# ANNUAL REPORT 2021

April 2022

SFI Manufacturing

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# In this report



## WORDS FROM THE CHAIR OF THE BOARD,

Our society is facing a number of crises simultaneously: global warming, Covid19-pandemic, lack of food, lack of energy, war in Europe and geopolitical instability.

We are usually talking about how the manufacturing industry shall handle external challenges, but perhaps we should rather focus on the role of the manufacturing industry in the society to be more robust for coping with such crisis on top of each other? The manufacturing industry is a key enabler for sustainable development with respect to environment, society and economy, and this industry is an important part of our common emergency preparedness.

Our best robustness for the future is a society that is prepared for facing a large variety of challenges. In this context, it is vital for Norway to maintain, and further develop, high quality in research, manufacturing and innovation. Governmental cofounding of R&D is one of the most effective efforts build national robustness for facing challenges to come.

Collaborative research, as all partners in SFI Manufacturing have joined in on, have contributed to our most powerful tool to build robustness for the future: knowledge. This annual report gives an overview of the contribution from the centre last year, and I hope you will read this report being motivated to seek possibilities to utilise this knowledge for a common sustainable development.

- Lars Stenerud, CEO Plasto AS
  Chair of the board, SFI Manufacturing

# What is SFI Manufacturing?

## The SFI program

An SFI is a program for industrially oriented research in active cooperation between innovative companies and prominent research groups.

- High potential for innovation and value creation
- Active cooperation between innovative companies and prominent research groups
- High scientific quality of research
- Bridgehead for international cooperation
- Recruitment of talented researchers

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

## SFI Manufacturing

SFI Manufacturing builds on existing national capabilities. Our aim is to strengthen the Norwegian manufacturing companies' ability to innovate.

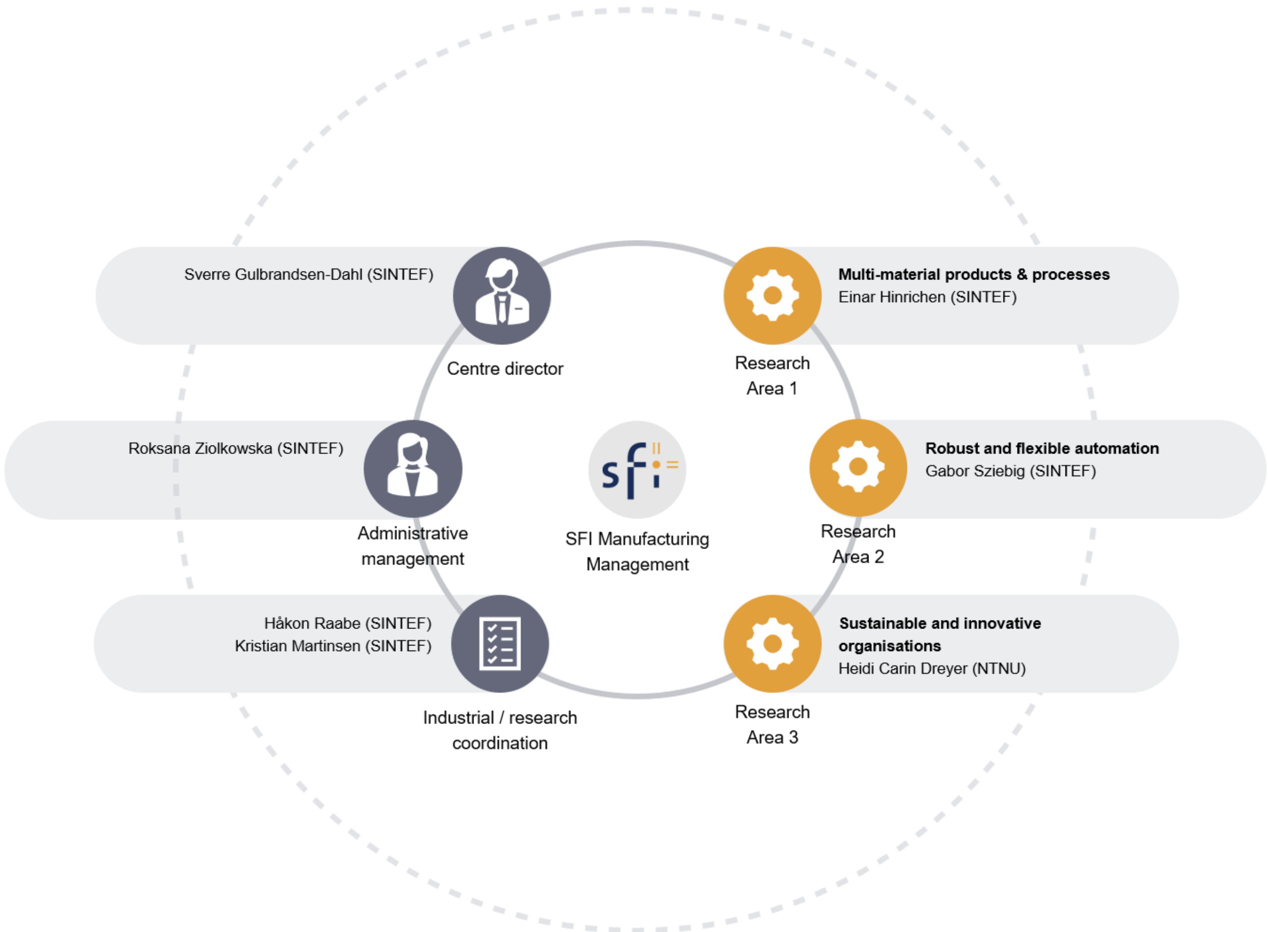
The centre seeks to mirror the inherent cross-disciplinary innovation systems in the industry and combine research on multi-material product solutions, flexible automated manufacturing and organisational processes.

The innovation process itself is a core research topic and SFI Manufacturing strives to be a basis for unleashing innovation potentials and research challenges embedded in the cross disciplinary interfaces, and to develop new research methods.

# Research and industrial partners

**Education and Research:** Physics, Materials Science, Cybernetics, Industrial economics and technology management, Geography, Manufacturing
**Host institution:** SINTEF Manufacturing
**Research:** SINTEF Manufacturing, SINTEF Industry, SINTEF Digital

# Centre Structure



## Our Research Areas (RA)


## Objectives of the Research Areas

**Multi-material products and processes**

To develop the ability to optimise material choice, multi-materials geometry, and processes simultaneously.

**Robust and flexible automation**

To further develop and link novel technologies and methodologies within automation to support innovation processes and advanced work systems in the manufacturing industries.

**Innovative and sustainable organisations**

To develop advanced work systems enabling utilisation of new technology and flexible and automated processes to manufacture sustainable multi-material product solutions.

# SFI Manufacturing and the green transition

During 2021 we still had to cope with the pandemic situation and the challenges that followed this.

Among the industrial partners the market situation have covered the whole range from a nearby collapse in aerospace to a booming market in furniture. The academic partners have struggled with limited access to research infrastructure and collaborative work spaces.

It was really nice to finally be able arrange a physical workshop at Gjøvik in October. We clearly see the extra dimensions a physical meeting provide compared to the digital substitutes we haven forced to use over the last years.

We intend to use this experience find a balance between physical and digital activities in the future, and to find the prioritised activities for the physical meetings to come.

**From 2021 I would like to highlight the following milestones of the centre:**

- Tina Bergh and Eirik Bådsvik Hamre Korsen have defended their PhD thesis

- 1 PhD candidate and 1 guest researcher have joined the centre

- The rest of the PhD candidates and post docs have maintained focus on their work and delivered very interesting results and progress in all their projects

- One partner have joined the consortium, Hapro, and one have left, HyBond. The partners have been able to prioritise financial and in-kind contribution to the centre.

- 21 scientific publications

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- Sverre Gulbrandsen-Dahl
  Chief Scientist & SFI Centre Manager

# Report from the Research Areas

SFI Manufacturing aims to strengthen the Norwegian manufacturing companies' ability to innovate, by doing research on multi-material product solutions, flexible automated manufacturing, and organizational processes. In this part of the annual report, we will give an insight into the research highlights that has been done in 2021. More information can be found in the newsletters available on www.sfimanufacturing.no.

## Research Area 1: Multi-material products and processes

In this research area we work towards an integrated understanding of multimaterial product design and production processes by focusing on selected scientific challenges in the chain: Material – Process – Structure – Property - Performance.

The overall objective is to develop the ability to optimize material choice, multimaterial geometry and processes simultaneously.

In this work we use a methodology where we combine advanced experimental characterization, experimental studies of production process and both physical simulation and numerical modelling of these.

Up until 2020 the two main topics for this research area has been challenges in joining of dissimilar materials with a special focus on interface region and adhesion, and additive manufacturing of metals and polymers.

Based on input from both the Scientific Advisory Board and Midterm evaluation there has been a focus towards identifying activities in cross-disciplinary topics both between work packages in RA1 and between the other research areas.

As we wrote in last year's annual report, the global trend towards circular economy thinking will have an influence product design, including choice of materials.

Solutions to this important challenge depends on innovations in all three research areas. Many of the spin-off projects established the last year has sustainability as a topic.

The research work in RA1 is heavily dependent on activities in our laboratories. The misfortunate Covid situation also caused some delays in our work in the start of 2021.

However, despite this we have managed to carry out most of our activities according to plan.

Additive manufacturing (AM) is an important key enabling technology in which the SFI is focusing much research on. Some of the highlights in this area in 2021 are:

**Improving multimaterial interfaces using AM**

When developing multimaterial structures, the interface between the components can be improved by chemical (for example priming a surface prior to adhesive bonding) or by physical (for example increasing the surface are to be bonded by roughening processes) methods.

In SFI Manufacturing, SINTEF has investigated how the surface of components manufactured using AM may be varied to increase the strength of the interface.

Specifically, surface features have been manufactured to increase mechanical interlocking of a polymer material on a metallic substrate.

By introducing these features during the AM process, they do not require a separate surface preparation step in manufacturing (reducing manufacturing steps), and AM can also enable complex surface features which are not easily created using conventional (subtractive) manufacturing processes.

This investigation is a also a cross-disciplinary collaboration between experts on metallic and polymeric materials, additive manufacturing and numerical modelling of interface properties.

**Developing a Norwegian additive manufacturing interest group: "Norwegian AM Hub"**

The growing momentum in the development of interest and applications of AM in Norway during the last few years, has had the effect that a large number of the key Norwegian AM stakeholders gathered at the "First National AM Conference" in Stavanger in October.

The general sentiment that was expressed at this meeting, was that while there have been many impressive breakthroughs on numerous application areas for AM, the development for AM in Norway is still lagging the international development, both in Europe and in other Nordic countries. Norway, being a small country, this means that there is limited access to AM expertise and capabilities, and finding the right resources is a critical steppingstone for small and medium sized companies as they are beginning to investigate the possibilities of AM technology.

At present there is a lack in coordination and collaboration, and inspired by the example of the Danish AM Hub, there was a clear consensus that this need could be addressed by the formation of a national additive manufacturing interest group in Norway.

The planning and discussions on the organization of this group has been ongoing during the winter 2021 and will continue during 2022. The results will be presented, and a formal decision to form the group, is expected to be taken at the next Norwegian AM conference, planned to take place in Trondheim in October 2022.

### Initiation of a joint effort to develop an ontology for additive manufacturing technology

The ongoing activity in development of international standards in AM has brought the publications of the second edition of the international standard for AM terminology: ISO/ASTM 52900:2021 Additive manufacturing – General principles – Fundamentals and vocabulary.

At the same time, the work in multi-scale modelling in SFI Manufacturing has identified a need for an ontology that would connect modelling of AM processes with the modelling of alloys in physical metallurgy.

This has brought the initiation of a cross-disciplinary collaboration between the expertise in AM fundamentals and terminology and the expertise in ontologies and multi-scale materials modelling with the intention to develop the basis for a generic ontology for processing and materials in AM technology.

### Installation of a new AM system with extended multi-material capabilities

The capabilities for research in industrial applications of AM and multi-materials has been greatly extended as a new robotic system for directed energy deposition (DED) of metallic materials was installed at the lab-facilities in Trondheim during a few exiting days in the last week of February 2022.

This new machine, a Meltio Engine Robot Integration, features an AM unit consisting of a build-head with six 200 W lasers, dual wire feeding and a complementary powder feeding system which can deliver two different types of powder simultaneously.

The AM unit is installed on a 6-axis industrial robot, and the system is complemented by a worktable that can be tilted and rotated.

Brought together, this combined solution enables building of complex geometries with up to four different materials.

However, this degree of freedom also comes with a corresponding level of complexity, both regarding the control of the additive process and regarding controlling the combined movements of the robot and build table.

In the present phase, the primary fucus is aimed at building experience and mastering this new tool, which brings a close collaboration between the research groups in AM and automation, represented by SFI manufacturing's RA1 and RA2.

Already from the very start of SFI Manufacturing, different methods for joining of dissimilar materials have been in focus of our research. Also in 2021 we have had focus on this.

**Laser and laser-assisted joining of dissimilar materials**

Aluminium alloys become more widely used in many industries due to low weight and high corrosion resistance. Therefore, there is necessity to join them with different ferrous and non-ferrous metals (copper and titanium).

Their application also extends to energy sector due to respectable electrical conductivity which is critically important nowadays.

The joining of two or more metals is challenging, due to formation of the intermetallic compound (IMC) layer with excessive brittleness. High differences in the thermophysical properties cause distortions, cracking, improper dilution, and numerous weld imperfections, having an adverse effect on strength.

Laser beam as a high concentration energy source is an alternative welding method for highly conductive metals, with significant improvement in productivity, compared to conventional joining processes. It may provide lower heat input and reduce the thickness of the IMC layer.

The laser beam can be combined with arc-forming hybrid processes for wider control over thermal cycle. Apart from the IMC layer thickness, there are many other factors that have a strong effect on the weld integrity; their optimisation and innovation is a key to successfully delivering high-quality joints.

In 2021, a review paper with a title "A Review on Laser-Assisted Joining of Aluminium Alloys to Other Metals" has been published in open-source Metals journal and has attracted attention from research both research community and industry.

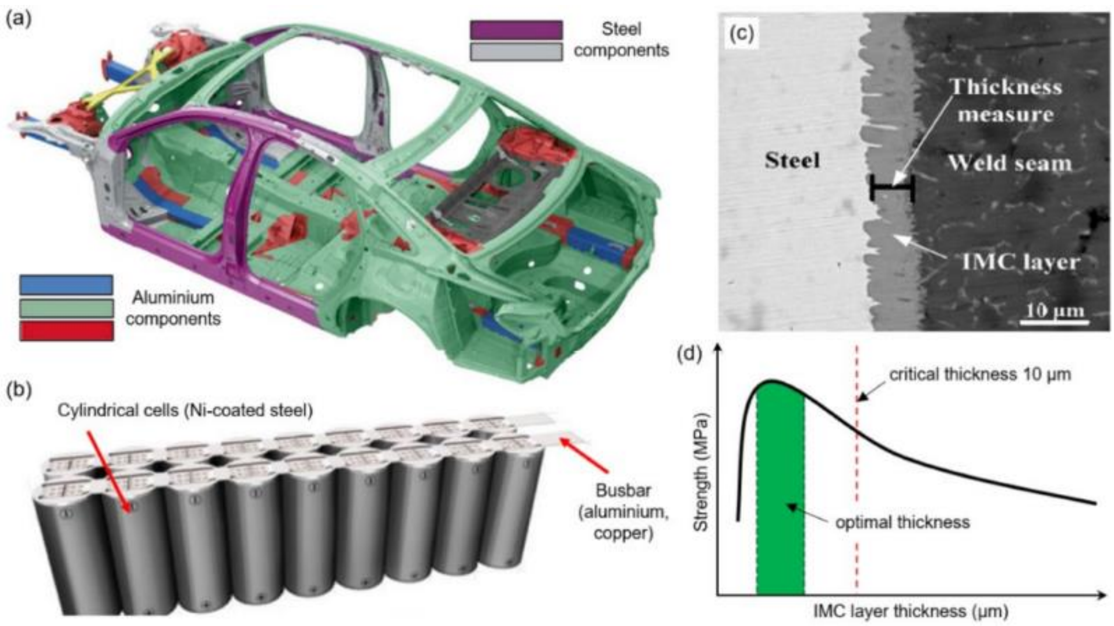



**Figure**: (a) Typical application of dissimilar materials in vehicles, various industries, where Audi A8 is presented as an example and (b) battery pack made of cylindrical cells; (c) Typical outlook and features of IMC layer by scanning electron microscope. (d) Effect of IMC layer thickness on strength. [Figure was taken from: https://www.mdpi.com/2075-4701/11/11/1680/htm]

**Multi-material parts using scrap metal**

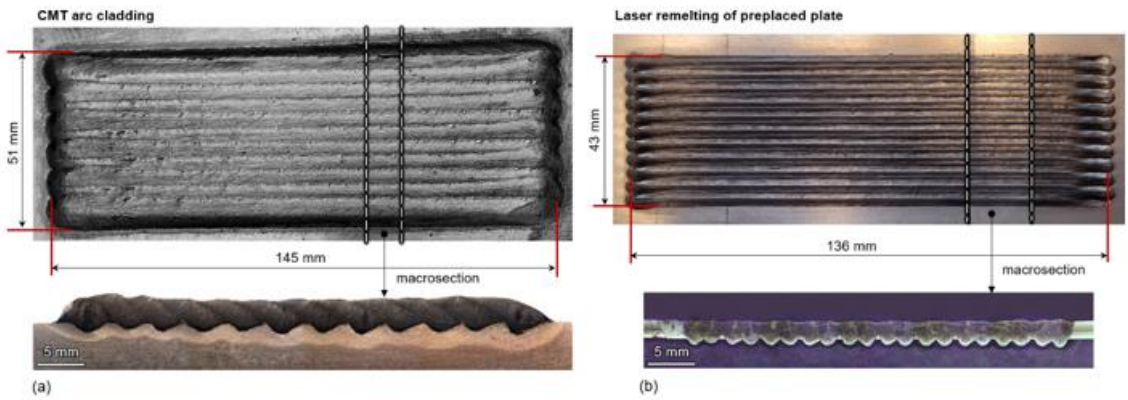
A laser beam is a flexible tool for melting different metals. Nowadays, circular economy is getting prioritized for smart utilization of the resources. Filler wire and powder are typical feedstock for cladding and additive manufacturing.

As an alternative, the feedstock in the form of plates can be used primarily for corrosive and wear resistance surfaces. Plates are easier to produce and much cheaper to use. Moreover, the plates used can be a waste sheet, or scrap metal. It may provide enhanced productivity and potentially even higher quality. This leads to smart utilization of resources supporting circular economy.

However, the process is not mature and requires more in-depth investigation to be competitive with well-research methods. Within the work, 316L stainless steel plates as a waste sheet were remelted by high power Yb:fiber laser beam for cladding purposes on carbon steel substrate.

Laser remelting provided twice higher productivity with two-fold lower heat input per pass improving reduction of distortions compared to conventional cold metal transfer (CMT) arc cladding.

Dendritic arm spacing was significantly reduced enhancing wear resistance. Corrosion test showed a slight improvement of laser remelted cladding which shows promising results.



**Nanomechanical testing for characterization of local mechanical properties of multi-material component**

Nanoindentation and accelerated property mapping of interphase between clad and carbon steel has been performed to characterize and obtained the local mechanical properties shown in Figure 1.

Hardness and elastic modulus maps of the areas of interest were obtained using the accelerated property mapping (XPM). The principle of this method is similar to classical quasi-static nanoindentation, but indentation can be performed at significantly shorter time, i.e., from minutes to tenths of seconds, defined in the load function.

During testing, the applied load and indenter displacement is continuously measured and automatically produce a load-displacement curve for each test, from which the reduced modulus and hardness were calculated by the Oliver and Pharr method and visualized in a property map. The advantage of this method is the high spatial resolution and lower acquisition time.

The microstructural alternations in the intermediate layers between cladding and carbon steel contains a great variety of properties that cannot easily be obtained by conventional testing methods due to the narrow region at micrometre scale. XPM and nanoindentation are one few method available that are able to extract the local mechanical properties in multi-material components at smaller scales.

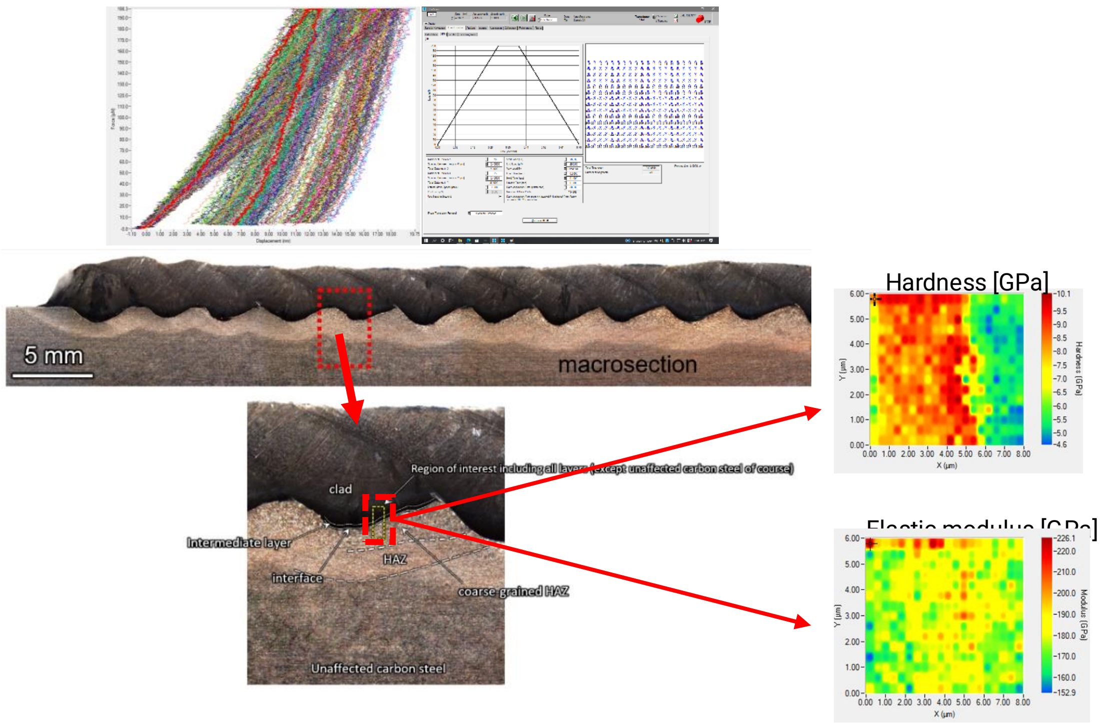



**Figure 1:** Results from accelerated nanoindentation on interphase between clad and carbon steel: Recorded load-displacement data from nanoindentation with corresponding load function and the resulting property map from the highlighted area investigated.

**A new experimental setup for determining the strength of interfaces**

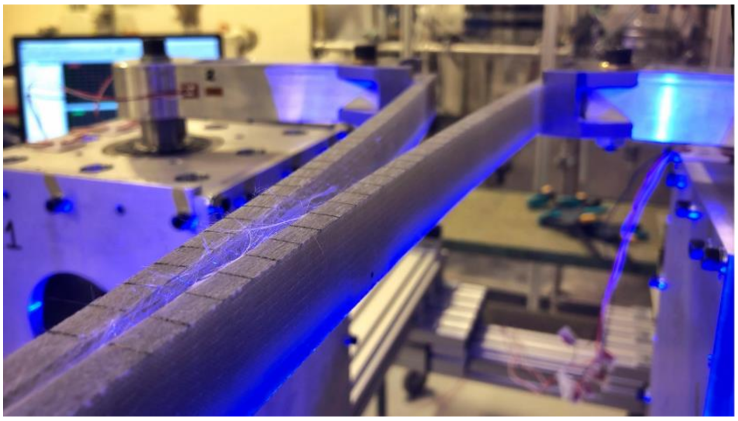
Of major importance to the success of multimaterial products is the strength of the interface between different materials, which can be a challenge when bonding very different materials.

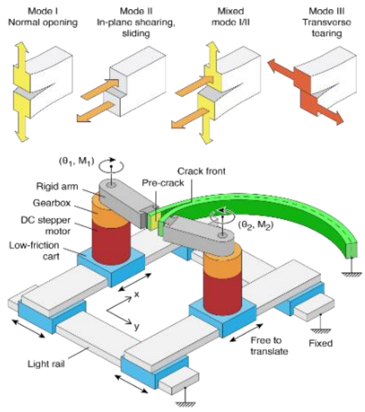
Building understanding of how delamination onsets and progresses is very valuable for predicting and characterising failure mechanisms, yet obtaining test data can be very challenging in parts with complex geometries.

Recently at SINTEF, new techniques have been developed which allow the characterisation of delamination in both flat and curved panels, giving valuable information on both the onset and propagation of failure in real parts.

These data can then be used to validate finite element models.  Examples of failure mechanisms which could be tested in this way are adhesively bonded curved metal laminates or delamination of filament wound fibre reinforced polymer composites.

The delamination between laminates of curved fibre reinforced composites is particularly interesting as it may involve fibre bridging across an opening crack, complicating the failure even further.  SINTEF has been working with partners of SFI Manufacturing to identify applications where this new experimental technique can be valuable.





# Research Area 2: Robust and flexible automation

The research area Robust and Flexible Automation concerns new ways of automation and robotics in manufacturing systems. The overall objective is to further develop and link novel technologies and methodologies within automation to support innovation processes and advanced work systems in manufacturing industries.

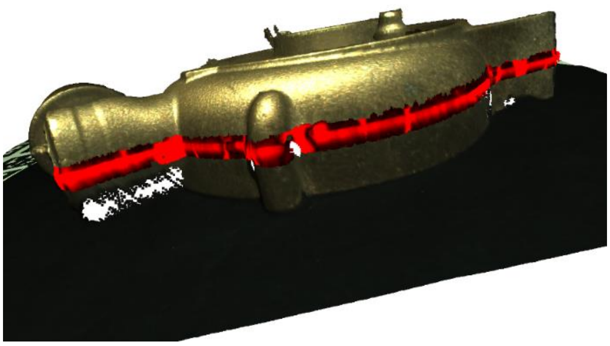
Novel automations technologies and methodologies, and smart integration of those, open new ways to use automation and robotics in manufacturing systems.

Within this research area we focused on bin-picking, safe and efficient motion planning in dynamic environments, "batch size one" robotic assembly, robotic flexibility in additive manufacturing, and effective and safe development of robotic assembly processes.

Several of these challenges also link to the other research areas within the SFI.

The research area 2 had again a very productive year in 2021.

3 conference publications and 5 journal articles were published. RA2 PhD's and Post-doc's have participated mostly on online conferences and contributed toward the very first physical workshop, arranged in 2021.



**3D vision-based registration and burr detection**

RGB-D scanning and reconstruction have advanced significantly in recent years, thanks to the growing availability of commodity range sensors like the Zivid, Microsoft Kinect, and Intel RealSense.

State-of-the-art 3D reconstruction techniques can now capture and recreate real-world objects with astonishing accuracy, spawning a slew of possible applications including manufacturing artifact detection, content production, and augmented reality.

Due to geometric incompleteness, noise, and uneven shrinkage and deformation during the production process, such breakthroughs in 3D scan reconstruction have remained limited to certain usage situations.

In particular, there is a notable limitation in matching 3D scans to clean, sharp 3D models for quality control. On this side, we propose a machine learning approach for Scan to CAD matching and automatic burr detection, that is robust to missing data in the scans, viewpoint, noise, rotation and scale.

Our approach is able to learn features of the CAD model/scan without any labeled data through a series of transformations of the CAD models.

Furthermore, using the learned features we show a burr localization approach that is able to estimate burr height similar to high-resolution CT scanners supporting the hypothesis that the CT measured and our estimate burr height distributions are similar.

**Tracking, loading- and unloading of overhanging trolleys**

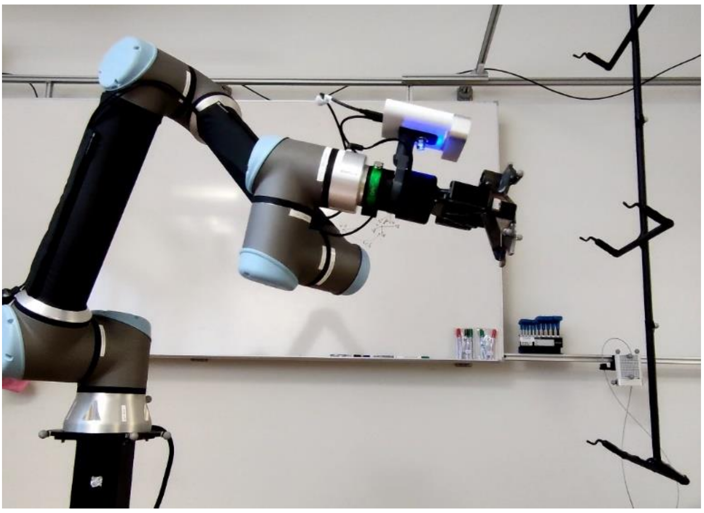
Loading and unloading of overhanging trolleys are common tasks for instance at spray painting facilities.

They are often manual and can therefore constitute a large cost to the manufacturing industry in Norway.

Furthermore, the tasks are tedious and can pose significant health-related issues.

Our automated solution consists roughly of 1) object pose prediction and velocity estimation, 2) real-time trajectory generation for the robot manipulator arm, and 3) robot trajectory tracking and gripper commands execution.

The current solution uses a marker-based real-time motion capture system to measure the position and orientation of the objects but we will in future work aim to replace this with a CAD-based object-tracking method.



**Develop model for process parameters related to robotised welding**

Another research activity was connected to the newly established MANULAB research infrastructure at NTNU in Trondheim.

The activity focused on startup and evaluation of technical capabilities and research potential of the robotic TIG cell.

Weld material deposition tests with different settings for both stainless steel and aluminum have been conducted, where bead overlay patterns where implemented.

As a part of the activity, the software prototype for path generation and postprocessing to Yaskawa native code language have been developed.

The activity revealed technical potential of the cell for conducting research within automation of TIG welding applications, cladding and reparations using TIG process.

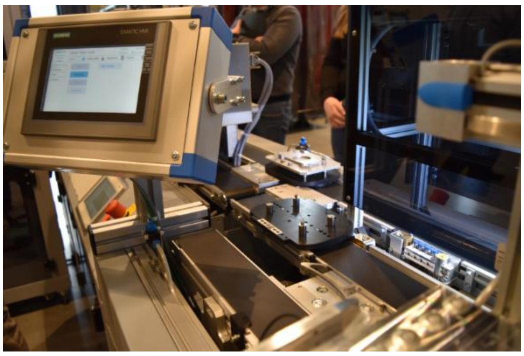
**Develop model for process in-inline quality control (Tamal Ghosh)**

The proposed system can monitor the product quality inside the learning factory for the production process on the go. The proposed method is contact-less and machine-vision-based.

My research exploits image processing, machine learning and optimization techniques to perform various tasks within the scope of my research.

The proposed work is based on Python and MATLAB based applications and it can identify product 'defects' in terms of surface roughness.

The obtained result is comparable with stylus-based profilometer readings. While the 'defects' are identified, there could be a signal generated inside the learning factory and the user can discard/recycle the product.



**Ongoing RA2 PhD/post-docs**

"Deburring Using Robot Manipulators",

o PhD: Ingrid Fjordheim Onstein (started August 2019)

"Digital twins in production",

o Researcher: Tamal Gosh (started January 2021)

## Research Area 3: Sustainable and innovative organisations

This research area concerns organisational and innovative sustainability aspects of advanced manufacturing companies.

The overall objective is to develop knowledge and solutions for advanced work systems that are able to utilize new technology and flexible and automated processes to manufacture sustainable multi-material products.

**3D vision-based registration and burr detection**

Pål Furu Kamsvåg, Sven-Vegard Buer, Stine Sonen Tveit, Eli Fyhn Ullern and Henrik Brynthe Lund is conducting an interview study under the headline "Industry 4.0 and circular economy – what is actually going on in the Norwegian manufacturing industry".

The ambition of the study is to dive deeper into what a set of Norwegian manufacturers – both SFI partners and others – have done and are doing (or believe they must do in the future) in relation to implementation of manufacturing technology and efforts to make their production more sustainable (circular).

The multi-disciplinary group of researchers for example explore barriers to implementation and adoption of manufacturing technologies, and how manufacturers' role in global value chains influence their ability and potential to make use of circular economy strategies (such as recycle, remanufacture, reuse).

The work will continue in the spring of 2022 and be presented at the upcoming workshop in Åndalsnes in June

**The pathway to an adaptive sales and operations planning process:**

Research by Sourav Sengupta and Heidi Dreyer identifies the importance of and the pathways to an adaptive sales and operations planning process (AS&OP).

The traditional S&OP process, which is designed to efficiently balance demand and supply, is not well suited to today's supply chain uncertainties and dynamic planning environments.

The pandemic, the Evergreen container sheep blocking the Suez Canal, and the Russia-Ukraine conflict are just a few examples of recent disruptions causing demand-supply imbalances that make it abundantly evident to organizations that a relentless focus on efficiency inhibits resilience and sustainability. The need for replanning and adjusting to the frequent changes in the environment thus calls for a more adaptive S&OP process enabled by the industry 4.0 technologies and real-time access to information from across the supply chain.

Seemingly, building dynamic digitalization capabilities is central to this transition. The research examines how digitalization can be leveraged to transition to an adaptive S&OP process and eventually categorizes the mechanisms that enable this transition using an integrative framework. The framework also highlights two adaptability pathways, one evolutionary and the other transformative. The research follows a novel methodology that requires involving managers as research partners in an integrative literature review process – managers from six SFI partner companies are participating in the study.

This research was recently presented at the IWSPE 2022 conference at Innsbruck, Austria. The research methodology proposed also being novel is being developed as an independent methodology paper – that is accepted for presentation at the IPSERA 2022 conference at Jönköping, Sweden in April.

# Meet the next generation scientists

## Disputants

**Digitalization reinforces existing management practices**

Eirik B. Hamre Korsen completed and submitted his PhD-thesis in 2021 and was successfully defended in February 2022. The thesis discusses how digitalization and industry 4.0 technologies influence the organizations performance measurement and management. Based on three cases form the SFI Manufacturing consortium, Korsen identifies how deployment of digital technologies reinforces existing management practice, and how organization uses the extended information to support the operators in their work. The case organizations management practices are based on Lean-thinking with high involvement of operators. This is an advantage when new digital technologies are introduced, as they avoid the technology to become a black box, and makes operators skilled in understanding the digital language.  Korsen work is published at NTNU Open

**Electron microscopy of intermetallic phases in aluminium-steel joints**

Tina Bergh submitted the following academic thesis as part of the doctoral work at the Norwegian University of Science and Technology (NTNU): Electron microscopy of intermetallic phases in aluminium-steel joints.

Tina has been part of Research Area 1 - Multi-Material Products and Processes.

She held a trial lecture May 28, 2021. Berghs work is published on NTNU Open

# PhD- and post-doc interviews

**Amalie Østhassel is a new PhD student at SFI Manufacturing**

On April 6, 2021, Amalie Østhassel started as a new PhD student at SFI Manufacturing. She has recently been working as a trainee in the European Free Trade Association (EFTA). Her PhD is being undertaken on behalf of NTNU.

As a first year PhD student, I am still in the planning phase of my project and have a lot to look forward to in the next few years! I will be looking at how business models in the developing and emerging markets influence regional sustainable development and explore how innovation is used to access these markets and integrated in the business model.

As an economic geographer I want to see how the global production networks of Norwegian multinational companies influence other regions, but also investigate what knowledge is being brought back into the value chain and core operations of the firm. I am interested in exploring the potential and hidden knowledge exchanges that occur in this globalisation process and how it affects regional development trajectories. I hope this research can provide useful insights for companies operating in fast-paced and unstructured markets, and give them directions on how to achieve sustainable development targets.

I plan to use a mix of qualitative and quantitative methods with a case study approach. Hopefully, if all goes well in the world, I will go on a few field trips visiting offices, production facilities and other stakeholders relevant to the case studies. I would also like to explore the use of new methods and data such as social media, as this could provide new insights from segments that are not always identified. If you would like to know more about my project, please don't hesitate to get in touch!

**Tamal Ghosh**

Postdoc, SFI Manufacturing (2021-2022)
Norwegian University of Science and Technology (NTNU i Gjøvik

I have started my research position within SFI Manufacturing in January 2021. My work is primarily based within Cyber-Physical learning factory at NTNU I Gjøvik. I am developing an inline process monitoring and adaptive control system for the learning factory. The proposed system can monitor the product quality inside the learning factory for the production process on the go. The proposed method is contact-less and machine-vision-based.

My research exploits image processing, machine learning and optimization techniques to perform various tasks within the scope of my research. The proposed work is based on Python and MATLAB based applications and it can identify product 'defects' in terms of surface roughness.

The obtained result is comparable with stylus-based profilometer readings. While the 'defects' are identified, there could be a signal generated inside the learning factory and the user can discard/recycle the product.

This proposed work can be extended further to develop the digital twin of the system. For that matter, PLC system should relate to the hardware of the inline control system and proper system level programs should be written using PLCSIM and OPC UA to communicate with the simulation model of the system.

# Industrial Coordination

## Three digital workshops and a physical one

Due to the continued Covid-19 pandemic, the physical workshops were further postponed. Before summer we had two digital workshops, both with around 60 participants. The first in March centered on presenting the research infrastructure in MANULAB including the Learning factory at NTNU Gjøvik. The NAPICS centre also presented its plans for One-Piece Flow Aluminium Forming.

The second digital workshop in June had sustainable manufacturing on the agenda and saw presentations from RA3 researchers and PhD-students on sustainable business models, LCA (life-cycle analysis) and environmental footprint, circular economy, digitalization for sustainability, and sustainable value chains. 40% of the participants were from the industry, and the short break-out session and following wrap up underlined the importance of sustainable operations and development towards more circular models in manufacturing.

In October we were finally able to host the first physical workshop exactly 2 years after the previous one at Ekornes in Sykkylven. This time in Gjøvik, over 60 participants were happy to meet, socialize and chat in a way we have not done for a long time.

Monday evening saw presentations on the 125 year anniversary of Raufoss Industrial Park. The workshop at NTNU Gjøvik centered on the host company Neuman Aluminium Raufoss Technology and saw research presentations, an in-depth company presentation on multimaterial technology, tracing technology and material science, and a virtual factory visit using live stream from digital goggles (some Covid restrictions still applied). We also had time to a physical visit at NTNU Gjøvik's MANULAB facilities.

The pandemic hit back in December, so the last workshop was yet again a digital one. Close to 50 participants (40% from industry) joined the Teams meeting to follow and discuss a presentation of the white paper "Trends influencing the Norwegian manufacturing industry in the next decade".

Despite digital workshops are working quite well, the workshop in October showed that a physical meeting is the preferred format. SFI Manufacturing arranged 4 workshops in 2021 with close to 230 participants. So far, we have had 22 industrial workshops with appr. 1250 participants in the project period.

## 1-to-1-meetings and initiation of case work for the industrial partners

The 1-1 meetings with the industrial partners in the first half of 2021 were all digital Teams meetings due to the pandemic. The impact of Covid19 was a recurring topic in the meetings, where the companies reported very differently on how they are affected.

6 of the companies have ideas/needs for new spin-off projects and the SFI have scheduled and initiated follow-up activites with 10 of the companies with respect to case work or other centre activities. Furthermore, all said the physical workshops are important to re-establish.

Research topics addressed by the industry partners include environmental accounts that verify improvements; AM (Additive Manufacturing) of dissimilar materials; automated, robotic, flexible assembly; how may the SFI be a catalysator for use of the catapult centre (MTNC); standard for calculation of CO2 footprint; and materials choice in new products where materials technology is aligned with sustainability and manufacturability.

Workshop in Gjøvik. Photo taken by Gabor Sziebig.

# International research coordination

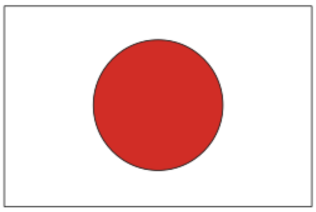
International collaboration in the SFI has, of course, been hampered by the global Covid-19 pandemic. We have however had some activities, mainly in the INTPART international partnership projects, attending CIRP and Manufuture meetings.

## INTPART international partnership projects

SFI Manufacturing has been a partner in a International Partnership (INTPART)-project INMAN ; Intelligent Circular Manufacturing research and educational collaboration with India and Japan. This project ended in October 2021, Read more at the project website: http://circularmanufacturing.net One of the outcomes was an open video-based course on Circular Manufacturing, available through the NTNU Panopto server

The INMAN -project is continued by another INTPART-project called CIRMAN: Circular Manufacturing research and educational collaboration with India and Japan with the same partners:

- NTNU, SFI Manufacturing (Norway)
- Waseda University and National Institute of Advanced Industrial Science and Technology (AIST) (Japan)
- And Indian Institute of Technology (IIT) (India)



On the Norwegian side also SFI Norwegian Centre for Cybersecurity in Critical Sectors (NORCICS) is added as partner.  CIRMAN build upon INMAN with the main objective of the to develop world-class research and education in Norway within the area of Circular Manufacturing through long-term international partnerships.

The plans include developing common research agendas and research funding proposals, joint seminars and educational programs, mobility of students and researchers and cooperation with businesses in Norway, Japan and India. Research topics will focus on circular manufacturing, remanufacturing, and the establishments of life-cycle digital twins useful for EOL-decisions.

The CIRMAN-project will broaden and deepen the strategic collaboration established in INMAN, and integration of business enterprises such as the SFI consortium is an important asset, both for research activities, to foster exchange of research results and technology transfer as well as to link Norwegian industry with the industry in Japan and India.

The mobility program in the project will be offered industry partners as well as academic partners. Yearly summer schools alternating between the three countries will be open for students from all countries.

Furthermore, SFI Manufacturing is a partner in another INTPART project called MAVIS: Industry 4.0 and Management of Variations in a Sustainable manufactured product life cycle

This project has similar main goal as INMAN and CIRMAN: To develop world-class research and education in Norway, through long-term international partnerships. MAVIS focus on how digitalization can be useful, create better products and contribute to UN SDGs, industry 4.0 and how IoT and cyber-physical systems can be useful to manage the inevitable variations in manufacturing of products, the product life cycle and at the end-of life/ reuse / remanufacturing.

**The MAVIS Partners are:**

University of Stuttgart, Fraunhofer IPA and IAO in Germany and

Grenoble INP, University of Technology of Compiègne and IRT Jules Verne in France

## CIRP meetings

All CIRP meetings has been digitally in 2021. For SFI Manufacturing the most interesting is perhaps the new keynote papers published in 2021 with the following titles:

- Electronic Module Assembly
- Structured and Textured Cutting Tool Surfaces for Machining Applications
- Coevolution of digitalisation, organisations and Product Development Cycle
- Ultrafast Laser Manufacturing: from physics to industrial applications
- Forming of Metal-Based Composite Parts
- Grinding and fine finishing of future automotive powertrain components
- Noise and Vibrations in Machine Tools
- Evolution and future of Manufacturing Systems
- Scalability of Precision Design Principles for Machines and Instruments
- Feature-based characterisation of surface topography and its application

All of these published in the CIRP Annals, Volume 70, Issue 2, 2021
https://www.sciencedirect.com/journal/cirp-annals/vol/70/issue/2

## Manufuture meetings

Also Manuture meetings has been fully digital in 2021. SFI Manufacturing personell has been taking part in the making of two important documents, the Manufuture Vision document and the Manufuture Strategic Research and Innovation Agenda. Bothe of these documents can be obtained here:

http://www.manufuture.org/wp-content/uploads/Manufuture-Vision-2030_DIGITAL.pdf

http://www.manufuture.org/wp-content/uploads/ManuFUTURE_SRIA_2030_Vfinal.pdf

SFI Manufacturing International Scientific Advisory Board

There has only been little interaction with the ISAB in 2021, mainly it has been discussions on the applications on the report form 2020 (however also interactions in adjacent EU projects).

# News from the Consortium

## White Paper: The Trends that Will Shape Norwegian Manufacturing in the Next 10 Years

Our white paper is published, and you can find the final report on our website.

Manufacturing in the 21st century has been characterized as a complex and dynamic sociotechnical system. The industry is currently being challenged by accelerated technological change, pressures, and regulations regarding reduction of its environmental footprint, novel knowledge demands, a turbulent economic landscape, and a pandemic creating a demanding and unforeseen context.

For manufacturers to make sense of ongoing changes and how to position themselves within this changing landscape, it is useful to start with developing a knowledge basis on the most pertinent trends.

This is the starting point for the white paper, which aims to provide an overview of some of the key technological, environmental, social, and economic trends that are both challenging and providing opportunities for the Norwegian manufacturing industry.


We have not provided an exhaustive list of trends, for more detail on other trends and more in-depth knowledge, we urge the reader to look further into the references provided. However, we have made a conscious and thorough selection among those we believe are of greatest interest and have the strongest influence on Norwegian manufacturing industries.

# Communication

**The SFI Website**

Our website, www.sfimanufacturing.no , includes updated information on the centre, partners, research areas, PhD candidates and publications. We share all blogposts on Twitter, and several of the blogposts on SINTEF Manufacturing's social media as well. We are actively using Twitter during conferences, workshops, meetings, and other gatherings where the centre is involved. SFI Manufacturing has tweeted 182 times and has 274 followers.

**Newsletter and annual report**

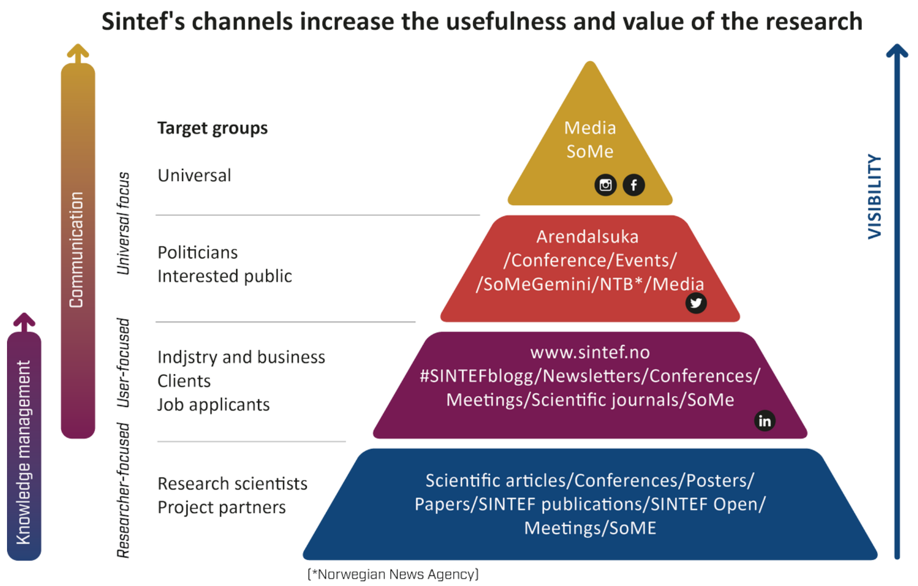
We have published one newsletter last year and its aim is to keep the community up to date with the current research that is being carried out within and related to the centre. All newsletters are available at www.sfimanufacturing.no/newsletters. In addition to the newsletter, we published the annual report of 2020 at the start of 2021.

**Communication plan and content calendar**

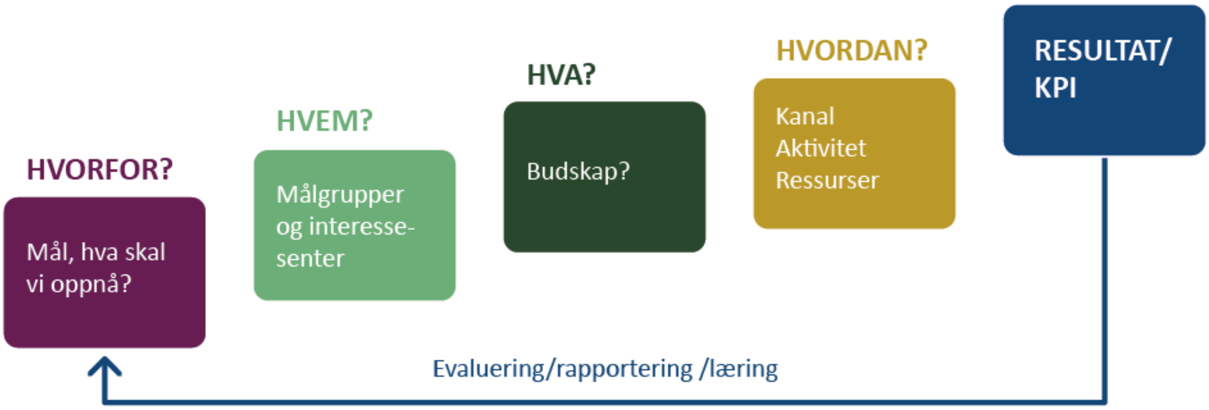
We have recently created a new communication plan. The plan defines the most key communication measures the SFI will undertake as we move towards the last year of the project. As an extension of this plan, we have created a content calendar which operationalizes our goals into concrete tasks and dates. Together, these tools make up a modern strategic communication approach, which will be key for the SFI and potential future project.

**The foundations of our strategic communication**

We use the SINTEF channel triangle as a guiding principle for our communication plan. The triangle demonstrates how different target audiences can be reached using different channels.



Furthermore, we have used the SINTEF communication staircase. It demonstrates the ideal approach to creating and solving a communication task.




# Key Researchers

| RA | Name | Institution | Main research area |
|---|---|---|---|
| 1 | Ida Westermann | NTNU-NV-IM | Joining aluminium to steel |
| 1 | Bjørn Holmedal | NTNU-NV-IM | Joining aluminium to steel |
| 1 | Vegard Brøtan | SINTEF Manufacturing | Additive manufacturing, Multi material products cont. polymers |
| 1 | Klas Boivie | SINTEF Manufacturing | Additive manufacturing |
| 1 | Olav Åsebø Berg | SINTEF Manufacturing | Additive manufacturing |
| 1 | Erik Andreassen | SINTEF Industry | Additive manufacturing |
| 1 | Per Erik Vullum | NTNU-NV-IF | Multi material metallic products |
| 1 | Randi Holmestad | NTNU-NV-IF | Multi material metallic products |
| 1 | Sotirios Grammatikos | NTNU-IV (Gjøvik) | Multi material products cont. Polymers |
| 1 | Are Strandlie | NTNU-IV (Gjøvik) | Multi material metallic products, Multiscale modelling |
| 1 | Per Harald Ninive | NTNU-IV (Gjøvik) | Multi material metallic products, Multiscale modelling |
| 1 | Xiaobo Ren | SINTEF Industry | Multi material metallic products, Multiscale modelling |
| 1 | Ivan Bunaziv | SINTEF Industry | Multi material metallic products |
| 1 | Magnus Eriksson | SINTEF Industry | Multi material metallic products |
| 1 | Ragnhild Aune | SINTEF Industry | Multi material metallic products |
| 1 | Odd M. Akselsen | SINTEF Industry | Multi material metallic products |
| 1 | Bård Nyhus | SINTEF Industry | Multi material metallic products |
| 1 | Dirk Nolte | SINTEF Industry | Multi material metallic products |
| 1 | Hoang Hieu Nguyen | SINTEF Industry | Multi material metallic products |
| 1 | Gaute Gruben | SINTEF Industry | Multi material metallic products |
| 1 | Ben Alcock | SINTEF Industry | Multi material products cont. Polymers |
| 1 | Afaf Saai | SINTEF Industry | Multi material products cont. polymers, Multiscale modelling |
| 1 | Christian Karl | SINTEF Industry | Multi material products cont. Polymers |
| 1 | Jesper Friis | SINTEF Industry | Multi material metallic products, Multi material products cont. polymers, Multiscale modelling |
| 1 | Ole Martin Løvvik | SINTEF Industry | Multiscale modelling |
| 1 | Rune Østhus | SINTEF Manufacturing | Multiscale modelling |
| 1 | Einar Hinrichsen | SINTEF Industry | Multi material |
| 1 | Sverre Gulbrandsen-Dahl | SINTEF Manufacturing | Multi material |
| 2 | Jan Tommy Gravdahl | NTNU-IE | Senor fusion |
| 2 | Esten Ingar Grøtli | SINTEF Digital | Robotic handling of flexible objects, Flexible and integrated production systems |
| 2 | Marianne Bakken | SINTEF Digital | Robotic handling of flexible objects |
| 2 | Helene Schulerud | SINTEF Digital | Robotic handling of flexible objects |
| 2 | Morten Lind | SINTEF Manufacturing | Robotic handling of flexible objects, Flexible and integrated production systems |
| 2 | Eirik Njåstad | SINTEF Manufacturing | Robotic handling of flexible objects |

| | | | |
|---|---|---|---|
| 2 | Ådne S. Linnerud | SINTEF Manufacturing | Flexible and integrated production systems |
| 2 | Sebastian Dransfeld | SINTEF Manufacturing | Flexible and integrated production systems |
| 2 | Per Nyen | SINTEF Manufacturing | Flexible and integrated production systems |
| 2 | Tone Beate Gjerstad | SINTEF Manufacturing | Flexible and integrated production systems |
| 2 | Geir Ole Tysse | SINTEF Manufacturing | Robotic handling of flexible objects, Flexible and integrated production systems |
| 2 | Gabor Sziebig | SINTEF Manufacturing | Robotic handling of flexible objects, Flexible and integrated production systems |
| 3 | Eva A. Seim | SINTEF Digital | Work systems and organization |
| 3 | Hans Torvatn | SINTEF Digital | Work systems and organization |
| 3 | Pål Kamsvåg | SINTEF Manufacturing | Work systems and organization |
| 3 | Eirin Lodgaard | SINTEF Manufacturing | Work systems and organization, Industrial clusters and learning systems, Innovation and product development |
| 3 | Gaute Knutstad | SINTEF Manufacturing | Work systems and organization, Industrial clusters and learning systems, Innovation and product development |
| 3 | Ragnhild Eleftheriadis | SINTEF Manufacturing | Industrial clusters and learning systems |
| 3 | Jonas Ingvaldsen | NTNU-Økonomi-IØT | Work systems and organization, Innovation and product development |
| 3 | Asbjørn Karlsen | NTNU-SU-GEO | Industrial clusters and learning systems |
| 3 | Eli Fyhn Ullern | SINTEF Digital | Industrial clusters and learning systems |
| 3 | Sigurd Vildåsen | SINTEF Manufacturing | Industrial clusters and learning systems |
| 3 | Maria Flavia Mogos | SINTEF Manufacturing | Industrial clusters and learning systems |
| 3 | Johanne Sørumsbrenden | SINTEF Manufacturing | Industrial clusters and learning systems |
| 3 | Monica Rolfsen | NTNU-Økonomi | Work systems and organization, Industrial clusters and learning systems, Innovation and product development |
| 3 | Heidi Dreyer | NTNU-Økonomi-IØT | Work systems and organization, Industrial clusters and learning systems, Innovation and product development |
| 1, 3 | Kristian Martinsen | SINTEF Manufacturing | Additive manufacturing, Work systems and organization |

# Scholarships

### Postdoctoral researchers with financial support from the Centre budget

| Name | Nationality | Period | Sex M/F | Topic |
|---|---|---|---|---|
| Signe Moe | Norwegian | 2017-2019 | F | Flexcible and robust autmation |
| Mathias Hauan Arbo | Norwegian | 2019-2021 | M | Flexcible and robust autmation |
| Sourav Sengupta | Indian | 2020-2022 | M | How Digitalization Affects the Organization and Planning of Manufacturing Supply Chains |
| Ding Peng | Chinese | 2020-2022 | M | Advanced electron microscopy characterization to understand interface physics in metal additive manufacturing of multi-material products. |

### PhD students with financial support from the Centre budget

| Name | Nationality | Period | Sex M/F | Topic |
|---|---|---|---|---|
| Siri Marthe Arbo | Norwegian | 2015-2019 | F | Joining aluminium to steel |
| Mathias Hauan Arbo | Norwegian | 2015-2019 | M | Sensor fusion |
| Henrik Brynthe Lund | Norwegian | 2016-2019 | M | Learning in networks |
| Tina Bergh | Norwegian | 2016-2020 | F | Advanced characterisation |
| Muhammad Zeeshan Khalid | Pakistani | 2016-2019 | M | Atomistic modelling |
| Linn Danielsen | Norwegian | 2016-2021 | F | Automatisaton of additive manufacturing |
| Eirik B.H. Korsen | Norwegian | 2017-2021 | M | Robustnes of MES and work systems |
| Andreas Molturmyr | Norwegian | 2019-2021 | M | Automatisaton of additive manufacturing |
| Chaman Srivastava | Indian | 2019-2023 | M | Liftime of polymer products |
| Ingrid Fjordheim Onstein | Norwegian | 2019-2023 | F | Sensor fusion |
| Assiya Kenzhegaliyeva | Norwegian | 2020-2023 | F | Developing sustainable supply chain based on emerging technologies |
| Håkon Linga | Norwegian | 2020-2024 | M | Material properties and geometry tolerances in additive manufacturing (AM) of multi-material metallic components |

### PhD students working on projects in the centre with financial support from other sources

| Name | Funding | Nationality | Period | Sex M/F | Topic |
|---|---|---|---|---|---|
| Vetle Engesbak | IPN Sprangforbedring | Norwegian | 2015-2021 | M | Business management, innovation and implementation of changes |
| Marit Moe Bjørnbet | KPN SISVI | Norwegian | 2016-2023 | F | Life cycle assessment as a management tool |
| Anna Maria Persson | SINTEF insitute funding | Norwegian | 2017-2021 | F | Mechanical properties of thermoplastic elastomers in injection moulded components |
| Amailie Østhassel | NTNU-SU | Norwegian | 2021-2024 | F | Sustainable business models for the green economy with specific emphasis on inclusive growth and innovation systems working within the planetary boundaries |

# Scientific publications

| Authors | Title of work | Book/compendium/journal | Page no. | Issue/Volume/Year | ISSN/ISBN |
|---|---|---|---|---|---|
| Arbo, Mathias Hauan; Eriksen, Ivar; Sanfilippo, Filippo; Gravdahl, Jan Tommy | Comparison of KVP and RSI for Controlling KUKA Robots Over ROS | IFAC-PapersOnLine | 9841-9846 | 2/53/2021 | |
| Bjørnbet, Marit Moe; Skaar, Christofer; Fet, Annik Magerholm; Schulte, Kjersti Øverbø | Circular economy in manufacturing companies: A review of case study literature | Journal of Cleaner Production | | 294/2021 | |
| Bjørnbet, Marit Moe; Vildåsen, Sigurd | Life cycle assessment to ensure sustainability of circular business models in manufacturing | Sustainability | 1-13 | 19/13/2021 | |
| Bunaziv, Ivan; Akselsen, Odd Magne; Ren, Xiaobo; Nyhus, Bård; Eriksson, Magnus Carl Fredrik; Gulbrandsen-Dahl, Sverre | A Review on Laser-Assisted Joining of Aluminium Alloys to Other Metals | Metals | | 11.11.2021 | |
| Degeorges, Theo Elie Valentin; Sziebig, Gabor | Communication Between Human and Robots Within a Collaborative Workspace | Lecture Notes in Electrical Engineering | 652-657 | 727/2021 | |
| Evjemo, Linn Danielsen; Moe, Signe; Gravdahl, Jan Tommy | Robotised Wire Arc Additive Manufacturing Using Set-based Control: Experimental Results | IFAC-PapersOnLine | 10044-10051 | 2/53/2021 | |
| Hekneby, Torbjørn; Benders, Jos; Ingvaldsen, Jonas A. | Not so different altogether: Putting lean and sociotechnical design into practice in a process industry | Journal of Industrial Engineering and Management | 219-230 | 2/14/2021 | |
| Hekneby, Torbjørn; Ingvaldsen, Jonas A; Benders, Jos | Orchestrated learning: creating a company-specific production system (XPS) | International Journal of Lean Six Sigma | 361-381 | 2/13/2021 | |
| Khalid, Muhammad Zeeshan; Friis, Jesper; Ninive, Per Harald; Marthinsen, Knut; Ringdalen, Inga Gudem; Strandlie, Are | First-principles study of tensile and shear strength of an Fe2Al5//Fe interface. | Computational Materials Science | | 192/2021 | |
| Khalid, Muhammad Zeeshan; Friis, Jesper; Ninive, Per Harald; Marthinsen, Knut; Ringdalen, Inga Gudem; Strandlie, Are | Modified embedded atom method potential for Fe-Al intermetallics mechanical strength: A comparative analysis of atomistic simulations | Physica. B, Condensed matter | | 618/2021 | |

| | | | | | |
|---|---|---|---|---|---|
| Khalid, Muhammad Zeeshan; Friis, Jesper; Ninive, Per Harald; Marthinsen, Knut; Strandlie, Are | First-principles study of tensile and shear strength of Fe-Al and -AlFeSi intermetallic compound interfaces. | Computational Materials Science | 1-9 | 187/2021 | |
| Korsen, Eirik Bådsvik Hamre; Holmemo, Marte Daae-Qvale; Ingvaldsen, Jonas A | Digital technologies and the balance between control and empowerment in performance management | Measuring Business Excellence | | | |
| Korsen, Eirik Bådsvik Hamre; Ingvaldsen, Jonas A | Digitalisation and the performance measurement and management system: reinforcing empowerment. | International Journal of Productivity and Performance Management | | 2021 | |
| Lodgaard, Eirin Anita; Powell, Daryl John. | The changing role of shop-floor operators in zero defect manufacturing | Procedia CIRP | 594-599 | 104/2021 | |
| Lodgaard, Eirin Anita; Sogstad, Maren Kristine Raknes. | Lean Translated from a Manufacturing Industry Context to Municipality Service Production: A Case Study | Learning in the Digital Era: 7th European Lean Educator Conference, ELEC 2021, Trondheim, Norway, October 25–27, 2021, Proceedings. Springer | 373-380 | 2021 | ISBN 978-3-030-92933-6 |
| Macintyre, Thomas; Witjes, Sjors; Vildåsen, Sigurd; Ramos Mejía, Mónica. | Embracing transdisciplinary tensions on the road to 2030 | Transdisciplinarity For Sustainability: Aligning Diverse Practices. Routledge | 179-199 | 2021 | ISBN 9780367189075 |
| Moltumyr, Andreas Hanssen; Ragazzon, Michael Remo Palmén; Gravdahl, Jan Tommy | Fractional-order Control: Nyquist Constrained Optimization. | IFAC-PapersOnLine | 8605-8612 | 2/53/2021 | |
| Ogorodnyk, Olga; Larsen, Mats; Martinsen, Kristian; Lyngstad, Ole Vidar | Development of application programming interface prototype for injection molding machines | Procedia CIRP | 453-458 | 97/2021 | |
| Ogorodnyk, Olga; Lyngstad, Ole Vidar; Larsen, Mats; Martinsen, Kristian | Prediction of Width and Thickness of Injection Molded Parts Using Machine Learning Methods | EcoDesign and Sustainability I: Products, Services, and Business Models. Springer | 455-469 | 2021 | ISBN 978-981-15-6778-0 |
| Onstein, Ingrid Fjordheim; Evjemo, Linn Danielsen; Gravdahl, Jan Tommy | Additive Manufacturing Path Generation for Robot Manipulators Based on CAD Models | IFAC-PapersOnLine | 10037-10043 | 2/53/2021 | |
| Sandnes, Lise; Bergh, Tina; Grong, Øystein; Holmestad, Randi; Vullum, Per Erik; Berto, Filippo | Interface Microstructure and Tensile Properties of a Third Generation Aluminium-Steel Butt Weld Produced Using the Hybrid Metal Extrusion & Bonding (HYB) Process | Materials Science & Engineering: A | | 809/2021 | |

# Key Performance Indicators

| KPI | Plan 2015-2023 | Sum 2015-2017 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|---|---|---|
| Book about MMP manufacturing | 1 | 0 | | | | | | | |
| Scientific paper publish in international journals and conferences with peer review | 112 | 137 | 1 | 7 | 28 | 32 | 23 | 25 | 21 |
| Popular science articles | 16 | 12 | | | 2 | 1 | 3 | 3 | 3 |
| National and international conferences and seminars/workshops | 2 | 2 | | 1 | | | | 1 | |
| PhD candidates | 17 | 16 | 2 | 7 | 1 | | 3 | 2 | 1 |
| Post docs | 3 | 4 | | | 1 | | 1 | 2 | |
| MSc students | 100 | 36 | | 2 | 7 | 11 | 6 | 4 | 6 |

# Statement of the Accounts

| | 2021 |
|---|---|
| **Funding** | |
| The Research Council | 13 286 472 |
| The Host Institution(SINTEF Manufacturing AS) | 946 393 |
| Research Partners | 4 627 390 |
| Enteprise Partners | 10 335 149 |
| **Total** | **29 195 404** |
| | |
| **Costs** | |
| The Host Institution (SINTEF Manufacturing AS) | 5 250 856 |
| Research Partners | 18 928 841 |
| Enterprise Partners | 5 015 707 |
| Public Partners | |
| Equipment | |
| **Total** | **29 195 404** |

# Contact us

## Contact information

| | |
|---|---|
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| Phone: | +47 916 01 205 |
| Email: | sverre.gulbrandsen-dahl@sintef.no |

## Follow us

| | |
|---|---|
| Website: | https://www.sfimanufacturing.no |
| Twitter: | @SFI_manufact |