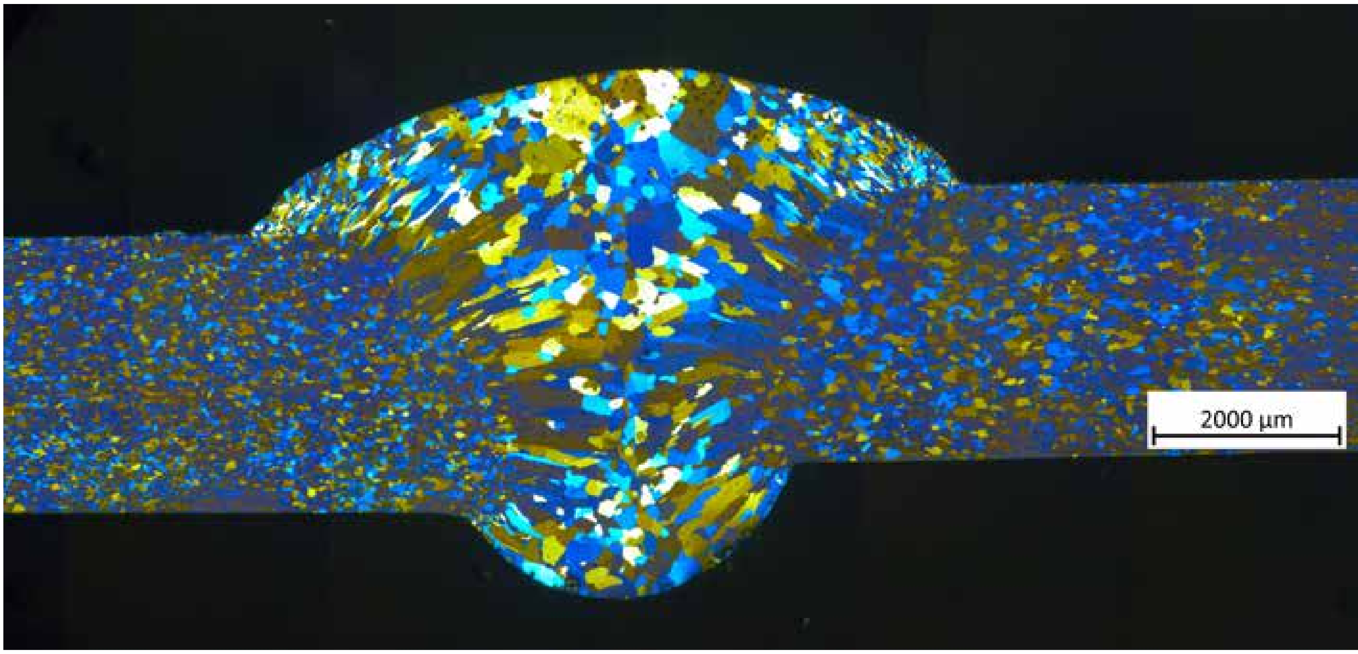
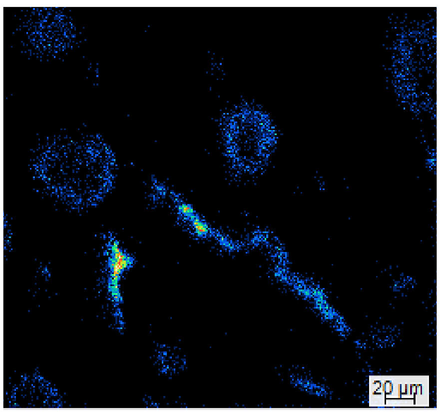
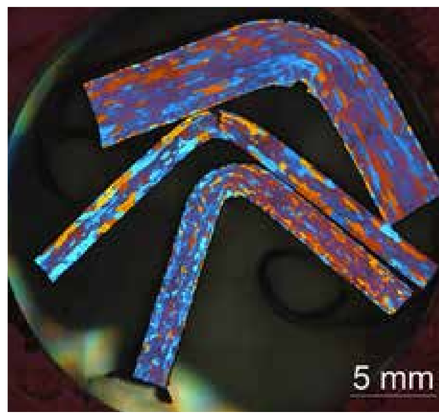
Centre for Sustainable and Competitive Metallurgical and Manufacturing Industry

ANNUAL REPORT 2023

SFI PHYSMET







PhysMet

Norwegian Centre for Research-based Innovation

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Frontpage:
Top: MIG weld with metal screw extruded AA7108 welding wire. Micrograph in polarised light on anodised samples. Credit: Steffen Samuelsen

Bottom left: Elemental map of boron in spheroidal graphite iron, obtained using secondary ion mass spectrometry (SIMS). Credit: Lasse Vines, UiO

Bottom middle: AA4047 aluminium-silicon block manufactured by WAAM.
Credit: Geir Kvam-Langelandsvik, SINTEF

Bottom right: Polarized light microscopy image of bend tested aluminium profiles.
Credit: Benteler

Layout and production: Monika Wist Solli, NTNU Grafisk senter

CONTENT

ANNUAL REPORT 2023
SFI PHYSMET

SUMMARY

BY CENTRE MANAGER
KNUT MARTHINSEN, NTNU

2023 has been a prosperous year for SFI PhysMet, in terms of scientific results and potential innovations. Some selected scientific highlights are briefly described below. More comprehensive and detailed presentations of the research activities and results for each Research Area are presented in the chapter Scientific Activities and Results.

Scientific highlights

An important aim of SFI PhysMet is to enable more use of recycled metal, e.g. by increasing the understanding of how alloying elements accumulated by recycling affect microstructure and properties. Boron is a common trace element in recycled cast iron with potentially harmful effects, and it is important to map out what those effects are, and even small amounts (ppm) are harmful. Several characterization techniques to study the detrimental effects of B have been used, and the influence of B on graphite growth seems to be central to understand the weakening of the material. In 2023, the consequence of using up to 40% aluminium (Al) from incinerator bottom ash (IBA) in industry-relevant Al alloys has been studied both experimentally and numerically. The addition of IBA leads to a distinct change in the microstructure, and new phases have been observed. Mechanical properties such as yield and tensile strength are not greatly affected, but ductility is significantly reduced when the content of recycled aluminium is increased.

The SFI develops numerical tools for solidification and defect formation using thermodynamic databases suitable for studying the effect of contaminant elements from recycling. This supports two activities aimed at i) the use of Al from IBA as a source in Al10SiMg and ii) the effect of impurities in cast iron. In 2023, models have also been developed for the microstructure of Al alloys produced by AM. Furthermore, work is conducted to establish an automatic workflow for calculating the basic thermodynamic parameters of crystals and solution atoms in alloys at finite temperatures. Such data is needed to generate phase diagrams and as input parameters for microstructure models.

Important progress has also been made with respect to the development and further improvement of microstructure models for recycling based aluminium alloys. A numerical model has been developed to predict the spatial evolution of non-equilibrium excess vacancies during quenching and subsequent ageing heat treatments of multicomponent aluminium alloys. The model has been successfully applied to understand the influences of cooling rate during quenching, time of natural aging (NA), temperature of artificial aging (AA), grain size, density of dislocations and alloy chemistry on the experimentally observed precipitation and age hardening kinetics of heat treatable aluminium alloys. Furthermore, the numerical model for Mg-Si atom clustering processes during NA and in the early-stage of AA are further developed. Finally, a physics-based analytical model informed by first-principles calculations is proposed to quantitatively calculate the vacancy diffusivity under the influence of substitutional solute atoms. The retarding effects of a wide variety of alloying elements on vacancy diffusion in solid aluminium at ambient temperature are predicted, which can provide new insights into the design of new aluminium alloys, with complex chemistries.

Both for welding of aluminium and steel and these in combination, and for their application in large structures (e.g. bridges and off-shore windmills), there is a need for improved and new welding methods, especially for welding thick materials. Steel sheets, 40-45 mm thick, have been joined by two-sided laser-hybrid technology, and microstructure and mechanical properties have been characterized. Full-scale bridge sections produced with laser welding have been tested for fatigue with very good lifetime results - at least as good as with traditional welding. Welding aluminium requires the development of high-strength Al welding wires with additives of alloying elements or nanoparticles, and we are studying the possibility of producing these by new innovative manufacturing processes. The microstructure of these welding wires is studied with TEM to understand material properties and pore formation. For the development of lighter battery systems, e.g., in cars, it is possible to replace copper with aluminium, so we are studying methods for using aluminium in these and joining aluminium and copper. Together with industry partners, we also develop solid-phase joining technology (HYB & friction welding) and study the properties of the joint.

The existing SFI PhysMet web portal has been updated and expanded with a database of available models and web apps for microstructure models. A new data catalog based on DataVerse has also been created and populated with TEM data and stress-strain curves. Also work on how data can best be documented so that it can easily be reused and understood by both machines and humans have been done, as well as a pilot on how the Centre connects to and utilizes SINTEF's upcoming data management system called data.sintef.no. The recommendations and methodology for traceable data documentation and efficient workflows have, together with Raufoss Technology, been tested on production data for damper forks.

Publications and international collaboration

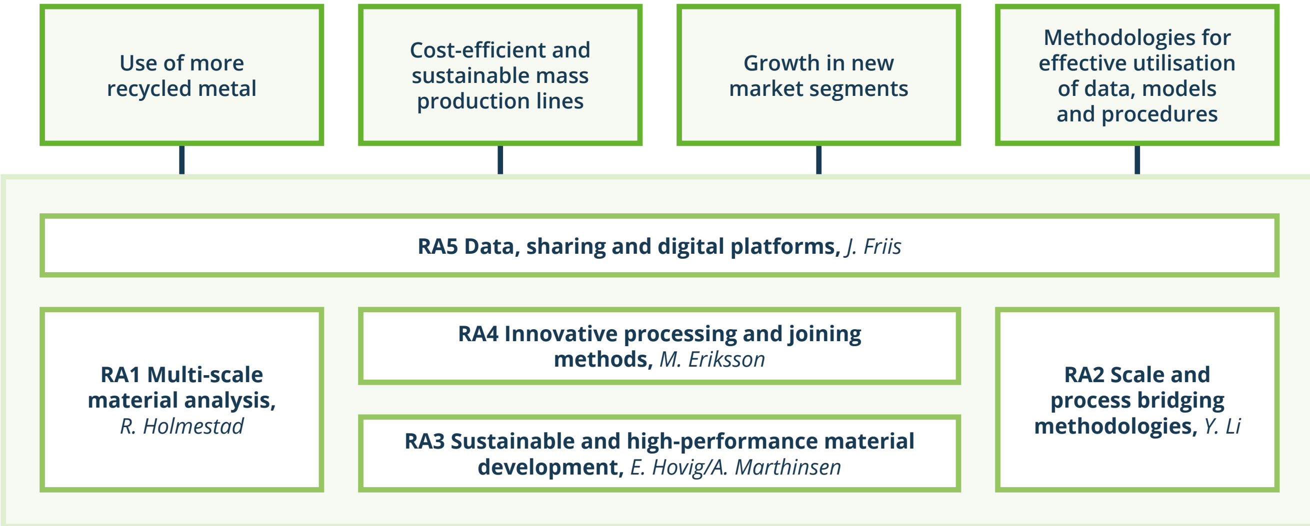
In total in 2023, researchers connected to SFI PhysMet have produced 19 articles in renowned international scientific journals and 32 presentations at conferences. In general, the SFI researchers have in 2023 been quite active and visible on the international arena and in different fora, to present our research and to foster and promote international collaboration. Publications, international collaboration and dissemination are further described in the annual report.

New recruitments

Recruitment of good PhDs and Postdoctoral Fellows is a key factor of success for an SFI. However, recruitment of good candidates is challenging and has become even more so, due to the turbulent geopolitical situation with even stricter practice concerning Export control issues. Still, we have been lucky to recruit two new well qualified PhD candidates, both master students from NTNU: Håkon Longva Korsvold and Supreet Kaur started as PhD candidates at SFI PhysMet in August 2023. They are given a more extensive presentation in the chapter Our PhD candidates, together with Trond Arne Hassel, an associated SINTEF funded PhD candidate, who joined the SFI in 2023.

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-efficient 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:

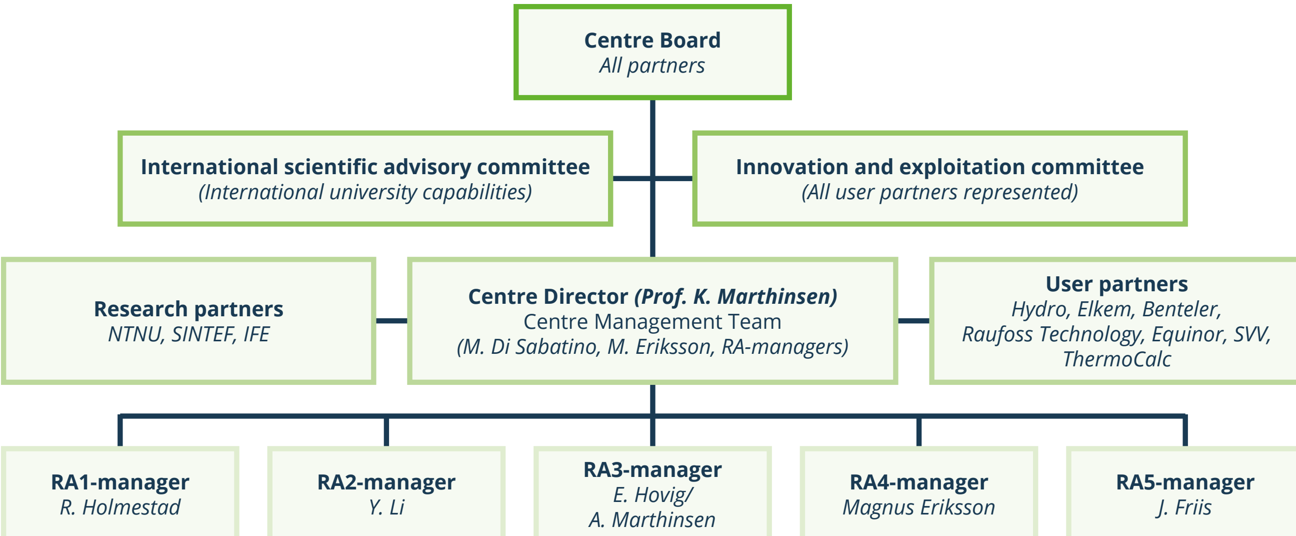
- **Use of more recycled metal**
- **Cost-efficient and sustainable mass production lines**
- **Growth in new market segments**
- **Methodologies for effective utilisation of data, models and procedures**

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.

MEMBERS OF THE BOARD ARE:
Nina Dahl, SINFEF Industry (Board leader)
Magnus Rønning, NTNU
Trond Furu, Hydro
Gro Eide, Elkem
Yngve Langsrud, Benteler
Stein Olsen/Gotthard Mälzer, Equinor
Jørgen Lie, Raufoss Technology
Cato Dørum, Statens Vegvesen
Anders Engström, Thermo-Calc Software
Tanja Pettersen, SINTEF Manufacturing
Øyvind Jensen, IFE
Øystein Asphjell, NFR (observer)

Picture from a Board meeting at the SFI centre, 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.

First row: Knut Marthinsen (NTNU, director), Randi Holmestad (NTNU, RA 1 manager), Yanjun Li (NTNU, RA 2 manager), Astrid Marthinsen and Even Hovig (SINTEF, RA 3 managers). Second row: Magnus Eriksson (SINTEF, RA 4 manager), Jesper Friis (SINTEF, RA 5 manager), Marisa Di Sabatino (NTNU, co-director) and Kari Håland (NTNU, admin.coordinator).

PARTNERS

User partners: SFI PhysMet's user partners include metal and material producers, downstream material processing industries as well as end users of metals and alloys. The user partners are: Equinor, Hydro, Elkem, Benteler, Raufoss Technology, Thermo-Calc Software and The Norwegian Public Roads Administration

Research partners: NTNU, SINTEF and IFE

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

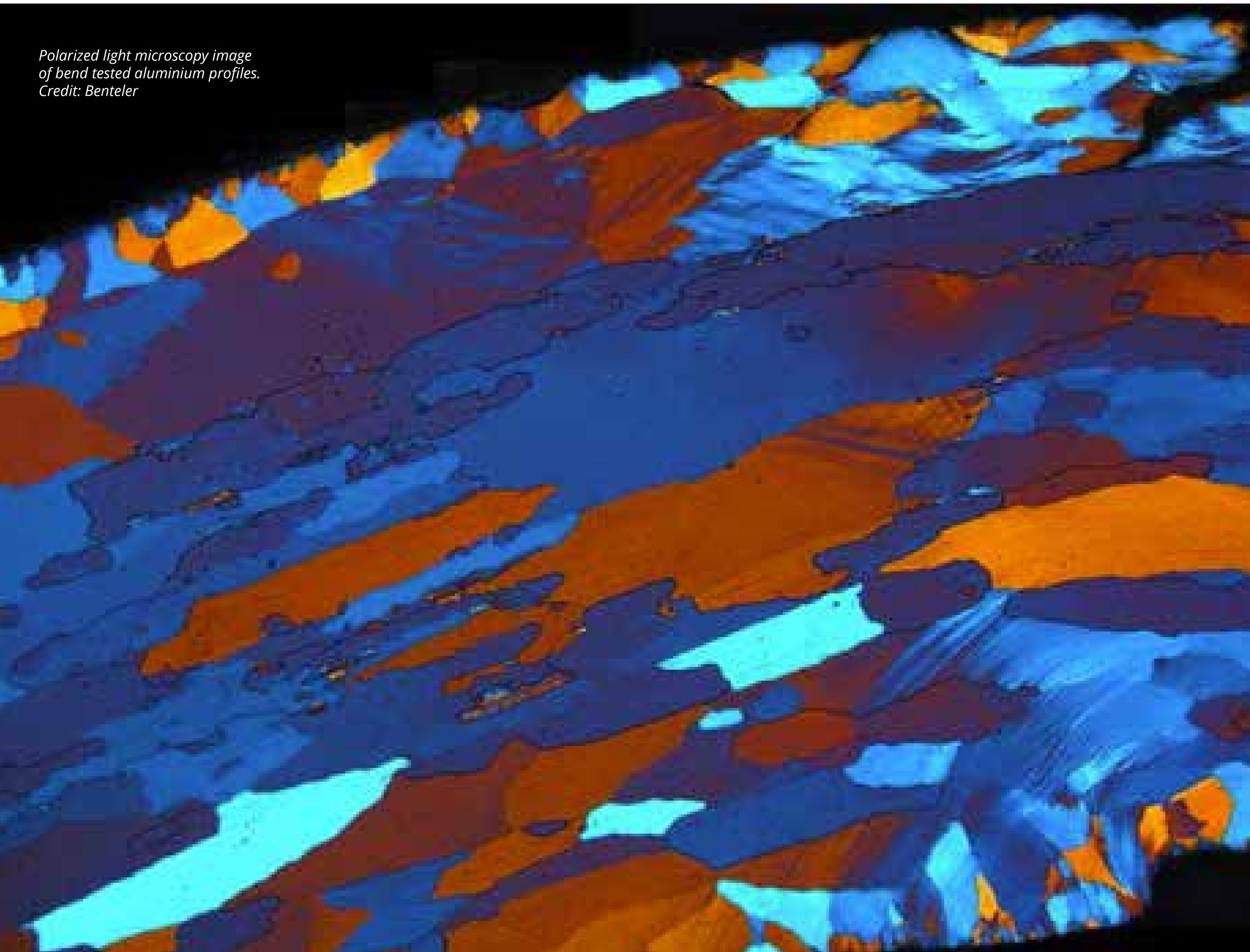
Professor
Dorte Juul Jensen,
DTU Technical university of Denmark

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. The centre is located at campus Gløshaugen, with offices available for all research- and industry partners. PhD candidates and Postdoctors recruited to the centre work closely together and with short distance to the project leaders and supervisors. The co-location in Kjemiblokk 1 ensures more effective collaboration between the research groups.

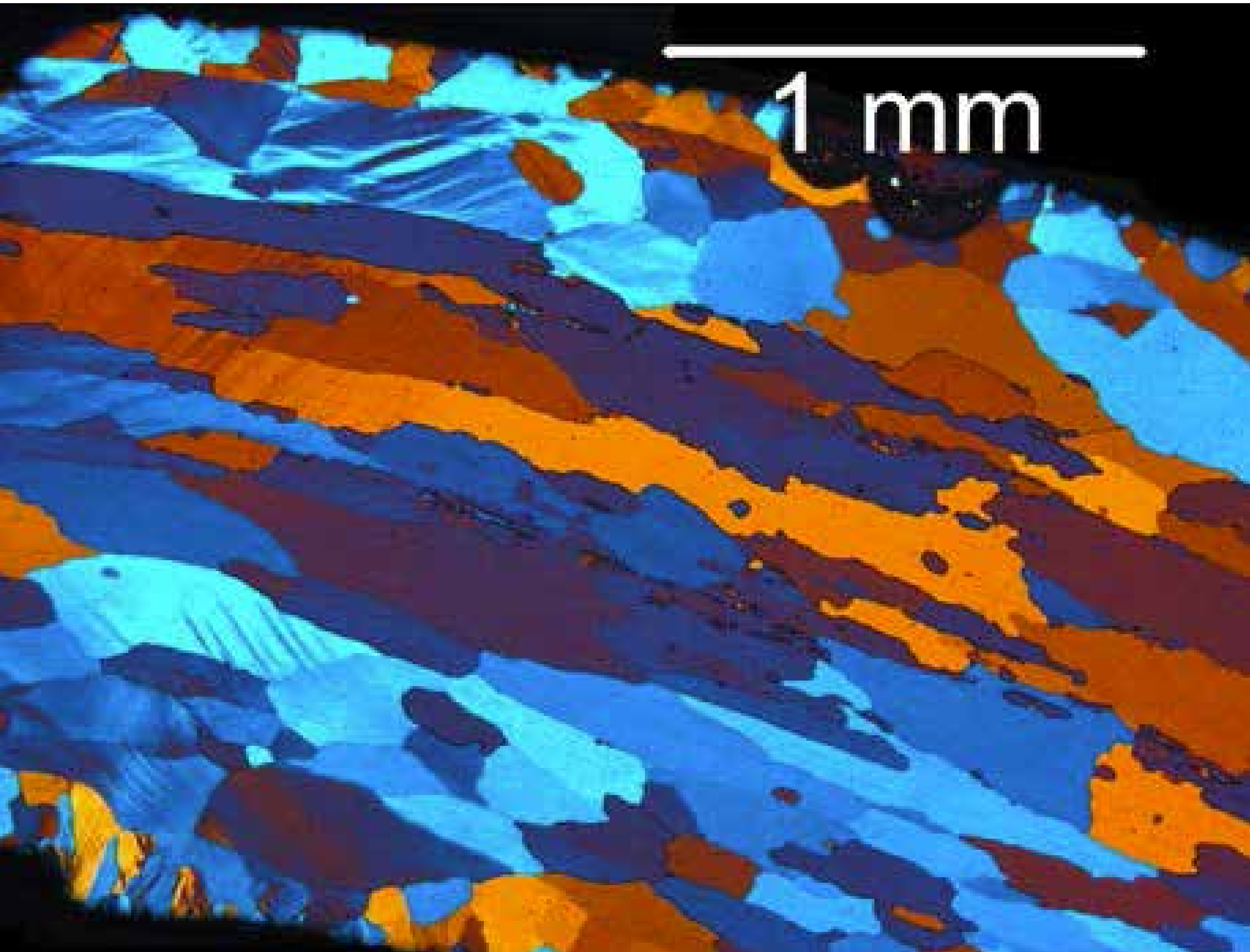
Campus Gløshaugen, Trondheim

SCIENTIFIC ACTIVITIES AND RESULTS



Polarized light microscopy image of bend tested aluminium profiles. Credit: Benteler

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 2023. The scientific activities are performed at NTNU, SINTEF and IFE, in close collaboration with the user partners.



RESEARCH AREA 1.
MULTI-SCALE MATERIAL ANALYSES

RESEARCH AREA LEADER:
RANDI HOLMESTAD
NTNU

CONTRIBUTIONS TO CENTRE OBJECTIVES

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. The objective of RA1 is to utilize these instruments to the best for SFI PhysMet.

- 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 transmission electron microscopy (TEM) and atom probe tomography (APT). The techniques are complementary and provide experimental data on the crystal structure and chemistry down to the atomic scale - crucial for developing and validating atomic scale simulations and through-process models.
- Develop and establish a framework for multiscale studies of material joints. The multiscale microstructure and complicated chemistry created when materials are joined (by welding or AM) require use of the entire characterization toolbox.
- Establish in-situ characterization techniques. Advanced in-situ characterization tools will be utilized to quantify the kinetics of microstructure evolution during solidification, heat treatment and deformation, at several length and time scales.

ACTIVITIES AND RESULTS IN 2023

The research activities in RA1 are organized into research tasks, six of which saw activity in 2023. In addition, we contribute with characterization work for the other RAs. The results obtained in 2023 are described in the following.

Investigations of shear bands in bent Al profiles

This is a project where Benteler in collaboration with SINTEF (Sigurd Wenner) investigated how texture influences bend ductility in 6xxx aluminium alloys. Before cracks start growing, slip bands appear in the Al grains. A 6005 aluminium alloy in T6 temper with wall thickness 4 mm was bent to 40%–90% of the fracture angle and studied. A high fraction of cube grains proves essential to absorb deformations through slip bands (Figure 1).

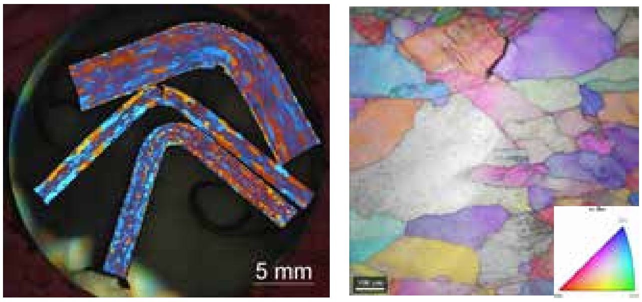


Figure 1. (left) Polarized light microscopy image of bend-tested profiles. (right) EBSD patterns from a brittle specimen showing localized deformation.

Additively manufactured aluminium alloys
The multiscale microstructure and complicated chemistry created when (dissimilar) materials are mixed together require use of different characterisation techniques, as crystallographically and chemically complex phases typically form during additive manufacturing, joining and welding. PhD student Tor Inge Thorsen has in collaboration with Tina Bergh studied aluminium (5083) welding wires for wire arc additive manufacturing (WAAM) made by Geir Langelandsvik (SINTEF). The wire was cut into snippets, then coated with a TiC powder (nanoparticles ~50 nm), and then screw extruded. The new wire with nanoparticles was then WAAMed to thin walls. These walls have been characterized. Several phases can be seen in scanning and transmission electron microscopy. The addition of TiC nanoparticles induces the formation of $TiAl_3$ particles that act as nucleation sites for Al. Different morphologies of the $TiAl_3$ particles are shown in Figure 2b. Phase mapping is done using scanning precession electron diffraction as shown in Figure 2c.

Figure 2a) WAAM material (added TiC particles, screw extruded, and wire arc welded).

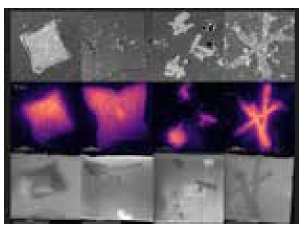


Figure 2b) SEM images of the WAAM material: Top: SEM images of $TiAl_3$ particles with different morphologies; mid: Corresponding EDS signal from Ti. Low: SEM images of the corresponding TEM lamellae.

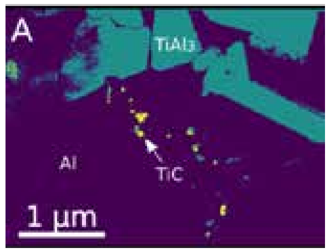


Figure 2c) Phase mapping of Al matrix, SiC and $TiAl_3$ particles in the WAAM material, obtained by scanning precession electron diffraction.

APT of grain boundary segregation in Al alloys
Håkon L. Korsvold started a PhD study in September 2023 on characterization of the structure and chemistry of grain boundary segregation in aluminium alloys, where a combined study of atom probe tomography and transmission electron microscopy will be performed. Studies will include precipitation free zones, intergranular corrosion, strength, impurity segregation, grain boundary precipitation and thermodynamic calculations.

TEM analysis of oxide layers in Si powders
Silicon powder has a wide range of applications, from manufacturing of electronics and batteries to additives in metallurgy. For both traditional casting methods and additive manufacturing of metals, the properties of the added silicon powders are crucial for the performance of the end product. In 2023 we have performed multi-technique characterization of the oxide and surface chemistry of silicon powders from Elkem, which greatly affect their agglomeration and chemical stability. Furthermore, we have investigated the crystallinity of powders that are milled to the sub-micron size and determined that amorphous areas and various defects are introduced by the milling process. Figure 3 shows examples of this. In addition to SINTEF (Sigurd Wenner), MSc student Inga Konow, has worked on this project.

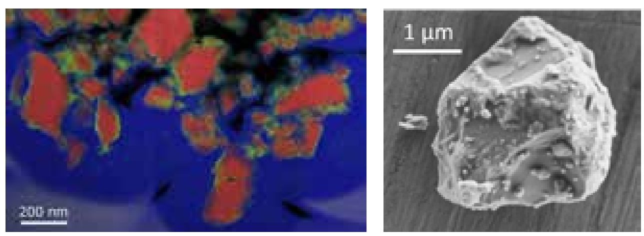


Figure 3 (left) Elemental map of a cross-section through Si particles, with Si in red, O in green and C in blue. (right) SEM image of a jet-milled Si particle.

TEM characterization of ferrous alloys

Ductile cast iron is studied by SINTEF (Ruben Bjørge) in collaboration with RA3 (PhD candidate Andreas Bugten). Here we want to understand why small amounts of boron in Cu-containing ductile cast iron form “spikes” on the surface of the spherical graphite nodules, which is associated with an undesirable decrease in ductility. TEM spectroscopy and orientation mapping have proven useful in understanding the growth of the graphite. Figure 4 shows one such spike, with orientations of the graphite and ferrite phases.

We also have a project with Elkem on grain refinement of cast austenitic stainless steels. By adding a master alloy containing cerium into the melt before casting, particles which act as nucleation sites are created which facilitates a finer grain structure, and the mechanical properties are improved. Ce forms stable compounds with different crystal structures when reacting with elements in the steel melt. There are several inclusions which cerium can potentially form within the cast (cerium oxides, sulphides, aluminates and oxysulphides) but it is not experimentally known which specific compounds are formed or which one is the acting grain refiner. Transmission electron microscopy is used to study samples of austenitic stainless steel (Figure 5) since the role of Ce in the alloy remains unclear, and MSc student Sindre Vie Jørgensen is working on this.

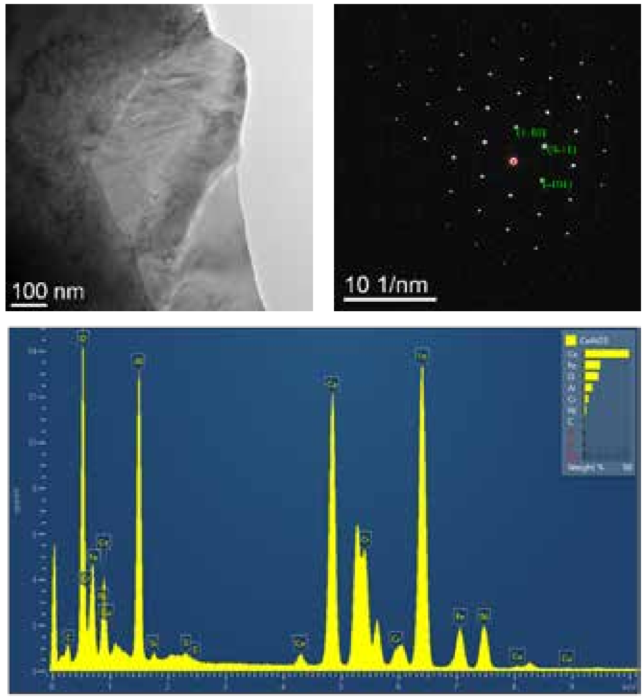


Figure 5 Top left: A verified CeAlO3 cerium particle (bright) bordered by the steel matrix on the left. Top right: Indexed selected area electron diffraction of the [111] phase of CeAlO3 originating from the central phase of the image on the left. Under: Corresponding energy dispersive spectroscopy (EDS) results of the central grain in the top left image, verifying the presence of Ce, Al and O.

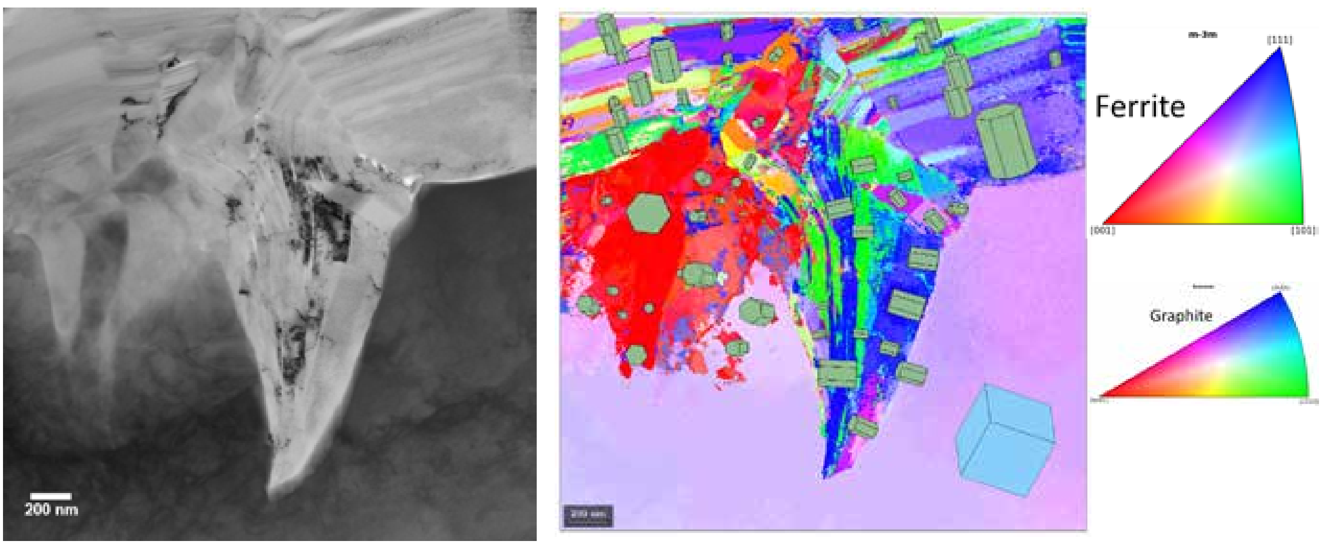


Figure 4 Scanning precession results from a spike on the surface of a graphite nodule, showing phase (ferrite at the bottom, the rest is graphite) and orientation of the different grains in ductile cast iron.

RESEARCH AREA 2.
SCALE AND PROCESS BRIDGING METHODOLOGIES

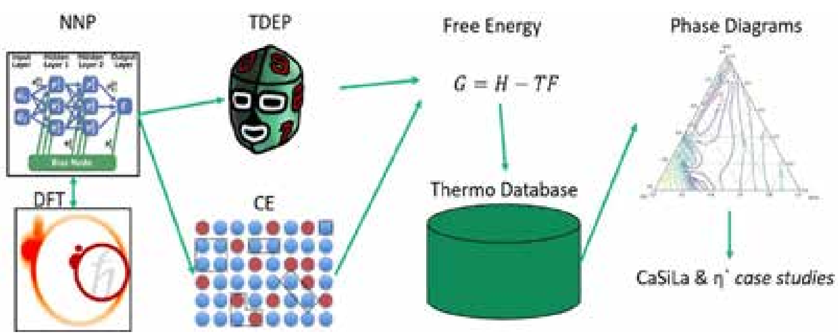
RESEARCH AREA LEADER:
YANJUN LI
NTNU

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 frame-work 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.

ACTIVITIES AND RESULTS IN 2023
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 2023.

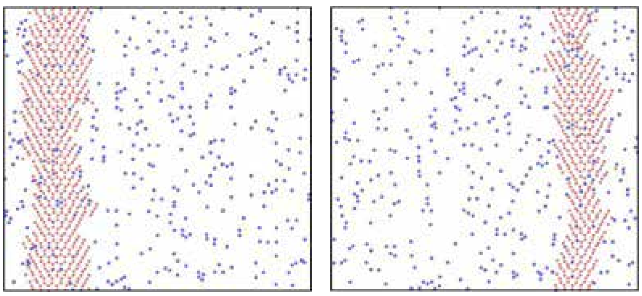
Task RA2.1: Atomic scale calculation and simulation
The objective of this research task is to use first principles atomic scale calculations to generate thermodynamic and kinetic material data for atom clusters, precipitates and intermetallic phases, including bonding energy, formation enthalpy, interfacial energy, segregation energy and diffusivity of impurities in relevant alloys (aluminium, steel, cast iron).



Schematic view of the framework for integrating atomistic models in thermodynamic database development.

In 2023, the activity on TDEP calculation of eta' phase in aluminium alloys has been extended in collaboration with an internal SINTEF project (PAINT). While the original calculations in SFI PhysMet were performed with DFT, similar calculations were performed by using neural network potentials that were trained separately. These calculations demonstrated that such potentials can be used together with TDEP in an automated way, potentially opening-up for high-throughput simulations with very low computational cost.

In collaboration with SFI CASA, the solute strengthening was studied from an atomistic perspective. The long-term objective is to predict the impacts of defects such as solutes, grain boundaries, precipitates on mechanical properties. These defects are atomic in nature. Neural networks potentials offer a massive speedup while retaining much of the underlying accuracy compared to ab initio simulations. The study focused primarily on the hardening contribution of individual solute species. Multi-element interactions with dislocations were also initiated at the end of the year.



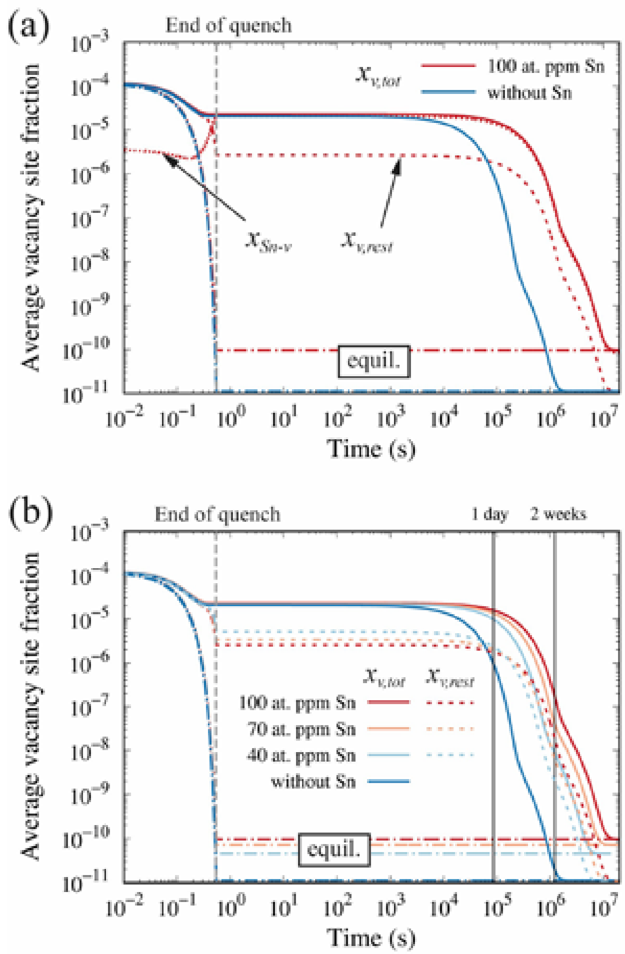
Simulation of a dislocation passing through a field of solutes. Red atoms - stacking fault, blue - random solute atoms

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

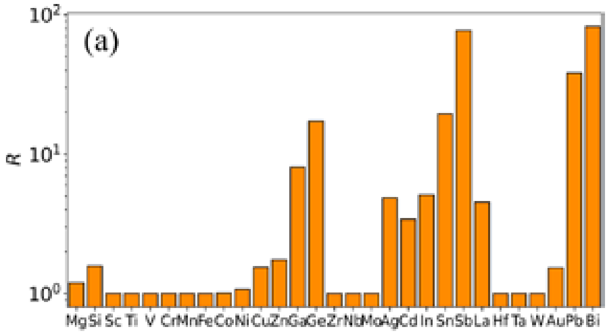
The objective is to develop advanced microstructure models for different alloys and processes. The initial focus is on precipitation model for age hardening aluminium alloys. By improving the atom clustering kinetics, the nucleation and growth of precipitates can be better predicted. The influences of impurity elements, excess vacancies, dislocations, and grain boundary precipitation/segregation will also be addressed.

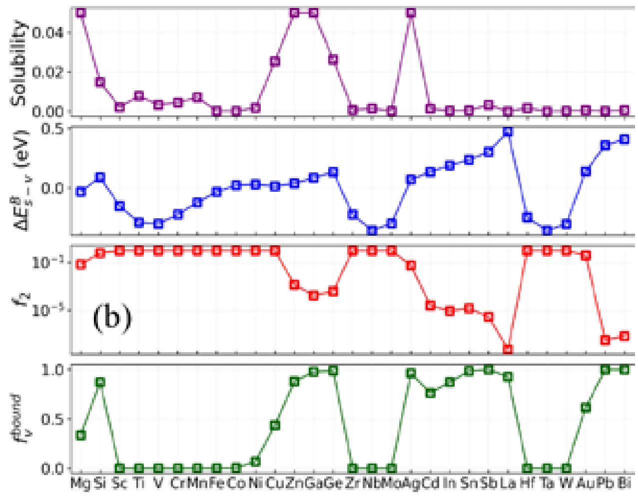
Modelling the diffusion behavior of vacancies in 6xxx alloys

In 2023, a numerical model has been developed to predict the spatial evolution of non-equilibrium excess vacancies during quenching and subsequent ageing heat treatments of multicomponent aluminium alloys. In the model, the annihilation mechanisms of vacancies at grain boundaries and at dislocation jogs have been rigorously treated while the effect of solute trapping on vacancy evolution has been well addressed. The model has been successfully applied to understand the influences of cooling rate during quenching, time of natural aging (NA), temperature of artificial aging (AA), grain size, density of dislocations and alloy chemistry on the experimentally observed precipitation and age hardening kinetics of heat treatable aluminium alloys. This work has been published in Acta Materialia 264 (2024).



Calculated time evolution of vacancies in an Al-Mg-Si(-Sn) alloy with and without Sn addition during quenching from 843 K at 1000 K/s and storage at RT. (a) In the case of 100 at. ppm Sn addition; (b) Comparison of the evolution of vacancies under different amounts of Sn addition.





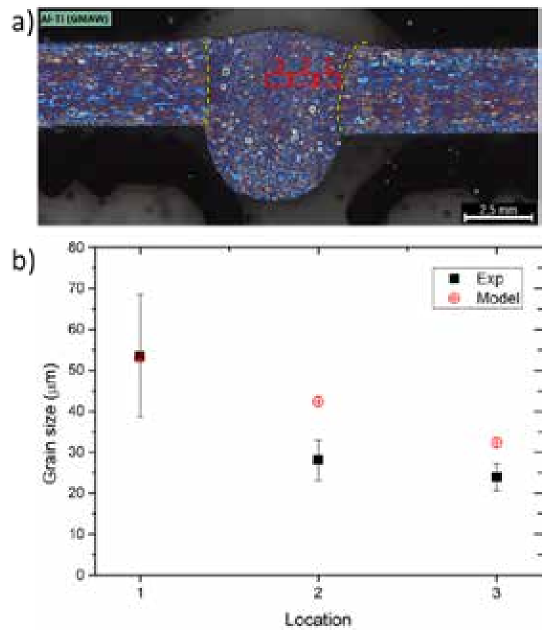
Retarding effects of solute elements at maximum solubility on the vacancy diffusivity in solid aluminium at 300 K. (a) The retarding factors R of solute elements at their maximum solubility (upper limit of 5 at. %). (b) shows the corresponding solubility, solute-vacancy binding energy at 1NN, correlation factor, and time fraction of solute trapping.

Modelling the influences of solute elements on diffusivity of vacancies

At the same time, the presence of solute atoms can have significant impacts on the vacancy diffusion in dilute alloys. A physics-based analytical model informed by first-principles calculations is proposed to quantitatively calculate the vacancy diffusivity under the influence of substitutional solute atoms. The diffusion of vacancies is rigorously treated as a combination of free diffusion within host atoms and co-diffusion together with solute atoms. The accuracy and reliability of the model have been evaluated by comparing the predicted vacancy diffusivities in show-case Al-Sn alloys to the values extracted by KMC simulations. The retarding effects of a wide variety of alloying elements on vacancy diffusion in solid aluminium at ambient temperature are predicted, which can provide new insights into the design of advanced aluminium alloys.

Numerical modelling of the solute clustering during ageing

Furthermore, the numerical model for Mg-Si atom clustering process during NA and in the early-stage of AA is further developed. In the model, the interplay between cluster growth and vacancy evolution has been well addressed. The single Mg and Si atoms are assumed to aggregate with each other to form Mg-Si dimers, whose subsequent growth is controlled by the absorption and emission of pseudo-monomers. The model can be applied to understand the influences of quenching modes, grain size, density of dislocations, and alloy compositions on the atom clustering kinetics of Al-Mg-Si alloys. This work will be continuing in 2024.



a) Optical microscope image of the cross section of the weld metal using the wire with Ti addition. The three areas marked as 1, 2 and 3 were used for grain size measurement. b) Grain size prediction of corresponding welding, in comparison to the experimental results.

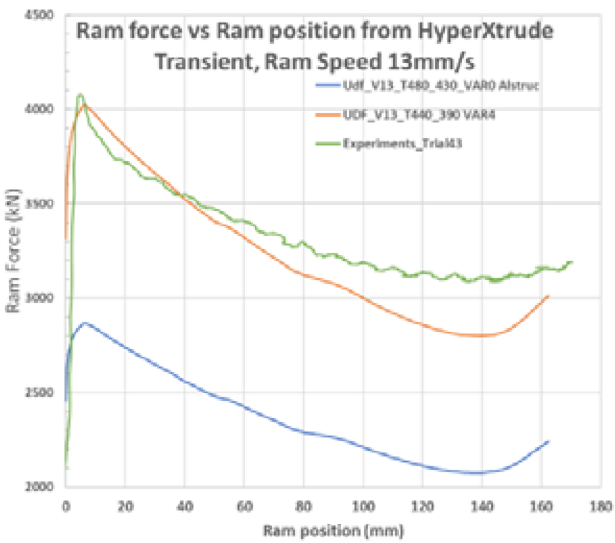
Modelling the grain development during solidification of AM and welding

In 2023, the grain size prediction model for welding of aluminium alloys has been further validated by the experimental data available in RA4. Gas metal arc welding of Al alloy using welding wires containing Ti and TiC

particles have been further simulated and the predicted grain size is in a reasonable agreement with the experimental results, in three different locations of welding zone. Based on those results, a paper on welding of Al alloys have been published.
In addition, a kinetic model in the nucleation stage has been developed to simulate the formation of initial spherical cap. Growth kinetics under high cooling rate has been simulated. Such kinetic effect of nucleation has been implemented into the grain size prediction model for additive manufacturing of Al alloys.

Task RA2.3: Through-process models under realistic industrial conditions
The objective is to generalize the existing and newly developed microstructure evolution models for heat treatment, recrystallization and work hardening. These models 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.

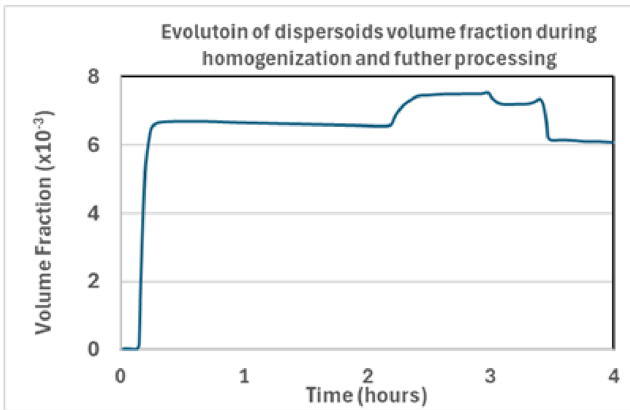
This task aims to collaborate closely with industrial partners via case-studies, to a) promote the usage of thermo-mechanical-microstructure models developed at SINTEF/NTNU, and to b) further develop those models. We conducted two case studies on this topic in 2023.



Simulated (blue and orange) vs. experimental extrusion force curve (green).

The first one was with Hydro Aluminium, to simulate the extrusion force for one extrusion trial performed at the SINTEF lab press. The simulation was done by using commercial software Altair HyperXtrude, with a material flow model developed by Hydro. At the end, with the material parameters fitted to the Gleeble experimental results, the software can reproduce the real force-ram curves with great accuracy. The parameters fitted to one homogenization model gave too low extrusion force. We learn that, among many other things, the FEM software can help to study the extrudability of recycling-oriented alloys when the flow stress model is properly fitted.

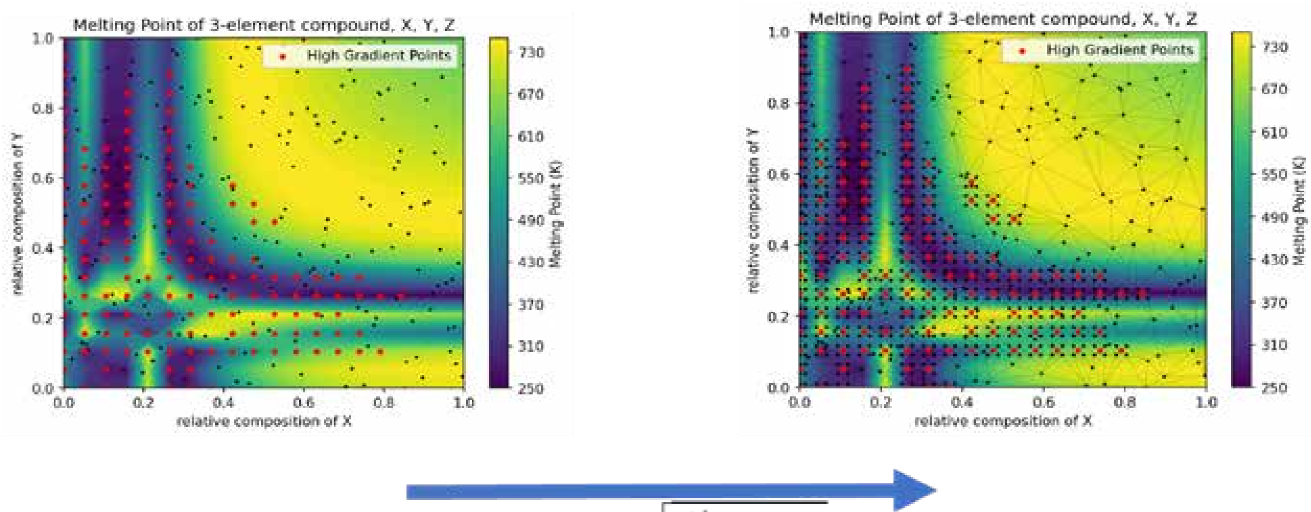
The second one was with Raufoss Technology, to simulate the microstructure and mechanical property evolutions during a lab forming with two different starting materials, as-extruded rods vs. cast billets. The evolution of constituent particles, dispersoids, alloying element concentrations in solid solution etc. during homogenization and further thermomechanical processing was simulated with the precipitation model *PreCism*. The artificial aging behaviour was simulated with the precipitation model *PreMod* and strength model available via pypremod. The grain structure after deformation was modeled with the softening model *Alsoft* with input from FEM simulations. The simulations results showed good agreements to the experimental observations. This work will continue in 2024 for industrial forming process. A project student is currently working on the work hardening and substructure model Alflow, to provide a cloud-based solution.



Predicted dispersoids volume fraction for cast billets as feedstock, with standard homogenization procedure.

Task RA2.4: Development of AI methods for alloy design and process parameter optimisation
The objective is to develop 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.

In 2023, a research focus has been put on the competences building for smart data generation, which is the key technique in establishing a data-driven and AI-based surrogate model. Design of Experiment Theory and local slope-based algorithm have been implemented to generate an accurate description of phase diagram data. The linking of the smart generation code with TC-Python has been attempted. The smart data generation algorithm could be valuable for other modelling activities (cross-scale simulation, phase diagram coupling, etc). The figure shows how we use the least amount of data to describe a 3D phase diagram for a given required accuracy. The intelligent sampling of local curvature technique has been used for a ternary phase diagram liquidus surface.



$$||M||_F = \sqrt{\sum_{i=1}^{n+1}\sum_{j=1}^{n}|m_{ij}|^2}$$

The melting point surface generated with the intelligent sampling of local curvature technique.

RESEARCH AREA 3.
SUSTAINABLE AND HIGH-PERFORMANCE MATERIAL DEVELOPMENT

RESEARCH AREA LEADERS:
EVEN WILBERG HOVIG
ASTRID MARTHINSEN
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 and additive manufacturing).
- 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

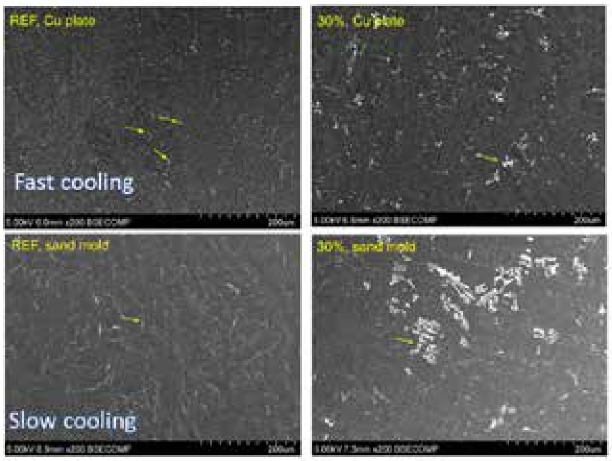
- How to understand the effect of, and compensate for, elevated levels of trace elements from recycled materials and develop robust/novel alloys.
- How to develop and tailor the microstructure of AM/rapid solidification alloys.
- How to recover or improve material properties through post-processing.

ACTIVITIES AND RESULTS IN 2023

The research activities in this Research Area are organized in four main tasks. Main objectives, activities and results from 2023 are listed below for each task.

Task RA3.1: Solid-state mixing by screw extrusion
The main objective of task RA3.1 is to prepare novel materials with superior properties by solid state mixing of granular feedstock, for example metal scraps, by screw extrusion. In 2023, a review paper summarizing the state of the art and beyond of screw extrusion has been prepared and submitted to the steering committee for approval. Due to a change in priorities of one of the main industry stakeholders remaining activities in this task has been put on hold.

Task RA3.2: Compensation metallurgy and alloy design
In 2023 the study of the effect of using post-consumer scrap (PCS) in Al-Si foundry alloys was continued. The motivation is to reduce the environmental impact of Al-alloys by replacing primary Al with recycled Al. The challenge is that secondary Al contains many impurity elements, and the effect on processability and properties is largely unknown. The strategy in RA3.2 is to build an efficient theoretical framework to understand, evaluate and combat the (negative) effects of the contaminants in secondary Al. Continuing the work from earlier years, the focus in 2023 has been on further analysis of the microstructure of cast samples with 30% PCS and compare it to primary material. The investigations reveal that for a high cooling rate, the same phases are observed with and without PCS,



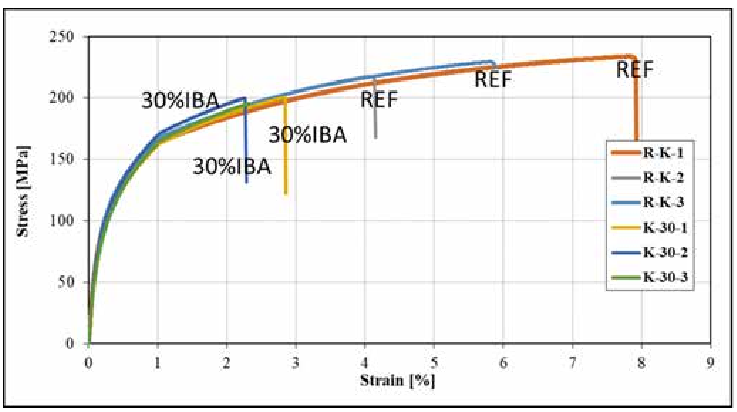
SEM Micrographs of AlSi10MnMg with and without the addition of 30% PCS with high and low cooling rate.

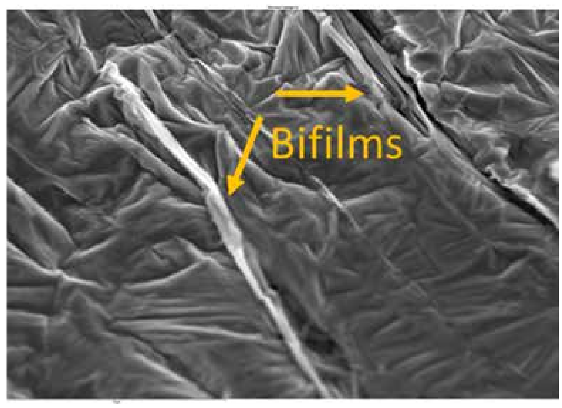
but the morphology transforms to a script-like phase. For slower cooling rates, a plate-like phase is observed in the primary sample, which transforms to a script-like phase when PCS is introduced. To better understand the observed phases butanol dissolution was done to isolate the intermetallic particles, which was then characterized by SEM and XRD. The script-like α-phase is confirmed by SEM and XRD. The plate-like phase is consistent with δ-Al when analysed by SEM/EDS, but the XRD does not identify the δ-phase as described in the literature.

Additionally, tensile tests were performed on samples cast in a steel mould with both primary metal and 30% PCS. There is no significant change in stiffness, yield strength or ultimate tensile strength, but the ductility is consistently reduced when 30% PCS is included. Fracture surface analysis reveals thick oxide films trapped within the samples, which is likely the cause of the reduced ductility.

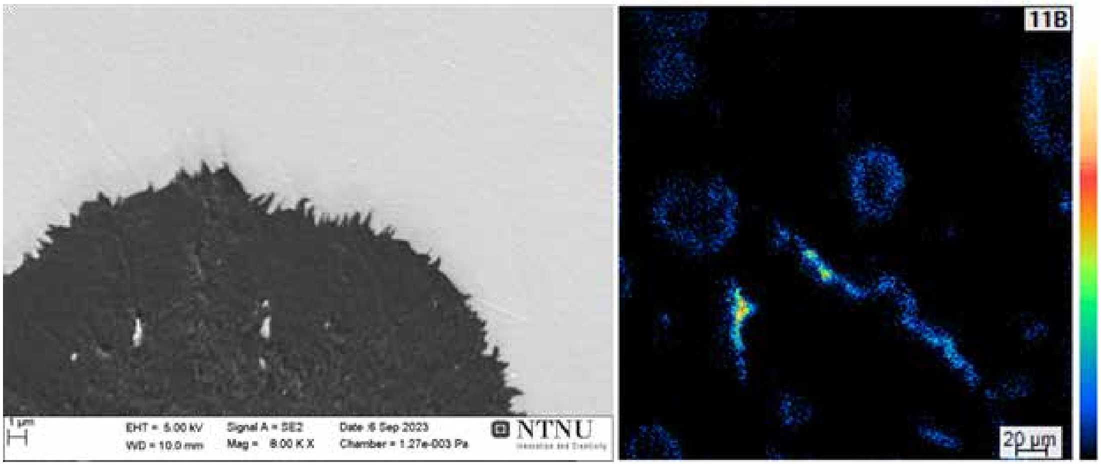
The use of PCS in cast iron is an important contribution to the sustainability of the steel and cast-iron industries. A current trend in the automotive industry is to introduce more and more Boron-containing steels, and when these components reach end-of-life, boron is introduced to cast iron. Small amounts of B (<70 ppm) have been shown to adversely affect the properties of spheroidal graphite iron (SGI) by promoting ferrite growth (ferrite is a softer phase). Studies by PhD candidate Andreas V. Bugten in RA3 has found that carbon deposits as sharp protrusions on the graphite nodule surface when ferrite grows, and B is observed in the graphite nodules. Further analysis reveals that when B is present, the growth direction of the graphite protrusion is rotated 90° compared to the spheroidal graphite. The change in orientation is believed to promote ferrite growth since C atoms preferentially attach to the crystallographic prism planes that are facing the matrix. The prism planes are not facing the matrix when the sharp protrusions are absent.

In 2023, a new PhD candidate was hired to study the role of impurities on different recycled high pressure die casting Al alloys and their properties. The position was originally intended to be with Task RA3.1 but was moved to Task RA3.2. We welcome new PhD candidate Supreet Kaur, who will focus on the characterization of the microstructural-, chemical-, and mechanical properties. Some of the techniques that will be used are: Scanning electron microscopy (SEM), Transmission Electron Microscopy (TEM), Glow Discharge Mass Spectrometry (GDMS), Hardness, and Tensile strength.





Left; Tensile test results of AlSi10MnMg with and without the addition of 30% PCS. Right; Fracture surface analysis reveals thick oxide films.

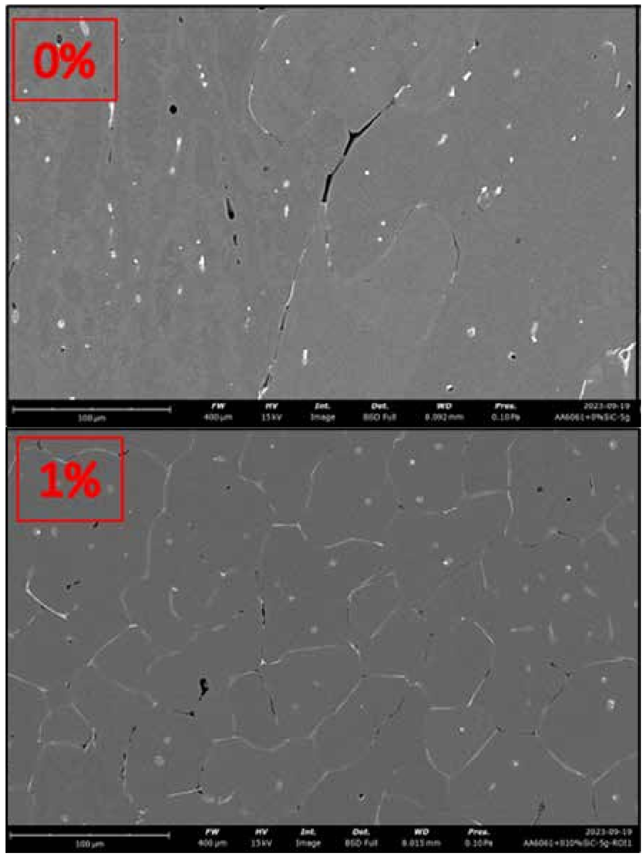


Left; Sharp protrusions on the graphite nodule. Middle; Boron confirmed on the surface of the nodules. Right; The growth direction of the protrusions are rotated 90°C compared to the spheroidal graphite.

Task RA3.3: Powder materials and rapid solidification
One focus area of Task RA3.3 in 2023 has been to develop numerical tools for microstructure prediction that account for the high cooling rates associated with AM. The work started in 2022 on predicting columnar-to-equiaxed transition has been concluded. Furthermore, a model to predict solute trapping in multi-component alloys has been developed.

Another focus area in 2023 has been on developing aluminium alloy 6061 for powder bed fusion additive manufacturing. Non-stochiometric SiCx nanoparticles were added to pre-alloyed 6061 powder, with the hypothesis that the SiCx particles would act as nucleation sites during solidification and promote grain refinement. The hypothesis was tested by preparing arc melted samples which were analysed using OM and SEM/EDS. The analysis revealed that the nanoparticles dissolve in the melt, which does lead to a small reduction of grain size, but this is likely due to the increased amount of Si rather than an increased number of nucleation sites.

Task RA3.4: Tailored properties through post-processing
This task focuses on microstructure tailoring during heat treatments of Al products to compensate for unwanted detrimental secondary phases and precipitates and to promote desired phase transformations. No activity was planned on this task in 2023.



Grain morphology of aluminium alloy 6061 with and without modification by introducing SiCx nanoparticles.

RESEARCH AREA 4.
INNOVATIVE PROCESSING AND JOINING METHODS

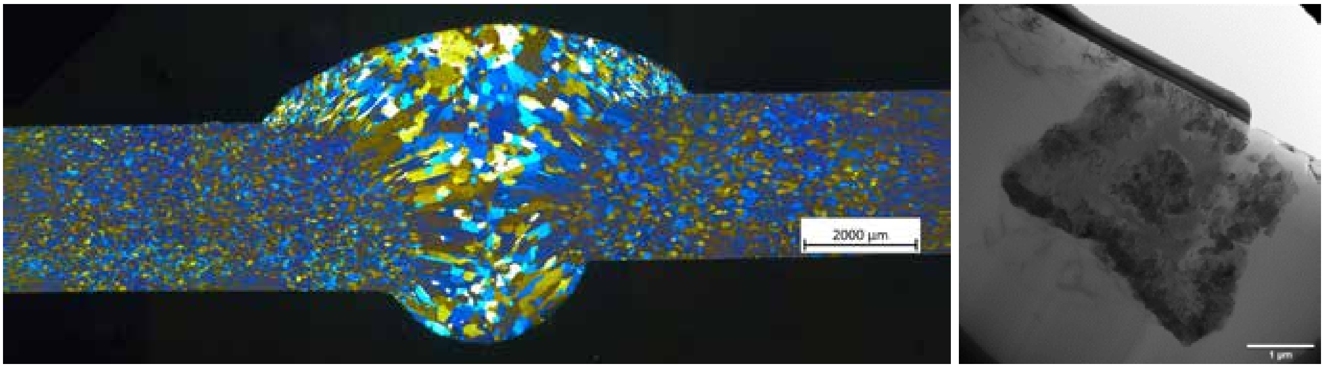
RESEARCH AREA LEADER:
MAGNUS ERIKSSON
SINTEF

CONTRIBUTIONS TO CENTRE OBJECTIVES

- Develop knowledge basis for welding of aluminium alloys including new wires using nanoparticles and alloying elements for grain refinement and particle strengthening.
- Develop welding technologies 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

- Low strength in weld metal and strength loss in soft parts of the heat affected zone (HAZ) represents a major challenge in welding of aluminium alloys. For improved utilization of aluminium in welded structures as well as additive manufacturing (AM) there is an urgent need for new high strength filler materials as well as developing innovative welding methods such as laser welding to minimize the width of HAZ, resulting in reduced strength loss in weld joints.
- 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. Innovative joining methods are therefore needed to overcome the above-mentioned challenges.
- 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-situ process monitoring by e.g. high-speed imaging can be one approach 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 (LMD) and wire arc additive manufacturing (WAAM). Applying these repair



MIG weld with 7108 and a TEM lamella with a Al3Ti-'flower' that forms in produced welds.

methods on a damaged component, including on-site repair, is very challenging due to uncertainties and variations of substrate material chemical composition, thickness, geometry, heat transfer etc.

ACTIVITIES AND RESULTS IN 2023

The research activities in this Research Area are organized into five main research tasks, listed below, together with their main results and highlights.

Task 4.1 New wires for welding of aluminium alloys

Joining and welding of high-strength aluminium alloys are challenging due to development of a weak heat-affected zone (HAZ) in vicinity to the weld, leading to a large strength penalty in design of structures. This task focuses on measures to overcome the HAZ softening of high-strength aluminium alloys by development of high strength weld metals and welding technologies in order to enable better material utilisation and weight savings followed by lower cost and CO2 emissions.

2023 was a busy year for RA4.1 with several activities. Development of novel filler wires for aluminium welding continued with student work at Masters' and doctoral level with supervision from NTNU and SINTEF. A scientific paper based on MSc Kjell Kirkbakk's work was published. Furthermore, MSc Steffen Samuelsen manufactured wires of 7108 (Al-Zn-Mg-Zr alloy) by metal screw extrusion and characterized the effect of welding method and the addition of titanium and TiC on microstructure, cracking tendency, and microstructure. A MIG weld with 7108 is shown in the Figure, where no cracking is observed. In parallel, MSc Simen Skurdal performed advanced characterization with focused ion beam (FIB) and TEM on Al3Ti-'flowers' that form in produced welds. A TEM lamella showing one of these flowers is shown below. Great collaboration with RA1 Multi-scale material analysis made this work possible.

In parallel, PhD Candidate Ingvild Runningen and MSc Sigbjørn Lærum developed a casting setup for in-situ mixing of ceramic TiC particles and salt fluxes. This is an innovative solution to incorporate particles into the aluminium matrix and fully utilize the ceramic phase. Post-casting characterization has revealed particle distribution, survivability, and grain refinement potency. Runningen has also studied the interaction between aluminium, TiC and salt fluxes by controlled wetting trials.

Task 4.2: Welding of aluminium alloys and dissimilar metals

Solid-state welding or low-heat input welding technologies have been demonstrated to be the optimal choice for production of multi-material components. This minimizes the risk of intermetallic phase formation along the joint interface, promoting desirable properties such as strength and ductility. In 2023, a new industrial Friction Stir Welding (FSW) machine was installed at SINTEF Manufacturing in Raufoss. The equipment is part of the infrastructure found in the Manufacturing Technology Norwegian Catapult Centre. The equipment offers a new range of opportunities in terms of weldable geometries (flat profiles, round pipes and corners can be welded), weldable thicknesses (up to 20 mm tested currently) and process parameters. The equipment also allows for welding using a stationary shoulder, which will contribute to keeping the heat input at absolute minimum.

The equipment will strongly contribute to advancing the studies on solid-state welding of dissimilar metals going forward in SFI PhysMet in 2024.

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

Results on hybrid laser-arc welding of thick steels

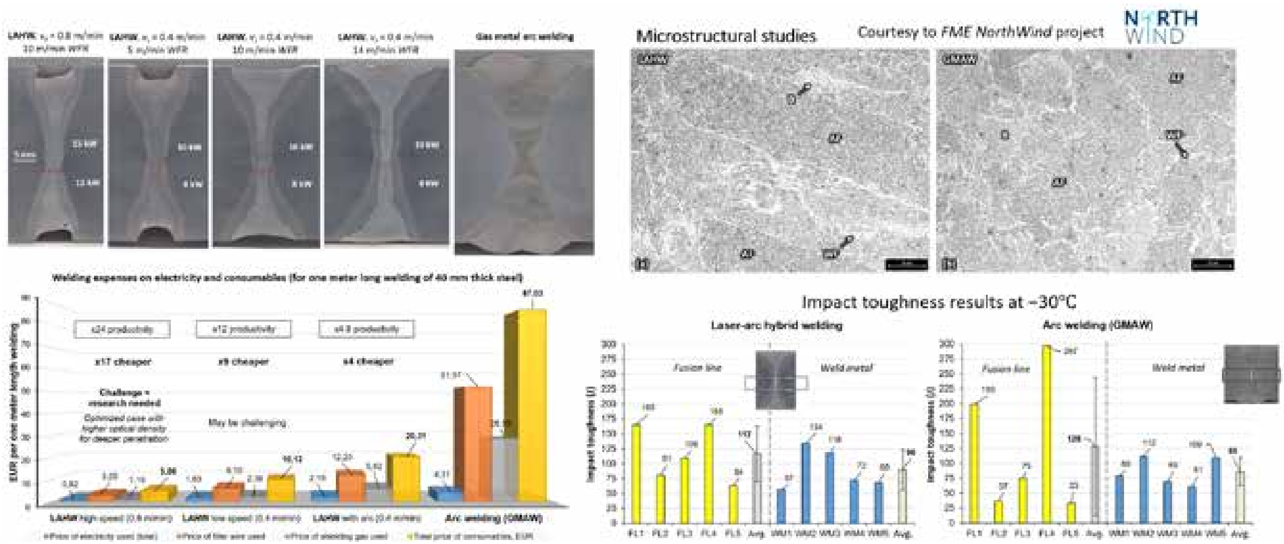
Deep penetration laser-arc hybrid welding (LAHW) may offer significant increase of productivity. It provides

Friction Stir Welding equipment installed at Raufoss, SINTEF Manufacturing.

low heat input which lowers distortions and residual stresses. The LAHW is complex due to significant amount of process parameters, thus optimization is important. Due to high depth-to-width ratio, there are both a significant risk of welding defects as well as brittle phases being present in weld metal and heat affected zone (HAZ).

During 2023, the highest priority for the research was hybrid welding of a typical 45 mm thick S355ML structural steel to achieve full penetration welds using double-sided welding technique. Optimized welding parameters with slower welding speed provided reduced hot cracking in the root area compared to faster welding speeds used for higher strength steels. Further reduction of cracking was achieved by preplacing 316L stainless steel plates into a gap prior welding. In 2024, further research on hot cracking will be conducted using low transformation temperature filler materials. The main outcome in 2023 was a publication related to efficiency of different welding processes. Studies showed that use of hybrid welding may significantly reduce consumption of welding consumables compared to traditional arc welding providing much faster production speeds. Optimized welding parameters for hybrid welding provided equivalent quality weld to the ones found in conventional arc welding showing a high potential for the laser-based processes, this is reflected in the figure below.

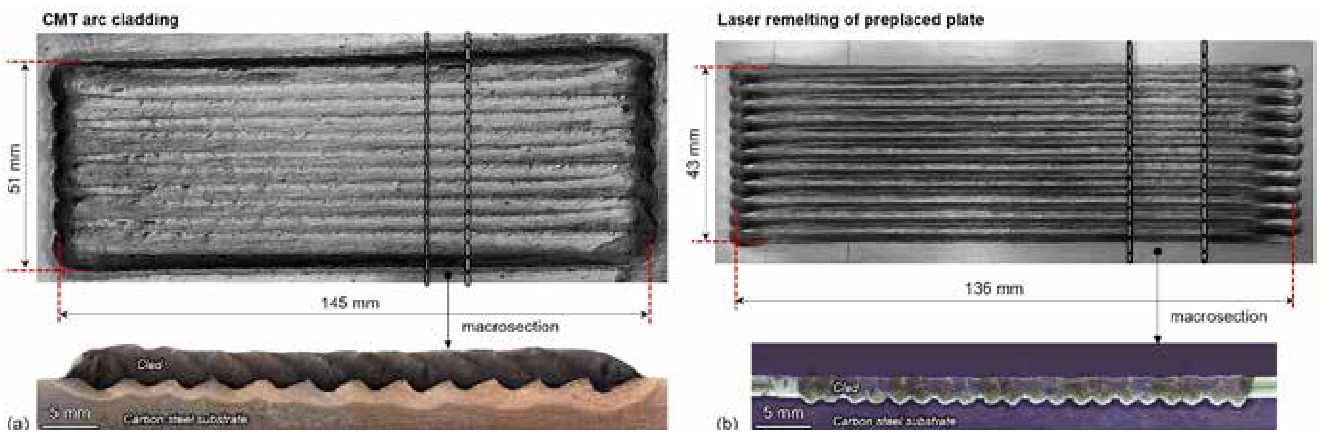
In single-pass laser beam welding of 15 mm thick plates, a high-speed imaging camera was used to record root formation at high resolution. Humping formation was recorded and will be studied further. High fidelity numerical modelling using computational fluid dynamics will be used to study and analyse different root formation modes.



Joining efficiency comparison of different welding methods and resulting toughness at low temperature.

Novel experiments with deposited microparticles on welding edges were made to induce acicular ferrite formation. Preliminary results were not conclusive and showed very limited difference from autogenous laser beam welding. Therefore, further experiments with different microparticles will be conducted in 2024.

Task 4.4 Laser cladding and surface treatment
Silicides may have excellent corrosion and wear resistance but have very limited applications so far. In a parallel project IPN MADAM, led by our centre partner Elkem, the focus is to develop production routes for high-performance silicon-based materials for additive manufacturing. The project has achieved good results and very promising materials have been developed and tested for powder bed fusion (PBF) and cladding in laboratory. These materials could be used to produce complex components with specific requirements for weight, strength, and wear resistance. The promising results from the MADAM project have laid a solid basis for further development in SFI PhysMet, which could lead to the creation of new and innovative products that are more efficient, durable, and cost-effective. In 2023, a potential field test case study has been identified through a joint effort between the centre partners. The test coupon will be prepared and installed for real condition field testing in 2024.



Example of laser cladding.

Task 4.5 AM by direct energy deposition (DED)
It is of high industrial interest to apply Directed Energy Deposition (DED) AM process combined with novel materials for repairing of damaged components. This AM-based repair will contribute to cost reduction, and reduced lead time and CO_2 emissions compared to ordering and producing a new component.

Duplex stainless steel is a popular material in the oil and gas and process industry due to its excellent corrosion resistance as well as high strength. Additive manufacturing (AM) of duplex steel including AM-based repair has attracted great attention in recent years and in the start of 2023, PhD student Trond Arne Hassel has joined the SFI PhysMet and focusing on this topic.

In 2023, AM of duplex stainless steels has been investigated using a coaxial DED-LB/wire system. Different consumables have been compared, as well as both 22Cr and 25Cr grades. Microstructure changes from build parameter variations and heat treatment has been studied and an article presenting the findings were submitted in December 2023. This activity will continue in 2024 with mechanical testing and EBSD characterisation.

Results this far indicate that the properties can overmatch conventional material, including impact toughness of forged material at -46°C.

Seminars and workshops
On the 10th of February the members of RA4 were invited to webinar organised by SFI BLUES, with the title: “SFI PhysMet and research on welding technologies for metallic materials and applications to offshore wind structures”.

RA4 hosted in May 2023 a workshop on high-speed imaging of welding together with Serof and Cavitar. Over 20 attendees received a thorough introduction to welding cameras and practical demonstrations in SINTEFs welding lab.

The 6th-7th of December representatives of RA4 attended the FME NORTHWIND innovation forum, including a specified workshop on aluminium in offshore wind, and presented some of the results and research topics for aluminium welding in RA 4.1.

Example of laser DED of Duplex specimens.

Seminar on High-speed camera.

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 features 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 reuse and connect existing data? 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.

To tackle these main challenges, the work in this Research Area is organised into three research tasks: platform design, platform implementation and platform exploitation.

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 partners, EMMC core team, and other leading actors will ensure that this ontology will be part of a widely adopted standard for metals and alloys.

Task 5.2: Platform implementation
The implementation of the platform is using core technology from various EU projects 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.

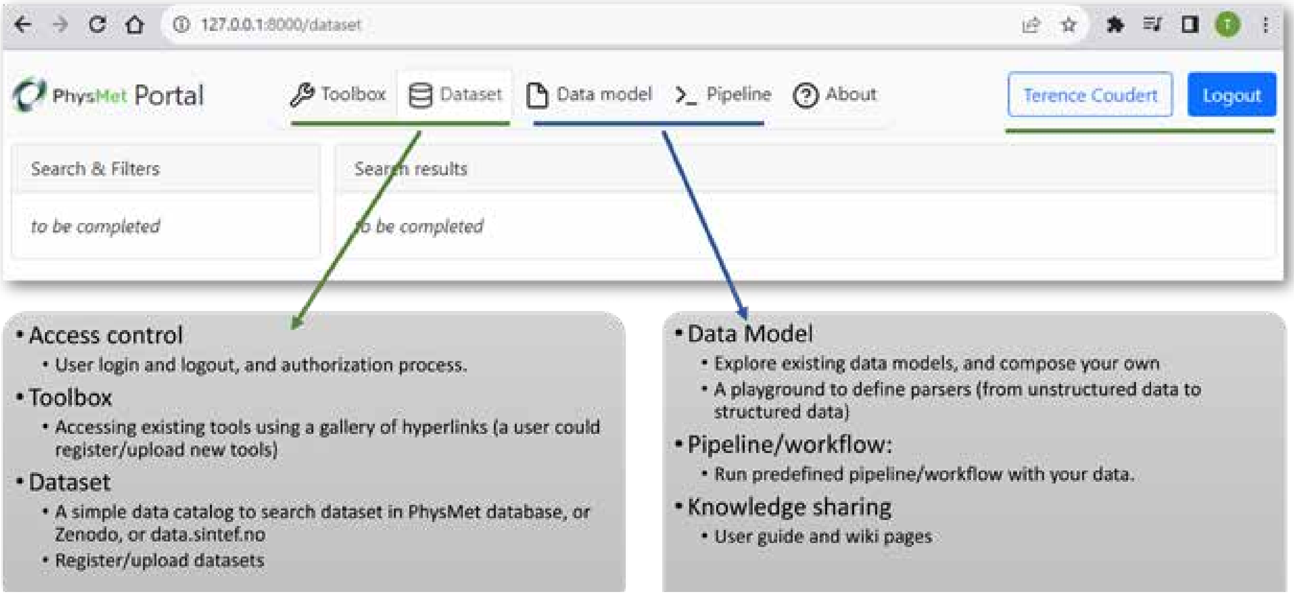


Figure 1. Features of the new web portal.

Task 5.3: Platform exploitation
This task focused 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.

ACTIVITIES AND RESULTS IN 2023
Here we will only highlight a few key activities. Other important activities in 2023 include a use case with Raufoss Technology on digitalisation and exchange of test results and further development of the microstructure ontology.

Design the PhysMet digital platform and Web portal
The design of the PhysMet platform was further elaborated in 2023 and the old PhysMet web portal was redesigned as shown in Figure 1, with a set of high-level components. It will be further developed and deployed in 2024. The web portal will serve as a gateway or starting point to the PhysMet digital platform that provides users access to various digital resources, services, and information.

The toolbox will provide access to a gallery of tools, as shown in Figure 2a. A design for how microstructure models can be turned into web applications in the toolbox was also developed and schematically illustrated in Figure 2b.

a) b)

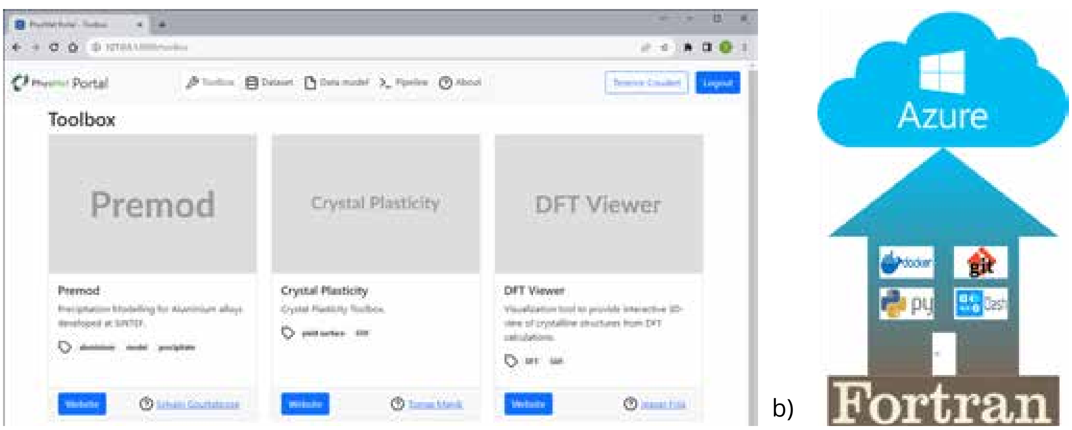


Figure 2. (a) PhysMet toolbox of various web applications and (b) schematics of how microstructure models can be turned into a web application by combining existing technologies.

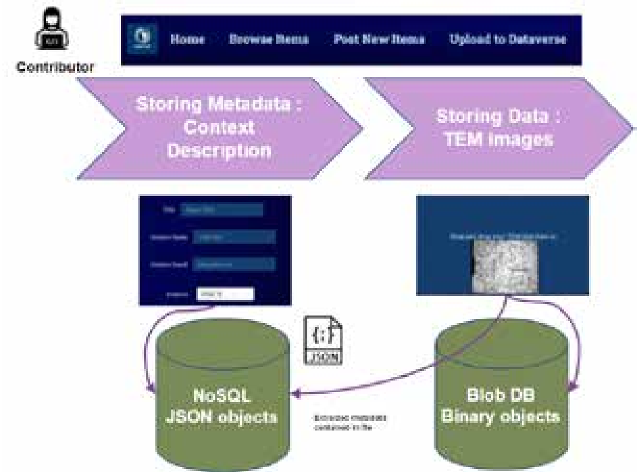


Figure 3. Schematic design of the data catalogue.

Furthermore, the platform will contain a catalogue of datasets from experiments and modelling results that are available to project partners. The structure of the datasets is formally described by data models who's semantic meaning is defined by ontologies. A demonstration of how TEM images can be semantically documented using data models and mapping to ontologies was also developed and presented at the consortium meeting in November.

New web applications

A set of new web applications was developed in 2023, including an overview of existing models, a data catalogue, a crystal plasticity toolbox and the AlFlow model. The data catalogue was developed together with the French student Léo Quignon. The aim of the data catalogue is to enable sharing of research data in a FAIR (findable, accessible, interoperable, and reusable) way. Dataverse (open source software) was selected for the data catalogue. The data itself was stored on Azure into two databases as illustrated in Figure 3; an object store with the raw datasets and a searchable database with metadata and references to the raw datasets. A web service allows seamless registration of data stored in these databases in the data catalogue.

The crystal plasticity toolbox and AlFlow web app were developed together with the master student Kim Dianne Bienes and project student Daniel Aron Preminger. Both follow the design illustrated in Figure 2b. The crystal plasticity toolbox predicts deformation texture in terms of main texture components (Cube, brass, Goss, S, copper and random). It allows plotting experimental

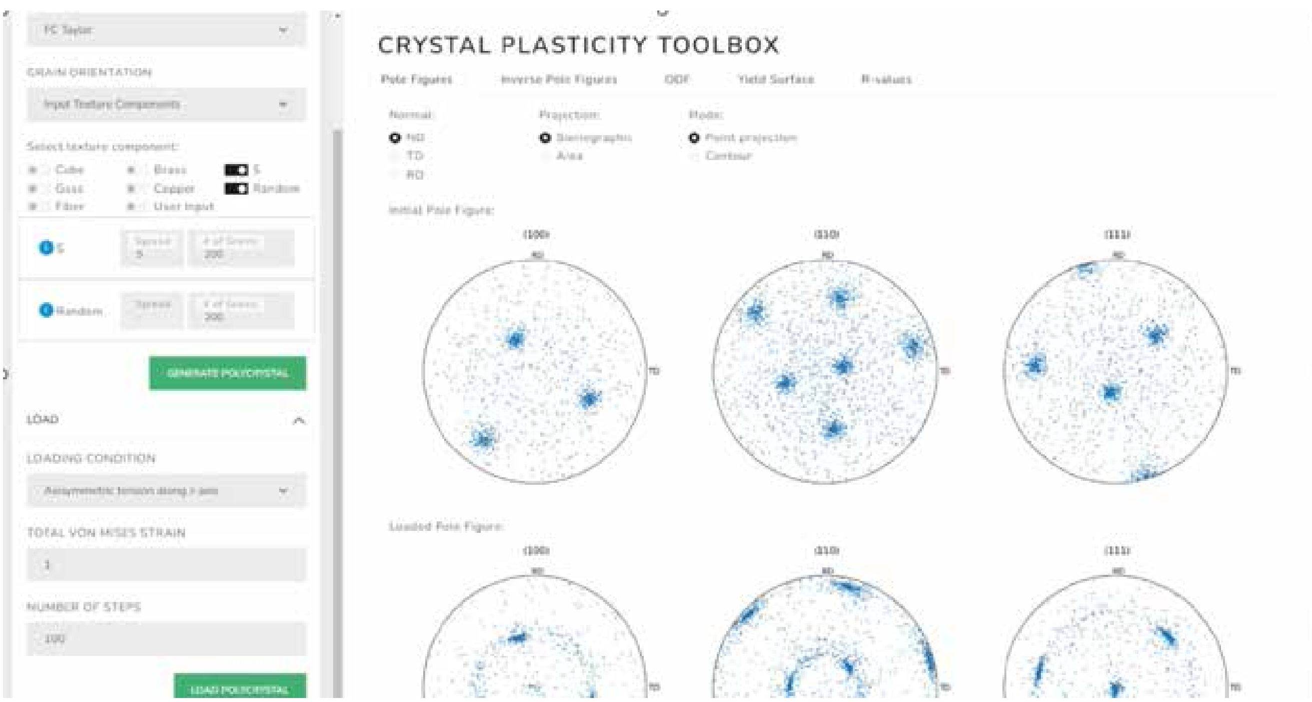


Figure 4. Screenshot from the crystal plasticity toolbox showing experimental pole figures.

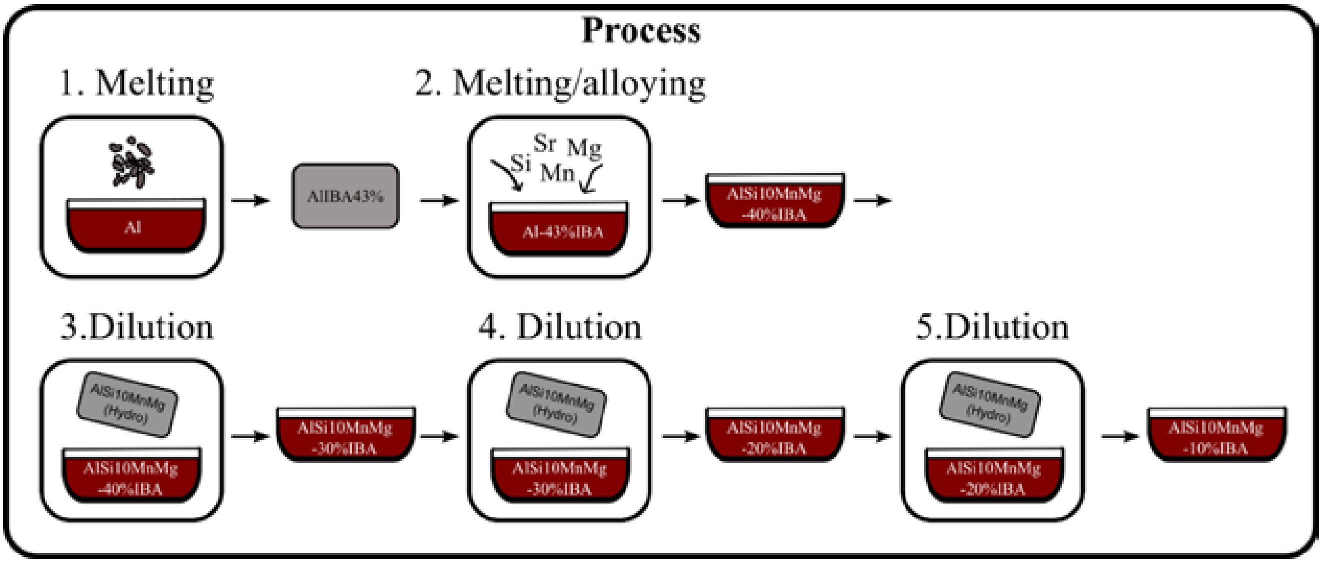


Figure 5. Workflow of experimental testing of IBA for Al alloying.

textures (shown in Figure 4) and calculation of Yield surfaces and r-values.

Collaboration with RA3 on data documentation for IBA

The methodology developed for automatically store data from research studies has been applied to the IBA case from RA3. An application specific description of the processing step was developed and applied to document the procedure and the type of measurements performed on the different samples. The collected data was then stored in a structured folder with consistent naming conventions and file formatting. It allowed to automatically parse the files, create instances according to pre-defined data models and store them in databases online. The raw data was also stored in an object store as well as the microstructure images.

OUR PHD CANDIDATES

During the eight years Centre period we will recruit and educate numerous PhD candidates, Postdoctors and master students. We are looking for competent and motivated candidates in all of the Centre's research areas.

Six talented PhD candidates have been recruited to SFI PhysMet, and two more started in 2023. We are looking forward to following their scientific progress in the years to come! Here is a short presentation of our PhD candidates.

PHD STUDENT
ANDREAS VOLL BUGTEN (2021-2025)

Research topic: The effect of trace elements on the microstructure development and mechanical properties of cast irons.

Supervisor: Prof. Marisa Di Sabatino

PHD STUDENT
XUEZHOU WANG (2021-2024)

Research topic: Develop precipitation model with improved nucleation concepts, addressing the influence of impurity elements, vacancy and atom clustering kinetics.

Supervisor: Prof. Yanjun Li

PHD STUDENT
TOR INGE THORSEN (2021-2023)

Research topic: Multiscale studies/advanced characterization (e.g. TEM/SEM) of materials joints.

Supervisor: Prof. Randi Holmestad

PHD STUDENT
INGVILD RUNNINGEN (2021-2025)

Research topic: Development of nanoparticle-containing aluminum filler wires

Supervisor: Prof. Ida Westermann

PHD STUDENT
MAGNUS REIERSEN (2021-2024)

Research topic: Material development and micro-structure control for powder based additive manufacturing processes

Supervisor: Assoc. Prof. Tomas Manik

PHD STUDENT
TROND ARNE HASSEL (2021-2024)

Research topic: Microstructure and properties of duplex stainless steel manufactured by directed energy deposition.

Supervisor: Prof. Knut Sørby

NEW PHD CANDIDATES IN 2023

Two new PhD candidates started in 2023, and more will start in 2024. We have asked the new PhD candidates to give a short description of their projects and the expected impact for industry.

PHD CANDIDATE
HÅKON LONGVA KORSVOLD (2023-2026)

Topic: Advanced nanoscale characterization of grain boundary segregation in metals.

Supervisor Prof. Yanjun Li

Background Master's degree in Nanotechnology from NTNU. Topic: TEM studies of precipitates in HYB welded Al-Mg-Si-Cu.

The PhD project Study segregation of solute atoms to grain boundaries in aluminium alloys using state-of-the-art characterization techniques. Solute atoms are known to influence grain boundary behavior and to affect properties such as strength, corrosion and recyclability.

Methods Samples of grain boundaries will be created using focused ion beam microscopy (FIB), these samples will then be studied using atom probe tomography (APT) and transmission electron microscopy (TEM)

Expected impact for industry Increased understanding of the effect of solute grain boundary segregation, aiding in alloy design and recyclability. Experimental data can be used to validate and develop atomic scale simulations for alloy design.

PHD CANDIDATE
SUPREET KAUR (2023-2026)

Topic: The effect of trace elements on recycled Al Alloys

Supervisor: Prof. Marisa Di Sabatino

Background: Master's degree in physics from NTNU. Topic: TEM characterization of Strontium Barium Niobate ($Sr_xBa_{1-x}Nb_2O_6$) thin films.

The PhD project: To understand the role of impurities on different recycled HPDC (High Pressure Die Casting) Al alloys and their properties.

Methods: The main focus will be on the characterization of the microstructural-, chemical-, and mechanical properties. Some of the techniques that will be used are: Scanning electron microscopy (SEM), Transmission Electron Microscopy (TEM), Glow Discharge Mass Spectrometry (GDMS), Hardness, and Tensile strength.

Expected impact for industry: Recycled Al alloys can be used in automotive components to save energy consumption and reduce weight and CO_2 emissions.

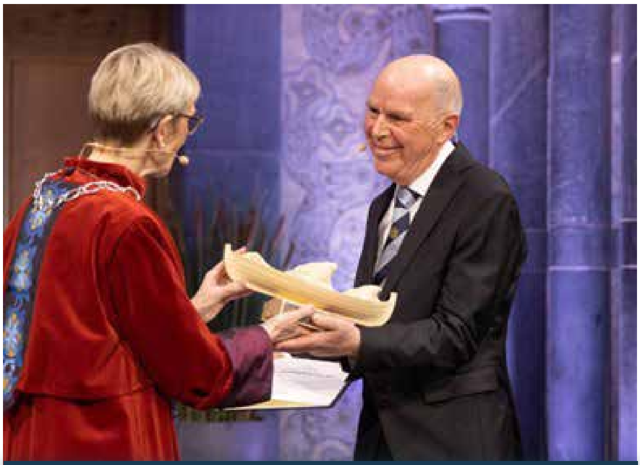
ALF BJØRSETH RECEIVED NTNU'S AWARD OF HONOUR

March 10th 2023 Alf Bjørseth received NTNU's Award of Honour. Alf Bjørseth has played a crucial role in Norwegian industry and has been a pioneer in research and production of renewable energy. He founded the company ScanWafer in 1994 (later REC). He was director of Research at Norsk Hydro, Herøya, from 1984-1990 and director of technology at Elkem from 1990-1994. He received NTNU's award of honour at the doctoral ceremony in the Aula at Gløshaugen.

March 9th SFI PhysMet organized a scientific seminar on the topic solar energy. Bjørseth gave a very interesting lecture on innovation and solar energy, and researchers from SINTEF and NTNU gave presentations on their research on silicon solar cells and solar energy.

NTNU's Award of Honour is presented to people who through their life and work have contributed to NTNU's development or made an exceptional social contribution nationally and internationally – individuals who:

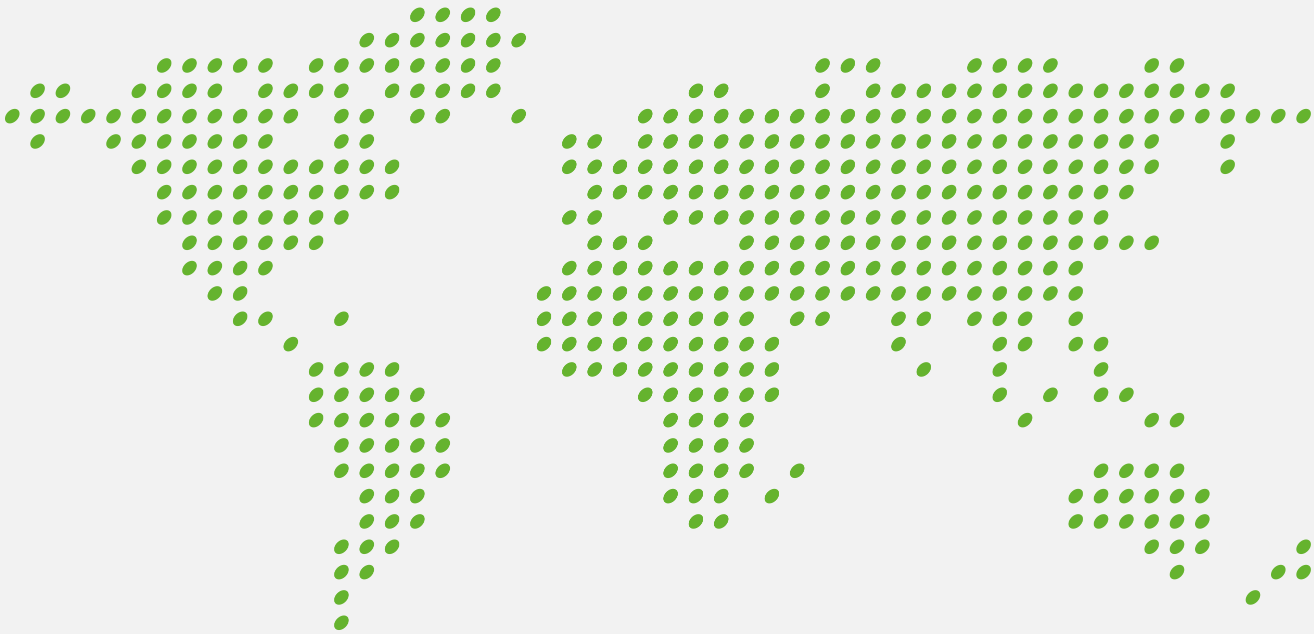
- deserve recognition because, through their personal dedication, they have been/are valuable partners for the university.
- are a role model for students and staff, showing how individuals can make a difference to society in a way that reflects NTNU's vision of «Knowledge for a Better World».



Alf Bjørseth receives the Award of honor from rector Anne Borg. March 10th 2023. Photo: Thor Nielsen/ NTNU

Prof. Marisa Di Sabatino, Alf Bjørseth and rector Anne Borg. Photo: Thor Nielsen/NTNU

INTERNATIONAL COLLABORATION



SFI PhysMet has an extensive international network, and several of our academic communities are highly internationally recognized in their fields. The researchers in and around SFI PhysMet are generally very active in terms of publishing in internationally renowned journals and many of the researchers give regularly invited presentations at major international scientific conferences in our fields.

The academic communities in SFI PhysMet cooperate with several leading universities and research environments abroad on border zone projects, as well as strategic education and research collaboration. The international collaboration is documented through numerous joint publications with international partners.

INTPART PROJECTS

The Intpart project *International Materials Science and Engineering education and research network*, IntMat (2020-2024) is managed by Prof. Ida Westermann, NTNU. Partners are NTNU, MIT, Shanghai Jiao Tong University, Jilin University, Chongqing University and Nanjing University of Science and Technology, Jiangsu Industrial Technology Research Institute and Aluminium Corporate of China. With partial funding from the IntMat project, three PhD students from Chongqing University (CSC fellows) had one-year residency at the centre from 2021 – 2022, where they worked on Al- and Mg alloy development using electron microscopy, Atom Probe

Tomography (APT) and machine learning. The visit has resulted in several joint publications.
The Intpart project *Norwegian-Japanese Aluminium alloy Research and Education Collaboration - Phase-2* (2019-2023) ended in June 2023. Project manager has been Prof. Randi Holmestad. Partners were NTNU, SINTEF, Hydro, University of Toyama, Tokyo Tech., Kyushu University, Japanese Aluminium Association, and Toyama Aluminium. The focus of this project was aluminium research and educational activities in general, including activities closely related to SFI PhysMet. The project included research collaboration, student exchange incl. Internships in industry which connect education, research and innovation (both in Japan and Norway) and has led to several joint publications.

Visit by University West, Sweden.

CONFERENCES AND SEMINARS

Staff from SFI PhysMet have participated in and organized numerous international conferences and seminars throughout 2023. Some of them are:

December - University West (Sweden) visited Trondheim to foster future collaboration within SFI PhysMet on topics related to welding and additive manufacturing. We expect a fruitful partnership with the Swedes in the years to come. In the image below we see RA leader Magnus Eriksson being a proud recipient of University Wests' book on additive manufacturing, fresh off the press.

October - The Seventh Chinese-Norwegian Symposium on Light Metals and New Energy Material in China. Profs. Yanjun Li and Knut Marthinsen, from SFI PhysMet, gave plenary lectures and attended the conference together with eight other Norwegian representatives. The Symposium is a platform for scientific and technological exchanges between China and Norway, with the aim of promoting the scientific development, technological innovation and achievement transformation of light alloys and new energy materials and cultivating excellent researchers. During the symposium Knut Marthinsen received the Outstanding contribution Award – in recognition of distinguished contribution to the academic exchanges in the field of light metals between China and Norway.

September - The Additive Manufacturing Course (EU project) in Trondheim.
SFI PhysMet and the EU project Smart-SWAAM organized an international course on additive manufacturing (AM). Several international and national experts were invited to give lectures about different aspects of AM from fundamental solidification, equipment, powder production, processing, microstructures and properties to applications. 29 participants including researchers, professors, master students, PhD students and postdocs from NTNU, SINTEF, Elkem, Equinor and IFE attended the course.

August – International Conference on Digitization and Advancements in Materials and Metallurgical Industries, Jaipur, India. Professor Marisa Di Sabatino gave a keynote lecture at the conference, that aims to provide a platform to present findings, ideas and innovations related to the conference theme. The title of Di Sabatino's talk was Sustainable and efficient crystalline silicon solar cells: Where do we stand?

June – The 7th International Conference of Engineering against Failure in Hellas.
SFI PhysMet PhD candidate Magnus Reiersen presented his work of combining experimental results with the Columnar to Equiaxed transition as a tool to identify and remove material candidates that can lead to a failed additively manufactured component an early stage of material development. The conference is set up to attract interdisciplinary work.

February - NTNU European Conference in Brussel: Demand for Raw Materials needed in the Green Transition. Centre leader Knut Marthinsen participated at the 7th NTNU European Conference, organized at the Residence Palace in Brussel, where he chaired a session on Critical Raw Materials. The topic of the conference was: The Future guiding the Present: The Role of R&I and Education in navigating current and incoming EU Challenges.

PhD candidate Magnus Reiersen in Hellas, June 2023

July - The 12th International Conference on Processing and Manufacturing of Advanced Materials in Vienna (THERMEC'2023). The conference connects professionals working in industry, academia and government research labs from around the world to present their research findings. More than 1100 participants attended and SFI PhysMet was represented by Profs. Randi Holmestad and Knut Marthinsen, who gave invited talks. At the conference Knut Marthinsen received the THERMEC'2023 Distinguished Award: For outstanding contributions in the area of physical metallurgy of aluminium alloys & for national and international leadership in the field of materials science and engineering.

Knut Marthinsen received the award from Prof. Christof Sommitsch, Graz Univ. of Technology, and Chairman of THERMEC'2023.

April - Visit to our partners in Japan.
A large delegation from NTNU, SINTEF and Hydro travelled to Japan to organize a two-day workshop and visit several universities and industry companies. The trip was made possible by the Intpart project Norwegian-Japanese Aluminium alloy Research and Education Collaboration. The workshop was organized at Tokyo University of Technology with invited participants from

Participants at the workshop, Tokyo University of Technology.

aluminium industry, professors, researchers and MSc students from the partners of the Intpart project.

INTERNATIONAL VISITS AND GUEST RESEARCHERS

Professor Javier LLorca from IMDEA Materials Institute and Polytechnic, University of Madrid, visited SFI PhysMet in September 2023. He gave a guest lecture and had meetings and discussions with multiple groups and individual researchers during his visit.
Professor Bradley Diak from Queens University, Canada, visited us through May and June 2023. Diak contributed with his expertise in discussions of dynamic measurements of the thermodynamics of plastic flow in alloys over large temperature ranges and volumes, solute-defect interactions in metallic solid solutions, control of texture and microstructure development and corresponding materials properties by processing. Professor Diak also gave lectures as part of the SFI Webinar series and at a seminar on clustering and precipitation in aluminium alloys.

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 the Green Deal) through increased uptake of material modelling in European companies. Specific EU projects that the centre exploits are MarketPlace, OntoTrans, OntoCommons, DOME 4.0, OpenModel VIPCOAT and NanoMECommons. Technology developed in the HE project MatCHMaker that connects characterization and modeling with the help of ontologies and the M-era.net project MEDIATE will also be utilized in the SFI. The microstructure ontology developed in the SFI is done in collaboration with ACCESS in Germany and IC2C in Austria.
Jesper Friis is a member of the Board of Directors of the EMMC and leads the focus area within interoperability.

COMMUNICATION AND DISSEMINATION ACTIVITIES

Our aim is that results from SFI PhysMet shall be visible and implemented. Scientific publications and conference presentations are our main and most important arena to make our research visible in the national and international research communities. However, an important aim is also to facilitate and ensure implementations of new results in the industry sector. Scientists also have a responsibility to build bridges between science and society and explain complex science and its potential impact of to the general public.

An important arena to reach out to the public and make information from the Centre easily available is our website **www.ntnu.edu/physmet/**

SFI PHYSMET IN THE MEDIA

Research activity and topics related to SFI PhysMet is frequently discussed and presented in the media. Here are some examples of researchers who have been interviewed or written popular science articles disseminated in Norwegian newspapers and websites.

SFI partner Statens vegvesen is responsible for a new aluminium bridge in Trondheim, potentially setting a standard for bridges in the future. The project builds on knowledge from SFI PhysMet researchers. iRADAR wrote about the project in June 2023.


Hangarbrua i Trondheim kan sette standarden for framtidas aluminiumsbruer

26/06/2023, 08:19

Aluminium er mer klimavennlig enn betong, og «pilotbrua» Hangarbrua som skal bygges i aluminium vil gi nyttig erfaring som kan sette en ny bransjestandard.


NRK
Nyheter Sport Kultur Humor Distrikt Mer
Logg på
Søk

Her deler kua og solcellene plassen

Både solceller og landbruk krever store områder. Men hva om plantene og solcellene kan dele samme område?


Bilen din gjenfødes som telysholdere. Den burde heller bli en ny bil

Uten økt kunnskap om hva som skjer i atomenes og molekylenes verden når materialer resirkuleres, vil sirkulærøkonomien aldri bli noe av.

An agrivoltaic project at Skjetlein high school has received attention in Norwegian media in 2023. The project combines agriculture with solar energy. Professor Marisa Di Sabatino from SFI PhysMet is involved in the project.

Professor Randi Holmestad et al. published a chronicle in Dagens Næringsliv in July with the (Norwegian) title Bilen din gjenfødes som telysholdere. Den burde heller bli en ny bil. We need more knowledge about what happens at the atomic and molecular scale during materials recycling to reach the goal of circular economy.

WEBINAR SERIES

Since 2021 we have invited all partners to attend monthly webinars with scientific presentations on topics relevant to SFI PhysMet members. The webinars are easily available for all researchers and industry partners, as they are presented online. The presentations have been a success, with many participants.

Date	Title	Responsible
Jan 19 14-15	*3D characterization of Precipitates in Al-Mg-Mn alloys*	Professor Kenji Kaneko, Kyushu university, Fukuoka
Febr 14 13-14	*Ontology – a language connecting humans and computers*	Jesper Friis, SINTEF
March 9 14-15	*Innovation and solar energy*	Alf Bjørseth
March 23 12-13	*HISC experiences in Equinor the last 25 years*	Gisle Rørvik, Equinor
April 27 09-10	*LIBS analysis of liquid aluminium and aluminium alloys*	Kristján Leósson, Univ.of Island
May 15 10-11	*Measurement and Analysis of Recovery at the Interalloy Region of a Rolled Clad Aluminum Alloy: Revisiting Eric Nes' Static Recovery Models*	Bradley J. Diak, Queen's University, Kingston, Canada
June 20 15-16	*The current and future challenges of metals processing technologies*	Professor Jianguo Lin, Imperial College London
Sept 21 10-11	*Accurate prediction of phase diagrams of binary and ternary metallic alloys from first-principles calculations and statistical mechanics*	Professor Javier LLorca, Polytechnical Univ. of Madrid
Oct 20 10-11	*The effect of Zn pollution in Al-Mg-Si(-Cu) and of Si pollution in Al-Mg-Zn aluminium alloys in the context of recycling*	Senior Research Scientist Calin Marioara, SINTEF
Dec 14 13-14	*The Fundamental Studies of Phase Transitions in Spheroidal Graphite Irons*	R&D Scientist Leander Michels, ELKEM

RECRUITMENT CAMPAIGN TO ATTRACT PHD CANDIDATES

The last years we have faced some problems with recruitment of PhD students. To attract candidates from the NTNU master student group and motivate them for an academic career several efforts have been made.

- We have invited to recruitment-meetings where PhD possibilities have been presented. Representatives from industry partners have talked about the need for competence and the relevance of PhD projects for the industry.
- Every year the material science and engineering students at NTNU invite material technology industry to «Materialdagen» - a seminar on career opportunities for the students. Professor Marisa Di Sabatino, co-director of SFI PhysMet, presented the centre, the PhD positions and our collaboration with industry partners.
- We have made roll ups and other promotion material to attract the students' attention on the possibilities to pursue an academic career.

STUDENT PROJECT PRESENTATIONS

The 5th year students with projects related to the physical metallurgy group at NTNU presented their results in a seminar in November. The SFI PhysMet partners could follow the presentations in the seminar room or online. In total we have 16 students in the group and some of them work in projects directly connected to SFI-PhysMet. Most of the studies are experimental work and deal with important topics for the industries, such as effect of alloying elements on recycled alloys, effect of microstructure on 3D printing materials etc. These students will continue with their master project during the spring semester in 2024.

NV FACULTY SUSTAINABILITY AWARD 2023

Professor Marisa Di Sabatino received the Sustainability Award 2023 from Faculty of Natural Sciences. The justification for the award included her effort in communicating her research to the public: "She has been active in solar silicon research throughout her professional career... She has been active in popular dissemination of the possibilities that solar cells can provide for the society, e.g. within AgriPV, and has also engaged many students through dedicated teaching. In general Marisa burns for increasing the overall knowledge about solar energy at NTNU and in the society, and for educating candidates with the competence that is needed to utilize solar energy in the future."

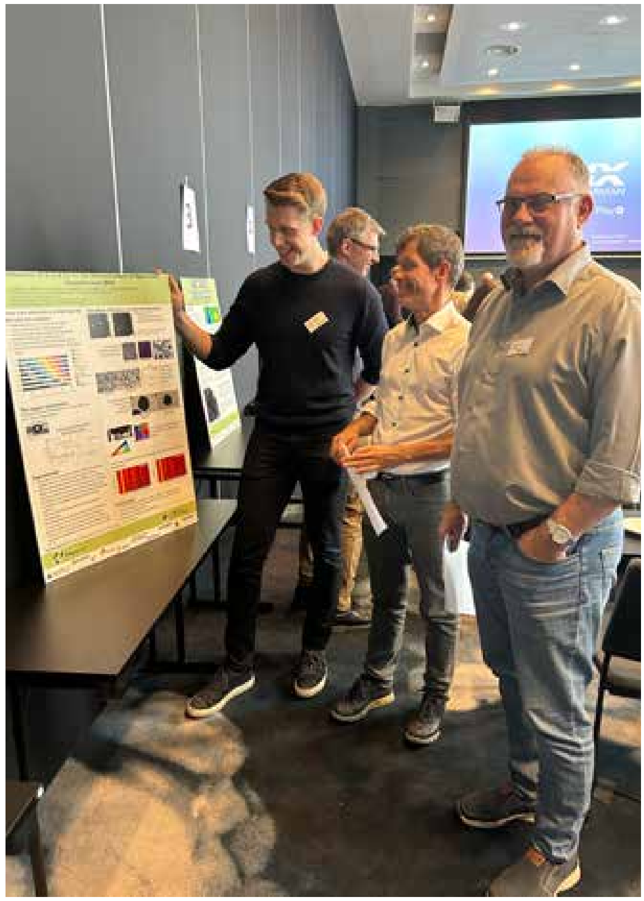
INTERNAL MEETINGS AND COMMUNICATIONS ACTIVITIES

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

Management meetings: The management group has weekly meetings to discuss progress and coordinate center activities.

Research Area meetings: 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. In 2023 the consortium meetings were held in May and November. These meetings are good arenas for exchange of ideas and dissemination of the latest scientific findings from the five research areas. The meeting program have included presentations as well as poster sessions and group discussions. The members of the Scientific Advisory Committee are invited to the meetings to give advice about research directions and how to maintain high international standards. It is of significant value to us to get input and feedback from external experts, and we highly appreciate their contributions.



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
Sigurd 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
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

Even Hovig	SINTEF Industry	Sustainable and high-performance material development
Astrid Marthinsen	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
David Wragg	IFE	Powder synthesis and characterization
Hanne Flåten Andersen	IFE	Powder synthesis and characterization
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
Kristian Grøtta Skorpen	SINTEF Industry	Sustainable and high-performance material development
Kai Zhang	SINTEF Industry	Sustainable and high-performance material development

RESEARCH AREA 4. INNOVATIVE PROCESSING AND JOINING METHODS

Magnus Eriksson	SINTEF Industry	Thermo-mechanical processing and welding
Geir Kvam-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
Xiaobo Ren	SINTEF Industry	Materials, processing and 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
Vegard Brøtan	SINTEF Manufacturing	Additive Manufacturing Materials, processing and properties
Luigi Viespoli	SINTEF Industry	Materials, processing and properties
Bård Nyhus	SINTEF Industry	Materials, processing and properties
Calin Marioara	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
Nikolai Marhaug	SINTEF Industry	Welding, Arc Welding, Processes
Sigurd Wenner	SINTEF Industry	Nano-/microstructure characterization (TEM and APT)

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
Tomas 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
Tor S. Haugland	SINTEF Industry	Data sharing and digital platforms
Thawin Hart-Rawung	SINTEF Manufacturing	Data sharing and digital platforms

VISITING RESEARCHERS

Bradley Diak	Queens University	Mechanical and materials engineering
Javier Llorca	University of Madrid	Prediction of phase diagrams of binary and ternary metallic alloys

PHD STUDENTS WITH FINANCIAL SUPPORT FROM THE CENTRE BUDGET

Ingvild Runningen	2021 - 2025	New wires for welding of aluminium alloys
Tor Inge Thorsen	2021 - 2023	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
Supreet Kaur	2023 - 2026	Effect of trace elements on recycled Al alloys
Håkon Longva Korsvold	2023 - 2026	Materials Physics and Transmission Electron Microscopy

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

Imani Aria Arash	NTNU Digital Transformation	Multiscale materials modelling; Crystal Plasticity
Håkon Wiik Ånes	NAPIC/NTNU internal	Recrystallization and textures in Al-alloys. SEM/EBSD methodologies and experimental characterization
Endre Aasheim	Nærings PhD - Hydro	Nucleation, growth and dissolution of ß-Mg2Si particles in Al-Mg-Si
Gabriela Kazimiera Warden	FME Susoltec	Quartz crucibles for PV silicon solidification
Chunan Li	NFR KPN SumAl	Clustering and precipiation in Al-alloys
Erlend Sølvberg	Nærings PhD-Kverneland Steel	
Håkon Linga	SFI Manufacturing	3D-printing
Hassan Moradi Asadkhandi	NFR FriNatek	Crystal Plasticity
Magnus Reiersen	Institutt-PhD SINTEF	Modelling and experimental framework for accelerated development of materials for Laser Powder Bed Fusion technology with application to Al alloys.
Trond Arne Hassel	SINTEF Manufacturing	Additiv manufacturing

MASTER STUDENTS

Adegbo Kayode	Effect of thermal history on the microstructure of ferrosilicon alloys
Daniel B. Johannessen	Silicon Powder Morphology as a Function of Size Reduction Process
Dianne Kim Bienes	Crystal plasticity toolbox development in Python
Hugo Rivera	Recrystallization behaviour and properties during hot rolling of recycle friendly 3000-series aluminum alloys
Lavrans Thorstensen	Welding and mechanical testing of aluminum alloys for use in constructions
Marie R. Sørlie	Experimental investigation of slant fractures in AlZnMg (7xxx) alloys
Martin Fast Buen	Grain Refinement of Austenitic Steels
Simen Skurdal	Characterization of Aluminium TiC nano-composite filler wire inoculated weld metal
Steffen Samuelsen	Effect of TiC nanoparticle addition in metal screw extruded AA7108 filler wire
Vegard Bjerve	Effect of alloying elements in cast aluminum components for hybrid and electric vehicles
Harald Skar	Develop aluminium alloy components with super properties by additive manufacturing process
Kjell M.Kirkbakk	Welding thread and screw extrusion

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

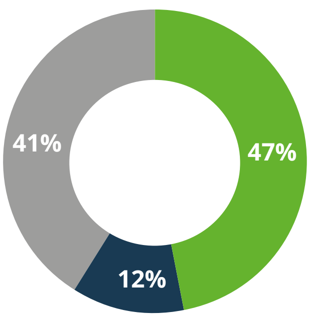
Rania Hendawi	FME Susoltec	Structure loss in CZ-silicon
Jochen Busan	IPN-HighVis	Viscosity in Quartz crucibles for PV silicon
Baptiste Reyne	Metplast, NFR	The next generation metal continuum plasticity theory
Yaping Wang	IPN-Dare2C2	Aluminium reinforced concrete

ANNUAL ACCOUNTS 2023

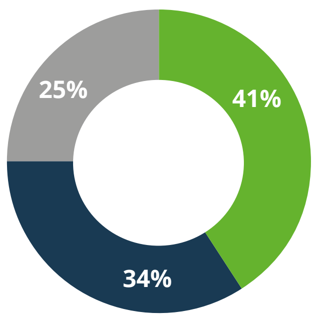
The total budget for the eight year SFI PhysMet centre periode is 208 mill NOK. The financing of SFI PhysMet is based on contribution from The Research Council of Norway and cash and in-kind contribution from the user partners and NTNU. Results for 2023:

Funding (1000 NOK)	Amount
Research Council	11 688
Host Institution (NTNU)	3 120
Research Partners*	0
User Partners**	10 103
Total	**24 911**

Costs (1000 NOK)	Amount
Host Institution (NTNU)	10 275
Research Partners*	8 334
User Partners**	6 302
Equipment	0
Total	**24 911**



Research Council
Host Institution (NTNU)
User Partners**



Host Institution (NTNU)
Research Partners*
User Partners**

* *SINTEF AS, SINTEF Manufacturing and IFE.*
** *Hydro Aluminium AS, Elkem AS, Equinor, Benteler, Raufoss Technology, Thermo-Calc Software, The Norwegian Public Roads Administration.*

PUBLICATIONS AND CONFERENCE PRESENTATIONS 2023

PUBLICATIONS DIRECTLY FUNDED BY SFI PHYSMET:

- **Bugten, Andreas Voll; Michels Brito Miranda, Leander Edward; Brurok, Rune Botnmark; Hartung, Cathrine; Ott, Emmanuelle; Vines, Lasse; Li, Yanjun; Arnberg, Lars Erik; Sabatino, Marisa Di.** *The Role of Boron in Low Copper Spheroidal Graphite Irons. Metallurgical and Materials Transactions A 2023*
- **Bugten, Andreas Voll; Sanders, Paul; Hartung, Cathrine; Logan, Robert; Sabatino, Marisa Di; Michels Brito Miranda, Leander Edward.** *The Influence of Boron (B), Tin (Sn), Copper (Cu), and Manganese (Mn) on the Microstructure of Spheroidal Graphite Irons. International Journal of metalcasting 2023*
- **Bunaziv, Ivan; Ren, Xiaobo; Olden, Vigdis.** *A comparative study of laser-arc hybrid welding with arc welding for fabrication of offshore substructures. Journal of Physics: Conference Series (JPCS) 2023*
- **de Baas, Anne F; Del Nostro, Pierluigi; Friis, Jesper; Ghedini, Emanuele; Goldbeck, Gerhard; Paponetti, Ilaria Maria; Pozzi, Andrea; Sarkar, Arkopaul; Yang, Lan; Zaccarini, Francesco Antonio; Toti, Daniele.** *Review and Alignment of Domain-Level Ontologies for Materials Science. IEEE Access 2023*
- **Flatscher, Florian; Todt, Juraj; Burghammer, Manfred; Søreide, Hanne-Sofie Marie Scisly; Porz, Lukas; Li, Yanjun; Wenner, Sigurd; Bobal, Viktor; Ganschow, Steffen; Sartory, Bernhard; Brunner, Roland; Hatzoglou, Constantinos; Keckes, Jozef; Rettenwander, Daniel.** *Deflecting Dendrites by Introducing Compressive Stress in Li7La3Zr2O12 Using Ion Implantation. Small 2023*
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