations, 3D printing of components, material tests, and characterizations, e.g., computer tomography. Component tests in The SIMLab shock tube were also part of the project.

ICILSM 2022. How heavy is the brick?
On the evening of 15 June, CASA invited the conference participants to a social gathering with quizzes, games, and a barbecue at a charming farm situated outside Trondheim. It was a typical early summer evening in mid-Norway, 12 degrees, cloudy, with some rain. However, the mood was excellent.
From left: Postdoc Jianbin Xu, Postdoc John Fredrick Berntsen, Centre coordinator Peter Karlsaune, and Professor Genevieve Langdon from the University of Sheffield. (Photo: Sølvi W. Normannsen)

Norwegian Centre for Research-based Innovation

SIMLab

CASA
Centre for Advanced Structural Analysis

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 researchintensive 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 current 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.

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