CASA

Centre for Advanced Structural Analysis

Potential Impact from SFI CASA

Projects and Innovations

Impello Management AS
Frode Iglebæk
Trondheim, 15 February 2019

sfi Centre for Research-based Innovation
The Research Council of Norway

NTNU
Norwegian University of Science and Technology

SINTEF

IMPELLO

SFI CASA – Centre for Advanced Structural Analysis

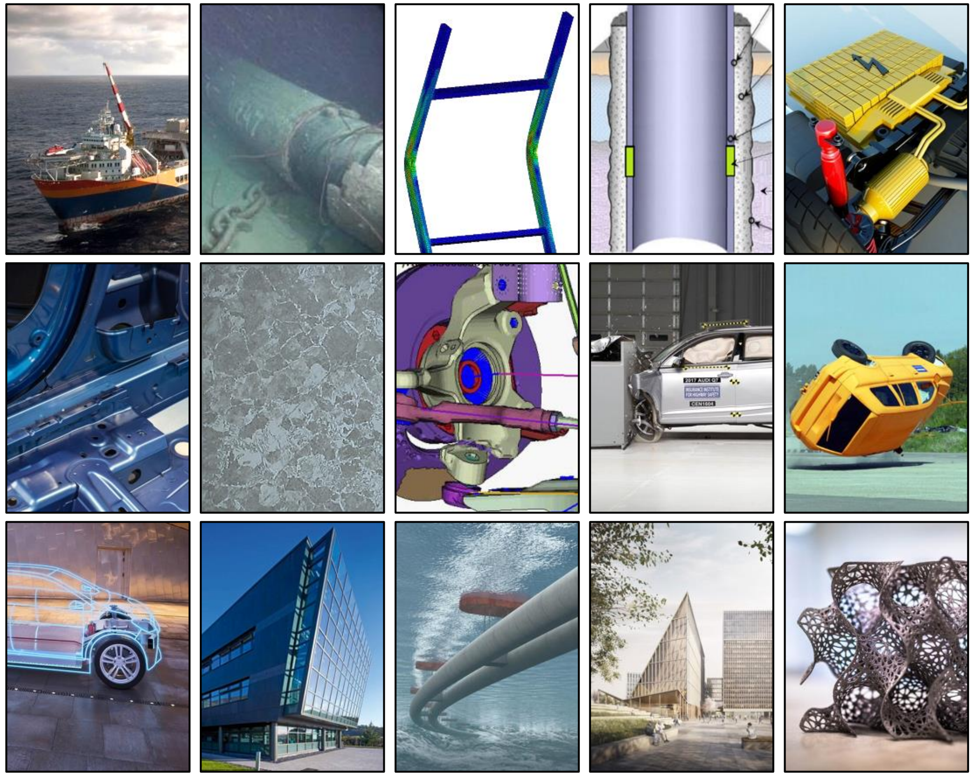
World-leading centre for multi-scale testing, modelling and simulation of materials and structures for industrial applications.

- The research is all about understanding how materials and structures react to impact and other extreme loadings: The more we know, the safer industry can design cars, pipelines and buildings.
- We aim to improve the survivability of people and vital infrastructure against any given threat.
- **Innovations are essential to achieve these goals.**

Summary – Impact from SFI CASA

Realized economic impact > 150 MNOK

Potential for saving hundreds of millions of euro when the industry implements SFI CASA's technologies and methods.



15 use cases documenting realized and potential impact:

Economic impact :

- Reduced costs
- Improved profitability
- Reduced time to market

Safety:

- Improved car passenger safety
- Improved design and regulatory guidelines

Technology:

- Increased performance of materials
- Reduced use of materials
- Improved/robust design

Societal:

- Reduced emissions and use of energy
- Maintain Norwegian industry's competitiveness
- Education and recruitment
- New employment

Commercialization:

- Enodo AS: Spin-off company established 2018
- eCorr – commercial software
- Several software tools and material models in pipeline for commercialization

The History of SFI CASA Started in 1990

1990	…	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	…	2023

Structural Impact Laboratory (SIMLab) was formed in 1997.

The basis for SFI CASA was several research projects carried out since 1990.

2007: Start of SFI SIMLab

SFI SIMLab (2007-2014)

SFI CASA (2015-2023)

Selected projects linked to SINTEF and SIMLab:

- **RoBDes** (2005-2008)
- **BIP nextGensi** (2009-2013)
- **AluMast** (2015-2018)
- **PolyCrash** (2006-2009)
- **FlexLinerLife** (2017-2020)
- **JIP CO2 Fracture Control** (2005-2008)
- **Duplex pipe fittings with sigma phase precipitation** (2009)
- **SMACC:** Fundamental studies of materials' behavior in future cold climate (2013-2018)
- **JIP CO2PIPETRANS** (2008-2009)
- **Crash systems in trucks** (2009-2011)
- **FractAl** (2016-2021)

What is an SFI – what is SIMLab – what is CASA...?

SFI is a funding scheme:

- «SFI» = Centre for research-based innovation
- 8-year research programme funded by the Research Council of Norway
- The host institution for an SFI is often a university or a research institution

SIMLab is a research group at NTNU:

- **S**tructural **Im**pact **Lab**oratory is a research group at the Department of Structural Engineering, NTNU

SFI SIMLab was an SFI centre at NTNU (2007-2014)

SFI CASA, **C**entre for **A**dvanced **S**tructural **A**nalysis (2015-2023) is the second SFI centre hosted by the SIMLab research group

Key Facts About SIMLab (2007-2014), the Predecessor to SFI CASA

SFI SIMLab

SFI SIMLab – Structural Impact Laboratory (2007-2014) – was hosted by NTNU with SINTEF as a research partner.

Research activities:

- Connectors and joints
- Fracture and crack propagation
- Multiscale modelling of metallic materials
- Optimal energy absorption and protection
- Polymers
- Demonstrators

PARTNERS

Industry:

- Equinor
- Hydro
- SSAB

Automotive:

- Audi
- Benteler Automotive
- BMW
- Renault
- Toyota

Public:

- Norwegian Public Roads Administration (Statens vegvesen)
- Norwegian Defence Estates Agency (Forsvarsbygg)

Key figures SFI SIMLab

Turnover	
Budget 2007-2014	226 MNOK
Concurrent projects 2007-2014	22 MNOK
PhDs and Masters	
PhDs in SFI SIMLab	21
PhDs in concurrent projects	3
Masters in SFI SIMLab	159
Peer-reviewed publications	
SFI SIMLab publications	157

Key Facts About SFI CASA (2015-2023)

SFI CASA

Centre for Advanced Structural Analysis (2015-2023) is hosted by NTNU, with SINTEF as a research partner.

Research areas:

- Lower scale
- Metallic materials
- Polymeric materials
- Structural joints
- Structures

Technology transfer:

- Methods and tools
- Industrial implementation

PARTNERS

Industry:

- DNV GL
- Equinor
- Hydro
- Multiconsult

Automotive:

- Audi
- Benteler Automotive
- BMW
- Honda
- Renault
- Toyota

Public:

- Norwegian Public Roads Administration (Statens vegvesen)
- Norwegian Defence Estates Agency (Forsvarsbygg)
- Norwegian Ministry of Local Government and Modernisation (KMD – Kommunal- og moderniseringsdepartementet)
- Norwegian National Security Authority (NSM – Nasjonal sikkerhetsmyndighet)

Key figures SFI CASA

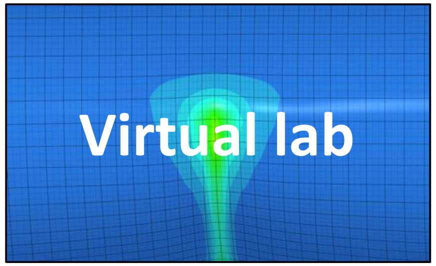
Turnover	
Budget 2015-2023	290 MNOK
Concurrent projects 2015-2018	24 MNOK

PhDs and Masters (31.12.2018)	
PhDs in SFI CASA	16
PhDs in concurrent projects	5
Masters in SFI CASA	69

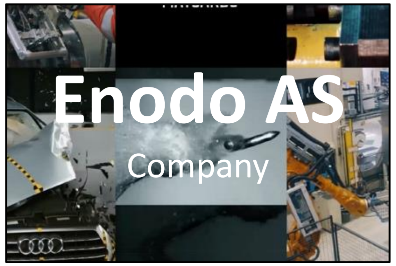
Peer-reviewed publications (31.12.2018)	
SFI CASA publications	81

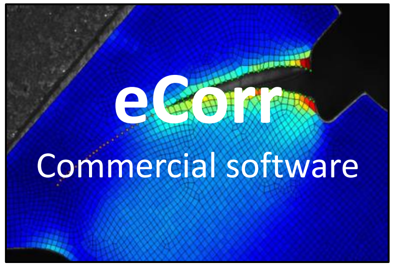
Innovations and Contributions from SFI CASA

INNOVATIONS AND KNOWHOW – Internal Innovations

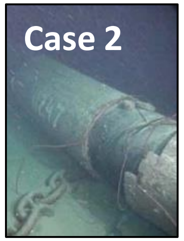


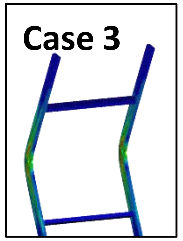
COMMERCIALIZATION

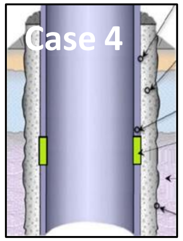


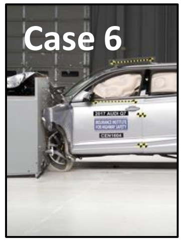


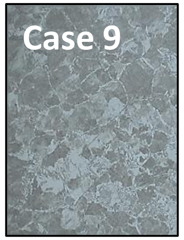
USE CASES – Onshore and Offshore, Automotive and Protective Structures

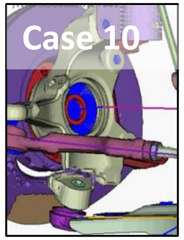


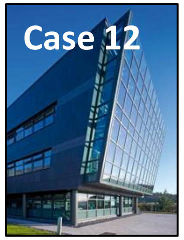


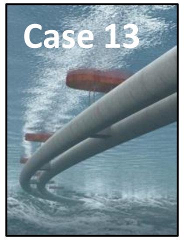


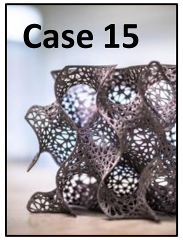












Potential for commercialization and industrial implementation

Virtual Laboratory for Metallic Structures

The Virtual Laboratory is one of the main achievements at SFI CASA – but it is still in the making.

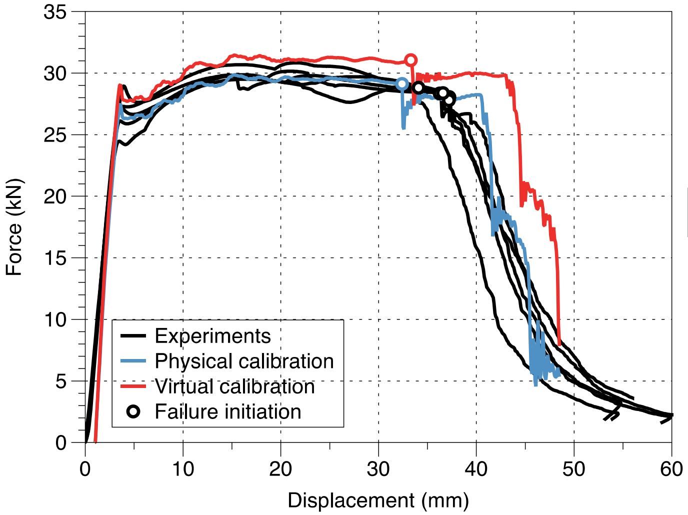
The objective is to make physical tests superfluous.

The idea is to obtain material parameters required for the design of a structure from lower scale analyses.

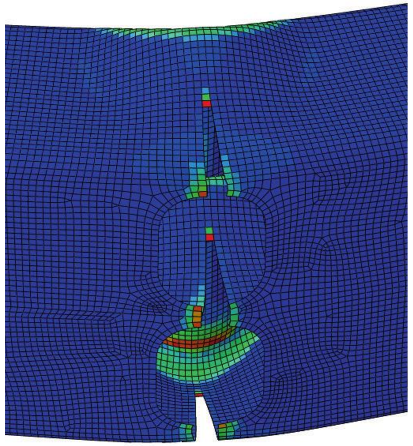
Example: Material calibration

Modelling of extruded aluminium profiles subjected to axial loading and three-point bending

Physical vs. virtual calibration of materials



Comparison of experiment and simulation

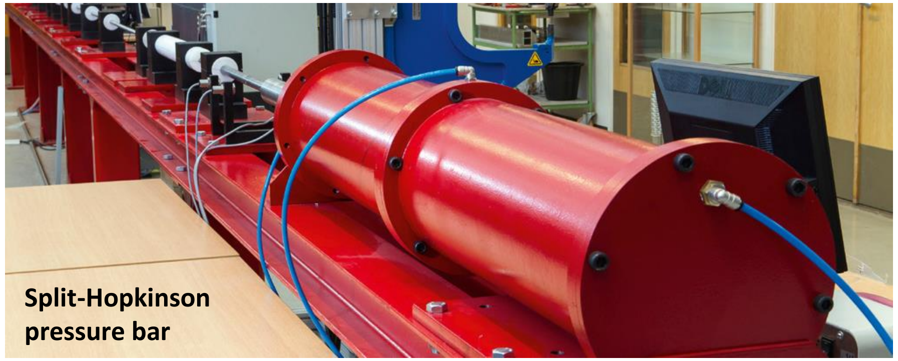


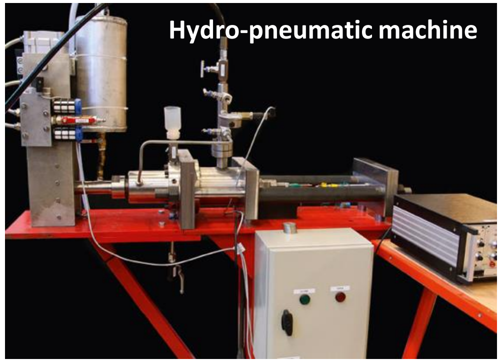
Physical Laboratory

SFI CASA has access to unique laboratory infrastructure and computer facilities at NTNU and SINTEF.

The unique 18 m **shock tube**, developed by CASA, allows recording and measuring blast loads on aluminium, steel, glass an concrete plates. This has led to important new knowledge, e.g. effects of an explosion inside a submerged tunnel and impact behaviour of laminated glass.

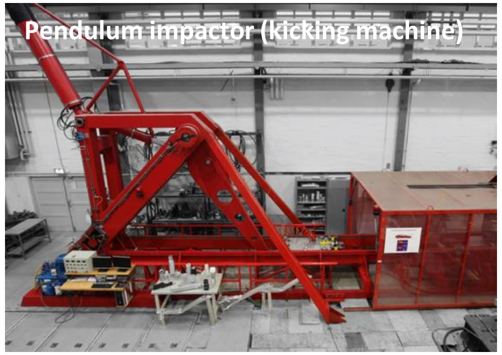

Shock tube

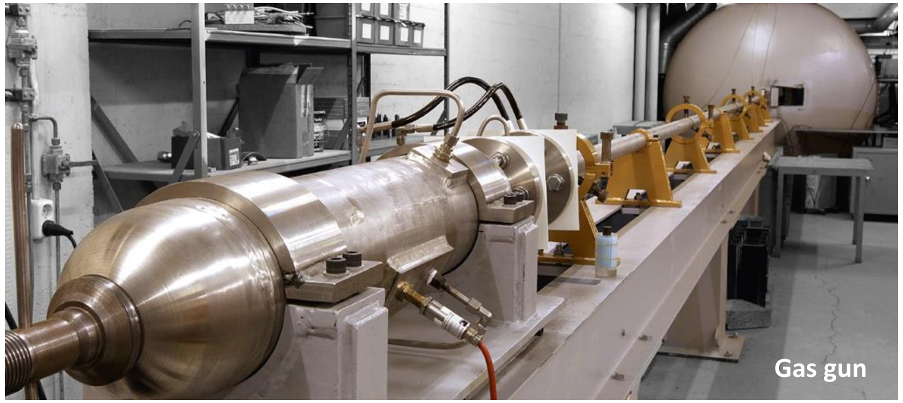

Split-Hopkinson pressure bar

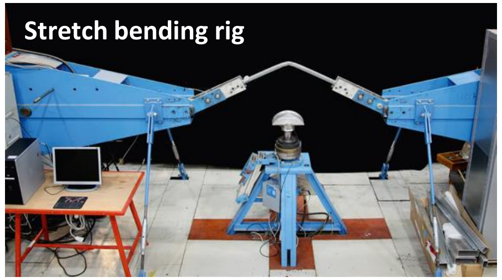

Hydro-pneumatic machine


High-speed cameras


Split-Hopkinson tension bar


Pendulum impactor (kicking machine)

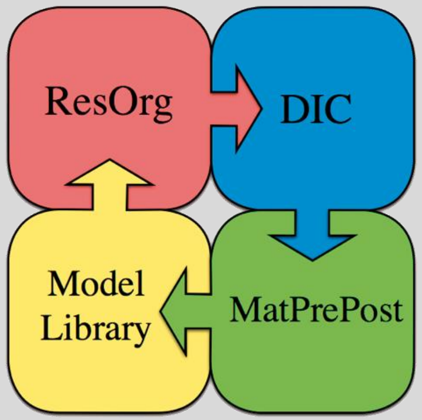

Gas gun


Stretch bending rig

More info: www.ntnu.edu/casa

SIMLab Toolbox

The SIMLab Toolbox is a collection of software tools and custom material models for calibration, simulation and validation of structural behaviour.



Research results from CASA projects are gathered in the SIMLab Toolbox.

Software modules

- **ResOrg** – Results Organizer
- **DIC** – Digital Image Correlation
- **MatPrePost** – calibration of material models

Model library

Collection of user-defined material models linked to commercial CAE solvers such as Abaqus, LS-DYNA, PAMCRASH and more:

- SIMLab Metal Model
- SIMLab Polymer Model
- SIMLab Porous Plasticity Model
- SIMLab Crystal Plasticity Model
- SIMLab Brittle Material Model

Key software developers of SIMLab Toolbox:
Afaf Saai, Térence Coudert and Stéphane Dumoulin.

More info: www.ntnu.edu/casa

COMMERCIALIZATION:

Enodo AS – Spin-off Company from SFI CASA

ENODO

Enodo develops technology and systems to provide material data for use in advanced numerical structural simulations.

The objective is to be a major provider of validated material cards and material card management systems.

- **Service offering**
  - Consultancy and engineering services related to material testing, material card calibration and validation.
  - Provide knowledge about the use of these material cards.
- **Product offering**
  - Validated material cards.
  - Material cards management system (in development).
- **MATCARDS**: Ongoing verification project supported by the Research Council of Norway's FORNY2020 scheme.
  - Partners: Audi, Hydro and DYNAmore Nordic.

More info: www.enodo.no

About the company

- Two employees in Trondheim/Oslo. Established 2018.
- Owners: NTNU Technology Transfer and Enodo employees.

Contact: Jens Kristian Holmen, jens@enodo.no, +47 93045837

eCorr – Commercial Tool for Digital Image Correlation

SIMLab Digital Image Correlation (DIC) software (eCorr)

Image correlation of specimen testing:

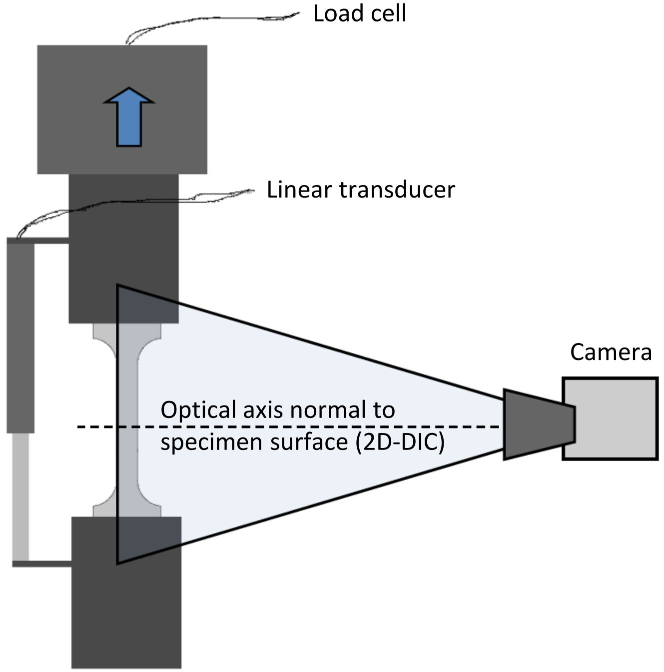
- Records high-speed image series
- Mesh generation and analysis
- Tracking of distinct points
- Edge tracking
- Real-time image processing
- Visualization

Customers and users

- Licensed to Federal University of Rio de Janeiro (UFRJ)
- Used by Equinor, Renault, SINTEF, NTNU and Norwegian Defence Estates Agency

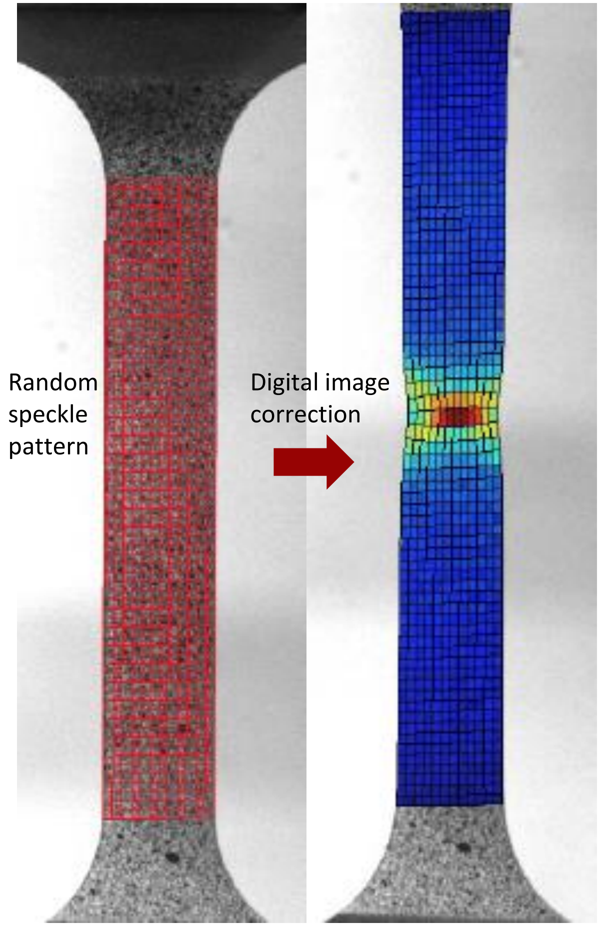
More info: www.ntnu.edu/kt/ecorr

Example: Uniaxial tension test



Displacement and strain fields are measured over the specimen as viewed by the camera.

Elongations can be extracted during post-processing.



Reference image
No deformation

Current image at
deformed stage

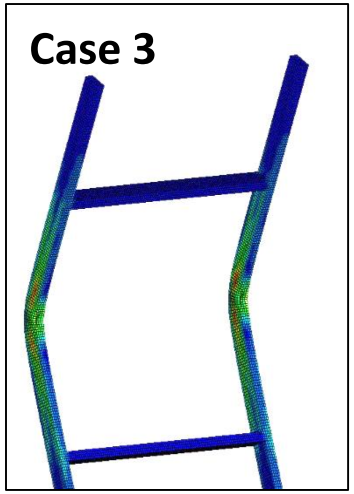
Use cases – Onshore and Offshore Structures

Optimized Pipeline Routing at Åsgard A

equinor

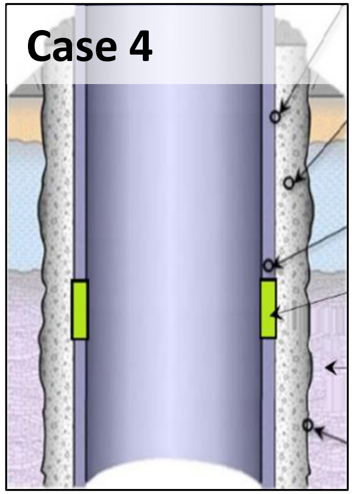
Material Models for X65 Grade Steel Pipeline

equinor



Standardization of Building Structures Using Advanced Non-Linear Analysis

Multiconsult



Innovative Casing Structures for Super High-Temperature Geothermal Wells

MANNVIT

Iceland Deep Drilling Project Consortium

Case 1

Photo: Øyvind Hagen

Illustration: Equinor

Optimized Pipeline Routing at Åsgard A

THE RESEARCH CHALLENGE

In 2015, Equinor was planning a new pipeline route from Trestakk North towards Åsgard A south. Different route alternatives were studied. However, the optimal one represented a risk of damage in the case of a mooring line failure of Åsgard A.

Equinor's main concern was to evaluate closely the risk of damage to the pipeline by considering the mechanical properties of the polymer coating protection, originally considered only for isolation purposes.

As a result, Equinor utilized the SIMLab laboratory facilities of NTNU to perform a series of impact tests on coated pipes to document the levels of energy the pipeline could resist without any risk of damage.

Equinor concluded that the pipeline could be laid under the ship with no risk of damage and saving 5 km of pipeline routing.

THE INNOVATION

The SIMLab laboratory documented the levels of energy during collision that was taken up by the polymer coating. Several impact tests were carried out. Equinor confirmed how polymeric coating contributes to pipeline protection.

Subsequent to these findings, Equinor has made requests for improved simulation tools for decision support. In the event of potential pipeline damage, such simulations are needed for damage assessment evaluation.

REALIZED AND POTENTIAL IMPACT

- 5 km shorter pipeline route.
- Cost saving >150 MNOK.
- NTNU's material models can be used to calculate the severity of damage, reduce the need for physical inspection and avoid unnecessary repairs (which could cost 100+ MNOK).

NTNU
Norwegian University of Science and Technology

equinor

Photos: Equinor

Material Models for X65 Grade Steel Pipeline

Initiated by a ship anchor impact incident at Kvitebjørn field in 2007

THE RESEARCH CHALLENGE

If a pipeline is left exposed on the seabed, it is vulnerable to impact from foreign objects. Falling and dragging anchors pose a serious threat to subsea equipment.

In 2007 a 10-ton ship anchor hooked onto and pulled the 32" Kvitebjørn gas pipeline 53 metres out of its installed position, which resulted in an extensive shut-down period and a very complicated repair operation costing more than 1 billion NOK.

As a result of this event, NTNU together with Equinor has initiated research on how coatings and pipelines are impacted by shock and collisions, and how pipeline integrity can be simulated in a virtual environment. One of the purposes with the research is to enhance the understanding of the remaining capacity of a damaged pipeline and further developed models that can predict the remaining life time.

THE INNOVATION

NTNU’s objective is to model the behaviour of a pipeline during impact. A new material model for X65 steel and a fracture model is currently in development. These models will be used with Finite Element programs (e.g. IMPETUS, Abaqus or similar) to simulate indentation and fracture behavior.

IMPACT AND POTENTIAL

- Several projects been initiated with Equinor and DNV GL within the SFI CASA framework.
- The new models will potentially have substantial impact on:
- Future guidelines for pipeline design.
- Improved safety.
- Optimized cost/performance by using numerical tools.
- Commercialization of models in collaboration with CAE software vendors.

Case 3

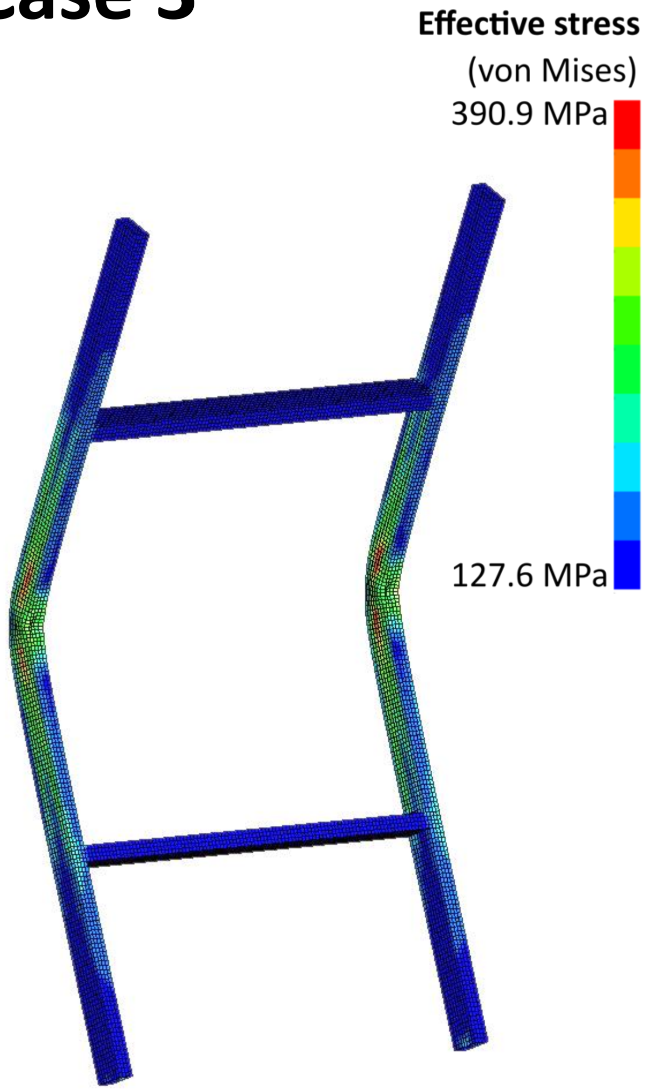


Illustration: Multiconsult

Standardization of Building Structures Using Advanced Non-Linear Analysis

For normal buildings, most structural problems can be treated as *linear*. However, high-security buildings must be designed to withstand severe impacts such as explosions, heavy vehicle impact, etc.

NON-LINEAR PROBLEMS

Critical scenarios can be progressive collapse, large deformations, and local failure without total breakdown.

In order to assess the robustness of the structural design of these scenarios, advanced, *non-linear* analysis is required. There is also an increased need for the use of both linear and advanced non-linear analyses in structural design in general.

SOME KEY QUESTIONS ARE:

- Is the building design itself safe (in addition to other security measures)?
- How to evaluate low-scale problems, e.g. façade elements being spread across a large area after an explosion?
- What are the best practices for robustness verifications and design against progressive collapse, and how can these be translated into design standards, guidelines and product requirements?
- What are the best practices for non-linear structural global and local analyses, and how can these be translated into design standards and guidelines?

IMPACT FOR MULTICONSULT

Existing standards for design do not cover these topics well enough, and Multiconsult expects increased standardization in the years to come.

Multiconsult’s goal is to contribute to expand today's design standards, product requirements and guidelines, and ensure that they are based on research-based knowledge and best practice.

Multiconsult’s motivation for participating in SFI CASA is knowledge-building and to secure access to state-of-the-art methods and technology.

Multiconsult can thus be active in establishing and participating in standardization work and thereby strengthening its knowledge and competitive position.

Multiconsult is one of the leading firms of consulting engineers and designers in Norway and Scandinavia. With near 3,000 employees, it offers multi-disciplinary consultancy and design, engineering and management services to land-based and offshore sectors.

Case 4

Innovative Casing Structures for Super High-Temperature Geothermal Wells

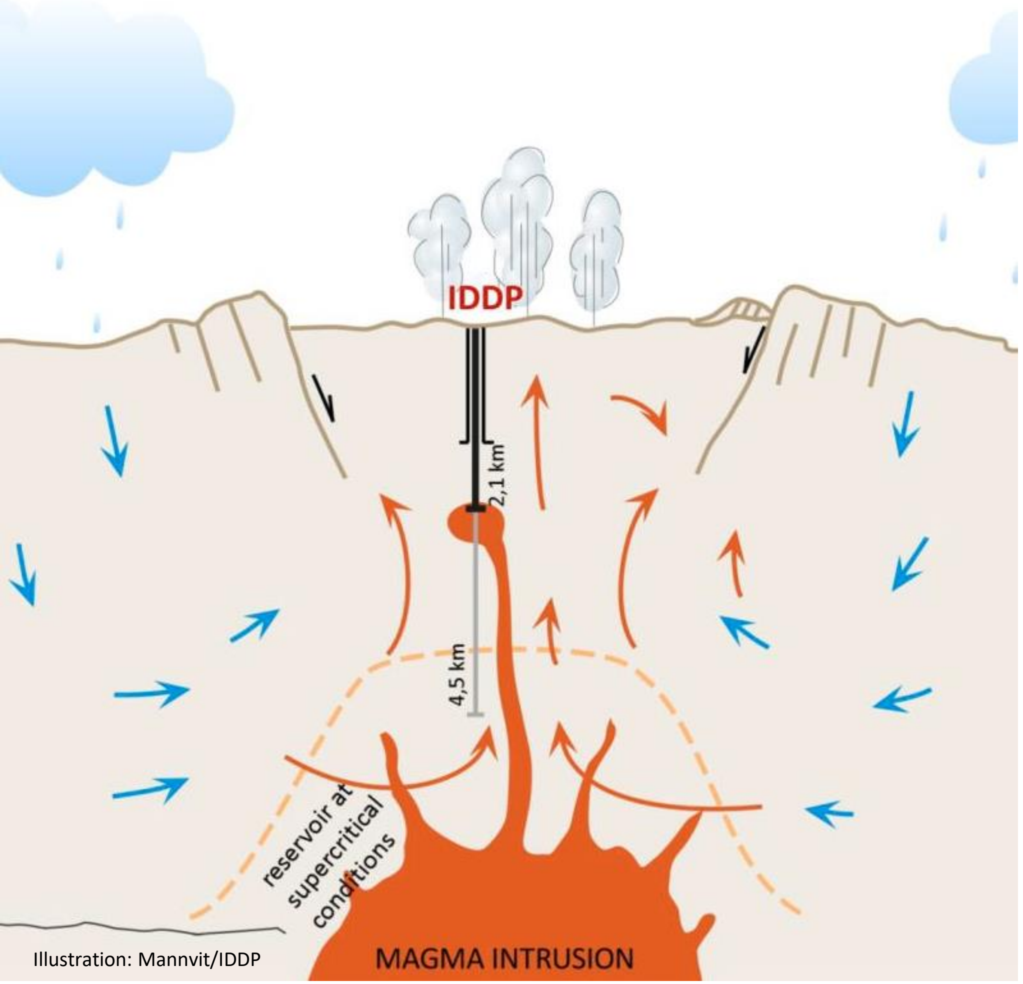


Illustration: Mannvit/IDDP

THE CHALLENGE

In geothermal energy, a huge potential lies in hydrothermal reservoirs where ultra-high temperature fluid (400-500 °C and pressure 300 bar) can be utilized to multiply the power production output.

However, the aggressive fluids and high temperatures encountered in these geothermal reservoirs are tough challenges for any materials and structures to sustain during the operation lifetime of up to 20 years.

The casing system, which is a composite structure with a steel casing and cement sheath on its outside, needs to be designed to protect the integrity of the geothermal well, and protecting the shallow environment against contamination, under the expected harsh conditions.

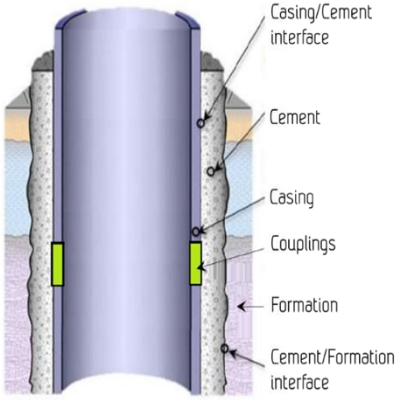
Faulty design may lead to severe failure in casing, e.g. by (1) mechanical buckling or (2) tensile failure in threaded connection or cross section. This will consequently result in loss of the well, which happened in the Iceland Deep Drilling Project's well no. 1 (IDDP1).

THE INNOVATION

- Sustainable casing design solutions for super HT geothermal wells.
- Design tool box.

IMPACT

- Reduced CO_2 emissions by promoting green energy.
- Safer and reliable geothermal production.



NTNU Norwegian University of Science and Technology

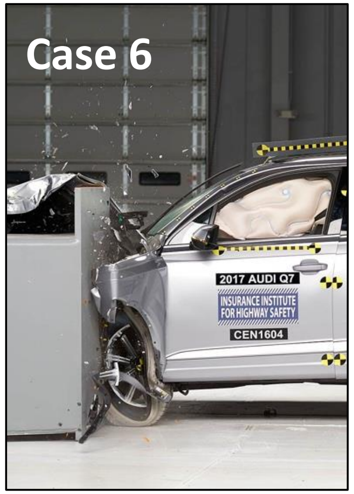
SINTEF

MANNVIT

IMPELLO

Use cases – Automotive Structures

Lightweight Battery Housing for Electric and Fuel Cell-Powered Cars



Reducing the Need for Physical Prototypes

Glass Failure and Roof Strength Testing

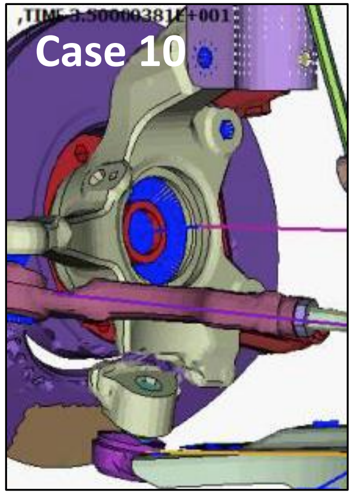
Numerical model

Virtual Testing

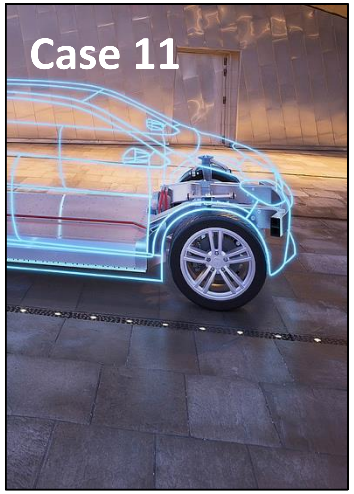
Joining technology

Virtual Testing

Metallic materials



Virtual Testing of Hybrid Structures



Competitive Manufacturing of Automotive Parts in Norway

Automotive partners and suppliers:

Audi BMW HONDA RENAULT TOYOTA BENTELER Automotive

Battery compartment in an electric vehicle

Lightweight Battery Housing for Electric and Fuel Cell-Powered Cars

THE CHALLENGE

Design of electric vehicles (EV) and fuel cell-powered cars has introduced several new engineering challenges. Since batteries add weight and have a high energy intensity, several parts of the car structure have been redesigned to accommodate safety requirements.

A critical component is the battery housing protecting the battery cells. A car manufacturer must be sure that the battery structure performs as expected in a high impact situation.

Since space is tight in EVs, the accuracy of simulated displacements for certain crash scenarios must be improved by factor 10, compared to fossil car simulations. For pole crash simulations where battery components are deformed, an accuracy improvement of +/-1 mm is required. This is a major research challenge.

THE INNOVATION

SFI CASA, Hydro and several car manufacturers are jointly developing:

- New aluminium alloys.
- New material models for joints.
- New material cards.
- New modelling techniques.

This will enable increased use of aluminium to make intelligent lightweight designs.

POTENTIAL IMPACT

- Safer electric cars.
- Reduced body weight.
- Reduced manufacturing costs.
- Reduced CO_2 emissions by replacing steel with aluminium.

Car crash laboratory tests at Euro NCAP. Photos: www.euroncap.com

Reducing the Need for Physical Prototypes

Improved material and joint models enable full vehicle car crash simulations and reducing the need for physical prototypes.

THE CHALLENGE

Crash testing of new car prototypes is very expensive. On average each prototype costs between 0.5 and 1.0 MEUR. Different scenarios are tested – frontal crash, side impact, pole crash, roll-over tests, etc.

Large car manufacturers run several crash tests every day, typically 500-1000 tests per year per car maker. This represents a huge financial cost.

The common goal is to move from physical to virtual testing in the coming years and reduce the number of physical prototypes by 50 %. This implies full vehicle simulations with a very high level of accuracy. New material models and improved multiphysics tools are key ingredients for achieving this goal.

The research at SFI CASA, particularly on material modelling and modelling of joints, are important contributions to improve the accuracy and efficiency of such virtual testing.

THE INNOVATION

SFI CASA has developed:

- New material model for shell elements. This model is in PAM-CRASH and LS-DYNA, which are the leading software tools for crash and impact simulations.
- Custom material cards for manufacturer-specific aluminium alloys, tested and verified at NTNU’s laboratories.

In addition SFI CASA has contributed to validation of a macroscopic model for joints.

POTENTIAL IMPACT

- Contribution to the objective of 50 % reduction in physical car crash testing.
- Potential for >100 MEUR in annual cost saving *per car maker*.
- Maintain competitiveness:
  - Reduced R&D and manufacturing costs.
  - Reduced time to market.
  - Make safer cars.

Case 7

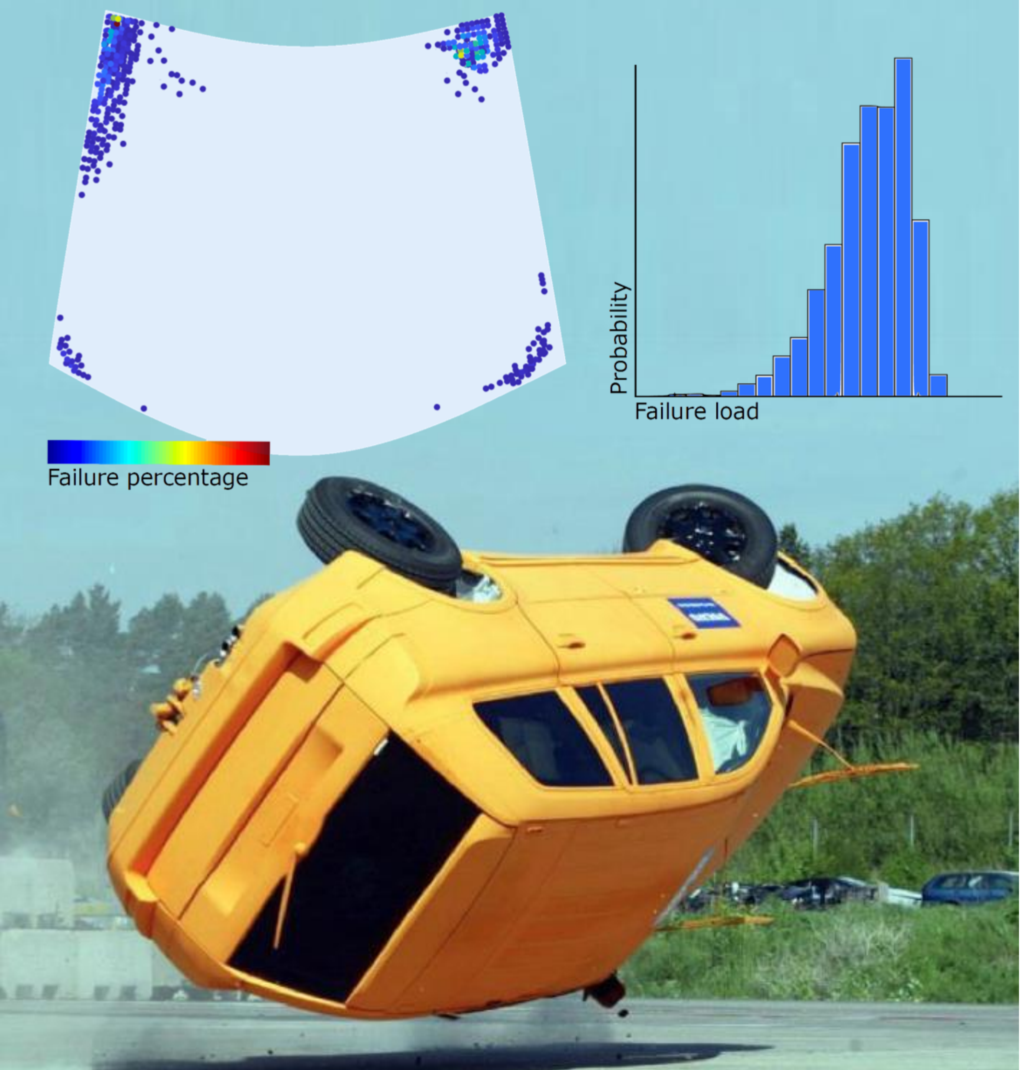


Photo: Volvo Car Group. Graph/plot: NTNU, SFI CASA. The photo and plots are not related – illustration only.

Glass Failure Prediction and Roof Strength Testing

THE CHALLENGE

Glass is a brittle material and it fails suddenly into sharp fragments. Car windshields are both safer and stronger due to the laminated structure.

When designing cars, the windshield causes large uncertainty. The reason is the presence of microscopic surface flaws in the glass. This results in a highly stochastic fracture behaviour, which in turn leads to a varying performance in e.g. the roof strength test. This test evaluates the capacity of a car during a roll-over.

The performance in the roof strength test is strongly correlated to fracture initiation in the windshield. The uncertainty linked to glass fracture often results in a conservative car design.

THE INNOVATION

SFI CASA has developed a numerical model that can predict fracture initiation in glass. The model can thus be used to conduct roof strength testing numerically and in a highly efficient manner. It can also be used as an optimization tool, which can help to make less conservative designs.

POTENTIAL IMPACT

- Predict the performance in the roof strength test.
- Optimize the car design, and thus reduce weight and cost.
- Reduce the amount of physical tests.
- Increase car safety.

Virtual Testing – Joining Technology

THE CHALLENGE

Modern cars are multi-material structures using sheet metal, cast aluminium and iron, polymers, carbon fiber reinforced parts, and more. Joining of materials with different properties is challenging due to non-uniform behaviour of the materials. Several joining techniques are applied such as welding, rivets, threaded fasteners and gluing.

Large-scale analyses of structures require appropriate models for joints and materials:

- For joints, simplified (macroscopic) models are used to increase computational efficiency.
- For materials, dedicated input parameters are required for each material and material thickness combination. For a new car model, the number of such new combinations could be in the range 50-100.

Calibration of a given joint/material combination normally requires nine tests with five repetitions (45 in total). With typical 50-100 different types of joints in a car body, the total number of required tests could easily exceed 2,000.

In real life, this is not achievable due to cost and strict time restraints. The solution is to replace physical testing with virtual testing.

THE INNOVATION

SFI CASA has developed new methodologies and numerical models for multiscale-analysis of rivets, screws and materials. These can be implemented in standard CAE simulation software (Abaqus, LS-DYNA, PAM-CRASH, etc.).

Physical testing can be replaced by virtual, computer-based testing. This will pave the way for automated «high volume» characterization of multi-material joints combinations.

POTENTIAL IMPACT

- Substantial reduced calibration costs due to automated characterization of a large number of joint/material combinations.
- Reduced calibration time – from typically 3 months to 48 hours. Use of external labs is no longer needed, which will speed up development.
- Commercialization in collaboration with vendors of standard engineering applications.

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Case 9

Virtual Testing – Metallic Materials

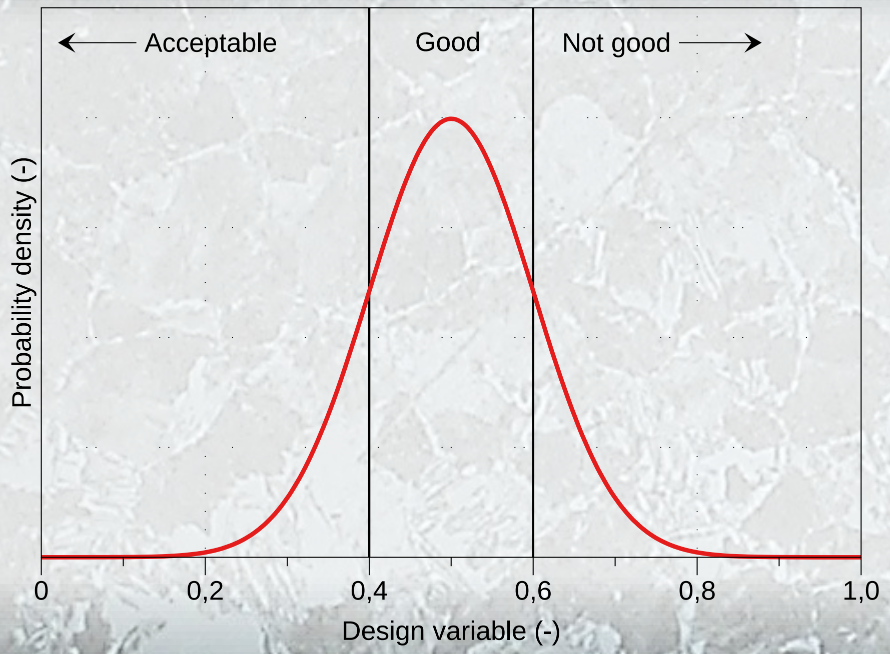

Photo: NTNU, SFI CASA

THE CHALLENGE

The material properties of an identically specified aluminium alloy may vary slightly from supplier to supplier of raw materials.

Small variations in terms of delivery specifications (the design window) is acceptable. However, if the deviation at material level is too high, the final component can have non-robust behaviour and degrade the properties of the final structure.

It is important to understand these variations when calibrating material cards.

THE INNOVATION

SFI CASA has developed new numerical models for multiscale-analysis and «high volume» calibration of material properties for 6XXX aluminium alloys. The numerical models can in the future be implemented in standard CAE simulation software (Abaqus, LS-DYNA, PAM-CRASH etc.).

The technology can be used to develop «virtual alloys»: Instead of changing the physical design of a car body to obtain a certain desired structural response, the material properties itself (the virtual alloy) can be changed to achieve the desired response of the final car body.

The car manufacturer can subsequently ask the materials supplier to provide the specified custom-alloy that is required.

POTENTIAL IMPACT

- Generate material cards for a large number of various virtual alloys. The robustness of a material can be checked in the process, e.g. if change of supplier.
- Material cards can be generated faster and more cost efficiently.
- Using the virtual test setup enables sensitivity and robustness analyses.
- Number of material combinations in the design can be increased.

Case 10

Virtual Testing of Hybrid Structures

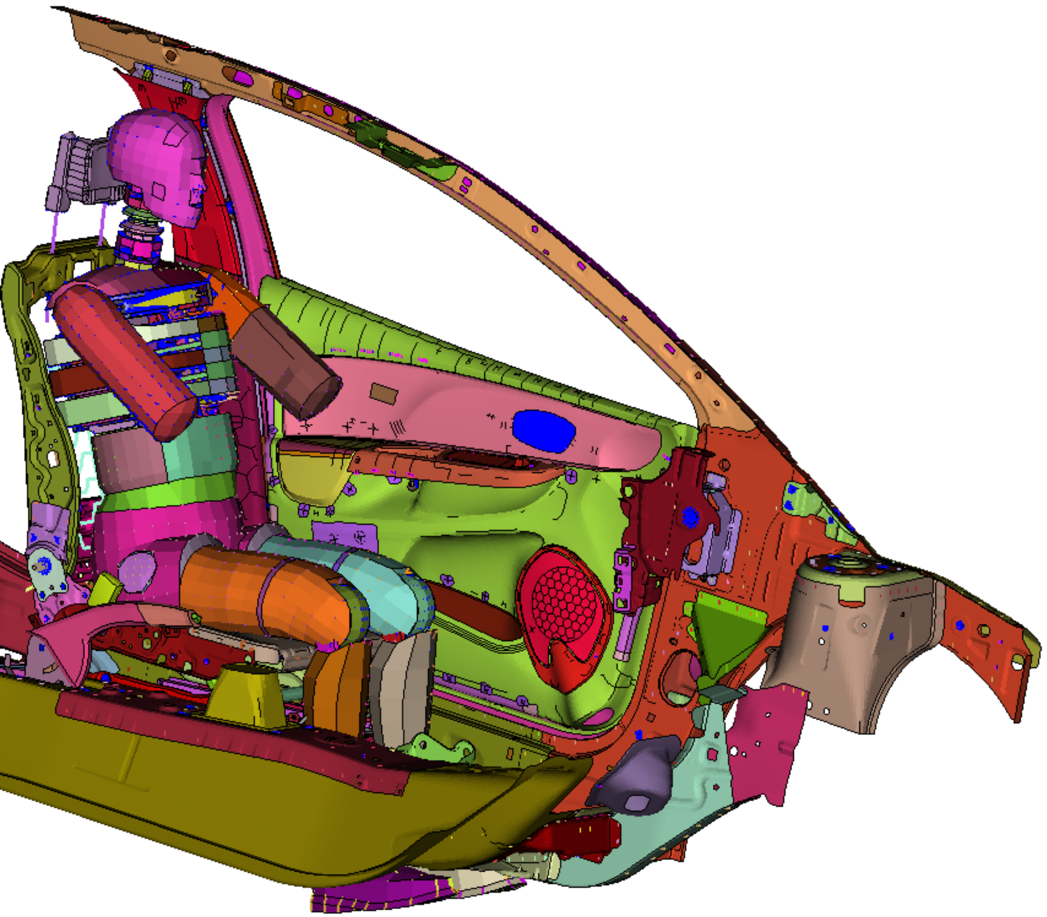

Photo: Renault

Hybrid structure model

THE CHALLENGE

Most EU member states currently apply some form of CO_2 tax to the registration and/or ownership of passenger cars. Since CO_2 tax constitute a significant part of the base price of a car, a major objective is to reduce CO_2 emissions by improving fuel-efficiency and/or reducing body weight of the car.

Renault's objective is to reduce CO_2 emissions. One (of several methods) is to lighten the body weight by using hybrid structures. Hybrid structures are components and subsystems combining two or more materials (e.g. steel and aluminium). This design can contribute to up to 10 % reduction of the body weight without significantly increasing material cost.

Modelling and simulation of multi-material components, subsystems and complete vehicles is however a complex task and require accurate material models. Renault need improved tools to help them decide the suitable type of structures, joints and materials to be used.

THE INNOVATION

SFI CASA has developed new methodologies and numerical models for multiscale-analysis of hybrid structures. Some of these are already implemented in the CAE tool PAMCRASH, which is used by Renault. Over the past few years, computational efficiency has been improved significantly, and will soon allow simulation of complete vehicle structures.

IMPACT

The participation in SFI CASA is helping Renault in the transition from steel-based car design to lightweight car design.

The technology is already implemented in the design and engineering process and used by several teams at Renault.

- **Reduced time to market** by speeding up the modelling and simulation phase, e.g.:
  - Material cards can be generated faster and more cost efficiently.
  - For joints, simplified models are used to increase computational efficiency.
- **Improved CO_2 emission car specifications**

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RENAULT

Case 11

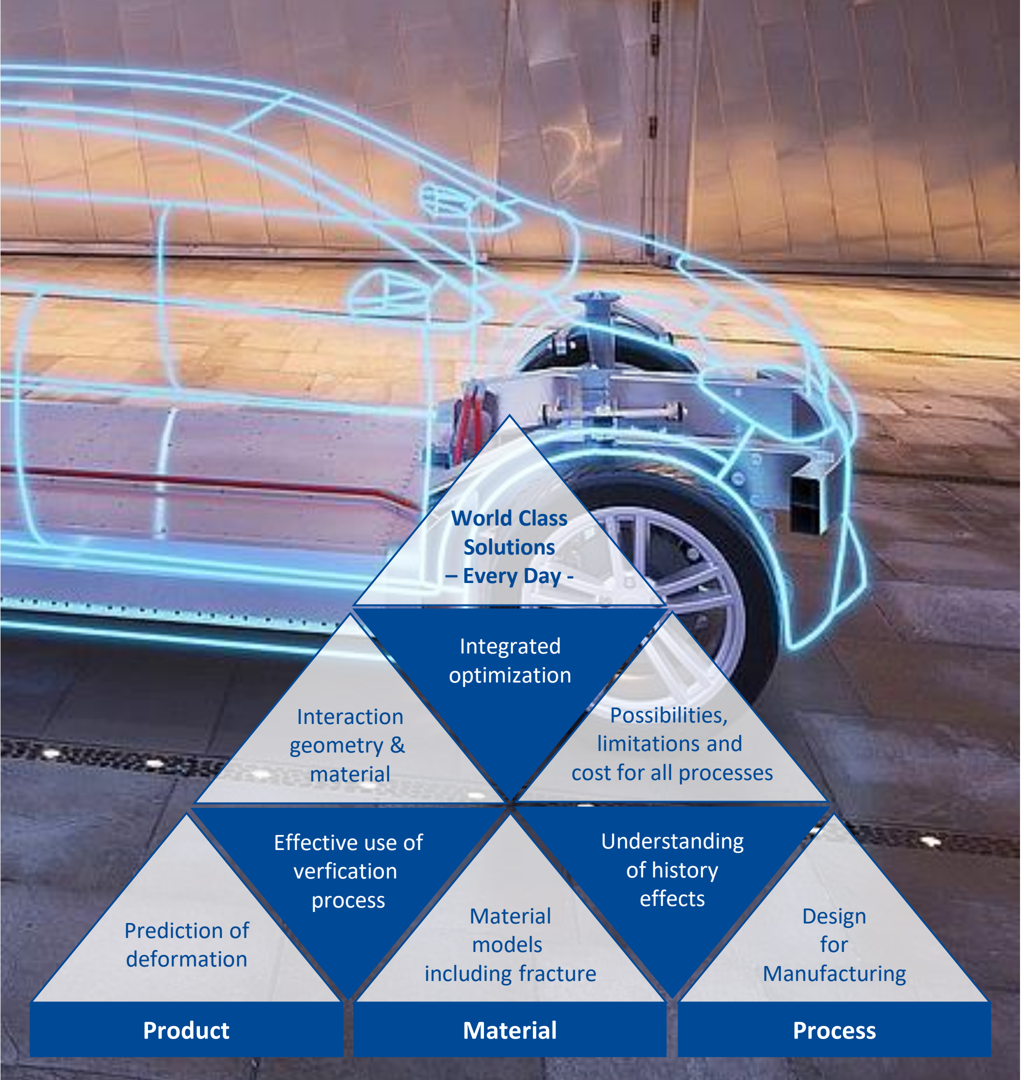

Photo: Benteler

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BENTELER makes it happen

Competitive Manufacturing of Automotive Parts in Norway

Benteler Automotive at Raufoss produces 8 million parts every year for automotive manufacturers such as Audi, BMW, Daimler and Volvo. Products include structural components such as crash management systems, suspension systems and also battery trays for electric vehicles.

It was not obvious that it was possible to develop an international competitive automotive supplier at Raufoss. One key aspect in achieving this was having access to state-of-art knowhow e.g. SFI CASA. Today world-class product with annual turnover of around 200 MEUR (with 90% export share) are being developed and produced by Benteler's 550 employees.

THE RIGHT MATERIAL IN THE RIGHT PLACE

World-class solutions are created by a through-process approach were numerical simulations and methods are used in finding optimized solutions and assess risk to reach competitiveness in function, cost and weight.

A clear trend in structural design is to use «the right material in the right place». Thus, integrated optimization of material, process and product is key in finding future structural design that meets future market requirements.

ACCESS TO SFI CASA TECHNOLOGY PLATFORM

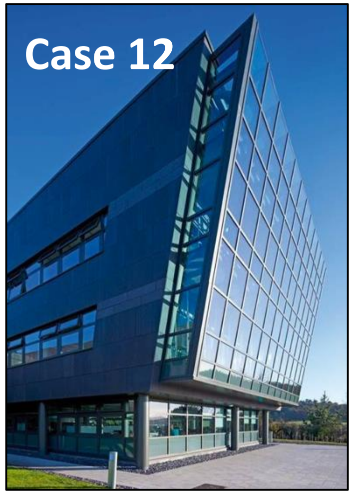
In order to be one of the top international suppliers, Benteler has joined SFI CASA to get access to knowhow and technology that supports development of such cost-effective, light-weight and safe structures.

Multi-scale testing, modelling and simulation for development of material models and effective characterization of metallic and hybrid structures is an important part of this.

IMPACT FOR BENTELER AT RAUFOSS

- Access to new state-of-the-art material models:
  - Prediction of fracture for robust design using higher strength aluminium alloys.
  - Implement full through-process approach.
  - Tailored alloy development to meet functional requirements.
- Recruitment of highly qualified employees.
- Secure and strengthen international competitiveness by a having access and competence to use world class tools and methods for product design.
- Network to international recognized experts, including key OEM suppliers to Benteler.

Use cases – Protective Structures



Blast Resistant Facades with Lightweight Aluminium Frames

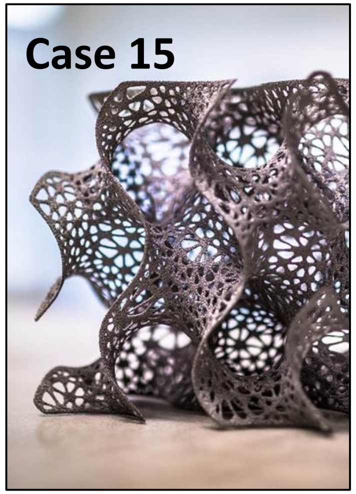
Hydro

Safety in Submerged Floating Tunnels

Statens vegvesen
Norwegian Public Roads Administration

Protection and Physical Security

FORSVARSBYGG



3D Printing of Metallic Materials

Multiconsult

Case 12

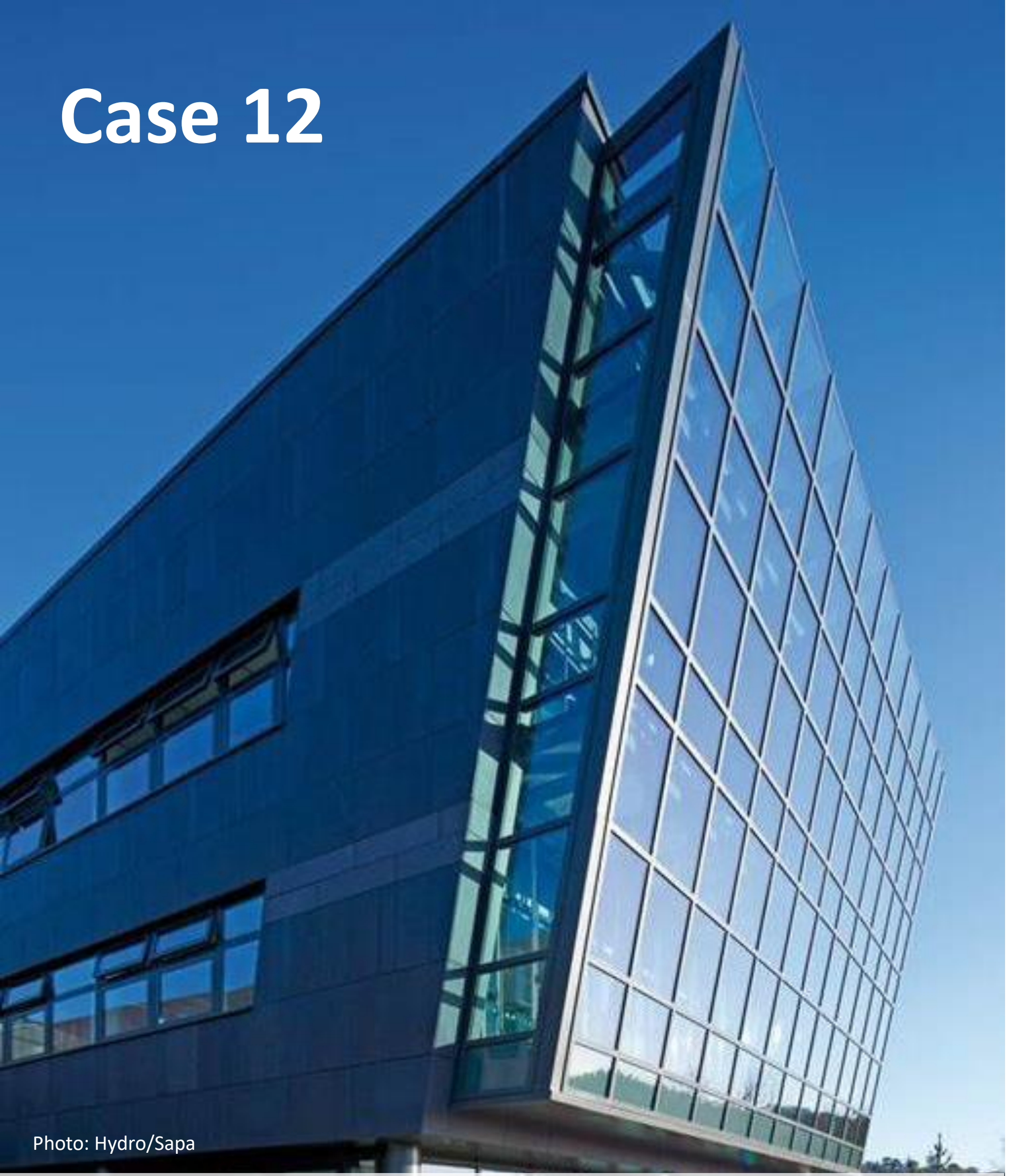


Photo: Hydro/Sapa

Welsh Assembly (parliament building) in Wales. Blast resistant facade with window frames in aluminium saving 30 % weight compared to steel.

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Hydro

Blast Resistant Facades with Lightweight Aluminium Frames

THE CHALLENGE

Many public buildings are classified as high-security objects and could be built with curtain walls and security glazing to withstand man-made events such as ballistics and high-explosive bomb blasts.

Hydro Extruded Solutions' focus is how to bring a level of blast mitigation to the more conventional building as an inherent feature of standard facades. Aluminium as raw material comes from a lower cost base than steel (lighter to handle, easier to prepare), while steel can provide equal or greater strength with a more slender profile.

With blast testing, there is no scope for failure. This leads to a conservative design and increased cost for the customer. The challenge is how to increase the accuracy of blast simulations; reduce the required level of safety factors adopted today; and allow use of more slender aluminium structures with lower weight and cost.

THE INNOVATION

Hydro, with support from SFI CASA, has developed:

- Improved aluminium material models.
- New laboratory testing procedures.
- New aluminium frame designs with similar impact resistance as steel.

IMPACT AND POTENTIAL

Market:

- Competitive aluminium facade products.
- Blast mitigation for conventional buildings.
- Increased competitiveness.

Financial:

- Reduced cost cap – more affordable.
- Increased profitability (Hydro/Sapa).

Environmental:

- Less use of building materials and energy.

Case 13

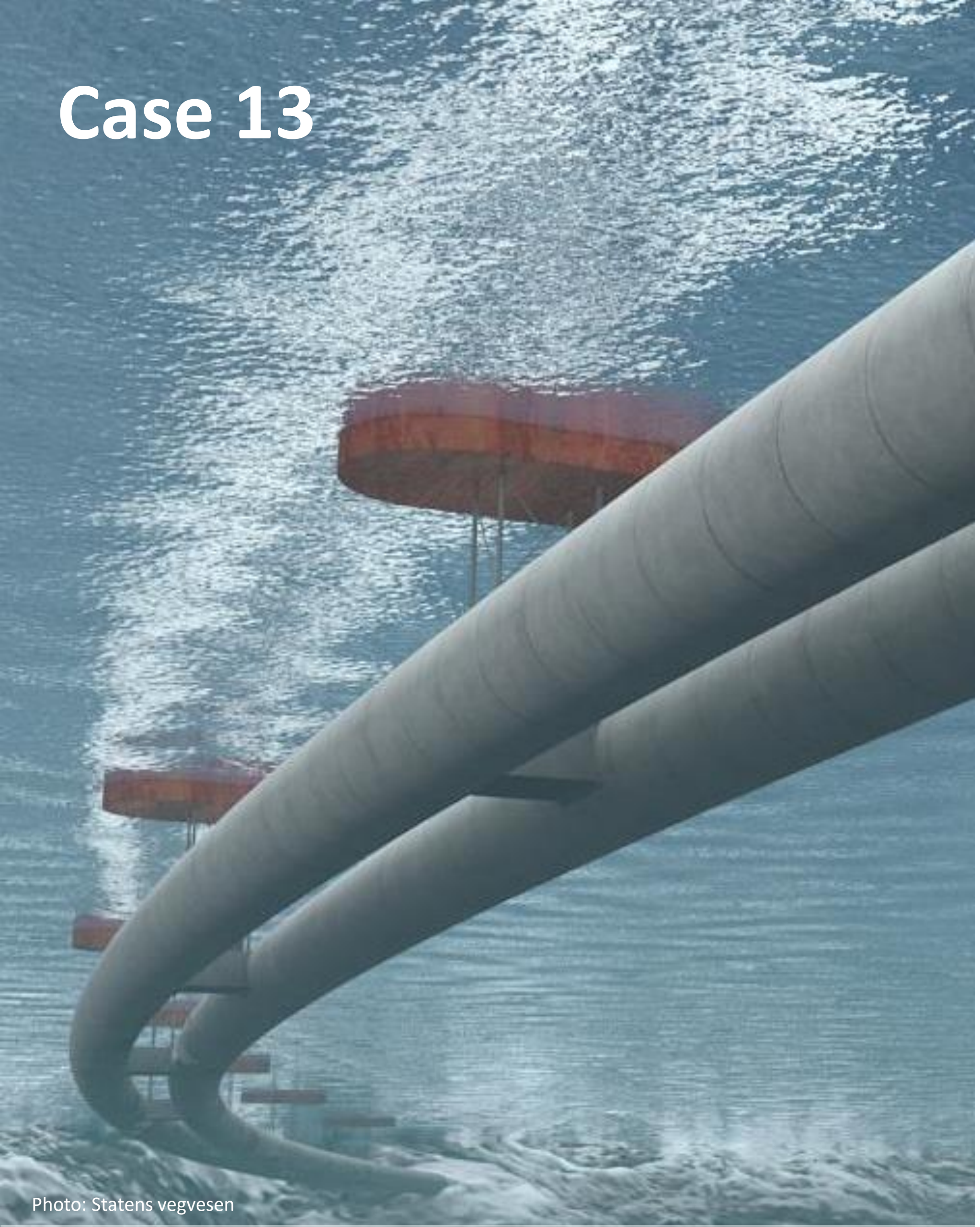

Photo: Statens vegvesen

Safety in Submerged Floating Tunnels

THE CHALLENGE

Concrete is the most widely used construction material in the world. Due to its inhomogeneous and stochastic nature, concrete is challenging to model accurately, especially if it is exposed to extreme loading conditions.

To understand the behavior of concrete subjected to rapid and intense loads, high quality experimental data are needed, which together with material testing and advanced computational tools help us to understand large structures if an accident were to occur.

As an example, doing full-scale physical testing of an internal explosion inside a submerged floating tunnel crossing, e.g. in the Sognefjord, would be impossible – hence we must rely on computer simulations.

THE INNOVATION

Using digital image correlation for material characterization has proven to be a useful tool for ductile materials, and the same is true for concrete. Combining quality measurements with models accounting for the inherent heterogeneity and random nature of concrete may enable better utilization of the material. By varying different parameters determining the behaviour of the concrete it is further possible to tailor materials with specific properties to customize the geometry to specific load scenarios.

POTENTIAL IMPACT

- By combining digital image correlation tools and physical measurements, it is possible to make structures more robust and minimize the consequences of an accident.
- This applies to areas outside the world of infrastructure – all kinds of protective structures can benefit from this research.

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Statens vegvesen
Norwegian Public Roads Administration

Case 14


Photo: Statsbygg

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Protection and Physical Security

THE CHALLENGE

Explosion, impact and collision can be classified as accidental loads from a design perspective. To meet such challenges, structural analyses are increasingly carried out in virtual environments to achieve safer and more cost-effective designs.

The goal of this simulation work is to improve the probability of survival of people and vital infra-structure for a given threat. A protective structure, e.g. a blast-proof facade or building structure, is the last layer of defence against a threat. It is thus of utmost importance that such structures are designed and validated on a sound theoretical and experimental basis.

New designs need to be validated through high-precision experimental testing and advanced instrumentation. Although much information can be obtained from laboratory tests, relying on such an approach would be too costly and inefficient. Use of computer-aided design and impact simulation, together with a strategy for material selection and well-selected validation tests, can significantly lower the cost and enhance the overall quality and performance of the required physical protection.

THE INNOVATION

SFI CASA has, in collaboration with Forsvarsbygg, NSM and KMD*, developed:

- Improved material models for structural materials such as aluminium, steel, polymers, concrete and glass.
- Improved numerical strategies for blast, impact and crash simulations.
- Reduced the need for expensive and time-consuming experimental testing.

POTENTIAL IMPACT

- It is impossible to base the protective design of vital infrastructure against terrorist attacks on full-scale experiments. The only viable solution is to use computer-aided design and virtual simulation models when making strategic decisions for physical protection.
- Improved material models and numerical methods established by SFI CASA, will contribute to safer and more cost-effective protective solutions.

*Norwegian Defence Estates Agency, Norwegian National Security Authority and Ministry of Local Government and Modernisation

Case 15

Photo: NTNU, Anders Gimmestad Gule

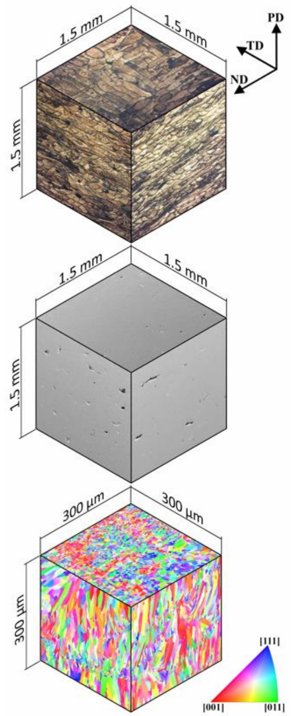

Photo: NTNU, SFI CASA

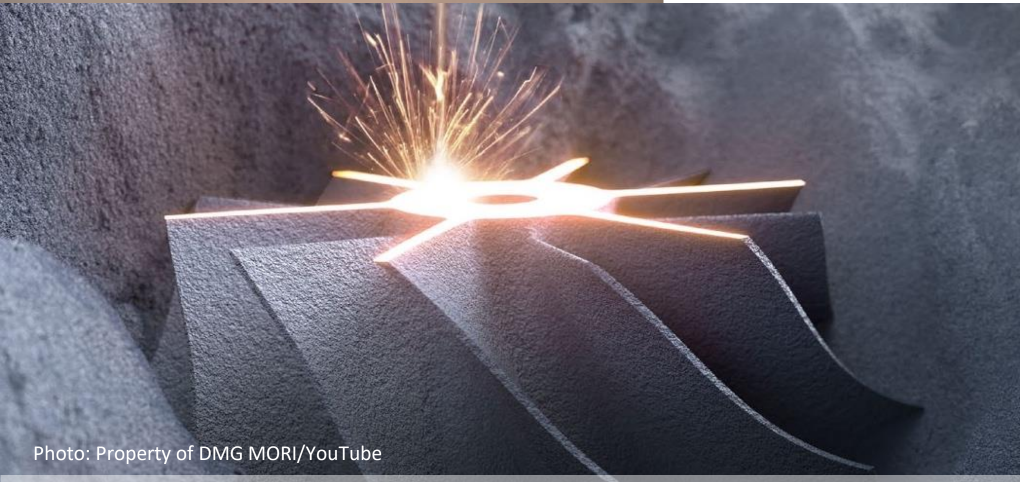

Photo: Property of DMG MORI/YouTube

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3D Printing of Metallic Materials

THE CHALLENGE

Additive manufacturing has experienced an exponential development in the last few years, enabling production of complex parts without the limitations inherent to traditional manufacturing routes.

Just like any other building material with industrial applications, there is a need for research regarding how 3D-printed parts should be modelled and their pros and cons compared to cast alloys, extrusions, etc.

This research is to be done in close cooperation with 3D printing companies, since the material behaviour is to a large extent linked to the production process.

THE INNOVATION

SFI CASA is currently investigating the following aspects related to additively manufactured metal parts:

- Links between the material properties and the production process.
- Metallurgical investigations on the microstructural configurations.
- Testing and modelling of 3D-printed components under crushing loads and ballistic penetration.

POTENTIAL IMPACT

Market:

- Time and cost reductions thanks to elimination of assembly steps.
- Greater customization of the product.
- Attractive to maintenance departments.

Financial:

- Shorter value chain.
- Small production batches become more cost-effective.

Environmental:

- Minimal waste of materials.
- Reduced emissions compared to traditional subtractive manufacturing processes such as machining and cutting.