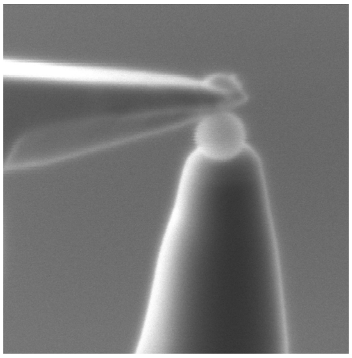
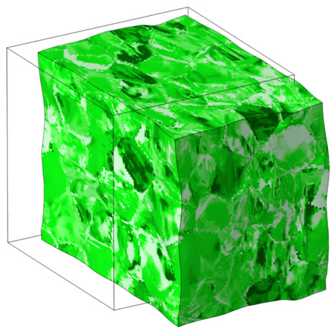
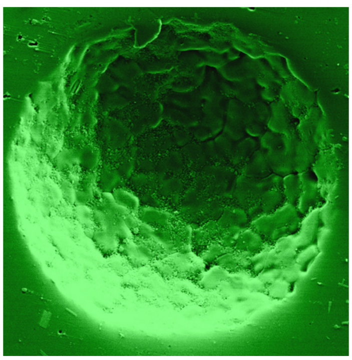
Centre for Sustainable and Competitive Metallurgical and Manufacturing Industry

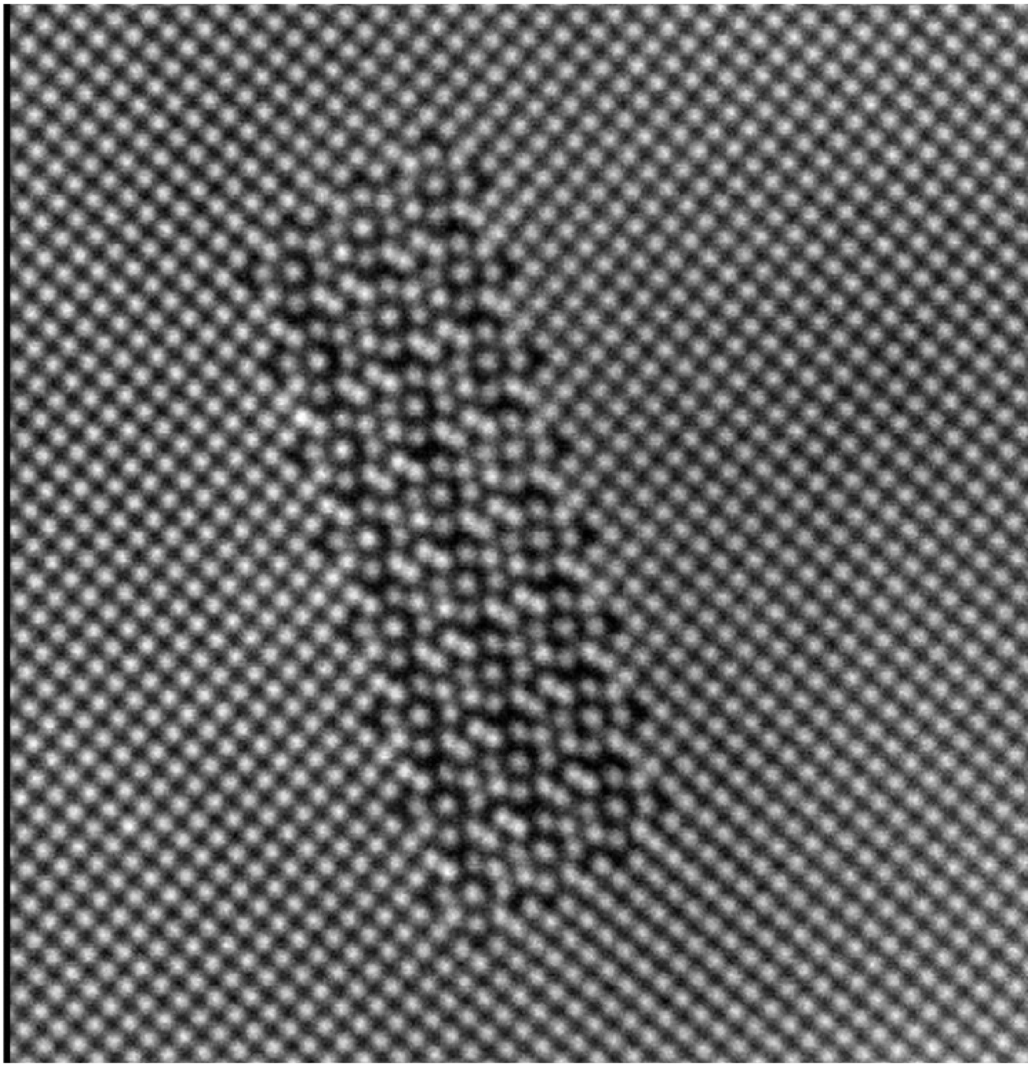
ANNUAL REPORT 2021

SFI PHYSMET









PhysMet

sfi Centre for Research-based Innovation

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NTNU, Faculty of Natural Sciences, Department of Materials Science and Engineering

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Frontpage:
Main picture: *High angle annular dark field scanning transmission electron microscopy (HAADF-STEM) image of a beta" precipitate in a 6xxx alloy*. Photo: Sigurd Wenner

Small pictures, from top:

- *SEM image of the preparation of a 200 nm polystyrene particle for atom probe tomography. Instrument: FEI Helios G4.* Operator: Sigurd Wenner
- *Stress field from a detailed crystal plasticity finite element simulation of a polycrystal deformed to 30%, run on 48 cpus for 8 days.* Photo: Tomas Manik
- *Pore in additive manufactured aluminium (SEM).* Photo: Geir Langelandsvik, SINTEF

Layout and production: Ida Følstad and Monika Wist Solli, NTNU Grafisk senter

CONTENT

ANNUAL REPORT 2021
SFI PHYSMET

SUMMARY

BY CENTRE MANAGER
KNUT MARTHINSEN, NTNU

Centre for Sustainable and Competitive Metallurgical and Manufacturing Industry, SFI PhysMet, has been appointed by The Research Council of Norway as a centre for Research-based Innovation from 2020-2028. SFI PhysMet is an interdisciplinary centre in the field of physical metallurgy, which in brief refers to **the science of making useful products out of metals.**

Organisation

SFI PhysMet - Centre for Sustainable and Competitive Metallurgical and Manufacturing Industry, is hosted by the Department of Materials Science and Engineering, NTNU, and include the research partners, SINTEF Industry, SINTEF Manufacturing and IFE, user partners from the metal-based industry in Norway (Hydro, Elkem, Benteler, Raufoss Technology), end users (Equinor, Norwegian Public Roads Administration) and an international partner (ThermoCalc (Sweden); making thermodynamical software).

An important achievement in 2021 was the establishment of a physical centre for SFI PhysMet in Chemistry Building 1 (K1) at Gløshaugen. The centre management, together with all the scientific staff in the physical metallurgy group, are now co-located with all their PhD students in K1. The new locations have guest offices and guest workplaces for representatives from the industry partners, which we want, and hope will be diligently used.

Research

The objective of SFI PhysMet is to enable and accelerate the transformation of the national metal industry towards more sustainable and cost-efficient production, future material products, solutions and improved processing methods. This will be realized by long-term competence building and to bring forward research activities and results with innovation potential through education and training of PhD-candidates, postdocs and master students with a good combination of fundamental physical metallurgy competence, digital skills and awareness of sustainability.

The research activities combine advanced characterization of structure and properties at all length-scales with development of numerical models adapted to industrial processing conditions that the industry can use in their own R&D and innovation activities. SFI PhysMet takes advantage of the comprehensive infrastructure and 'state-of-the-art' laboratories for synthesis, processing and characterization available at NTNU, SINTEF and IFE, including the national infrastructures, NORTEM, MIMAC and Manulab and collaborate with leading international partners.

SFI PhysMet formally started in the fall 2020, but 2021 was our first year in full operation. During 2021 the first 5 PhD students were hired (of which one is funded by SINTEF Industry). They cover different focus areas and have gradually started their research activities, and a closer presentation is given later in the Annual Report together with several other research activities that has started at NTNU, SINTEF and IFE, in close collaboration with the different user partners.

Visibility and dissemination

The COVID-9 pandemic has also throughout 2021 significantly affected our general working conditions, with 'working from home' as the normal during several extended periods during the year. This has limited our possibilities for in-person meetings and social and professional events with physical presence. All meetings up to summer 2021 were digital, incl. kick-off and the first ordinary consortium meeting in June 2021. Nevertheless, the pandemic has to a limited extent influenced the actual research activities (incl. experimental laboratory work that has mainly been able to take place as planned). Moreover, we were able to organize the first physical consortium meeting in October 2021 and in that connection an official opening of our physical center.

A very positive consequence has been the establishment of monthly webinars, including presentations from the industry partners and from the three members of the Scientific Advisory Board. These events have been very well received and have provided the possible to attend without spending time for travelling. The webinars have typically had 40 – 50 attendants.

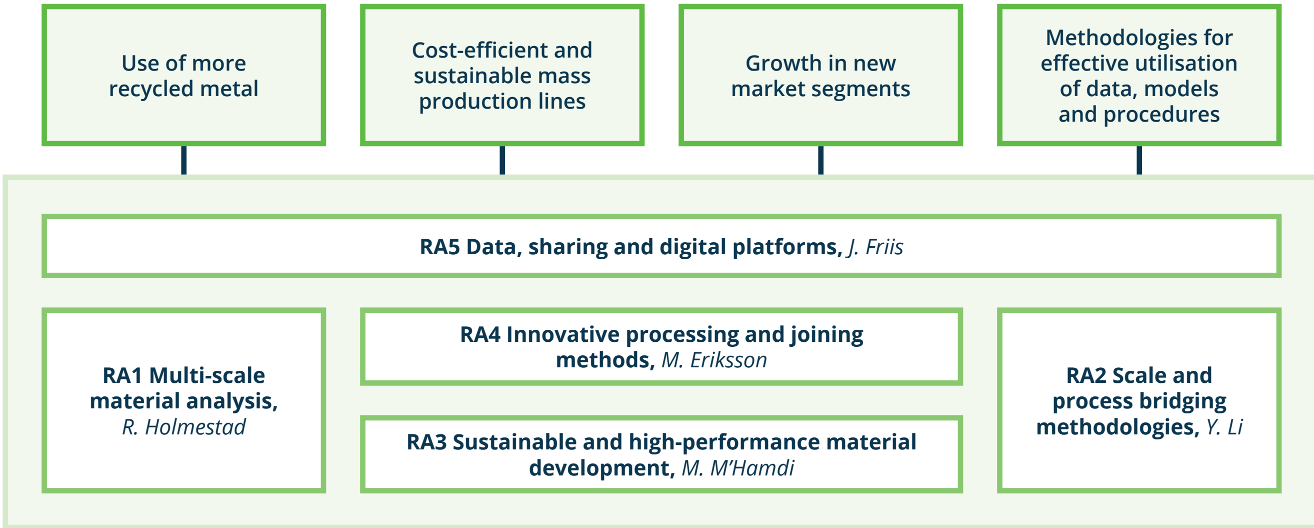
A main objective of the SFI is to perform cutting-edge research with a potential for industrial innovations. Main channels for dissemination are scientific papers in international peer-reviewed journals and to make presentations at relevant international scientific conferences. The number of scientific papers directly funded by the centre are still limited, however, key researchers have given a number of invited and keynote lecturers at relevant national and international seminars and conferences and promoting the SFI.. Another important objective is to reach out to a broader audience, including the general public, to contribute to increased knowledge and understanding on how research/ innovation can bring a sustainable value creation in the metals industry and how it can contribute to the green shift. In this respect our SFI PhysMet webpages, monthly webinars and other meetings/seminars are important tools. A popular science article **'Would you drive a car built from recycled materials?'** originally published in the newspaper Adressa, has also been widely spread in relevant media.

International collaboration

International collaboration is an important objective for SFI PhysMet. The key researchers in SFI PhysMet have an extensive international network and active collaboration with a number of academic institutions around the world, documented by co-authorship of scientific publications, memberships in international scientific committees and a number of invitations to give key-note and invited lectures at relevant scientific conferences. Key researchers in SFI PhysMet are involved in two INTPART projects, for educational and research collaboration, with leading R&D institutions and industry in Japan, China and USA.

VISION AND RESEARCH STRATEGY

Vision: *SFI PhysMet aims to be a world leading research centre in the field of physical metallurgy, required to accelerate the transformation of the national metal industry towards more sustainable and cost-effecient production and future material products, solutions and improved processing methods.*



RESEARCH STRATEGY

The energy-demanding land-based industry sectors in Norway, i.e., the *metallurgical and manufacturing industry* have been of vital importance for Norwegian export and national value creation. However, *their presence and future sustainable growth in Norway depend on a competitive advantage in terms of high-technology competence and superior quality in their businesses*. In order to secure their position and prepare for further growth, four main industrial technology challenges that need to be solved to enable future new jobs, competitiveness and sustainable growth have been identified, and described in detail in the SFI PhysMet project description:

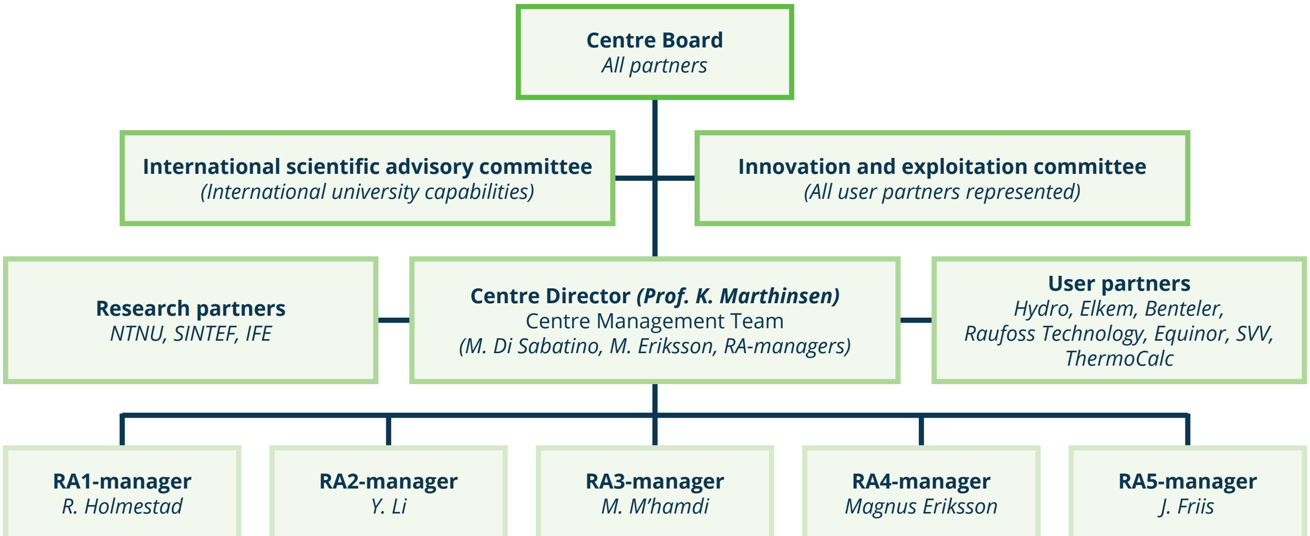
- **Use of more recycled metal**
- **Cost-efficient and sustainable mass production lines**
- **Growth in new market segments**
- **Methodologies for effective utilisation of data, models and procedures**

Even though these four main industrial challenges are comprehensive, requiring new innovative alloys, materials and processes, their basic knowledge needs are overlapping and generic. Extensive knowledge is required, about the mechanisms for formation and evolution of microstructures, and about the underlying principles. Then processing routes can be designed or improved, to provide cost-efficiently the desired properties of the products. Progress and innovations are accelerated when the knowledge and associated methodologies, models and data are efficiently stored and made available to academic and industrial researchers and engineers in the Centre.

The figure above illustrates the structure of SFI PhysMet, for which five *Research Areas* (RA1-RA5) are designed to meet the targeted industrial knowledge needs. Material characterisation in RA1 and modelling in RA2 represent the basic research required for developing the desired material design in RA3 and innovative processing in RA4. A separate RA5 is dedicated for developing a platform for storage and sharing of data and models, facilitating accelerated progress in RA1-RA4 and making results available for exploitation.

The targeted industrial knowledge needs serve as the basis for the specific work plans in each Research Area as further described in this report.

ORGANIZATION



THE CENTRE BOARD
Board meetings are held at least twice a year. The board's main responsibility is to ensure that the intentions and plans underlying the contract for the establishment of the centre are fulfilled. The board is to ensure that cooperation proceeds smoothly between the centre, the host institution and the partners in the consortium. In 2021 the board had online and physical meetings.

MEMBERS OF THE BOARD ARE:
Nina Dahl, SINFEF Industri (Board leader)
Magnus Rønning, NTNU
Trond Furu, Hydro
Gro Eide, Elkem
Yngve Langsrud, Benteler
Stein Olsen, Equinor
Thorbjørn Høiland, Raufoss Technology
Cato Dørum, Statens Vegvesen
Anders Engström, Thermo-Calc Software
Silje Aschehoug, SINTEF Manufacturing
Arve Holt, IFE
Øystein Asphjell, NFR (observer)

The board met physically for the first time in October 2021, in the new centre location at Gløshaugen.

THE CENTRE MANAGEMENT TEAM
The centre manager is Knut Marthinsen. Co-manager is Marisa Di Sabatino and administrative coordinator is Kari Håland. Magnus Eriksson represents SINTEF in the management team. The five Research Area (RA) leaders are also part of the management team.

The management team (from left): Magnus Eriksson (SINTEF, RA 4 manager), Kari Håland (NTNU, coordinator), Mohammed M'Hamdi (SINTEF, RA 3 manager), Knut Marthinsen (NTNU, director), Jesper Friis (SINTEF, RA 5 manager) Randi Holmestad (NTNU, RA 1 manager), Yanjun Li (NTNU, RA 2 manager), Marisa Di Sabatino (NTNU, co-director).

THE SCIENTIFIC ADVISORY COMMITTEE

In order to secure that the centre activities hold an excellent scientific standard and that we are closely connected with leading scientific groups in metallurgy around the world, we have appointed a scientific advisory committee (SAC). The members of SAC are:

Professor
Dierk Raabe,
Max Planck Institute for Iron Research, Düsseldorf, Germany

Professor
Aude Simar,
UC Lovain, Belgium

Professor
Dorte Juul Jensen,
DTU Technical university of Denmark

LOCATION

SFI PhysMet is hosted by NTNU, Department of Material Science and Engineering. The managers of the centre's five research areas work in Trondheim at campus Gløshaugen and at SINTEF Industry in Oslo. From October 2021 the centre has been co-located at campus Gløshaugen, with offices available for all research- and industry partners. PhD candidates and Postdoctors recruited to the centre will work closely together and with short distance to the project leaders and supervisors. The co-location ensure more effective collaboration between the research groups.

Campus Gløshaugen, Trondheim

CO-LOCATION OF SFI PHYSMET FROM OCTOBER 2021

SFI PhysMet officially opened the new centre location in Kjemiblokk 1 at Gløshaugen campus October 27th. The new location makes the centre more visible and a meeting point for all centre partners. PhD candidates and Postdoctors recruited to the centre work closely together and with short distance to the project leaders, supervisors and the centre management. We believe that co-location of the centre members ensures more effective collaboration between colleagues and between research groups.

Dean Øyvind Gregersen congratulated the centre manager and officially opened the new location on October 27th.

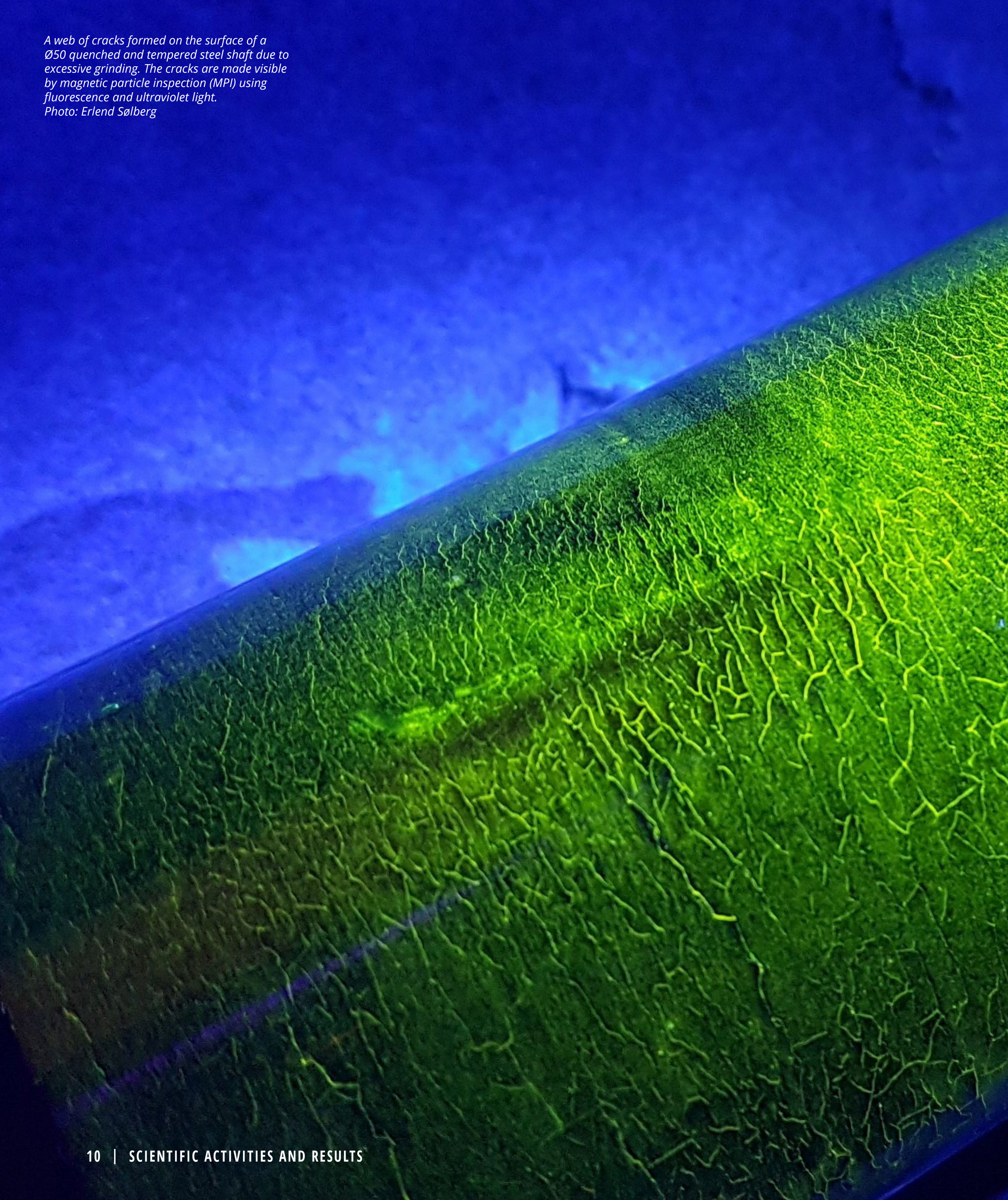
All partners were represented at the official opening of the new centre location. In addition to offices the location has several well-equipped meeting rooms as well as a large social area.

The social area is suitable for lunchbreaks, informal scientific meetings as well as social gatherings. When the corona pandemic situation is under control, we will organize more regular social meetings in this area.

Excellent meeting room facilities

PhDs and Postdocs working together

Social gathering with pizza in October 2021



A web of cracks formed on the surface of a Ø50 quenched and tempered steel shaft due to excessive grinding. The cracks are made visible by magnetic particle inspection (MPI) using fluorescence and ultraviolet light.
Photo: Erlend Sølberg

SCIENTIFIC ACTIVITIES AND RESULTS

From 2021 SFI PhysMet has been in full operation. The following pages give a brief overview of our Research Areas in terms of contributions to the centre objectives, main challenges to be met, research activities with focus on the specific activities performed in 2021. The scientific activities have started at NTNU, SINTEF and IFE, in close collaboration with the different user partners

RESEARCH AREA 1. MULTI-SCALE MATERIAL ANALYSES

RESEARCH AREA LEADER:
RANDI HOLMESTAD
NTNU

Production of advanced materials for the future requires detailed knowledge of the structure and chemical composition of materials at several length scales. NTNU hosts a world-class characterization infrastructure that is especially equipped to tackle metallurgical problems.

CONTRIBUTIONS TO CENTRE OBJECTIVES

- Develop a world leading platform and corresponding methodologies for multiscale and multidimensional structure characterization and high-sensitivity chemical analysis of metals, alloys and advanced nanomaterials.
- Contribute to other RAs by providing detailed characterization information, revealing in-depth mechanisms, providing reliable experimental data, and validating through-process modelling.

MAIN CHALLENGES TO BE MET

- Develop correlative use of TEM and APT.
- Develop and establish a framework for multiscale studies of material joints.
- Establish in-situ characterization techniques.

ACTIVITIES AND RESULTS IN 2021

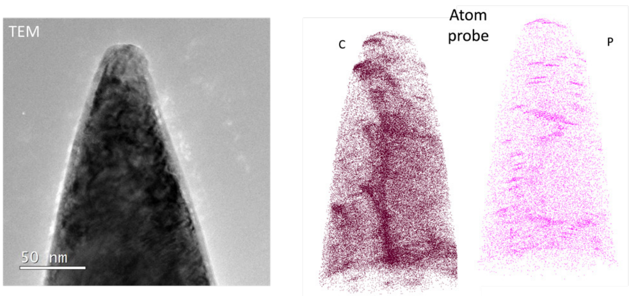
The research activities in RA1 are organized into three main research tasks, corresponding to the three main challenges mentioned above. In addition, characterization tasks connected to the other RAs will be done. The ongoing activities and results obtained in 2021 are described in the following.

RA1.1. Correlative use of TEM and APT

State-of-the-art transmission electron microscopy (TEM) and atom probe tomography (APT) are complementary techniques and provide experimental data on the crystal structure (TEM) and chemistry (APT) down to the atomic scale - crucial for developing and validating atomic scale simulations and micro scale through-process models. This will be used to extract 3D information, for example in the field of compensation metallurgy. However, we first have to establish sample preparation methods and competence in the field for different materials. So - the objective in this task in the beginning of the SFI is to build up competence on doing these techniques in a correlated way for different materials.

Task RA1.1A: Correlative TEM and APT for steels

This study takes place in collaboration with RA4 and industry and involves studies of the M-A (Martensite – Austenite) phase. This phase occurs when welding unalloyed and low-alloyed structural steels when the temperature in the base material reaches just above the transformation temperature in the two-phase range $\alpha + \gamma$ (ferrite and austenite). The phase is detrimental to the toughness of the steel, especially after it has undergone temperature cycles. This zone is called the inter-critically heated coarse-grained heat-affected zone (ICCGHAZ). Weld simulations was done in the Gleeble 3800 thermal-mechanical physical simulation system, and samples were prepared by focused ion beam (FIB). The figure shows an image of the sample in the TEM and the distribution of carbon and phosphorous as measured by APT. Experiments are done by Sigurd Wenner and Ruben Bjørge in SINTEF Industry. The studies will continue in 2022.



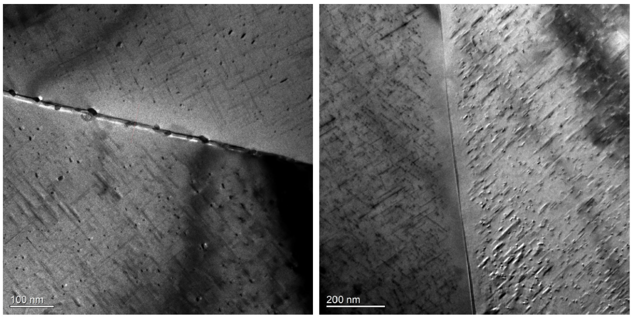
Segregation of carbon and phosphorous

Task RA1.1B: Correlative TEM and APT in dense Al alloys

In this task correlative APT and TEM will be used to study structure and chemistry of 6005 type aluminium alloys with different additions of Ti and V. The scientific task is to understand the effect of added Ti and V on precipitate statistics and on the overall solute distribution in the microstructure. Hydro has produced the alloys and performed several property tests, with the conclusion that the alloys with the additions show improved crush behavior and corrosion resistance. Hedda Øye at NTNU had a summer job and wrote her specialization project work on these alloys. She started with measuring hardness and conductivity evolution of some alloy variants during various heat treatments, learning TEM and doing initial investigations of the microstructure. She will do her MSc thesis in the spring of 2022 studying with TEM the precipitate parameters as function of alloy composition and thermomechanical treatment in selected conditions. Together with Hedda, Calin Marioara from SINTEF will investigate the influence of Ti and V on precipitate structure and morphology using TEM. The next step is to study the composition of the grain boundaries and precipitate free zones (PFZ) using APT, which will be performed by Sigurd Wenner from SINTEF. In this task we will develop correlative TEM/APT methodologies for accurate measurements of solute variation across bulk (in-between needle precipitates) -> PFZ -> GB in the Al matrix.

The figure below shows TEM images taken by Hedda Øye of the 6005 alloy without V and T additions, illustrating different types of GBs and PFZs.

The results obtained will relate to material behavior and will also be used in RA2 to further develop microstructural models.



Task RA1.2: Multiscale studies of materials joints

Through PhDs (Bergh/Arbo) in SFI Manufacturing techniques were established to do multiscale studies of joints, from atomic scale to more macroscopic scale. This activity will be continued and further developed by PhD student Tor Inge Thorsen and Ingvild Runningen (PhD student in RA4). The multiscale microstructure and complicated chemistry created when (dissimilar) materials are joined together require use of a large characterization toolbox, as crystallographically and chemically complex phases typically form near joints and welds. Initially, aluminium (5083) welding wires for WAAM (wire arc additive manufacturing) made by Geir Langelandsvik (SINTEF) using screw extrusion, with and without TiC nanoparticles, will be studied by different transmission electron microscopy (TEM) techniques.

RESEARCH AREA 2.
SCALE AND PROCESS BRIDGING METHODOLOGIES

RESEARCH AREA LEADER:
YANJUN LI
NTNU

CONTRIBUTIONS TO CENTRE OBJECTIVES

- Provide fundamental material data and understanding through high-throughput calculations and simulations from atomistic to micro-structure scale.
- Develop and validate specific models for alloy recycling, AM and innovative processing.
- Establish and validate multiscale and multi process modelling framework and AI methods, providing smart design and developing tools of innovative alloys and products.

MAIN CHALLENGES TO BE MET

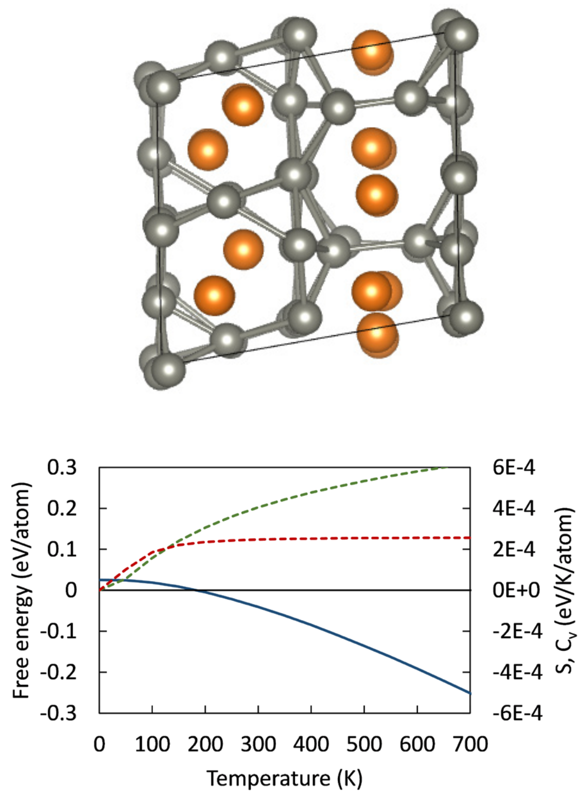
- How to reach a deeper understanding on the mechanisms and kinetics behind the physical metallurgical phenomena down to atomic scales.
- How to realize computational engineering based smart design of alloys and products with tailored properties.
- How to realize digitalization and automatization of the production in physical metallurgical industry.

The research activities in this Research Area are organized into four main research tasks, listed below, together with their main objectives and initial activities as part of work plans for 2021.

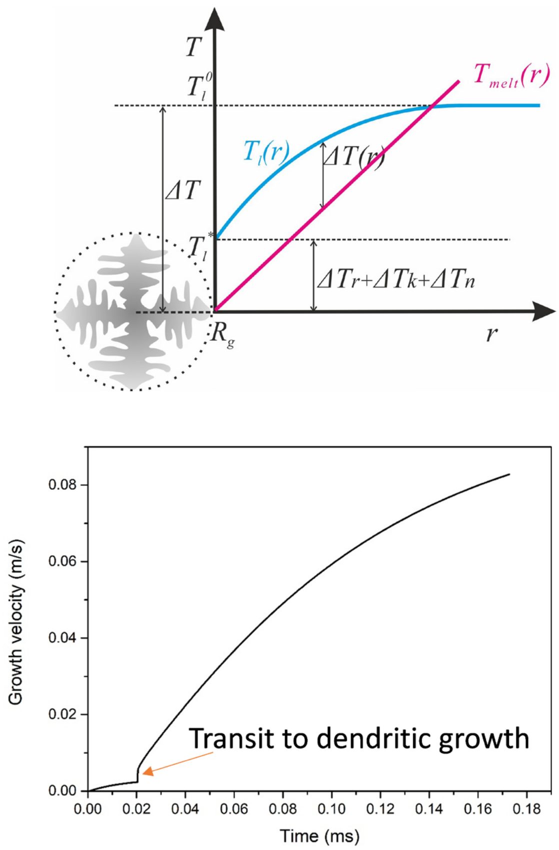
ACTIVITIES AND RESULTS IN 2021

The research activities in RA1 are organized into three main research tasks, corresponding to the three main challenges mentioned above. In addition, characterization tasks connected to the other RAs will be done. The ongoing activities and results obtained in 2021 are described in the following.

Task RA2.1: Atomic scale calculation and simulation
In this task, the objective is to use first principles atomic scale calculations obtaining thermodynamic and kinetic material data for atom clusters, precipitates and intermetallic phases, including bonding energy, formation enthalpy, interfacial energy, segregation energy and diffusivity of impurities in relevant alloys (aluminium, steel, cast iron).
In 2021, the Temperature Dependent Effective Potential (TDEP) method based on first principles molecular dynamics (MD) simulations has been tested and applied to calculate thermodynamic data for an important age hardening precipitate eta' phase in Al-Zn-Mg alloys as a function of temperature. The Gibbs free energy and bulk modulus of the eta' phase with different atomic structures have been calculated.
Another activity is an implementation of the Automated interactive infrastructure and database computational Science (AiiDA). Initial work-flows have been established for running VASP within AiiDA to calculate



Atomic structure and calculated photon free energy, entropy (S) and heat capacity Cv) of eta' as a function of temperature (by Ole Martin Løvvik).



Schematic drawing of the temperature field and undercooling region in front of dendrite tip growth, and the simulated growth velocity of grains in Al-7Cu alloy during powder bed fusion based AM process (by Yijiang Xu).

the formation energy of atom clusters, binding energy between atoms and vacancy and diffusion energy barriers of atoms in Al-Zr-Sc systems. By using the calculated data, a Kinetic Monte Carlo (KMC) model has been used to study the atom clustering process of Sc atoms. Atom clusters have been observed. However, L12 structured Al3Sc is not observed, indicating some further improvements of the KMC model and the Cluster expansion calculations have to be made.

Task RA2.2: Development and further improvement of microstructure models for recycling-based alloys, AM and welding

The objective is to develop microstructure prediction models for solidification and heat treatments of recycling based aluminium alloys, cast iron, AM alloys and welding of dissimilar metals. With more and more recycled metals used in the production of products, the influences of impurity elements on the solidification path, defect formation and heat treatment response will be addressed.

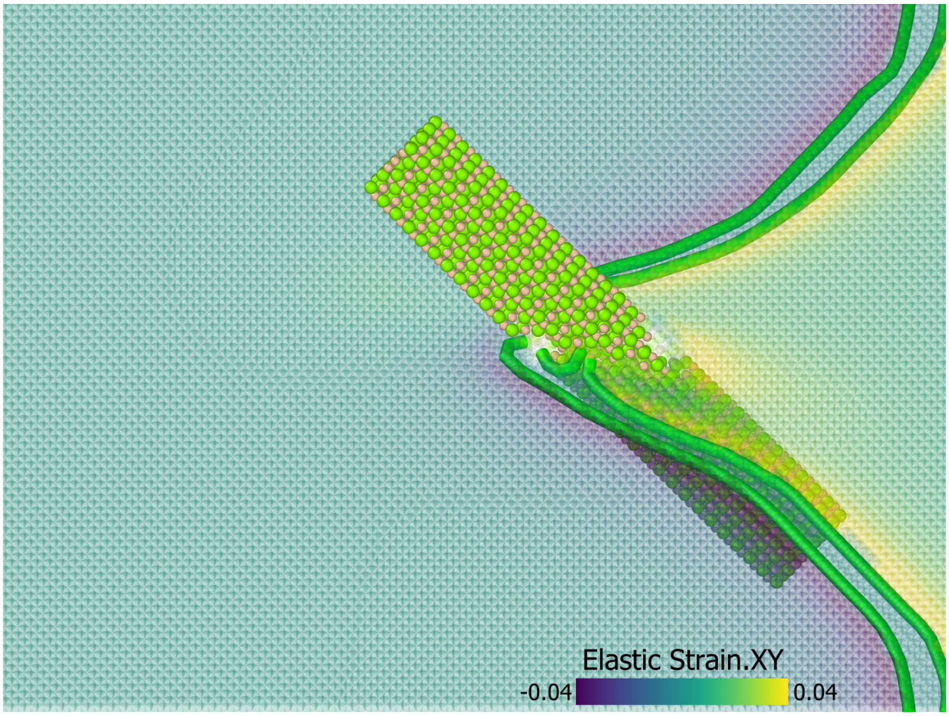
For AM processing of alloys, the influence of high cooling rates and high temperature gradients on the nucleation and growth kinetics of grains, solute re-distribution and solubility, and formation of metastable phases will be studied. For welding of dissimilar metals, a special focus will be put on the formation of intermetallic particles at bonding interfaces.

In 2021, a single grain growth model was developed to quantitatively assess the growth velocity dependent partition coefficient Kv, and liquidus slope mv of Al-Cu alloys during solidification. The effects of superhigh cooling

rates and temperature gradients on the evolution of dendrite tip growth velocity, and effective undercooling experienced by inoculation particles positioned at different distances to the growth front as a function of time have also been quantitatively evaluated. All these will be used for the development of a grain size prediction model for AM and welding process of aluminum alloys. Furthermore, a literature study on the microstructure modelling approaches for AM/welding has been done. Another important activity in this task is to develop a numerical microstructure simulation model to predict the precipitation behavior of age hardening precipitates during artificial ageing. A special focus will be put on the nucleation kinetics of atom clusters and precipitates, the segregation and precipitation behaviors at grain boundaries, the influences of impurity elements and vacancies, and the strengthening effect of precipitates.
A PhD student hired in December 2021 will be responsible for this task.

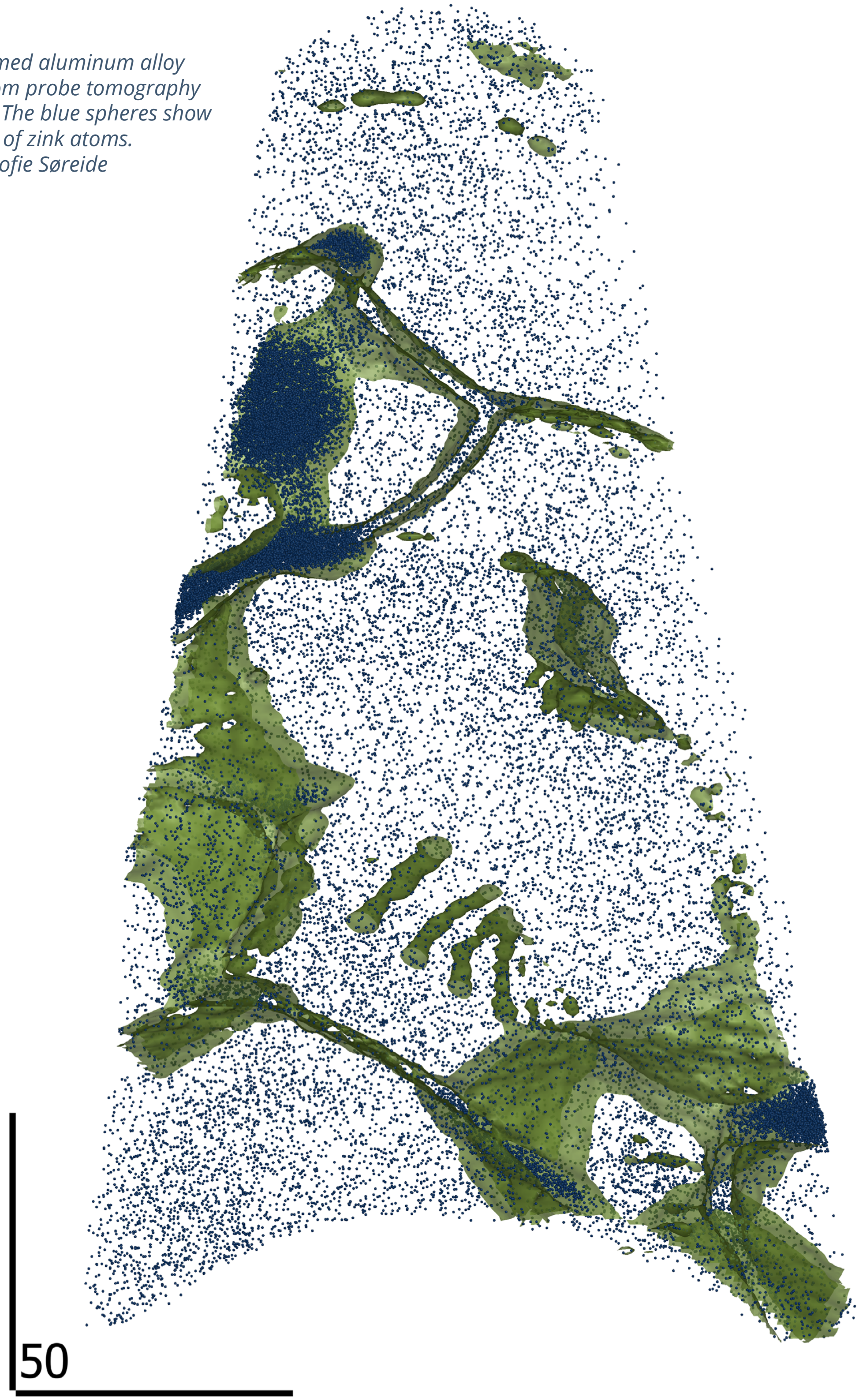
Task RA2.3: Through-process models under realistic industrial conditions
The objective is a generalization of existing microstructure evolution models for heat treatment, recrystallization and work hardening, which will be used as sub-models in finite element simulation software to simulate the transient conditions experienced during complex thermomechanical processes and predict the material performance and failure behavior and properties of products. This task will be starting in the late stage of the project when different relevant sub-models have been developed in the project.

Task RA2.4: Development of AI methods for alloy design and process parameter optimisation
The objective is the development of machine learning techniques for big data analysis of alloy chemistry, process parameters, and mechanical properties to generate constitutive equations and quantitative correlations of chemistry-structure-process-properties of alloys with complex chemistry and processing step and parameters. A combination of AI methods with through-process modelling tools will be implemented, applying for design and development of innovative new alloys for AM and recycling-friendly aluminium alloys with broader chemistry window and high concentration impurity elements.
In 2022, a neural network parameterization method is planned to be used to eliminate the discrete data points of calculated thermodynamic data, especially for solidification of multiple component alloys under ultrahigh solidification rates, and therefore generate more reasonable phase diagrams as a function of growth rate of primary phases. Such kinetic phase diagrams will be used for the grain size prediction model developed in RA2.2.



Molecular dynamics (MD) simulation of a screw dislocation bowing out around a beta” hardening precipitate in an AlMgSi-alloy. Photo: Inga Ringdalen

A heavily deformed aluminum alloy analyzed by atom probe tomography (LEAP 5000 XS). The blue spheres show the distribution of zink atoms.
Photo: Hanne-Sofie Søreide



RESEARCH AREA 3.
SUSTAINABLE AND HIGH-PERFORMANCE MATERIAL DEVELOPMENT

RESEARCH AREA LEADER:
MOHAMMED M'HAMDI
SINTEF

CONTRIBUTIONS TO CENTRE OBJECTIVES

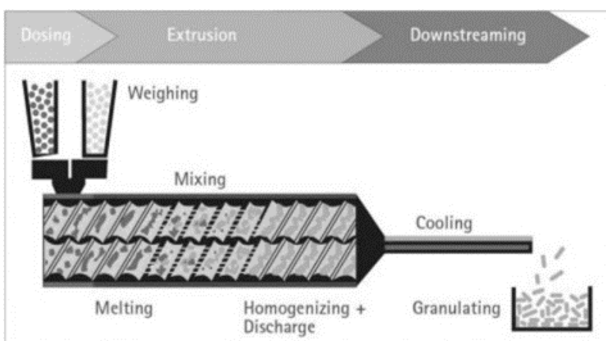
- The aim of RA3 is to establish fundamental knowledge and understanding of materials with recycled content and/or materials for new processes and applications (e.g. rapid solidification, additive manufacturing, and screw extrusion).
- To accelerate the design of new materials and alloys and/or industrial processes relationships will be systematized using modelling tools in collaboration with other RA combined with experimental work.

MAIN CHALLENGES TO BE MET

- How to compensate for unwanted elements from recycled materials and develop robust/novel alloys.
- How to develop and tailor-make the microstructure of AM/rapid solidification materials.
- How to recover or improve material properties through post-processing.

The research activities in this Research Area are organized into four main research tasks, listed below, together with their main objectives and initial activities as part of work plans for 2021.

Task RA3.1: Solid-state mixing by screw extrusion
This activity focuses on the preparation of novel materials with superior properties by solid state mixing of granular solid feedstocks, for example metal scraps, strips produced by rapid solidification and powders of different materials by using the novel Screw extrusion (SE) process. Although no activity has been planned in this task, work has been carried out through the involvement of 1 master student, a planned webinar on this process scheduled for February 2022 to present the methods and the possibilities, and the initial planning of a PhD study to be started in 2022 under supervision of Professor Hans Jørgen Roven.



Task RA3.2: Compensation metallurgy and alloy design

Enable the development of materials with a higher recycled content by understanding of the relationships between alloy composition (with recycled content) and solidification, heat treatment and mechanical processing. A focus will be put on the influence of impurity elements on nucleation, growth and morphology of grains and intermetallic particles, precipitation behavior of secondary phases, grain boundary segregation and processability of the alloys, etc. Activities in 2021 focused on the following tasks:

Solidification framework for high throughput calculations: Work has focused on the design and establishment of a solidification framework for high throughput evaluation of alloys under various solidification conditions to predict resulting thermophysical properties, solidification path, main microstructure feature (dendrite arm spacings and phases). The framework has been expanded by integration of the evaluation of hot tearing tendency using several criteria, application and comparison with literature data and link to process modeling for Al alloys. The framework is built on TC-python and available thermodynamic databases. As part of the work, a review on available databases has been carried out with the aim of enabling the analysis of wide range of alloying elements and elements from recycled materials.

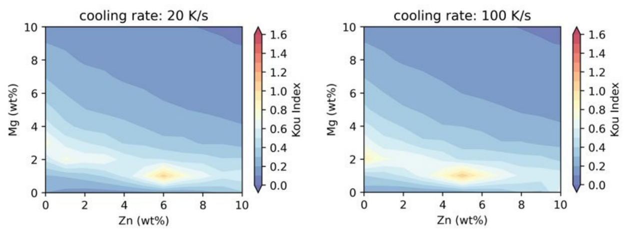


Fig: Impact of the Mg and Zn on the hot tearing tendency of Al-Zn-Mg-Cu at 0.5wt%Cu alloys for two cooling rates.

Formulation of Al alloys using recycled materials: Whereas a large amount of the Al scrap is recovered from separate sorting, there is still much of the household Al that is not sorted and ends up in the household waste bins. Municipal Solid Waste Incineration (MSWI) is one of the dominant waste management technologies in Europe today, as landfilling is being gradually phased out. The main solid residue from MSWI is Incineration Bottom Ash (IBA), with an annual European production of about 20 million tons. Metal recovery from IBA is a growing industry with continuously evolving technology and has become common practise in many developed countries and aluminium from IBA is a potential secondary raw material for the aluminium industry. In this work we have investigated the potential to produce an AlSi10Mg alloy using incinerator bottom ash (IBA) towards applications such as Additive Manufacturing and High Pressure Die Casting. For this we have used arc melting as a fast material screening technique and SEM imaging and EDS analysis to evaluate the resulting composition and microstructure after arc melting.

Our results reveal that the composition of unprocessed IBA (size fraction 10-15 mm) is highly inhomogeneous resulting in large variations in composition between different single particles. This limits the potential of arc melting to directly yield representative results for larger batches since the sample size in the arc melter is limited to 5-10 grams. However, due to significant amounts of impurities in unprocessed IBA, some pre-treatment to remove the impurities (mostly oxides and carbides) is in any case necessary.

Our results shows that salt-treatment of IBA results in a significant reduction in impurities such as oxides oxides. They also indicate that arc melting can contribute to reduce the oxide concentrations in IBA. However, the composition of unprocessed IBA (size fraction 10-15 mm) is highly inhomogeneous resulting in large variations in composition across and between different single samples particles. This limits the potential of arc melting to directly yield representative results for larger batches since the sample size in the arc melter is limited to ~5-10 grams.

EDS analysis showed that except from Al, Si is the most abundant element impurity in IBA Al, followed by Fe, Mn, Cu and Zn. With respect to the target alloy, AlSi10Mg, the measured concentrations of these impurity elements were within the specifications. Importantly, we did not observe the formation of the Al5FeSi phase which is a brittle phase detrimental to properties that may form in Al-Si alloys with too high Fe impurity levels.

Samples of salt-treated IBA were successfully alloyed up to AlSi10Mg. It was found that Mg addition needs to be calibrated to hit the target composition, due to some material loss during arc melting. Comparison of the resulting microstructure with arc-melted shavings of AlSi10Mg, showed that the alloyed IBA had similar features, however slightly more rod like Si phases grains. As for impurity elements, only Fe and Mn were detected in the alloyed IBA samples. Further property analysis of the alloyed IBA will be performed in coming studies.

Impact of recycled content on cast iron:
An activity on understanding the role of trace elements on the microstructure and properties of cast iron has been initiated in the form of the PhD program of Andreas Bugten under supervision of Professor Marisa Di Sabatino. The increased recycling of high-performance steel in the cast iron foundries and results in changing and increasing levels and types of impurities. There is therefore a need to understand how selected trace elements affect the microstructure and properties of the final products. Results from this program are shown in a separated section related to the PhD programs.

In his specialization project (autumn 2021), master's student Rune Botnmark Brurok investigated the microstructure and mechanical properties of ductile cast iron with boron additions, as well as the critical temperatures in the cooling curves after casting. The phase fractions and graphite nodule count were determined by optical microscopy using ASTM standards (by Elkem). The observations were correlated to the results of tensile tests. The fracture surfaces of the tensile tests were examined using SEM. Critical temperatures during cooling were compared for various boron contents to investigate the effects of boron on graphite formation.

Task RA3.3: Powder materials and rapid solidification
Develop powder-based materials with improved properties based on rapid solidification technology. Expanding the range of AM materials is targeted by tailoring the microstructure through-process control (solidification conditions), mixing powders with inoculants (to favor equiaxed instead of columnar structures) and additives (e.g., nanoparticles for improved properties), and mixtures of elemental powders. Activities in 2021 included:

Multi-component CALPHAD approach for S-L interface response under rapid solidification:
Solid-liquid Interface response function or the analysis of kinetic interfacial conditions under rapid solidification setting occupies a central role in solidification research. With the concepts of solute drag and solute trapping and on the base of irreversible thermodynamics, the calculation of kinetic interface condition phase diagram for binary alloys has been well established owing to the well-established continuous growth model by Aziz et al. Motivated by the fast development of various additive manufacturing (AM) technologies, clear needs to extend the kinetic phase diagram calculation towards multi-component alloy systems emerge to meet the challenges of processing parameter optimization encountered under those sub-rapid or rapid AM solidification conditions for new alloys. In this work the irreversible thermodynamics analysis and the binary continuous growth model have been reformulated into a form suitable for the coupling with the multi-component CALPHAD databases. Then the numerical solution to the CALPHAD-coupled multi-component model has been described. The model and its numerical solution were verified by comparing its calculation results with those reported in literature for A-B hypothetical ideal solution phases, Ag-Cu and Al-Be alloys. The model predictive power has been demonstrated by calculating the kinetic diagram of Al-Ti, Fe-Cr-Ni and Al-Cu-Mg-Si-Zn alloys. To illustrate one of the practical values of the proposed model kinetic growth restriction factor is calculated from the predicted Al-Ti and Al-Cu-Mg-Si-Zn kinetic phase diagram. It is concluded that the proposed multi-component model and its numerical solution can calculate kinetic phase diagram of any multi-component alloys. Moreover, the proposed model can be used in evaluating solute effect for grain refinement under sub-rapid or rapid solidification conditions, which is of great value to understand the solidification phenomenon in AM. The model is expected to be useful in many scenarios to guide the optimization of AM processing parameters and alloy design.

Fast screening of materials, and characterization of resulting microstructures using NP:
The proposed methodology for fast screening of materials is presented in the figure with i) preparation of materials from either pre-alloyed sample or elemental mixing including possible additives in the form of powders

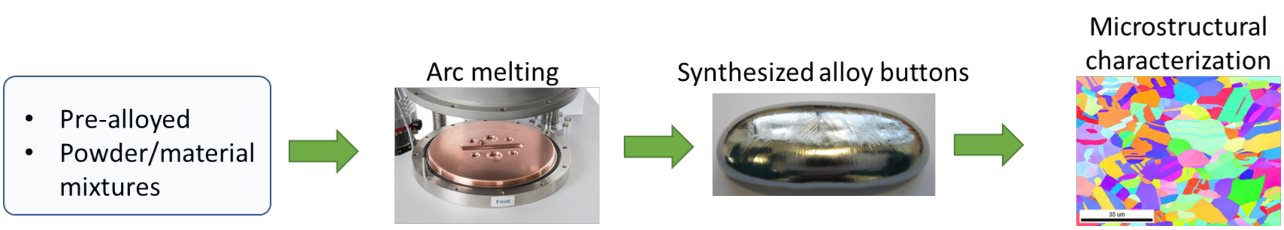


Fig: Methodology for fast material screening.

or nanoparticles; ii) arc melting of sample using small amounts of materials (typically 20 g) and production of alloys in the form of buttons, iii) characterization of the samples. In this initial phase of this work, focus has been on resulting microstructures and favoring columnar to equiaxed transition in AM materials using alloying and nanoparticle (NP) additions.

A PhD program focusing on the establishing a modeling and experimental framework for the development of Al AM alloys has been initiated with Magnus Reiersen under supervision of Professor II Mohammed M'Hamdi. Motivation for this program is that only a few materials are presently commercially available for AM due to issues such as hot cracking and there is a need to understand how to control/refine the microstructure to avoid cracking using alloying and additives such NP. This methodology outlined above has been applied to the study of NP additions to favor the columnar to equiaxed transition in Al alloys. The results of the application of this approach have been applied to TiC additions under various contents to 5xxx alloys in collaboration with RA4. The figure shows the impact of the amount of additions on the obtained grain size. A similar study has been carried out on 7xxx alloys demonstrating the grain refining effect of ZrH2 NP additions and the impact of Si additions.

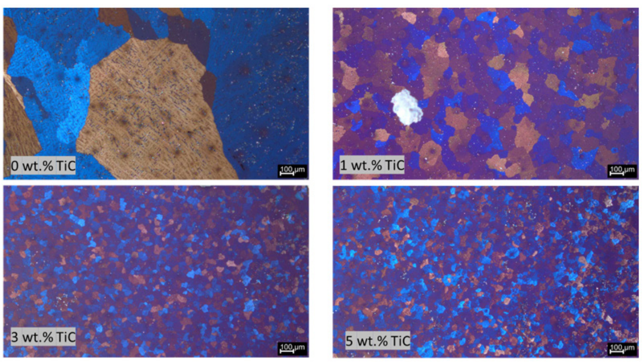
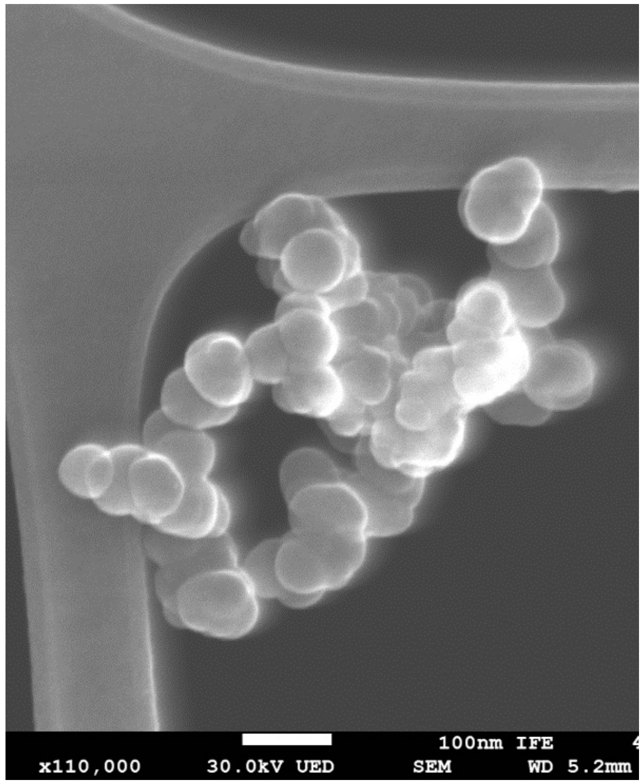


Fig: Impact of TiC additions on the grain size of 5xxx alloys using arc melting.

Production of silicon-based powder material
Pure, amorphous silicon nanoparticles have been produced from silane gas. The primary particle size is



roughly 100 nm, although the particles tend to agglomerate to larger clusters.
The silicon powder is synthesized in a free-space reactor at IFE, where silane gas decomposes at around 800 °C. The particles are formed in the inner tube and are harvested after the experiment. The free-space reactor can form particles from 50 nm up to 1 micron. In addition to pure silicon, also silicon carbides, silicon oxides and silicon nitrides can be synthesized.
The pure silicon nano powder will be tested as a supplement in additive manufacturing processes.

Task RA3.4: Tailored properties through post-processing
This task focuses on microstructure tailoring during heat treatments of Al (e.g. AM and rapid solidification or with recycled content) products to compensate for unwanted detrimental secondary phases and precipitates (e.g. Fe containing phases due to recycled content) and to promote desired phase transformations (in steels). No activity has been planned on this task in 2021.

RESEARCH AREA 4.
INNOVATIVE PROCESSING AND JOINING METHODS

RESEARCH AREA LEADER:
MAGNUS ERIKSSON
SINTEF

CONTRIBUTIONS TO CENTRE OBJECTIVES

- Develop knowledge basis for new wires for welding of aluminium alloys, using nanoparticles and alloying elements for grain refinement and particle strengthening
- Develop laser beam/laser-arc hybrid welding of dissimilar metals (e.g. Al-Cu, Al-Fe, Al-Ti)
- Develop laser-arc hybrid welding for thick steel and aluminium alloys (process-microstructures-properties) including numerical simulations.
- Develop laser assisted AM- and cladding processes.
- Establish process-microstructure-properties relations in laser cladding of metals with new powders (e.g., silicides).

MAIN CHALLENGES TO BE MET

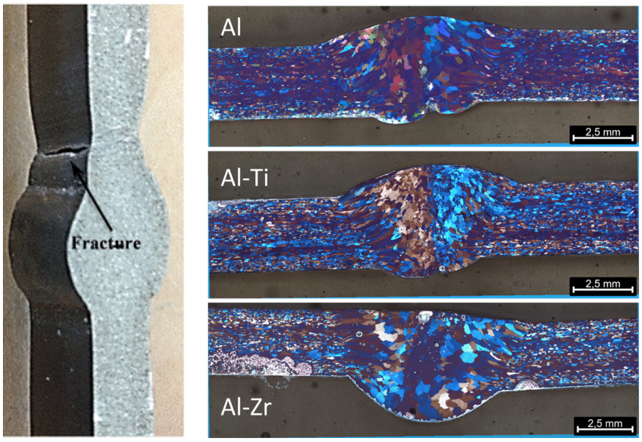
- Aluminium welding: Strength loss in soft parts of the heat affected zone (HAZ) represents a major challenge in aluminium welding. Both HAZ and weld metal will be addressed through adjustments of the welding process and the addition of nanoparticles, respectively. For additive manufacturing (AM) of aluminium alloys there is an urgent need for new wires and powders for direct energy deposition (DED).
- Welding/joining of aluminium to steel, copper, titanium and other aluminium alloys is desirable for weight reduction of components. However, a big challenge to achieve high quality welding is the formation of inert aluminium oxide films and intermetallic layers that forms during solidification at the welding interface, which strongly resist the formation of high strength metallic bonding.
- Laser welding of thick steel and aluminium alloys: Welding of heavy steel is challenging with laser-arc hybrid welding. Narrow and deep welds frequently provide excessive hardness in the root consisting of lath martensite and retained austenite in case of steels. Moreover, there are porosity and cracking issues. In welding of thick aluminium, the problem is significant softening in HAZ due to high heat input. In-situ process monitoring is challenging but required to understand underlying process physics to minimize weld imperfections.
- Cladding: Silicides may have excellent corrosion and wear resistance but have very limited applications so far. Tungsten carbides deposited by thermal spraying has dominated this business. More knowledge is needed on silicides as coating and actual coating processes will be important.
- DED is one of the many additive manufacturing (AM) methods, using laser or arc as heating methods. There is increasing interest to apply DED methods for repair purpose, e.g., laser metal deposition and wire arc additive manufacturing (WAAM). Applying these repair methods on a damaged component, on-site, is very challenging due to

uncertainties and variations of substrate material chemical composition, thickness, geometry, heat transfer etc.

The research activities in this Research Area are organized into five main research tasks, listed below, together with their main objectives and initial activities as part of work plans for 2021.

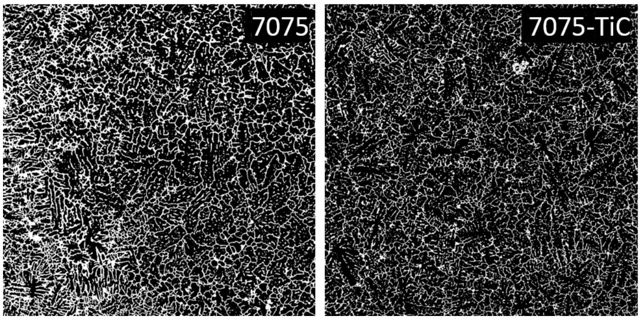
Task RA4.1: New wires for welding of aluminium alloys
In welding of aluminium and aluminium alloys, the weakest point is usually close to the weld, in the so-called heat affected zone. As seen in the tensile test, the fracture goes in the heat affected zone adjacent to the weld. One solution to mitigate the allocation of stress close to weld is by development of high strength aluminium filler wires. Superior welding wires can be achieved by increasing the weldability of high-strength 6xxx and 7xxx alloys through grain refinement, as well as incorporation hard ceramic nanoparticles as strengthening phase. Concurrent realisation of these two strategies is challenging, and a literature study to survey different processing techniques was performed in 2021. A state-of-the-art review paper was also published in Materials related to alloy development of aluminium alloys for welding and additive manufacturing, surveying the current selection of aluminium alloys available.

From the literature survey, solid state screw extrusion proved to be an interesting alternative for manufacturing of wires. In 2021, MSc-student Kjell Martin Kirkbakk has examined the effect of different microparticle additions on the grain refinement in aluminium welding wires processed by screw extrusion. High-quality welds were developed, showing low degree of porosity and significant grain refinement. The results are promising for developing nanoparticle reinforced wires in 2022.



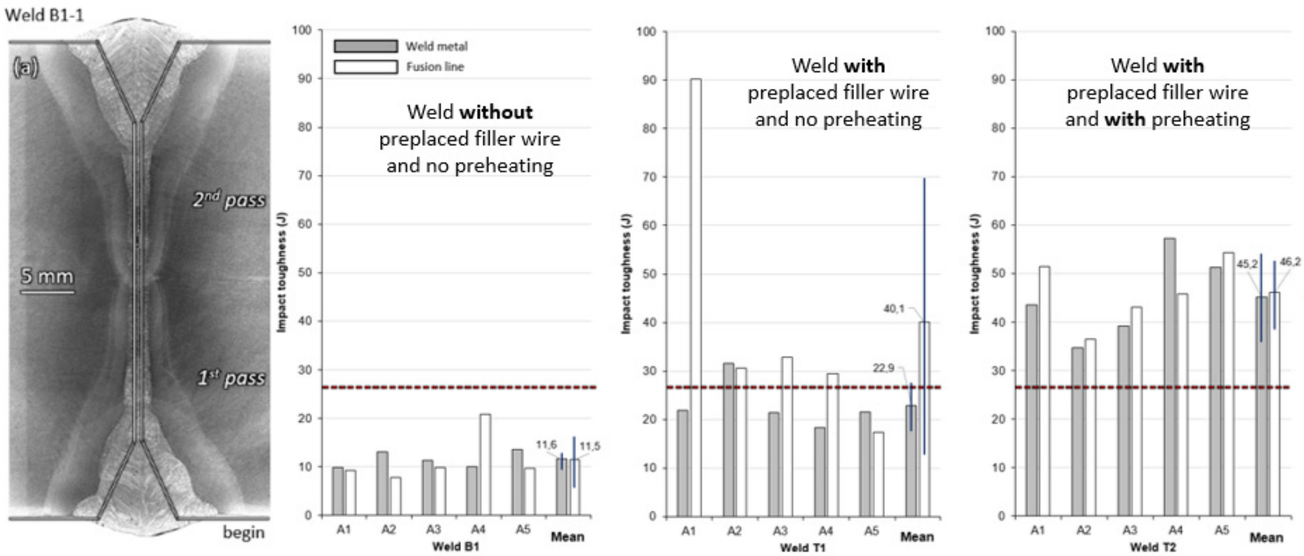
Aluminium HAZ fracture and microstructure images

Different aluminium alloy – particle additions has been screened by arc melting in collaboration with RA3. Three different alloys and nine particle additions were considered. The effect of particle additions on microstructure have been assessed. An example of an AA7075 alloy with and without TiC are shown in the figure below, indicating a refined microstructure with the use of TiC.



Task RA4.1 hired a PhD candidate in August 2021, Ingvild Runningen. Ms. Runningen started a state-of-the-art literature survey of production and properties of nanoparticle reinforced aluminium and taking mandatory educational courses. Ms. Runningen will during February 2022 finish all four courses. Ms. Runningen is on a four-year PhD contract with one year duty work at Department of Materials Science and Engineering. The duty work will be fulfilled during 2022 with Ms. Runningen serving as an engineer.

Task 4.2 Laser welding of aluminium alloys and dissimilar metals
In the automotive and electrical industry, welding/joining of aluminium to steel, copper, titanium and other aluminium alloys is desirable for weight reduction of components. However, a big challenge to achieve high quality welding is the formation of inert aluminium oxide films and intermetallic layers that forms during solidification at the welding interface, which strongly resist the formation of high strength metallic bonding. In 2021 a case study has been defined with welding of aluminium to copper in busbars and for other electronic applications. A state-of-the-art report is initiated, to be finalised in 2022. In addition, preparation for work to be performed in 2022 was started and together with the industrial partners, aluminium alloys were chosen for the Al-Cu welding trials.



Task 4.3 Laser-arc hybrid welding of thick steel and aluminum alloys

Deep penetration laser beam (LBW) and laser-arc hybrid welding (LAHW) is a promising technology for joining of >10 mm thickness metallic alloys offering a greatly enhanced productivity (10-30 times) and mechanical properties. To achieve the goals, there are many challenges to be solved. Initially, 540 MPa low carbon high strength steel of 45 mm thickness was chosen for double-sided welding. A preliminary welding was performed using LAHW with stainless steel wire to study its distribution to the root area which is susceptible to martensite and bainite formation. Thereafter, more optimized parameters were developed using carbon wire. The welds showed high hardness in the center of the plate/root-area, with martensite formation due to strong physical limitations of filler material distribution as the material mostly stays in the upper(cap) area of the weld. Welds showed high hardness in root area with martensite formation due to strong physical limitations of filler wire delivery to the root where the wire material mostly stays in the upper part of weld. Moreover, much porosity and cracking in the root areas was observed due to rapid solidification of molten metal. And consequently, low impact toughness was achieved at low temperatures –50°C. Preplaced filler wire in the gap prior welding, improved grain refinement and decreased hardness with improvement in toughness. Applied preheating and preplaced filler wire provided a significant improvement in acicular ferrite formation with high impact toughness. The results were consistent with thermal numerical simulations made in Abaqus. Advanced SEM studies of welds and Charpy specimens were performed and correlated with observations. Extensive statistical analysis of non-metallic inclusions was performed. Based on the results, two articles are written and prepared for submitting in relevant journals. The article with the title – Root formation and mechanical properties in laser keyhole welding of 15 mm thick HSLA steel was published in IOP Conference Series: Materials Science and Engineering and is presented at NOLAMP 2021 conference in Luleå, January 2022.

Task 4.4 Laser cladding

This task is planned to start in 2022. We have initiated discussion with relevant industry partners to define case studies to be initiated in 2022. Preliminary trials will start in 2022 in collaboration with partners. One possibility is using the silicides developed in RA3.

Task 4.5 AM by direct energy deposition (DED)

This task is coordinated with ongoing activities in RA2 and RA3. In 2021 we have initiated discussion with relevant industry partners to define case studies. Preliminary trials will start in 2022 using the aluminium wires developed in Task 4.1.

RESEARCH AREA 5.
DATA, SHARING AND DIGITAL PLATFORMS

RESEARCH AREA LEADER:
JESPER FRIIS
SINTEF

CONTRIBUTIONS TO CENTRE OBJECTIVES
- Make research results (data and modelling tools) accessible and easy to combine and reuse
- Enabling both industry and research partners to make efficiently use of the project results promoting rapid innovation

MAIN CHALLENGES TO BE MET
- How to formulate an ontology for physical metallurgy that covers all relevant quantities and at the same time is easy to learn and use? This is a key question for success and will be addressed together with other key international players in the field.
- How to realize the FAIR data principles? The main strategy here, is to reuse experience and state-of-art technology developed in collaborative European efforts.
- How to exploit the platform for increased quality and productivity in research and industrial innovation? Important steps when addressing this are involvement of all stakeholders from the beginning and early demonstrations.

The research activities in this Research Area are organized into three main research tasks, listed below, together with their main objectives and initial activities as part of work plans for 2022.

Task 5.1: Platform design
This task focuses on the design of a digital platform for the centre that will allow to document and seamless connect results from advanced characterisation, experimental testing, data processing and modelling from electronic to continuum scale. Surrounding projects and other target users will also be invited to ensure that the platform will expand after the end of the SFI and serve as a national digital hub for innovation and collaboration within physical metallurgy. An important part of this task is to create a domain ontology for metals and alloys, focusing on the needs for RA1-RA4. Close collaboration with international collaboration partners (mainly ACCESS), EMMC and other leading actors will ensure that this ontology will be part of a widely adopted standard for metals and alloys. Initial activities involve:
- Establish an international standard for physical metallurgy enabling easier integration of characterisation, data analysis and physics-based microstructure modelling covering the needs by RA1-RA4.
- Architecture design of the PhysMet Digital Platform based on the user stories.
- Overview and coordination with related projects working with potential synergies for shared digital infrastructure.

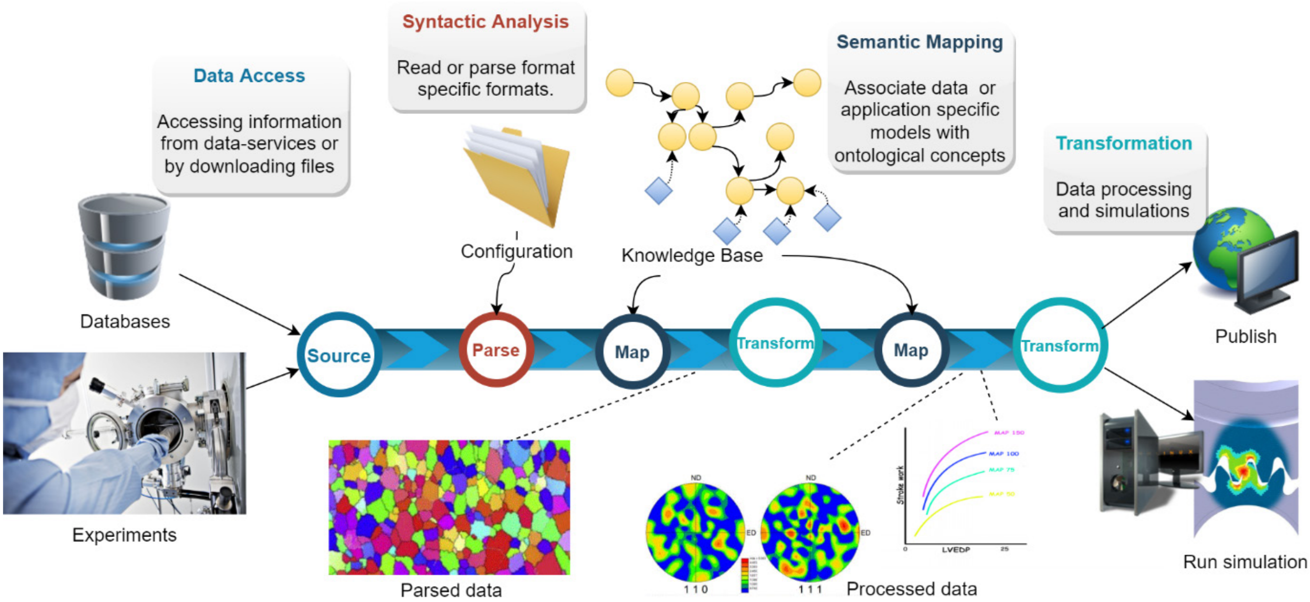


Figure 1. How concepts and technology developed in EU projects can be utilised to set up reusable pipelines for FAIR data handling and seamless connection of instruments, models and tools that have never been designed to communicate with each other.

Activities so far:

- Organised a set of dedicated meetings to discuss user stories, wishes and requirements with individual industry partners.
- Developed an initial version of a microstructure domain ontology.
- Established an EMMC task group lead by representatives for the SFI, for further development of the microstructure domain ontology in collaboration with key international collaboration partners, like ACCESS (Germany), AT2T (Austria) and ANSYS/Granta (UK). This is an important step to ensure impact and that the ontology we develop will be an upcoming standard within physical metallurgy and metallic microstructures.

Task 5.2: Platform implementation
The platform will be implemented using core technology from MarketPlace and tailored to the user needs expressed in task 5.1. It will combine existing and new components: i) database management and associated search and visualization tools, ii) interoperability modules to apply seamlessly various numerical models, iii) secured and user-friendly web interface.

Initial activities involve:

- Set up and maintain shared collaboration tools and infrastructure.
- Implementation of a PhysMet Digital Platform realizing the FAIR data principles and enabling rapid innovation.
- Provide a system for setting up workflows for data analysis, through scale/process modelling.

Activities so far:

- We have set up code repositories on https://gitlab.com/sfi-physmet with continuous integration services.

Task 5.3: Platform exploitation
This task will focus on exploiting both the data and available models to produce new analysis and support innovation. This task will involve workflow demonstrators, development of application specific interfaces for data analysis, as well as training and frequent user meetings to encourage the active use of the platform in all RAs.
Initial activities involve:

- Promote use of the Digital Platform to strengthen the metallurgy environment in Norway.

- Gather and communicate expected usage and requirements of the platform.
- Share and collect best practices for data sharing and digital corporation and provide training in how to use the tools and services developed in the RA.
- Provide “success stories” demonstrating the platform.

Activities so far:

- User meetings.
- Presenting SFI PhysMet and RA5 at the EMMC International Workshop.
- Implemented a set of demonstrations of technology and concepts:
  - Premod WebAPP – web application for precipitation modelling.
  - FastAPI SlagViscosity – separate function, independent resource.
  - sqlMicress – how to store simulation data as structured objects.
  - solidificationpath – combines models and database. Python wrapper to store data.
  - ASE view – Interactive viewer for crystal structures.
  - slagCalculator – secured, multi-property material data calculation.

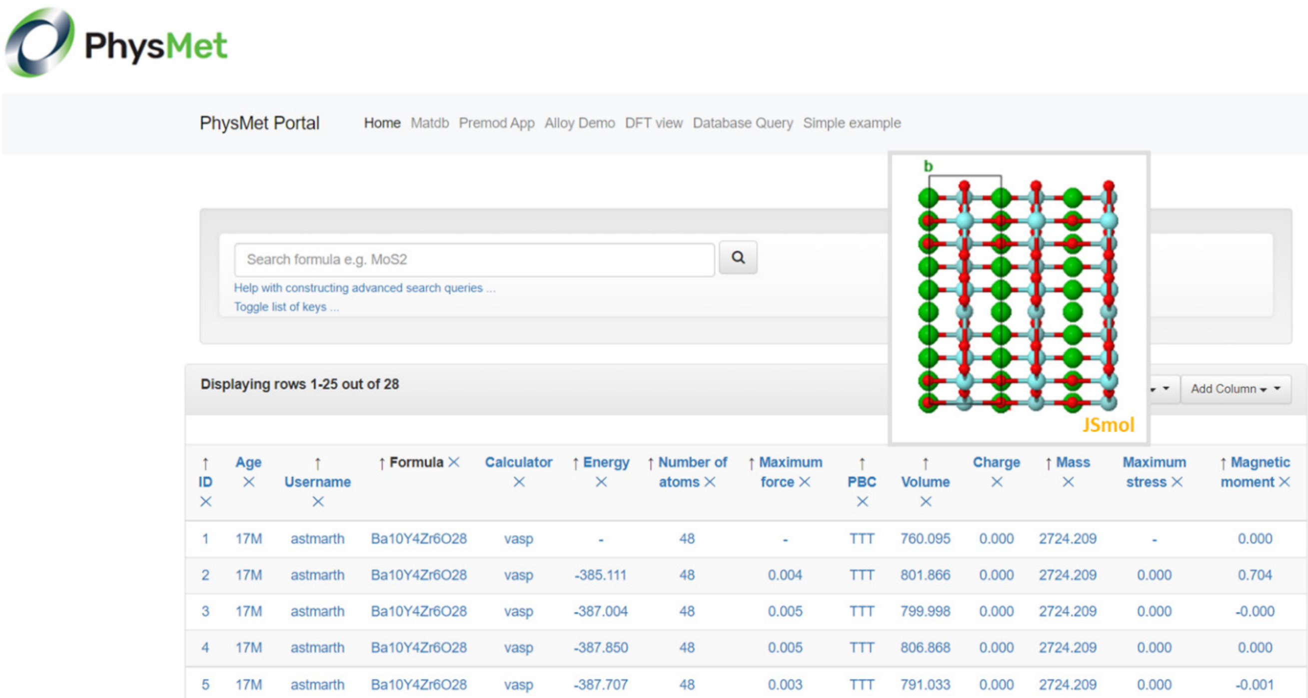
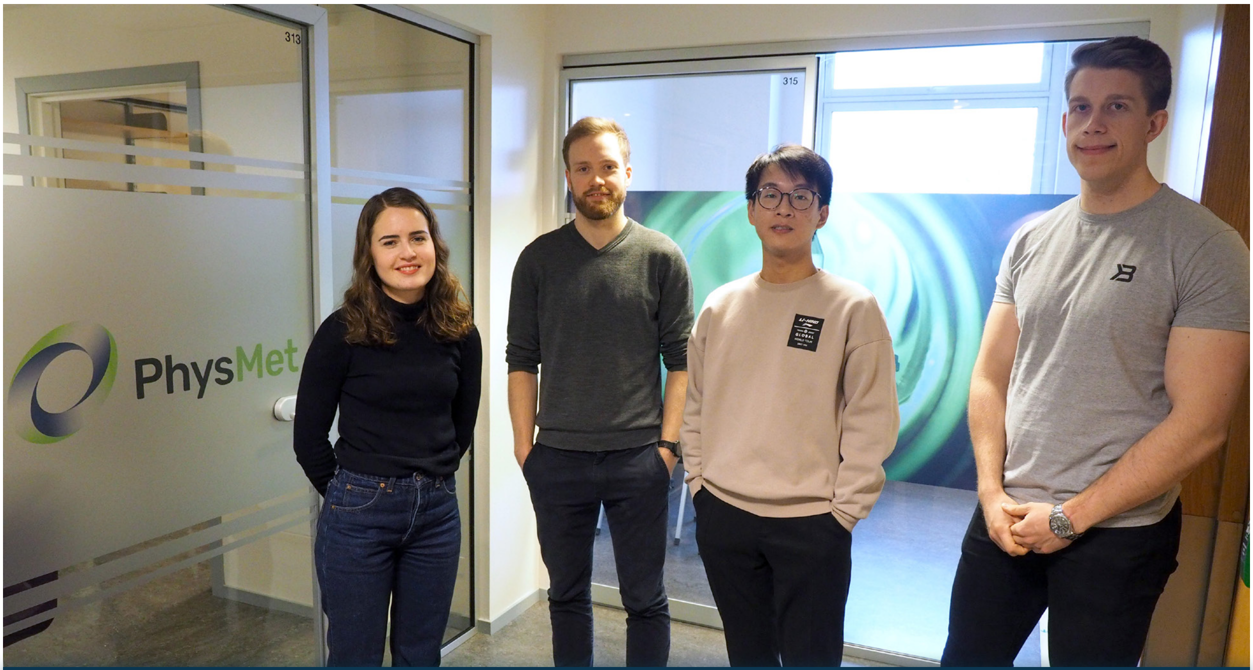


Figure 2. Screenshot of the ASE view demo application which already used in WP2.

RECRUITMENT

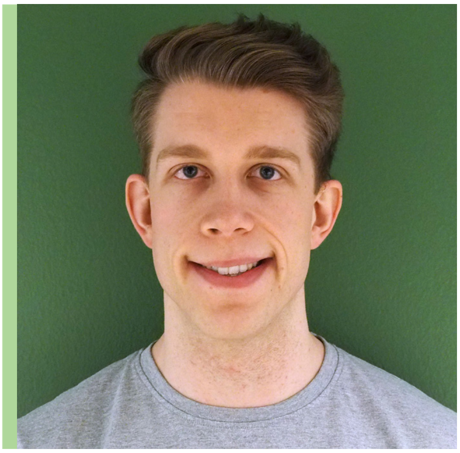


PhD candidates Ingvild Runningen, Tor-Inge Thorsen, Xuezhou Wang and Andreas Voll Bugten works in the SFI location in Trondheim. Magnus Reiersen (not in the picture) works at SINTEF in Oslo.

– NEW PHD CANDIDATES TO SFI PHYSMET IN 2021

Education of master and PhD students as well as postdoctors is an important ingredient of an SFI centre. Students, PhDs and postdoctors recruited to the SFI centre are exposed to scientific questions and topics highly relevant for the industrial partners. Through the close collaboration between the university, institutes and industry partners, these candidates learn the interplay between research activity and implementation of results and innovations in industry. The goal of the centre activity is to develop competence and skills to solve industrial questions and to produce new knowledge with strong innovation potential.

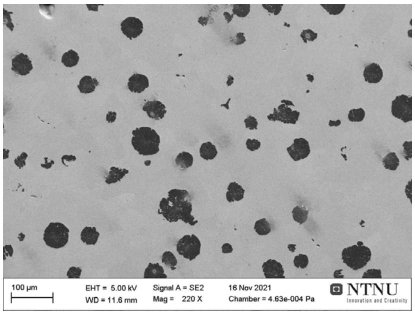
In 2021 five talented young PhD candidates were recruited to SFI PhysMet. Four of them are working in the SFI locations in Trondheim and one candidate is an "institute PhD" working at SINTEF in Oslo. Here is a presentation of their background and projects. We look forward to following their scientific achievements in the years to come!



PHD CANDIDATE
ANDREAS VOLL BUGTEN

Age: 26
From: Trondheim, Norway
Supervisor: Marisa Di Sabatino

My research is important for the cast iron industry who produces sustainable and environmentally friendly ductile cast iron components.



Ferritic sample 5f2 EHT=5k9

Background
My background is in physical metallurgy, and I obtained my master's degree at the Norwegian University of Science and Technology (NTNU). The topic of my master's degree was welding of aluminium. More specifically, I looked at possibilities for improving the structural properties of welded Al-Mg-Si alloys by local induction heat treatments. Al-Mg-Si alloys are strengthened by MgSi precipitates that may dissolve in the material adjacent to the weld, thereby lowering the strength of the material locally.

The PhD project: What are you going to study?
Ductile cast iron is a type of cast iron where the graphite precipitates as spherical structures (called graphite nodules) in the iron matrix. In manufacturing of ductile cast iron, steel scrap is often added to the metal charge to lower costs and recycle materials. As the utilisation of more advanced steels with more complex chemical compositions increases, e.g. in the automotive industry, the chemical composition of the available steel scrap will change accordingly. It is therefore crucial to determine the effects of trace elements from new steels on the microstructure and properties of ductile cast iron. An example of such a trace element is boron. In my studies I will use scanning electron microscopy (SEM) in combination with secondary ion mass spectrometry (SIMS), mechanical testing, thermal analysis (TA), and advanced characterization methods such as atom probe tomography (APT), to study the chemistry, microstructure and properties of the ductile cast iron. Examples of key questions to answer are: Where does boron go in the material? Does boron affect the nucleation of graphite? Does boron affect the phase fractions of the material? The boron concentration in the material will be varied systematically from 0 ppm to around 150 ppm.

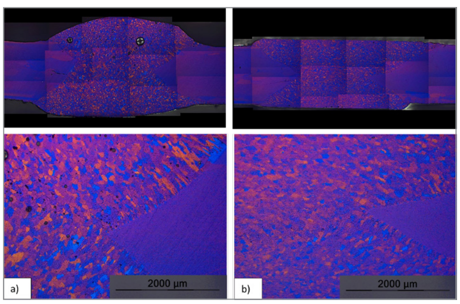
Why is your project important?
My research is important for the cast iron industry who produces sustainable and environmentally friendly ductile cast iron components for applications such as windmills, automotive, pipes and pumps, etc.

In your opinion, what are the benefits of being part of a center when working on a PhD?
I find it inspiring and valuable to have a tight connection and cooperation with the involved industry and research partners of SFI PhysMet. It makes it possible to maintain good communication between the parties involved in the PhD. Also, by performing the metallurgical experiments at the facilities of the industry partner involved in my PhD (ELKEM ASA, Kristiansand), we can ensure that the research is relevant for real life purposes. Visiting ELKEM ASA also gives me the opportunity to learn a lot from professionals, both with regards to the theoretical aspects of materials science, and to the social aspects of work life!

PHD CANDIDATE
INGVILD RUNNINGEN

Age: 24
From: Norway, Skien
Supervisor: Ida Westermann

Being part of SFI PhysMet makes it easy to collaborate with industry partners, establishing a unique foundation for new networks in the scientific community.



Fusion weld of T6 6082 with 5183 filler wire, where weld b) has been cold rolled to improve the mechanical properties of the fusion zone compared to a).

Background
I finished my master's degree at the Department of Materials Science and Engineering at NTNU in 2021. For my master thesis, I worked with the research project Durable Aluminium-Reinforced Environmentally-friendly Concrete Construction (DARE2C), investigating aluminium alloys' chemical stability during cement hydration in a cement paste with 55% supplementary cementitious material (SCM).

The PhD project: What are you going to study?
I am going to develop nanoparticle-containing aluminium filler wires for fusion welding by molten salt-assisted flux casting, extrusion, and cold drawing. I will investigate the TiC nanoparticles' microstructural influence during processing and the mechanical properties of the weld zone.

With its high strength-to-weight ratio, 100% recyclability, and excellent corrosion properties, aluminium is well suited for new sustainable engineering solutions. Unfortunately, fusion welding of aluminium and its alloys is challenging. The combination of a wide heat-affected zone (HAZ) with low strength and a poor assortment of filler wires makes the fusion weld a weak link in the structure. Slimmer, and therefore more environmentally friendly structures may be manufactured if the weakest link behavior in aluminium fusion welding can be solved.

By incorporating TiC nanoceramic particles into the filler wire, the fusion zone could be grain refined, and dispersion strengthened, resulting in a so-called overmatch of the weld that could protect a weak HAZ. Hence, the dimensioning of the welded component could be based on the strength of the base material instead of the weak HAZ, saving material in various engineering solutions as the design could be slimmer and stronger.

Why is your project important?
Results from this research could open up a new market for fusion welding and processing high-strength heat-treatable aluminium alloys within the 6xxx and 7xxx series. Being able to weld high-strength aluminium alloys could enable lighter cars in the automotive industry with a reduced carbon footprint.

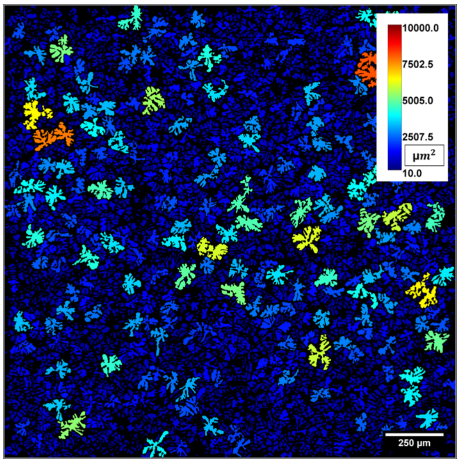
The produced filler wires could also be used in other fusion processing methods, such as wire arc additive manufacturing (WAAM), saving material and reducing emissions during manufacturing complex components.

In your opinion, what are the benefits of being part of a center when working on a PhD?
Being part of SFI PhysMet makes it easy to collaborate with industry partners, establishing a unique foundation for new networks in the scientific community. This, as well as being a part of a positive and collaborative working environment where we push innovative research towards sustainability, is a big motivation for me.

PHD CANDIDATE
MAGNUS REIERSEN

Age: 24
From: Norway
Supervisor: Mohammed M'hamdi

The result of my project can be used by industries that work with the specific alloys or for companies interested in the methodology of investigating potential alloy systems quickly and at a reduced cost.



Colourized_grain_size: An example of the result of the optical image analysis, where the grain size of each grain is colour coded proportional to its size.

Background
I took a master in Material Science for Energy and Nanotechnology at the University of Oslo. My master thesis was mainly focused on microscopy. I investigated the Al-Zn-Mg-Cu alloy system alloyed with silicon to resolve the issue of hot tearing occurring during rapid solidification conditions. Another aspect of the work was to find an efficient method of screening potential material systems for use in additive manufacturing.

The PhD project: What are you going to study?
The scientific topic for the PhD will be related to material development and microstructure control for powder based additive manufacturing processes with the ambition of expanding the material range for AM including the use of recycled (powder) materials.
A material processed with AM experience rapid solidification in comparison to the slower cooling present in the conventional methods, and as a result the compositions of the established alloys are often not suitable for AM processing. The challenging environment limits the selection of materials, and this calls for a method to screen potential material systems to effectively find suitable candidates. The goal is to establish a fast methodology for material screening and microstructure modification including the use of additives and alloying for microstructure refinement is needed.
Focus will be on modelling of microstructure to i) favour the columnar to equiaxed transition and ii) the impact of alloying elements on cracking tendency. Moreover, understanding of the processing conditions to modify solidification parameters (Gradient and solidification speed) in the melt pool in combination with in-situ monitoring and FEM simulations, as well as post-processing operations such as heat treatments to enhance the as built properties.

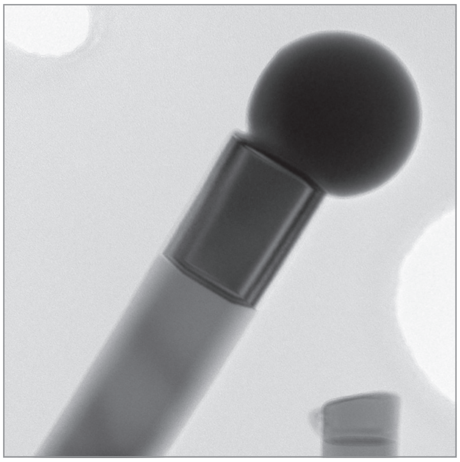
Why is your project important?
The result of the project can be used by industries that work with the specific alloys used in the work or are interested in the methodology of investigating potential alloy systems quickly and at a reduced cost to eliminate poor candidates at an early stage of researching it. Additive manufacturing has already redefined several conventional designs of components and has the potential to affect even more. However, to make this processing technology relevant for more industries the selection of materials that can be processes has to be expanded, which is where my work might make a difference in speeding up this process.

In your opinion, what are the benefits of being part of a center when working on a PhD?
Being connected to the SFI Physmet centre makes it possible for me to acquire knowledge from a society of different researchers being experts in their respective fields, so if I have a question about something there will always be a person with an answer for me.

PHD CANDIDATE
TOR INGE THORSEN

Age: 28
From: Sandnes, Rogaland, Norway
Supervisor: Randi Holmestad

If the welds can be made stronger through adding nanoparticles, the use of aluminium can be increased.



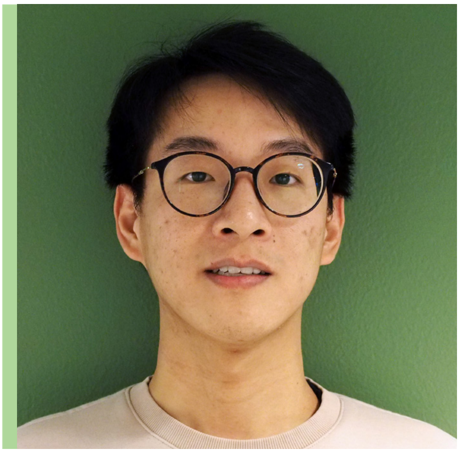
Bright Field (BF) image of GaAs nanowire with a phase change from zinc-blende (ZB) to wurtzite (WZ) at the top of the wire. Photo: Tor Inge Thorsen

Background
I took my master's degree in the Department of Physics at NTNU in 2019. The work I did was transmission electron microscopy (TEM) studies of heterostructured GaAs/GaAsSb nanowires meaning a small region of the wire had a different composition from GaAs where also Sb was present. GaAsSb has a different lattice parameter than GaAs which induce strain and a phase change close to the insert region. The task was to study the phases present and map out the strain field around the insert region using Scanning Precession Electron Diffraction or SPED for short. This method scans a small precessed electron probe across the sample and collects a diffraction pattern from each position. This gives a stack of diffraction patterns where each pattern is associated to a specific location on the sample. These images can be studied using python programming and the open source packages HyperSpy and pyXem to map out phases, composition, strain and more.

The PhD project: What are you going to study?
The PhD project will be TEM studies of aluminium welds where nanoparticles have been added to increase the strength of the welds. A common problem in construction of aluminium products is that the welded regions are the weakest link in the product. There are many possibilities to improve this, and one idea is to add nanoparticles to the welding material. The small size of these particles makes them difficult to observe and study. And this is where TEM studies can come in handy to allow high enough resolution to answer important questions such as where the nanoparticles are in the aluminium structure, e.g. if the nanoparticles are distributed evenly in the material or agglomerates, find possible presence of oxides and hydrogen and more. To do this, different measurement techniques in TEM will be used such as high resolution imaging, scanning precession electron diffraction (SPED), scanning transmission electron microscopy (STEM), energy dispersive X-ray spectroscopy (EDS) and maybe more. My PhD will rely on heavy use of the NORTEM infrastructure.

Why is your project important?
Aluminium has many positive properties and can be a big part in a greener future. The Norwegian production of aluminium also bases most of its energy consumption on hydropower giving it a lower emission than many other countries. The energy consumption from production can also be drastically reduced by recycling the material. However, the welded regions of products are typically much weaker than the base material in the construction. For some applications the choice of aluminium alloys is limited or aluminium may not be usable at all. If the welds can be made stronger through adding nanoparticles, the use of aluminium can be increased.

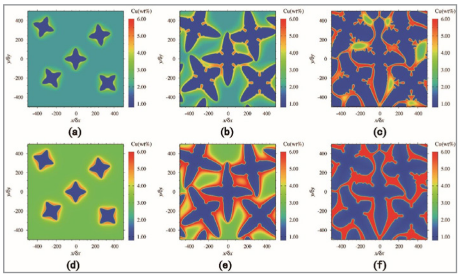
In your opinion, what are the benefits of being part of a center when working on a PhD?
I am hired through the Department of Physics, NTNU, in the TEM Gemini Centre research group. Through the centre we have been given a comfortable office where we are positioned close to colleagues working in the same field. This makes the communication between the different factions of the PhysMet group much easier.



PHD CANDIDATE
XUEZHOU WANG

Age: 26
From: China
Supervisor: Yanjun Li

It is crucial to predict and control the influences of impurity elements and vacancies on the age hardening response of recycling-based aluminium alloys.



Multi-crystal growth evolution at a reference temperature of T0 = 923.2 K for (a-c) Al-2.0wt% and (d-f) Al-3.0wt%Cu. (X.Z. Wang, et al., Computational Materials Science 184 (2020) 109855)

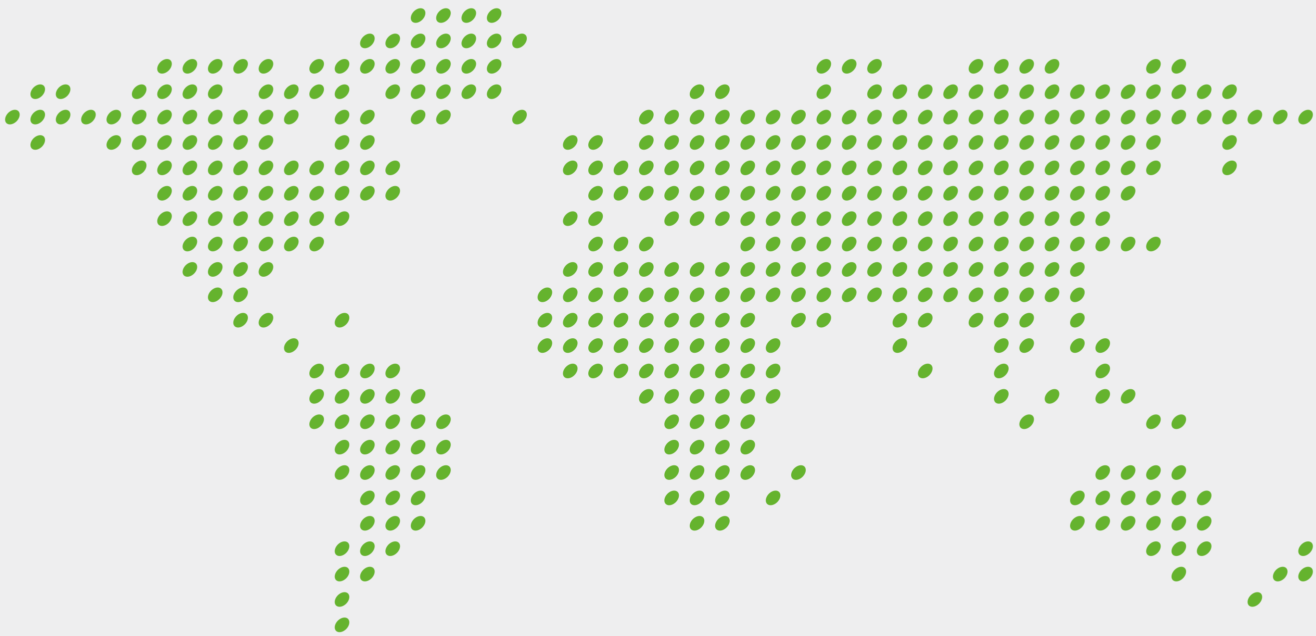
Background
I received the B.Sc. degree in 2018 and the M.Sc. degree in Mechanical Engineering in 2021 from Southeast University, China. During my master's degree, I conducted the modelling and simulation of dendritic growth in the melt of binary alloys, to numerically investigate the complex interactions between solute transport, melt convection, phase transformation and crystal movement, by using the combination of phase field method and lattice Boltzmann method. This work has important instructional significance for regulating the microscopic dendritic morphologies during solidification, and further improving the macroscopic mechanical properties of final components.

The PhD project: What are you going to study?
In my PhD project, an advanced precipitation model will be developed with significantly improved nucleation kinetics of precipitates in both bulk of grains and grain boundaries, by well addressing the diffusion kinetics of solute atoms under the influences of impurity elements and vacancies, and the atom clustering kinetics. With the predicted number density and volume fraction of age hardening precipitates, a strength model will be further coupled into the model to predict the mechanical properties of Al-Mg-Si alloys.

Why is your project important?
Aluminium alloys, due to their high specific strength, excellent surface properties and good corrosion resistance, combined with the advantages of cost saving and eco-friendliness, have been widely used in aeronautic engineering, automotive industries and oil and gas industries. In order to mitigate global climate change problems, recycle-based metal production is considered to be an important driver, where 90% energy savings can be reached to reduce CO2 emissions. Against this background, it is crucial to predict and control the influences of impurity elements and vacancies on the age hardening response of recycling-based aluminium alloys.

In your opinion, what are the benefits of being part of a center when working on a PhD?
Being a part of world-class research centre, that is, SFI PhysMet, provides me a strong international academic environment, which also enables me to work in close collaboration with the research- and industry partners. I can communicate with many high-level researchers to address questions that confuses me during my research. In addition, frequent lectures presented by accomplished researchers can broaden my horizons and give me an opportunity to find what I am really interested in.

INTERNATIONAL COLLABORATION



OUR AIM

The areas covered by SFI PhysMet are internationally competitive, with strong international industrial- and academic actors. Access to cutting-edge knowledge, facilities and networks through collaboration with key organisations abroad, is therefore essential for further competitiveness and value creation in Norway.
We aim at enhancing the Centre impact through activities with funding from the Horizon Europe program, and peripheral funding schemes, e.g., ERA-NETs. NTNU, SINTEF and some user partners in the Centre have long experience in initiating and running EU framework programme projects. Our ambition is to increase the involvement in European stakeholder organisations such as SPIRE, EMIRI and EMMC to promote research topics covered by the Centre.

INTERNATIONAL COLLABORATION ACTIVITIES

INTERNATIONAL SFI PARTNER

The SFI partner Thermo-Calc Software is world-leading on computational thermodynamics. Their expertise will be essential for effective integration of highly accurate thermodynamics data into industrially modelling workflows. They have special interest in the work on software interoperability and linkage to various simulation platforms and machine learning. Thermo-Calc has provided licenses for software and databases to NTNU/SINTEF and they provide training courses on the use of their products to all partners. Thermo-Calc will mainly contribute in Research area 2 and 5.

SAC-MEMBERS

The centre has an international Scientific Advisory Committee (SAC) with three members of high scientific standing:

- Professor Dierk Raabe, Max Planck Institute for Iron Research, Düsseldorf, Germany
- Professor Aude Simar, UC Lovain, Belgium
- Professor Dorthe Juul Jensen, DTU Technical university of Denmark

We are looking forward to the collaboration with the SAC. Spring 2021 the three SAC members gave guest lectures at the SFI PhysMet webinar series.

INTERNATIONAL CONFERENCES AND COURSES

International courses and conferences are important arenas for connecting with international scientists. The researchers in SFI PhysMet normally participate in broad range of international conferences and workshops throughout the year. 2020 and 2021 have been special years due to the COVID-19 pandemic, and some conferences were postponed or cancelled. However, many conferences have been organized as virtual conferences with digital participation, and SFI members have contributed with presentations and lectures.

Professors Randi Holmestad and Knut Marthinsen (NTNU), and senior researcher Calin D. Marioara, (SINTEF), collaborate closely with Center for Advanced Materials Research and International Collaboration (CAMRIC), Toyama University, Japan. Autumn 2021 they gave lectures at the 7th Forum of Center for Advanced Materials Research and International Collaboration. The audience were from Japanese industry and research institutions. Holmestad, Marthinsen and Marioara are members of Advisory Board for International Science Network (i-MSN) at Toyoma University.

Signing of the collaboration contract with Japanese academic and industrial partners of INTPART project Norwegian-Japanese Aluminium alloy Research and Education Collaboration - Phase-2 (NJALC II) at the Norwegian Embassy in Tokyo, May 2019.

Other international conferences and workshop with SFI PhysMet contributions in 2021:

- 4th International Conference on Light Materials - Science and Technology
- 7th Forum of Center for Advanced Materials Research and International Collaboration (CAMRIC), Toyoma University
- Online seminar Chongqing ("111" and "International Joint Lab")
- Thermec'2021 Virtual Conference
- Workshop on Ontologies for Materials-Databases Interoperability
- INTERSECT International Workshop on Advanced Materials-to-Device Solutions for Synaptic Electronics
- EIT-Raw Materials RAIDMAP (Raw Ideas for Materials Projects) workshop in Berlin and online 4-5/11/2021
- EERA JP PV meeting, Online 16/11/2021

DIGITAL PLATFORM BASED ON EUROPEAN MATERIALS MODELING COUNCIL

The activities related to the establishment of an SFI PhysMet Digital Platform are largely based on technology developed in a number of EU projects related to the European Materials Modelling Council (EMMC), which aims to increase European value creation and the ability to solve societal challenges (e.g. within Green Deal) through increased adoption of material modelling in European companies. The centre will utilise technology for semantic interoperability, workflows and data documentation developed in a range of EU projects, including MarketPlace, OntoTrans, OntoCommons, DOME 4.0, OpenModel, VIPCOAT and NanoMECommons. Furthermore, is the development of the microstructure ontology done as a task group in EMMC in close collaboration with EMMC ASBL, ACCESS in Germany and IC2C in Austria.
Partners from the centre are also active in the creating consortia towards the HORIZON-CL4-2022-RESILIENCE-01-19 and HORIZON-CL4-2022-RESILIENCE-01-25 calls.

PHD EXCHANGE AND GUEST LECTURES

The PhD projects in the Centre will include plans for shorter or longer stays at selected research organisations abroad. Furthermore, guest researchers will be included in the research education at NTNU, through guest lectures on specific topics.

TWO INTPART-PROJECTS

International Materials Science and Engineering education and research network (IntMat) (2020-2024: Project leader Assoc. Prof. Ida Westermann)
Partners: NTNU, Massachusetts Institute of Technology (MIT), Shanghai Jiao Tong University, Jilin University, Chongqing University and Nanjing University of Science and Technology, The Jiangsu Industrial Technology Research Institute and the Research center at the Aluminum Corporate of China.
The objective is to develop world-class research and education in Norway through long-term international cooperation with high quality universities and industries within the materials domain in US and China, with specialized infrastructures and competences that complement our own. This will be realized through exchange of academic staff and students, seminars, workshops and symposiums among the partners, as well as double master degrees and joint PhD supervision.
Three PhD students from our partner at Chongqing University are visiting researchers at SFI PhysMet from August 2021-August 2022. They are working on Al- and Mg alloy research by using electron microscopy, Atom Probe Tomography (APT) and machine learning.

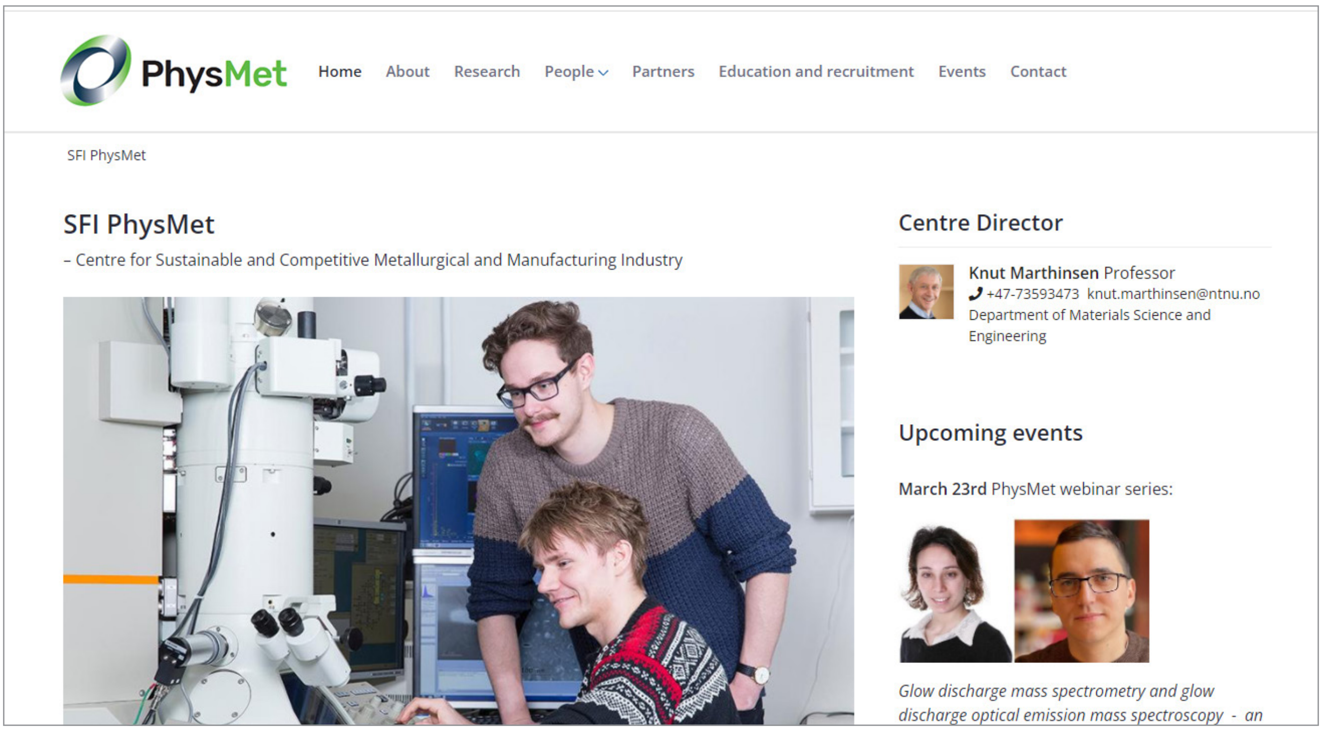
Norwegian-Japanese Aluminium alloy Research and Education Collaboration - Phase-2 (2019-2023; Project leader Prof. Randi Holmestad)
Partners: NTNU, SINTEF, Hydro, University of Toyama, Tokyo Institute of Technology, Kyushu University, Japanese Aluminium Association, and Toyama Aluminium
The focus is on i) Research collaboration, ii) student exchange and collaboration on education, including joint supervision of MSc and PhD candidates and joint courses and summer schools, iii) Internships in industry which connect education, research and innovation (both in Japan and Norway). The objective of the project is to consolidate and further develop relations and collaborative activities developed in the Phase-1 project (2016-2019) first phase of this project, both with academia and industry in Japan, as a basis for stronger and more formalized bonds.

Visiting researchers from Chongqing University in 2021/2022: Fang Han, Xiaoxi Mi and Ruojin Zang

COMMUNICATION AND DISSEMINATION ACTIVITIES

The overall communication aim of SFI PhysMet is to disseminate knowledge, engage relevant target groups and ensure that inputs from stakeholders at all levels can influence and improve the results and impact of the Centre. Relevant stakeholders are the centre partners, students and researchers, other industry sectors, the general public, international research communities etc. Scientists have a responsibility to build bridges between science, industry and society, and to transfer the new knowledge to potential user groups and society as a whole. Our aim is that results from SFI PhysMet shall be visible and implemented at internal and external/public arenas in the years to come.

An important arena to reach out to the public and making information easily available is the centre website **www.ntnu.edu/physmet/**



WOULD YOU DRIVE A CAR MADE OF RECYCLED MATERIALS?

In November SFI PhysMet published a chronicle in Adresseavisa, Teknisk Ukeblad and in Gemini. Close collaboration between research institutions and industry is crucial to make the transition to a green future. In the chronicle we discuss the need to produce more knowledge on recycling and sustainable production of metal products.

Adresseavisa 4.11.21

PRESENTATION AT MATERIALDAGEN

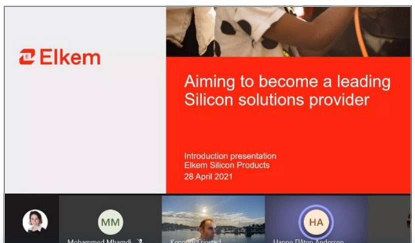
An important academic objective of SFI PhysMet is education and training the next generation of physical metallurgists. Students are invited to complete their master or apply for PhD position in collaboration with the centre. Every year the material science and engineering students at NTNU invite material technology industry to «Materialdagen» - a seminar where companies can present potential career opportunities for the students. This year Marisa Di Sabatino, co-director of SFI PhysMet, presented the centre and our close collaboration with relevant industry partners.

NTNU WEB – INFORMATION ABOUT THE NEW SFI CENTRES

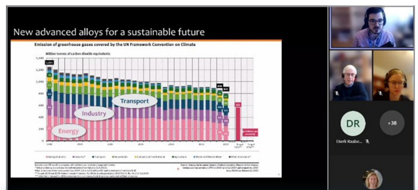
Five new SFI centres have started at NTNU. Information has been published in various internal communication channels to make the new centres known in the organization.

WEBINAR SERIES

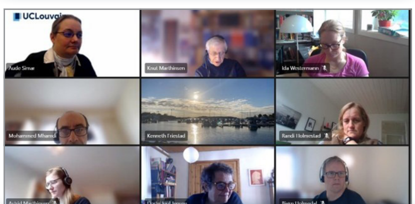
From 2021 we have invited all partners to attend monthly digital webinars with scientific presentations on topics relevant to SFI PhysMet members. The webinars are easily available for all research and industry partners, as they are presented online. The presentations have been a success, with many participants. Here are examples of presentations from 2021:



Kenneth Friestad, Elkem, 28.04.2021



Paris Kontis, NTNU, 29.09.2021



Professor Aude Simar, UCL Lovain, 19.05.2021

Professor Filippo Berto, NTNU, 18.11.2021

INTERNAL MEETINGS AND COMMUNICATIONS ACTIVITIES

An important task when organizing a centre is to establish and maintain effective routines for meetings, information sharing and internal communication in general.

The management group has weekly meetings to discuss progress and coordinate center activities. Due to the corona virus situation most of the meetings in 2021 have been digital on Teams.

RESEARCH AREA MEETINGS

We have established a meeting structure that involves all members of the centre. The managers of the five Research areas (RA) are responsible for the involvement of all relevant partners in the implementation of the various RA activities. In order to involve all partners, we organize regular meetings on an RA-level. The main focus on the agenda for the meetings is to follow up the plans and activities described in the annual work plans. The meetings are also excellent arenas for discussing student projects, student summer jobs and project development.

CONSORTIUM MEETINGS

We organize bi-annual SFI meetings with participants from all partners. The purpose of these meetings is to exchange information on major results as well as presenting overall thoughts and strategies vital to the centre progress. Due to the corona pandemic most of the meetings in 2021 were online meetings.

Finally, in October we were allowed to organize a physical meeting. All research- and industry partners were represented when we met at Scandic Lerkendal Hotel October 26th. Scientific results and plans for the five research areas were presented and discussed. The main topic of the meeting was *The Green Shift*. Innovation and technological development are key elements to the green shift, and a transition must occur to significantly reduce the negative consequences for climate and environment. External and internal speakers were invited to give talks based on the question: What opportunities can the green shift offer and how should the metallurgical and manufacturing industry meet the challenges? Gunnar Grini from *Norsk Industri* gave an inspiring talk on the importance of Norwegian industry's participation in the green shift. *Norway is in a position to succeed*, Grini said. We must explore and utilize the many possibilities for increased innovation on the way to the main goal – carbon neutral industry.

We all agreed that physical meetings are crucial for informal talks, networking and fruitful discussions of scientific and innovative ideas!

PERSONELL SFI PHYSMET

CENTRE ADMINISTRATION

Knut Marthinsen	NTNU	Centre Director
Marisa di Sabatino	NTNU	Deputy Centre Director
Kari Håland	NTNU	Adminsitrative Coordinator
Magnus Eriksson	SINTEF Industry	Scientific Coordinator

KEY RESEARCHERS

RESEARCH AREA 1. MULTI-SCALE MATERIAL ANALYSES

Randi Holmestad	NTNU	Multi-scale material analyses
Ida Westermann	NTNU	Thermo-mechanical processing, microstructure and mechanical properties (steel and aluminium)
Sigrud Wenner	SINTEF Industry	Nano-/microstructure characterization (TEM and APT)
Marisa Di Sabatino	NTNU	Material-processing and characterization (GDMS and GDOES)
Calin D. Mariora	SINTEF Industry	Nano-/microstructure characterization (TEM)
Yanjun Li	NTNU	Scale and process bridging methodologies
Siri Marthe Aarbo	SINTEF Manufacturing	Materials, processing and properties
Ruben Bjørge	SINTEF Industry	Nano-/microstructure characterization (TEM and APT)
Tina Bergh	NTNU	Nano-/microstructure characterization (TEM, FIB, SEM)
Ivan Bunaziv	SINTEF Industry	Steels

RESEARCH AREA 2. SCALE AND PROCESS BRIDGING METHODOLOGIES

Yanjun Li	NTNU	Scale and process bridging methodologies
Bjørn Holmedal	NTNU	Crystal Plasticity, microstructure- and property modelling
Knut Marthinsen	NTNU	Microstructure-, texture and property modelling
Tomas Manik	NTNU	Crystal plasticity modelling
Inga Ringdalen	SINTEF Industry	Atomic scale modelling
Jesper Friis	SINTEF Industry	Data, sharing and digital platforms
Sylvain Gouttebroze	SINTEF Industry	Materials modelling
Qiang Du	SINTEF Industry	Thermodynamical and microstructure modeling
Mohammed M'hamdi	SINTEF Industry	Sustainable and high-performance material development
Stephane Dumoulin	SINTEF Industry	Materials modelling
Ole Martin Løvvik	SINTEF Industry	Atomic scale modelling
Yijang Xu	SINTEF Industry	Materials modelling

RESEARCH AREA 3. SUSTAINABLE AND HIGH-PERFORMANCE MATERIAL DEVELOPMENT

Mohammed M'hamdi	SINTEF Industry	Sustainable and high-performance material development
Marisa Di Sabatino	NTNU	Material-processing, properties and characterization
Yanjun Li	NTNU	Scale and process bridging methodologies
Hans Jorgen Roven	NTNU	Thermo-mechanical processing, microstructure and mechanical properties (steel and aluminium)
Hanne Flåten Andersen	IFE	Powder synthesis and characterization
Mohammed M'Hamdi	SINTEF Industry	Sustainable and high-performance material development
Morten Onsøien	SINTEF Industry	Thermomechanical processing
Kjerstin Ellingsen	SINTEF Industry	Sustainable and high-performance material development
Qiang Du	SINTEF Industry	Thermomechanical processing
Sylvain Gouttebroze	SINTEF Industry	Sustainable and high-performance material development
Amin Azar	SINTEF Industry	Sustainable and high-performance material development
Kai Zhang	SINTEF Industry	Sustainable and high-performance material development
Astrid Mathinsen	SINTEF Industry	Sustainable and high-performance material development

RESEARCH AREA 4. WELDING AND WELDABILITY OF METALS, PHASE TRANSFORMATIONS AND MECHANICAL PROPERTIES

Magnus Eriksson	SINTEF Industry	Thermo-mechanical processing and welding
Geir Langelandsvik	SINTEF Industry	Aluminium alloy process developments and characterisation for welding and AM
Ivan Bunaziv	SINTEF Industry	Laser materials processing; process study and stability, microstructure and properties
Hans Jørgen Roven	NTNU	Alloy-design and process developments (screw extsruion, AM)
Anette B. Hagen	SINTEF Industry	Thermo-mechanical processing, characterisation of microstructure and mechanical properties
Ida Westermann	NTNU	Thermo-mechanical processing, microstructure and mechanical properties
Jens Christofer Werenskiold	NTNU	Thermo-mechanical processing, microstructure and mechanical properties
Siri Marthe Aarbo	SINTEF Manufacturing	Materials, processing and properties
Jon Holmestad	SINTEF Manufacturing	Materials, processing and properties
Xiaobo Ren	SINTEF Industry	Materials, processing and properties
Bård Nyhus	SINTEF Industry	Materials, processing and properties
Ruben Bjørge	SINTEF Industry	Nano-/microstructure characterization (TEM and APT)
Ragnhild Aune	SINTEF Industry	Welding, processing and properties
Morten Høgseth Danielsen	SINTEF Industry	Welding, Laser Arc Hybrid Welding, Processes

RESEARCH AREA 5. DATA, SHARING AND DIGITAL PLATFORMS

Jesper Friis	SINTEF Industry	Data, sharing and digital platforms
Sylvain Gouttebroze	SINTEF Industry	Materials modelling and digital platform
Thomas Manik	NTNU	Crystal plasticity modelling and digital platform
Terence Coudert	SINTEF Industry	Data, sharing and digital platforms
Stephane Dumoulin	SINTEF Industry	Materials modelling, digital platform
Astrid Marthinsen	SINTEF Industry	Data sharing and digital platforms
Johan Andreas Stendal	SINTEF Manufacturing	Data sharing and digital platforms

VISITING RESEARCHERS

Ruojin Zang	Chongqing University	Intpart project: International Materials science
Fang Han	Chongqing University	Intpart project: International Materials science
Xiaoxi Mi	Chongqing University	Intpart project: International Materials science

POSTDOCTORAL RESERACHERS WORKING ON PROJECTS IN THE CENTRE WITH FINANCIAL SUPPORT FROM OTHER SOURCES

Rania Hendawi	2022-2023	Structure loss in CZ-silicon
Jochen Busam	2021-2023	Viscosity in Quartz crucibles for PV silicon
Witold Chrominski	2021-2021	TEM studies of deformed/rolled Aluminium

PHD STUDENTS WITH FINANCIAL SUPPORT FROM THE CENTRE BUDGET

Ingvild Runningen	2021-2025	New wires for welding of aluminium alloys
Tor Inge Thorsen	2021-2025	Advanced characterization of materials joints
Andreas Voll Bugten	2021-2025	The effect of trace elements on the microstructure development and mechanical properties of cast irons
Xuezhou Wang	2021.2024	Develop precipitation model with improved nucleation concepts

PHD STUDENTS WORKING ON PROJECTS IN THE CENTRE WITH FINANCIAL SUPPORT FROM OTHER SOURCES

Arash Imani Aria	2019-2022	Multiscale materials modelling; Crystal Plasticity
Håkon Wiik Ånes	2017-2022	Recrystallization and textures in Al-alloys
Endre Aasheim	2018-2022	Nucleation, growth and dissolution of ß-Mg2Si particles in Al-Mg-Si
Gabriela Kazimiera Warden	2020-2023	Quartz crucibles for PV silicon solidification
Chunan Li	2020-2023	Clustering and precipiation in Al-alloys
Hanne Sofie Scisly Søreide	2018-2022	Clustering in Al-alloys by APT
Erlend Sølvberg	2020-2023	Steel
Håkon Linga	2020-2024	3D-printing
Sohail Shah	2019-2022	Preciptation and properties of
Hassan Moradi Asadkhandi	2021-2024	Crystal Plasticity
Magne Reiersen	2021-2024	Modelling and experimental framework for accelerated development of materials for Laser Powder Bed Fusion technology

MASTER STUDENTS

Hedda Øye	Investigation of Aluminium Alloys Containing Vanadium and Titanium
Martin Lesjø	The effect of cooling from solution heat treatment on ductility in a 6063 crashbox aluminium alloy
Tonje Aasheim Nymark	Micro cracks in wind turbine bearings
Herman Hanssen	Develop super aluminium alloys for additive manufacturing
Kjell Martin Kirkbakk	Utvikling av sveisetråd ved skrueekskrudering
Tonje Aasheim Nymark	Micro cracks in wind turbin bearings
Rune Botnmark Brurok	Effect of Boron in spheroidal graphite irons
Magnus Johansen Vad	Creep deformation of an additively manufactured nickel-based superalloy

ANNUAL ACCOUNTS 2021

The total budget for the eight year SFI PhysMet centre periode is 208 mill NOK. The financing of SFI PhysMet are based on contribution from The Research Council of Norway and cash and in-kind contribution from the user partners and NTNU.

Funding (1000 NOK)	Amount
Research Council	7 334
Host Institution (NTNU)	1 584
Research Partners*	0
User Partners**	10 512
Total	**19 430**

Costs (1000 NOK)	Amount
Host Institution (NTNU)	4 658
Research Partners*	8 122
User Partners**	6 650
Equipment	0
Total	**19 430**

* *SINTEF AS, SINTEF Manufacturing and IFE.*

** *Hydro Aluminium AS, Elkem AS, Equinor, Benteler, Neuman Aluminium, Thermo-Calc Software, The Norwegian Public Roads Administration.*

PUBLICATIONS AND THESIS

PUBLICATIONS DIRECTLY FUNDED BY SFI PHYSMET:

- **Langelandsvik, Geir; Akselsen, Odd Magne; Furu, Trond; Roven, Hans Jørgen.** *Review of aluminum alloy development for wire arc additive manufacturing.* Materials 2021
- **Manik, Tomas; Marthinsen, Knut; Zhang, Kai; Imani Aria, Arash; Holmedal, Bjørn.** *Deformation Texture Evolution in Flat Profile AlMgSi Extrusions: Experiments, FEM, and Crystal Plasticity Modeling.* Frontiers in Materials 2021
- **Ivan Bunaziv, Ivan; Dørum, Cato; Nielsen, Steen Erik; Suikkanen, Pasi; Ren, Xiaobo; Nyhus, Bård; Eriksson, Magnus; Akselsen, Odd Magne**. *Root formation and mechanical properties in laser keyhole welding of 15 mm thick HSLA steel. IOP Conf. Ser.: Mater. Sci. Eng. 1135 012011. 2021*

PUBLICATIONS FROM COLLABORATING PROJECTS

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