Centre for Sustainable and Competitive Metallurgical and Manufacturing Industry

ANNUAL REPORT 2022

SFI PHYSMET

PhysMet

Norwegian Centre for Research-based Innovation

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Photos from SFI PhysMet activities in 2022.

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CONTENT

ANNUAL REPORT 2022
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SUMMARY

BY CENTRE MANAGER
KNUT MARTHINSEN, NTNU

The overall objective of SFI PhysMet is to enable and accelerate the transformation of the national metal industry towards more sustainable and cost-efficient production, future material products, solutions and improved processing methods. 2022 has been a very positive and productive year for the SFI, and some research highlights are briefly described below.

Research

An important goal of SFI PhysMet is more use of recycled metal, through new methods of recycling (e.g., screw extrusion), increased understanding of how alloying elements accumulated through recycling affect microstructure and properties, and the development of new recycling-friendly alloys. In 2022, we have e.g., investigated the effects of small additions of Ti and V in aluminium by transmission electron microscopy (TEM), while the effect of boron in globular graphite iron has been investigated using a number of characterization methods. Activities have also included casting trials of industry-relevant aluminium alloys where up to 40% aluminium from combustion ash is mixed into a foundry alloy. The purpose is to understand the effect of increased values of contaminants such as Fe, Zn and Cu on resulting microstructure and properties, including sensitivity to hot cracking during casting.

Another focus area for the SFI is new welding and joining methods: Both for welding aluminium and steel and these in combination, for use in large structures (e.g. bridges and wind turbines at sea), there is a need for improved and new welding methods, specifically for welding thick materials. In 2022, steel plates of 40-45 mm thickness were joined with duplex laser-hybrid technology and microstructure and mechanical properties characterized. Welding of aluminum requires the development of high-strength aluminum welding wires with the addition of alloying elements or nanoparticles, and the possibility of producing these using screw extrusion has been tested. For lighter battery systems in, e.g., cars, it is possible to replace copper with aluminium, so methods for joining aluminium to copper has also been tested.

Yet another focus area is the development of robust numerical tools, including models for additive manufacturing (AM). In 2022, a solidification model has been used to support the experimental work on the addition of aluminium from combustion ash to Al foundry alloys. In addition, models for hot crack sensitivity have been further developed to include more alloy-specific properties. Implementation of multi-object optimization has also begun; numerical algorithms that can be used, among other things, to design new alloys based on a set of specifications for chemistry, process or properties. Moreover, a new solidification model to evaluate the influence of cooling rate and temperature gradient on the solidification process, relevant for both welding and additive manufacturing has been implemented and tested. The model significantly reduces the need for experiments when working with material and parameter development for additive manufacturing.

In addition to a repository (GitLab) for source codes, we have in 2022 worked on the design and initial implementation of the digital platform for SFI PhysMet, published an updated version of the domain ontology for microstructures on GitHub and continued work with tools and demos. Among these, a simple QR code app for registering samples, an app with a frontend for the precipitation model PREMOD and a simple database of microstructure models are available.

Visibility and dissemination

The research activities and results have been published in well renowned scientific journals and presented in plenary, key-note and invited oral presentations at national and international meetings and conferences (see publication list for details In particular, SFI PhysMet was well represented at the 18th International Conference on Aluminium Alloys (ICAA18) in Japan, with one plenary, two key-note and as well as several other oral presentations.

Visibility also includes appearances in several public settings and popular science articles in public media.

Internationalization and international collaboration

Key researchers in SFI PhysMet are involved in two INTPART projects, for educational and research collaboration, with leading R&D institutions and industry in Japan, China and USA. In 2022 three PhD students from Chongqing University stayed with us for 8 months (12 months in total starting from September 2021). During fall 2022 three Japanese students from Tokyo Institute of Technology and Kyushu University have been visiting the Department of Physics to do TEM on aluminum alloys, linked to the INTPART project with Japan.

PhD student Alejandra Torres from EUROCAT, Spain, had a 3-month visiting research stay in SFI PhysMet in the spring of 2022 where she studied wear and friction in the production of welding wire containing nanoparticles.

At the invitation of Hydro Aluminium, Prof. Paul Sanders, Michigan Tech, spent a 6-month research stay at NTNU in the fall of 2022. During his stay in Norway, Prof. Sanders has also established good relations with Elkem, which hopefully can form the basis for further cooperation.

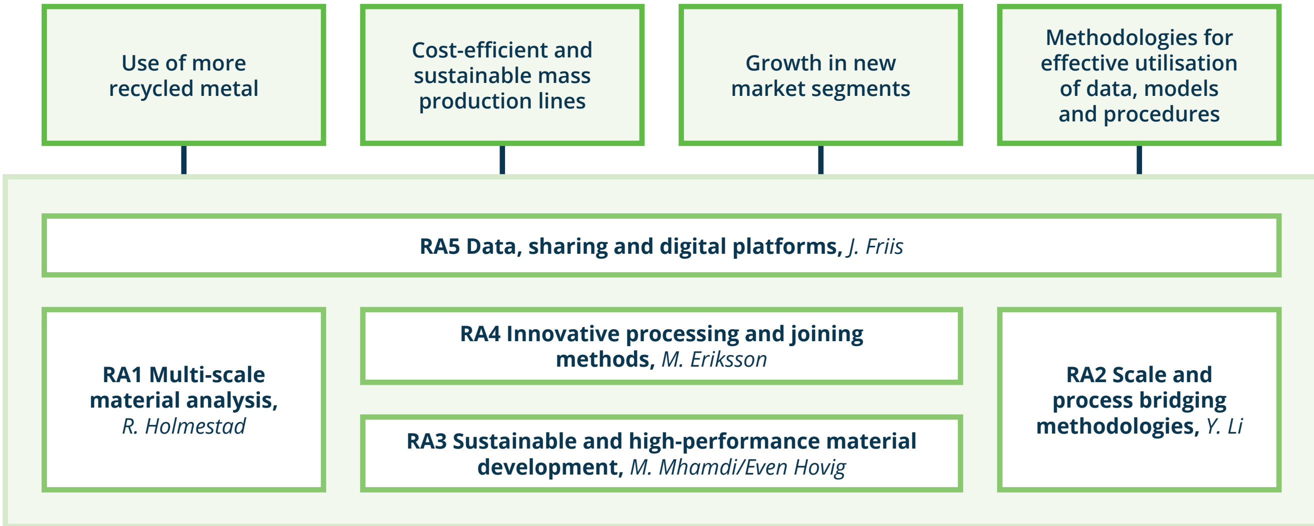
Recruitment

Recruitment of talented and motivated students for PhD projects is indeed a challenge, especially of Norwegian students. In 2022, SFI PhysMet took part in several recruitments campaigns to promote PhD studies in general and SFI PhysMet in particular.

An important approach to attract good students is through master student projects, in collaboration with the industrial partners. This is a win-win situation, which benefits all parts, as it is an excellent possibility to realize small industry relevant projects, as well as recruiting potential candidates for later PhD studies. In this year’s annual report, we therefore also present an overview of the student projects that have been carried out during 2022.

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:

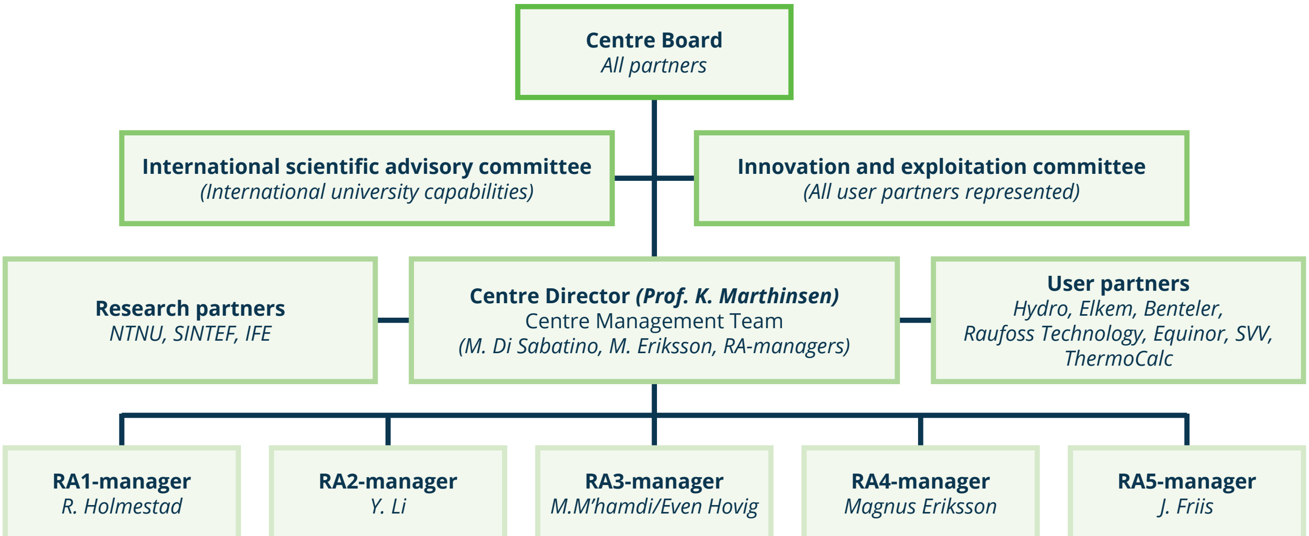
- **Use of more recycled metal**
- **Cost-efficient and sustainable mass production lines**
- **Growth in new market segments**
- **Methodologies for effective utilisation of data, models and procedures**

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, Equinor
Jørgen Lie, Raufoss Technology
Cato Dørum, Statens Vegvesen
Anders Engström, Thermo-Calc Software
Tanja Pettersen, SINTEF Manufacturing
Arve Holt, 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.

The management team (from left): Magnus Eriksson (SINTEF, RA 4 manager), Kari Håland (NTNU, coordinator), Mohammed M'Hamdi (SINTEF, RA 3 manager), Knut Marthinsen (NTNU, director), Jesper Friis (SINTEF, RA 5 manager) Randi Holmestad (NTNU, RA 1 manager), Yanjun Li (NTNU, RA 2 manager), Marisa Di Sabatino (NTNU, co-director). In 2022 Even Hovig and Astrid Marthinsen have been in charge of RA 3.

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

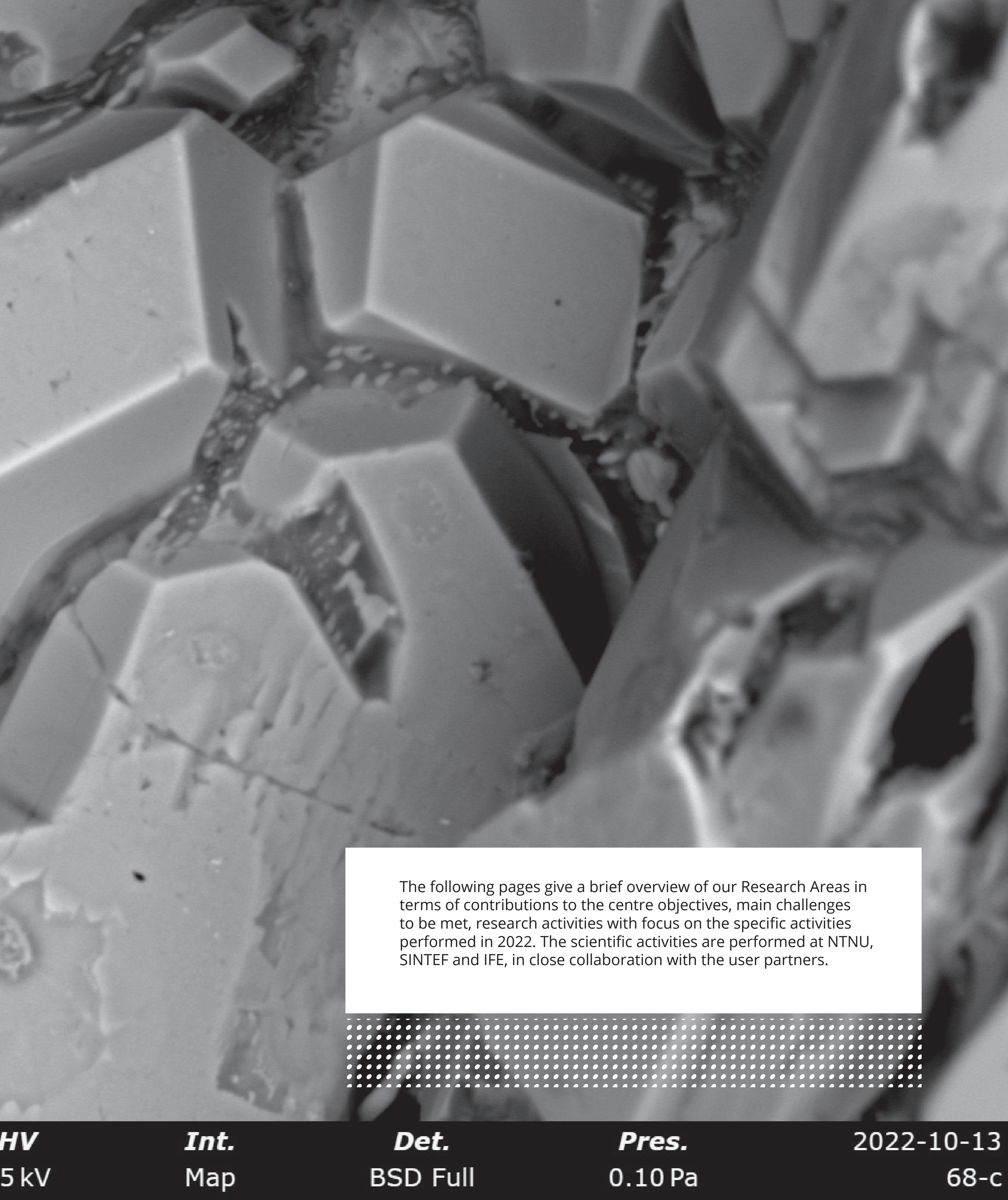
LOCATION

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

SEM image of hexagonal τ5 phase found in iron-rich Al-Si alloy. Photo: Joachim Seland Graff (SINTEF Industry)



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 2022. 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

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.

CONTRIBUTIONS TO CENTRE OBJECTIVES

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

MAIN CHALLENGES TO BE MET

- Develop correlative use of 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 2022

The research activities in RA1 are organized into three main research tasks, corresponding to the three main challenges mentioned above. In addition, smaller (and larger) characterization tasks connected to the other RAs or initiated by the industry partners are done. The results obtained in 2022 are described in the following.

Task 1.1A: Correlative use of TEM and APT in steels
By doing correlative TEM and APT, crystal structure and chemistry down to the atomic scale can be studied and correlated. 3D information can be extracted, for example in the field of compensation metallurgy. However, first we need to establish sample preparation methods and competence in the field for different materials. So - the objective in this task in

the beginning of the SFI is to build up competence on doing these techniques in a correlated way for different materials.

The study on steels is done in collaboration with RA4 and industry. Here, the M-A (Martensite – Austenite) phase is examined. The phase occurs when welding unalloyed and low-alloyed structural steels when the temperature in the base material reaches just above the transformation temperature in the two-phase range $\alpha + \gamma$ (ferrite and austenite). The phase is detrimental to the toughness of the steel, especially after it has undergone temperature cycles, such as in the inter-critically reheated coarse-grained heat-affected zone. Weld simulations were done in the Gleeble 3800 thermal-mechanical physical simulation system, and samples were prepared by focused ion beam (FIB). Figure 1 shows the carbon distribution in two samples for different cooling rates between 800 °C and 500 C°. Experiments were performed by Sigurd Wenner and Ruben Bjørge in SINTEF Industry.

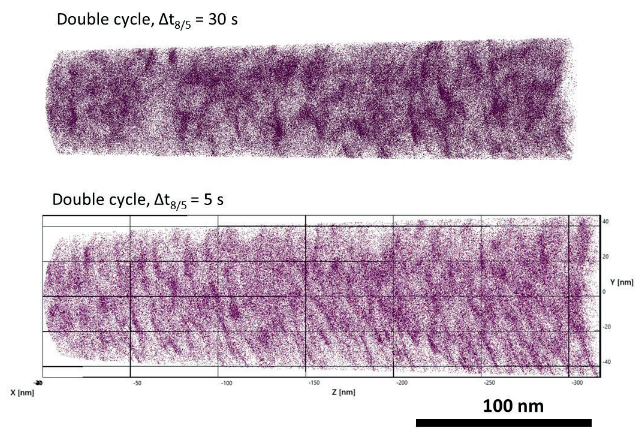


Figure 1. Carbon segregation in two APT volumes from M-A constituents in weld-simulated steel.

RA1.1B1 TEM studies of 6005 with different additions of Ti and V

A 6005 type aluminium alloy with different additions of Ti and V have been studied. Hydro has produced the alloys and performed several property tests, with the conclusion that the alloys with the additions show improved crash behavior and corrosion resistance without loss in strength. Pre-deformation improved crash behaviour, regardless of additions. The task here was to understand where Ti and V segregate and why it improves the mentioned properties. Hedda Øye did her MSc thesis on these alloys, measuring hardness and conductivity evolution of some alloy variants during various heat treatments. The microstructure in TEM was studied, and precipitate parameters as function of alloy composition and thermomechanical treatment in selected conditions were found. The conclusion was that the additions do not have a strong effect on grain structure (or segregation towards grain boundaries), hardness, precipitate statistics or precipitate types. On the other hand, electron probe microanalysis (EPMA) using wavelength dispersive spectroscopy (WDS) mapping indicates Ti and V segregation in micrometer thick bands along the extrusion direction, probably due to their concentration in the centres of grains prior to extrusion. APT results indicate a weak segregation of V to precipitates, without significant microstructural consequences. Measurement of nano-hardness was done on the etched samples, where topography can be used to locate Ti/V bands. A small increase in hardness is seen in the high Ti/V areas, but not significant. In corrosion tested samples, corrosion attacks proceed horizontally along the bands instead of going deeper into the material, which can give products a longer lifetime. The results obtained will relate to material behavior and will also be used in RA2 to further develop microstructural models. Figure 2 shows a few of the experiments done.

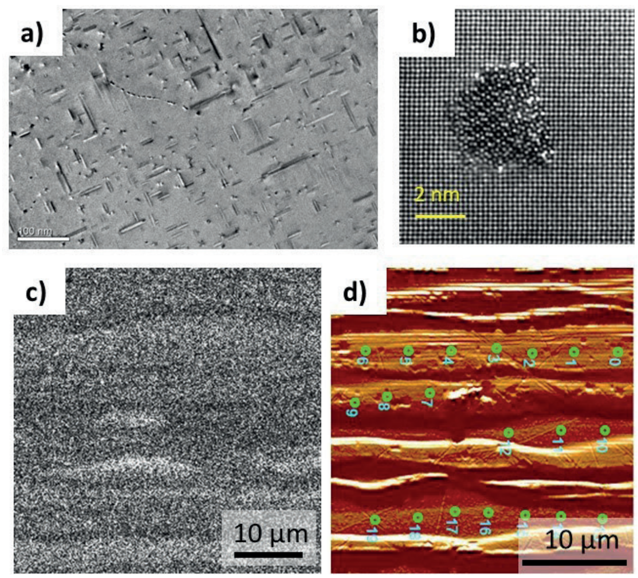


Figure 2. Example results from studies of 6005 with Ti and V. a) Overview TEM image of precipitates, b) HAADF-STEM to see the detailed structure of one precipitate, c) WDS mapping of titanium, d) height variations in etched sample with hardness measurements.

Task 1.2: Multiscale studies of materials joints
The multiscale microstructure and complicated microchemistry created when (dissimilar) materials are joined together require use of a different characterization techniques, as crystallographically and chemically complex phases typically form near joints and welds. PhD student Tor Inge Thorsen has 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 wire arc additive manufactured to thin walls. These walls have been characterized, and this is shown in Figure 3. The wall is porous, and 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 a nucleation site for Al. The orientation relationship with Al matrix and the presence of TiC nanoparticles in the center of these particles will be further investigated using focused ion beam (FIB) to prepare lamellas for the TEM.

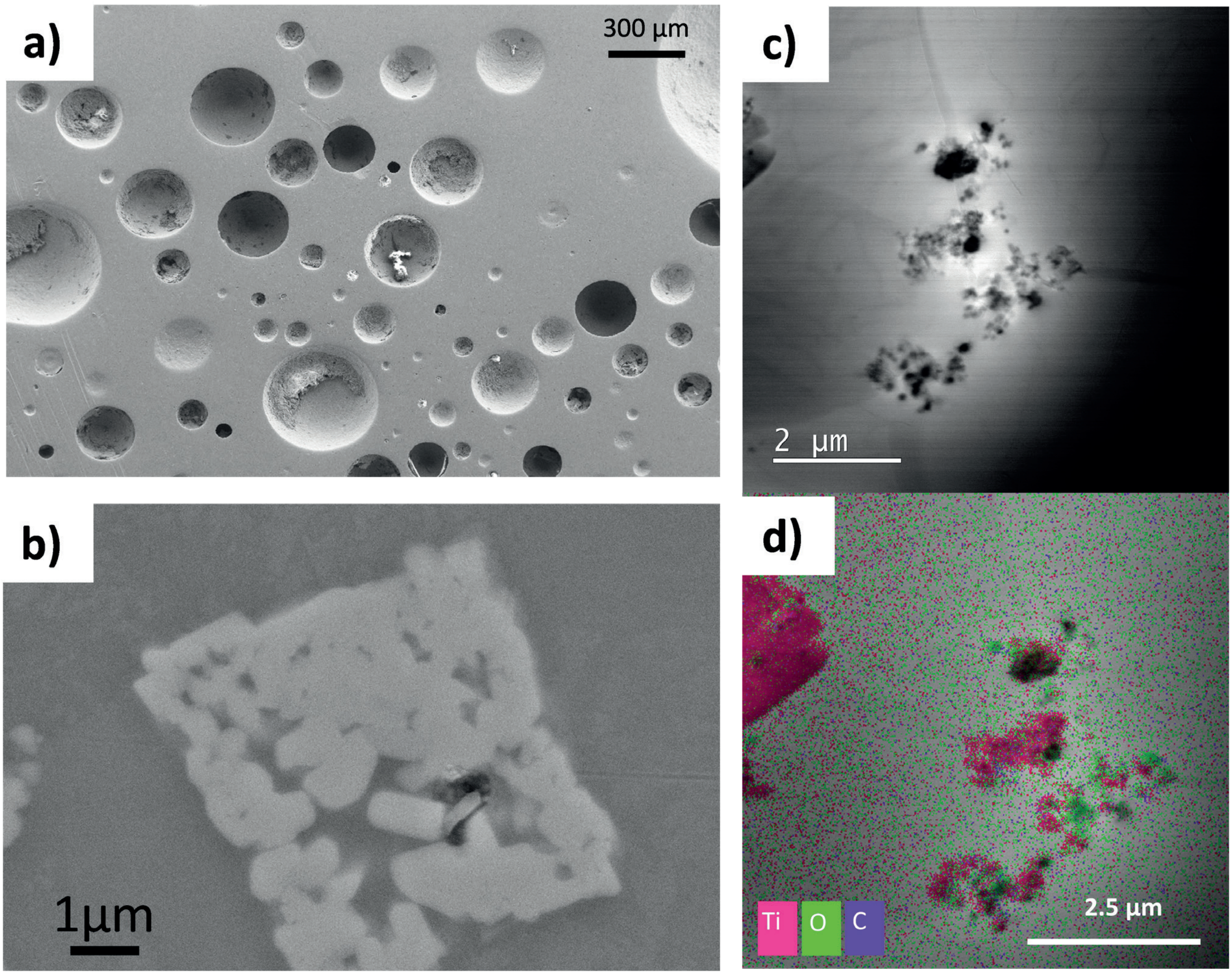


Figure 3. WAAM material (added TiC particles, screw extruded, and wire arc welded) studied at different scales. a) SEM image of pores formed in the welded material, b) SEM of micrometer sized particles around nanoparticles, c) TEM image of nanoparticles with d) corresponding EDS mapping.

RESEARCH AREA 2.
SCALE AND PROCESS BRIDGING METHODOLOGIES

RESEARCH AREA LEADER:
YANJUN LI
NTNU

CONTRIBUTIONS TO CENTRE OBJECTIVES

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

MAIN CHALLENGES TO BE MET

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

ACTIVITIES AND RESULTS IN 2022

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 2022.

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

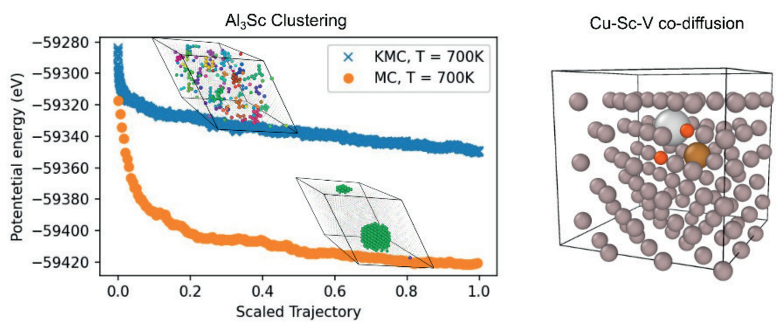


Fig. 1 KMC simulation for the formation of Al3Sc precipitates (left) and Cu-Sc-Vacancy complex (right)

diffusivity of impurities in relevant alloys (aluminium, steel, cast iron).
A Kinetic Monte Carlo (KMC) model recently developed at NTNU/SINTEF has been used to simulate the diffusion of Zr atoms and the precipitation of L12 structured Al3Sc precipitate in Al-Sc alloys. The simulation results have been validated with previous publications. The KMC model has also been applied to simulate the influences of excess vacancy on the formation and thermal stability of Vacancy-Cu-Sc-Vacancy complexes, showing that formation of such complexes can slow down the diffusion of Cu atom in aluminium matrix. The simulation results prove that the KMC model can be used to simulate the kinetics of atom clustering processes in the early stage of artificial aging treatment of 6xxx and 7xxx alloys.

The Temperature Dependent Effective Potential (TDEP) method based on DFT calculation has been applied to calculate the free energy of formation for the most important metastable precipitate η′ phase in Al- Zn-Mg alloys as a function of temperature. The variation of the atomic structure of the precipitate as a bulk phase or embedded in the Al matrix has been considered.

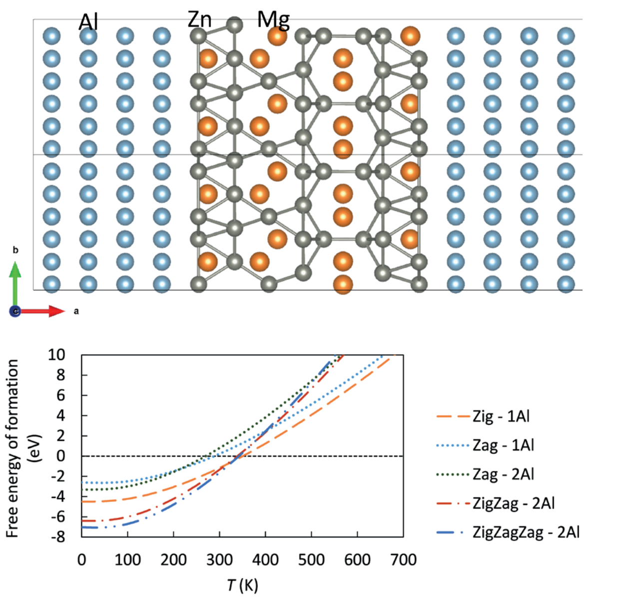


Figure 2. Atomistic models of η′ precipitates embedded in an Al matrix (left) were used to calculate the total free energy of formation (right) as a function of temperature, using the temperature dependent effective potential (TDEP) method.

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

RA2.2.1 The objective is to develop an advanced 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.

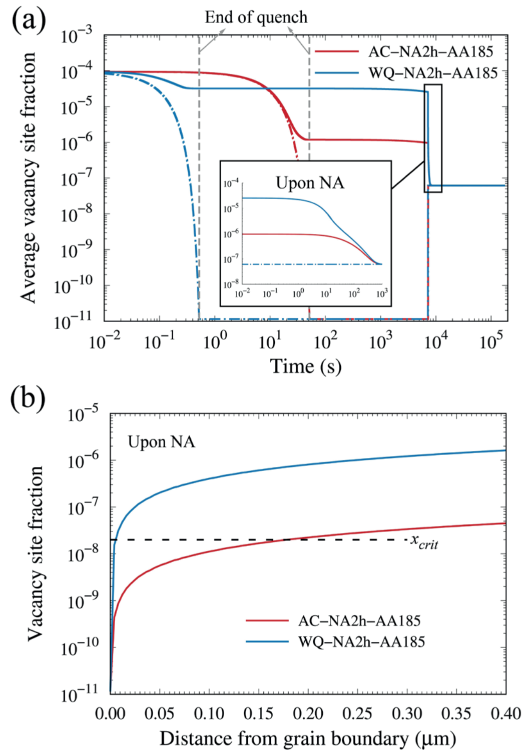


Figure 3 Calculated time evolution of excess vacancies in an Al-Mg-Si(-Cu) alloy during water quenching (WQ) and air cooling (AC) from 550 °C, natural aging (NA) for 2h, and subsequently artificial ageing (AA) at 185°C. (a) Evolutions of vacancy site fraction with time; (b) Comparison of the distributions of vacancy site fraction in the vicinity of GB after natural ageing

A Ph.D. student, Xuezhou Wang, started in the end of 2021 with research focus on further development of precipitation models for age hardening precipitates in aluminium alloys. In 2022, a preliminary modelling framework has been constructed to simulate the Mg-Si atom clustering process in the early stage of artificial ageing in an 6xxx aluminium alloy. The input binding energies are based on first principles DFT calculation. Multi-size classes and multi-energy classes of clusters are considered. At the same time, a numerical model has been developed to predict the spatial evolution of quenched-in vacancies during cooling and subsequent aging process. The annihilation of vacancies at grain boundaries and dislocations can be well predicted.

In RA2.2.2, the objective is to develop microstructure prediction models for solidification and heat treatments of recycling based aluminium alloys, cast iron, AM alloys and welding of dissimilar metals. The influences of impurity elements on the solidification path, defect formation and heat treatment response will be investigated.

In 2022, a grain size prediction model for AM process of aluminium alloys has been developed. In the model the influences of cooling rate, temperature gradient, size distribution and number density of inoculant particles on the nucleation and growth kinetics of grains have been addressed. The simulation results have been compared with experimental data; a good agreement is achieved. In collaboration with RA4, the grain size prediction model has also been used to calculate the grain size of welding zones of aluminium alloys.

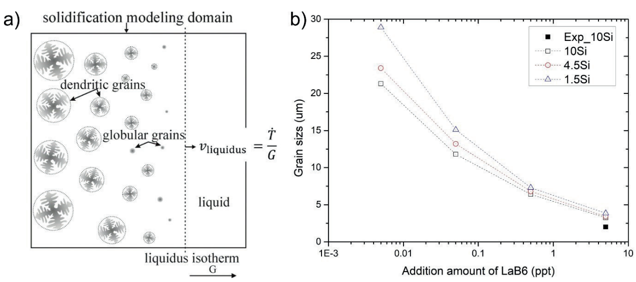


Figure 4: a) Schematic figure showing the solidification model with multiple grains under temperature gradient G. Nucleation and grain growth propagates from the left colder side towards the right hotter side. b) Grain size predicted by the developed model, in comparison to the experimental results for selective laser melting type additive manufacturing of Al-Si alloys inoculated with LaB6 particles.

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 research tasked is planned to start from 2023.

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 RA3, a research activity has been conducted to calculate kinetic multiple component phase diagrams, namely the influence of growth rate of primary phases on the values of partitioning coefficient K and liquidus slope m in phase diagrams. This is important for the solidification structure modelling of AM process. In 2022, a major research focus of RA2.4 was to develop a neural network method to achieve efficient and accurate parameterization of large amount of (up to millions) discrete data points in the kinetic phase diagrams. This method has been tested to create equilibrium/kinetic phase diagram data points.

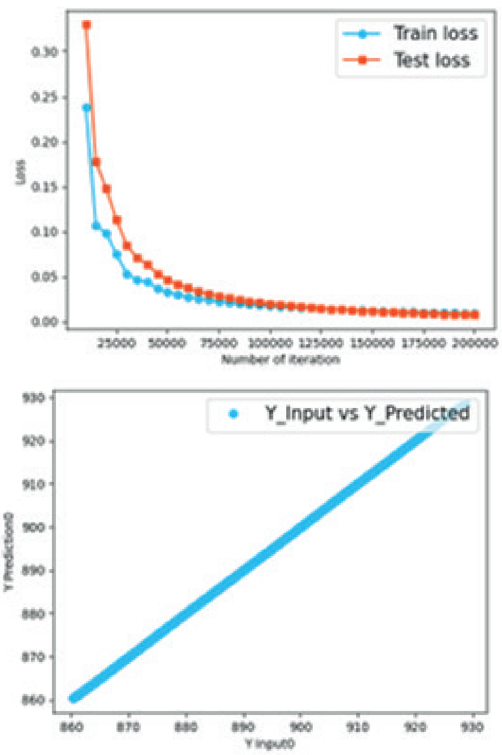
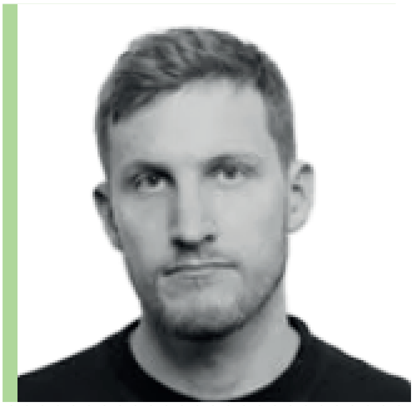


Figure 5: Parameterization results of Al-Mg-Si kinetic phase diagram

RESEARCH AREA 3.
SUSTAINABLE AND HIGH-PERFORMANCE MATERIAL DEVELOPMENT



RESEARCH AREA LEADERS:
EVEN WILBERG HOVIG
ASTRID MARTHINSEN
SINTEF
(FOR MOHAMMED M'HAMDI IN 2022)

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

MAIN CHALLENGES TO BE MET
- How to 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 2022
The research activities in this Research Area are organized in four main tasks. Main objectives, activities and results from 2022 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. The main activity of 2022 was to recruit a PhD candidate, which we unfortunately did not succeed with. The activity is postponed to 2023.

Task RA3.2: Compensation metallurgy and alloy design
The effect of using post-consumer scrap (PCS) in formulation of Al-Si foundry alloys was studied by casting AlSi10MnMg with different amounts of Al recovered from incinerator bottom ash. The purpose is to understand how impurities present in PCS will impact the microstructure, properties and castability of Al-Si foundry alloys. Effects of cooling rate was investigated by comparing sand mould castings with metallic mould castings. The resulting microstructures investigated by SEM and EDS, and hot tearing experiments were performed as an initial castability assessment. This work will continue in 2023, with further property evaluation and thermodynamic modelling to support experimental observations. Figure 1 shows the cast samples for various chemical and mechanical analysis (top) and SEM micrographs comparing the microstructure of AlSi10MnMg with (left) and without (right) added IBA-AL. The use of PCS

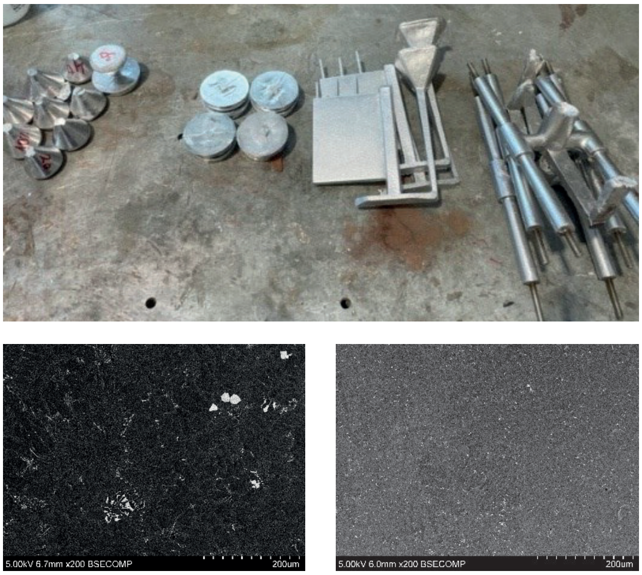


Figure 1 AlSi10MnMg with incinerator bottom ash (IBA) aluminium. Top: cast samples, Left: Microstructure with 30% added IBA, Right: Microstructure of reference sample.

in production of cast iron is an important contribution to the sustainability of the steel and cast iron industries. With increasing amounts of trace elements in steels utilized by the automotive and agricultural industry, the need to understand how trace elements affect the microstructure and properties of cast iron also grows. The influence of boron on the microstructure in various alloys of spheroidal graphite cast iron (SGI) both high and low in copper was studied. It was found that boron in concentrations of 70 ppm led to formation of brittle intercellular borocarbides. In pearlitic SGI high in copper, boron was observed to promote formation of ferrite, which softens the material and leads to a change in the growth morphology of the graphite spheroid surface. Boron was not observed to promote formation of ferrite in SGI low in copper. The investigation of the ferrite promoting effect of boron in SGI high in copper will continue in 2023. We aim to use TEM to investigate the change in surface morphology of graphite when boron is present in copper-alloyed SGI. Figure 2 presents elemental mapping of carbon and boron in SGI using secondary ion mass spectrometry (SIMS), showing that boron segregates to the graphite spheroids and also forming borocarbides in the matrix.

A microstructure modelling framework coupled with Thermo-Calc for prediction of microstructure features, properties and castability is also being developed in this task, with particular application towards recycling. In

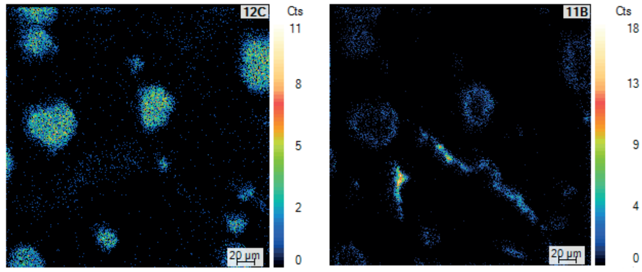


Figure 2 Elemental mapping of carbon and boron in SGI using secondary ion mass spectrometry (SIMS).

2022 this framework was extended by including multi-objective optimization, which can greatly accelerate the research on green alloy design by identifying alloys with the best compromise of a given set of objectives. This task will continue in 2023 with further property model development.

Task RA3.3: Powder materials and rapid solidification
Additive manufacturing (AM) is a trending field of interest in the industry. Challenging the established manufacturing processes and finding new ways to utilize the technology for innovative purposes. However, a bottleneck of the process among metal AM is the availability of materials for the process. With an increasing number of application areas and an urgency to expand available materials, this leads to the need for quick material development specifically targeted toward processes challenged by the effects present under rapid solidification conditions.

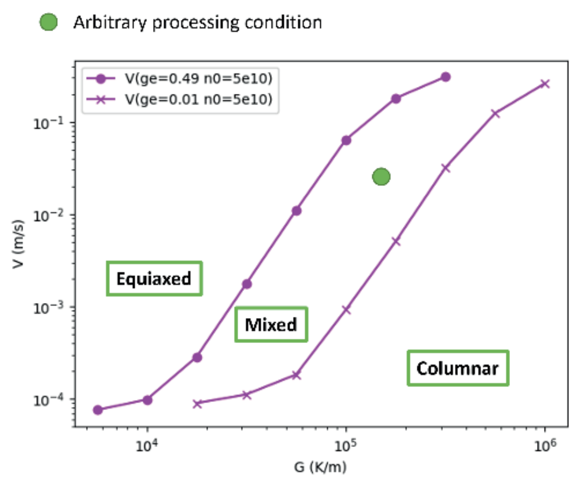


Figure 3 Predicted grain structure for different solidification rates and gradients coupled with processing conditions in powder bed fusion additive manufacturing.

The impact of microalloying and additions of nano-particles has been studied on the Al6061 and Al7075 alloy systems as a tool to refine the microstructure and reduce residual stresses in the microstructure. A model for a moving heat source has been coupled to a model for finding the Columnar to Equiaxed Transition (CET) for an alloy, which connects the experimental aspect of a laser heat source in Laser Powder-Bed fusion processes to what solidified microstructure can be expected. The combination of these two models creates a process map in which the microstructure can be tailored by either changing the composition of the alloy or the processing parameters to yield a processable material. Continuing in 2023, experimental work focused on laser-remelted alloys and investigating melt pool characteristics and microstructure will be used to supplement and verify the validity of the coupled models, starting with the AlSi10Mg alloy and then targeting more challenging systems. Figure 3 shows the coupling of the models, where an arbitrary processing condition is observed to be in the mixed region. The expected microstructure for this specific alloy processed under these parameters will therefore be a combination of equiaxed and columnar dendritic grains.

CET has been proven to be related to crack formation during additive manufacturing of metallic alloys. While previous SFI PhysMet activities and experiments have clearly shown that CET is tunable via its alloying elements and process parameters, a rigorous multi-component model to reveal the effects of multiple alloying components on CET is still lacking. In this activity we have developed a CALPHAD-coupled multi-component CET model to fill this gap. Figure 4 shows the predicted columnar to equiaxed transitions curve of original AA7075 and Si-rich AA7075. For a given temperature gradient, the addition of Si greatly reduces the critical interface growth rate for CET thus promoting CET. The prediction is in good agreement with the two alloys grain morphology shown with EBSD orientation map in Figure 5.

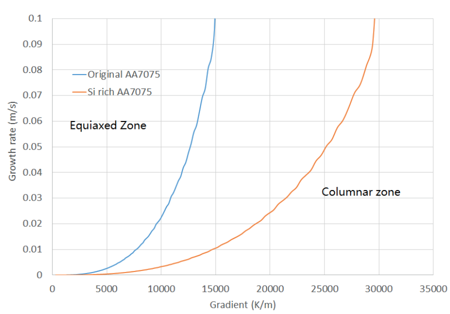


Figure 4 predicted columnar to equiaxed transition curves of original AA7075 and Si-rich AA7075.

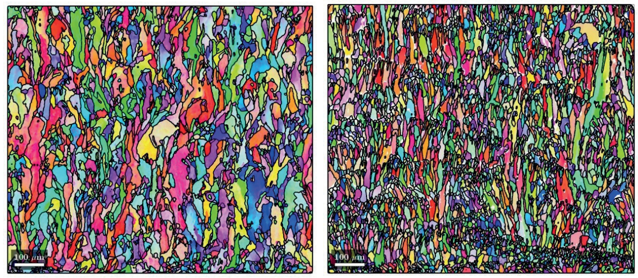


Figure 5 The EBSD orientation maps of (a) an original 7075 alloy sample and (b) Si-modified AA7075 alloy. The observed plane is parallel to the building direction. It is color-coded by inverse pole figure, and black lines indicate grain boundaries.

The effect of Si nanoparticles on the microstructure and laser reflectance of aluminium alloy 7075 was studied as a potential candidate to limit the crack formation associated with the alloy when processed by laser beam powder bed fusion AM. The hypothesis was that Si nanoparticles would act as nucleation sites and reduce the grain size. Samples were prepared by mixing pre-alloyed AA7075 with Si nanoparticles and Si microparticles for comparison. Arc melting was used to produce samples for microstructure evaluation, and the reflectance of AA7075 powder with different levels of added nanoparticles was determined using a photometer. The results show that adding Si to AA7075 will promote an equiaxed grain structure (as also shown with the CET model), but there was no evidence that adding Si as nanoparticles led to further grain refinement. The conclusion is that the nanoparticles melt during processing and can such only be considered as an alloying element. Adding Si as nanoparticles improves the reflectance for the relevant AM laser wavelengths, with a reduction in reflectance of up to 25%. This could reduce the energy requirement for the AM process step, but the overall energy consumption for a process including synthesis of nanoparticles must also be considered. Based on the findings, adding Si as nanoparticles is not considered as an effective way to improve the processability of AA7075, and other options will be explored in 2023 (non-stochiometric SiCx nanoparticles).

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 2022.

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) including laser beam/laser-arc hybrid welding.
- Develop laser-arc hybrid welding for thick steel and aluminium alloys (process-microstructures-properties) including numerical simulations.
- Develop laser assisted AM- and cladding processes.
- Establish process-microstructure-properties relations in laser cladding of metals with new powders (e.g., silicides).

MAIN CHALLENGES TO BE MET

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

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

Task 4.1 New wires for welding of aluminium alloys
Results on new aluminium wires
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 CO_2 emissions.

A virtual workshop related to joining of aluminium alloys was arranged in March 2022, to highlight and discuss possibilities, challenges and technical solutions. With over thirty attendees and excellent presentations from SINTEF, NTNU and the industry, SFI PhysMet plans to follow-up with a new joining-related workshop in 2023.

One of the outcomes from the workshop was the importance of developing high-strength aluminium wires to increase the mechanical integrity of the weld. Nanoparticle additions and grain refinement have been pointed out as co-operative mechanisms for a strong and tough weld. A steppingstone in this work is to understand the grain refinement in welding of aluminium, and the material interaction with nanoparticles. By using metal screw extrusion, several aluminium wires have been manufactured together with the master students Kjell Kirkbakk, Simen Skurdal and Steffen Samuelsen. A highly refined microstructure after welding has been obtained with additions of titanium and titanium carbide, as seen in the micrograph. The work performed in 2022 will work as a basis for exploring more complex aluminium systems in 2023.

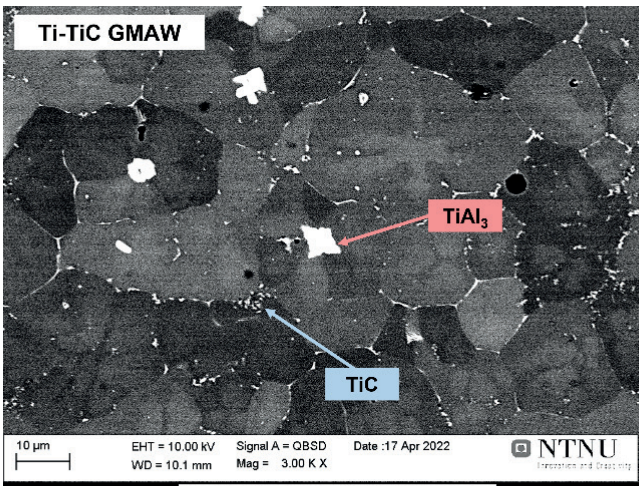


Figure 1: SEM micrograph of Al-Ti-TiC weld with refined grain structure.

Task 4.2: Welding of aluminium alloys and dissimilar metals
Results on multi-material joining for future battery applications

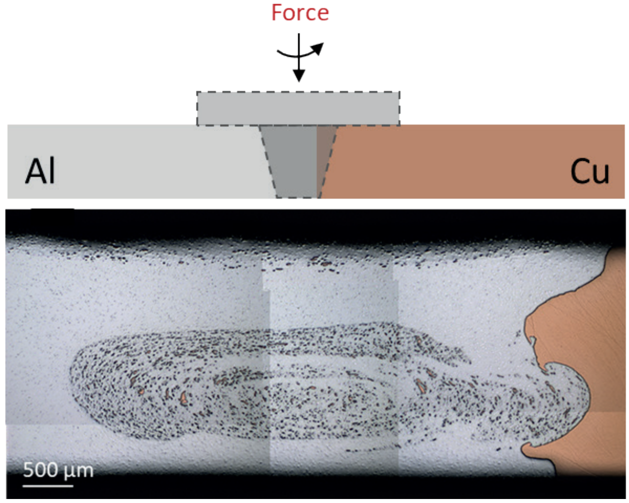


Figure 2: FSW joint produced from 6101-Cu.

Multi-materials allow us to jointly utilize the mechanical properties of each material. Aluminum-copper joints are of high interest in electrical applications, such as busbars in batteries or cables. By replacing copper with aluminum, the weight can be reduced while keeping the electrical conductivity high. Thus, finding suitable joining processes creating high quality joints is of high importance. The work in 2022 has focused on exploring the suitability of two different welding technologies; laser welding and Friction Stir Welding (FSW).

Preliminary studies have been performed, exploring the influence of process parameters on weld quality. FSW has so far produced the best results, providing sound welds with minor defects. The mechanical properties and microstructure of the FSW joints have been evaluated to optimize the process parameters further. From the trials, it is clear that copper and aluminium are challenging to join, due to their high thermal conductivity. The generated heat from the welding process is quickly dissipated, promoting the formation of welding defects. The temperature at the joint interface cannot be measured during welding. Thus, moving forward, temperature measurements obtained in the base materials will be combined with welding simulations to predict the temperature at the interface. The goal in 2023 is to better understand the relationship between the different process parameter, weld quality and interface temperature and thus produce joints with better quality.

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 low heat inputs 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 many welding defects and brittle phases may present in weld metal.

In 2022, most of research was performed using high strength 45 mm steel to achieve full penetration welds using double-sided welding technique. Using standard LAHW conditions and optimized parameters, high lath martensite volume fraction was achieved promoting high hardness due to lack of filler wire and rapid cooling rate in the root of weld metal. Two external methods were used to improve the quality of joints, i.e. preplaced filler and preheating prior welding. Preplaced filler wire mitigated lath martensite formation and increased volume fraction of tougher acicular ferrite (AF) due to increased number of non-metallic inclusions (NMIs). In combination with preheating, the volume fraction of AF was further improved, and hardness decreased. Based on extensive EDS studies, the cooling rate had a strong effect on size and chemical composition of NMIs. Standard impact toughness tests at –50°C, showed that the microstructural studies are in good agreement with the mechanical properties of welds (Bunaziv, Langelandsvik, Ren, Westermann, Rørvik, Dørum, Danielsen, Eriksson 2022). Micro computed tomography of welds revealed thin centreline solidification cracks in weld metal regardless welding parameters and conditions. Therefore, activities in upcoming 2023 will concentrate on understanding of formation and suppression of solidification cracking in deep welds.

Task 4.4 Laser cladding and surface treatment

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. In 2022, we have been discussing with industry partners to identify possible case studies and key technical challenges. We have found some relevant cases and possible technical solutions, which will be the basis for planning the activities in 2023 and beyond.

Task 4.5 AM by directed 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. In 2022, we have been discussing with industry partners to identify possible case studies and key technical challenges. We have found some relevant cases and possible technical solutions, which will be the basis for planning the activities in 2023 and beyond.

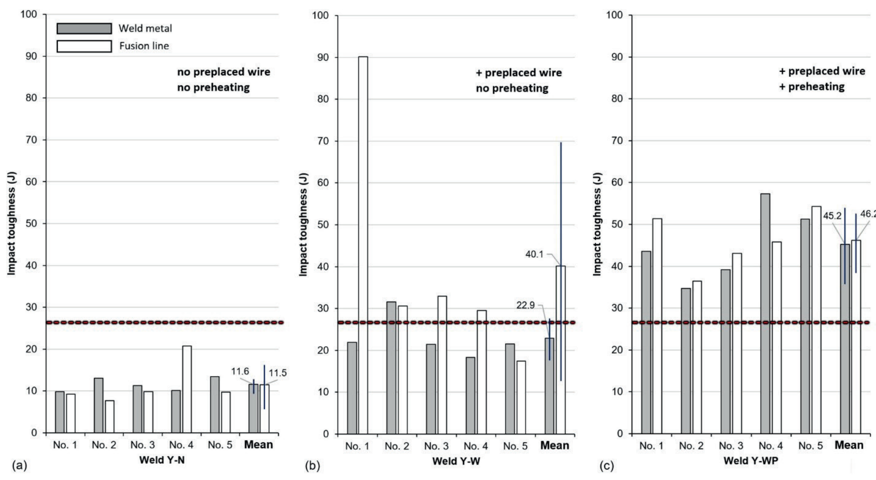


Figure 3. CVN impact toughness values conducted at −50 °C of each individual sample (denoted as no. 1—5) and mean result for (a) weld Y-N, (b) weld Y-W, and (c) weld Y-WP. Minimum acceptable toughness value of 27 J is indicated by red dashed line.

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.

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

Task 5.1: Platform design
This task focuses on the design of a digital platform for the centre that will allow to document and seamless connect results from advanced characterisation, experimental testing, data processing and modelling from electronic to continuum scale. Surrounding projects and other target users will also be invited to ensure that the platform will expand after the end of the SFI and serve as a national digital hub for innovation and collaboration within physical metallurgy. An important part of this task is to create a domain ontology for metals and alloys, focusing on the needs for RA1-RA4. Close collaboration with international 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.
Activities in 2022:
- Architecture design of the PhysMet platform based on the user stories:
  - Reviewed possible data catalogue open-source solutions, Dataverse chosen for testing (see Figure 1)
  - Investigated possibility to connect to multiple solutions for data storage (Azure and on-premises).
- Investigated applicability of DLite approach to represent TEM microstructure data and related alloy and heat treatment.

- Organised some dedicated meetings to discuss user stories, wishes and requirements with individual industry partners.
- Continued development of the microstructure domain ontology and contributed to Additive Manufacturing ontology based on ASTM standard terms definition.
- Strong involvement in EMMC task groups to influence and benefit from the developments at EU level. Application of H2020 OntoTrans methodology and tools for physical metallurgy

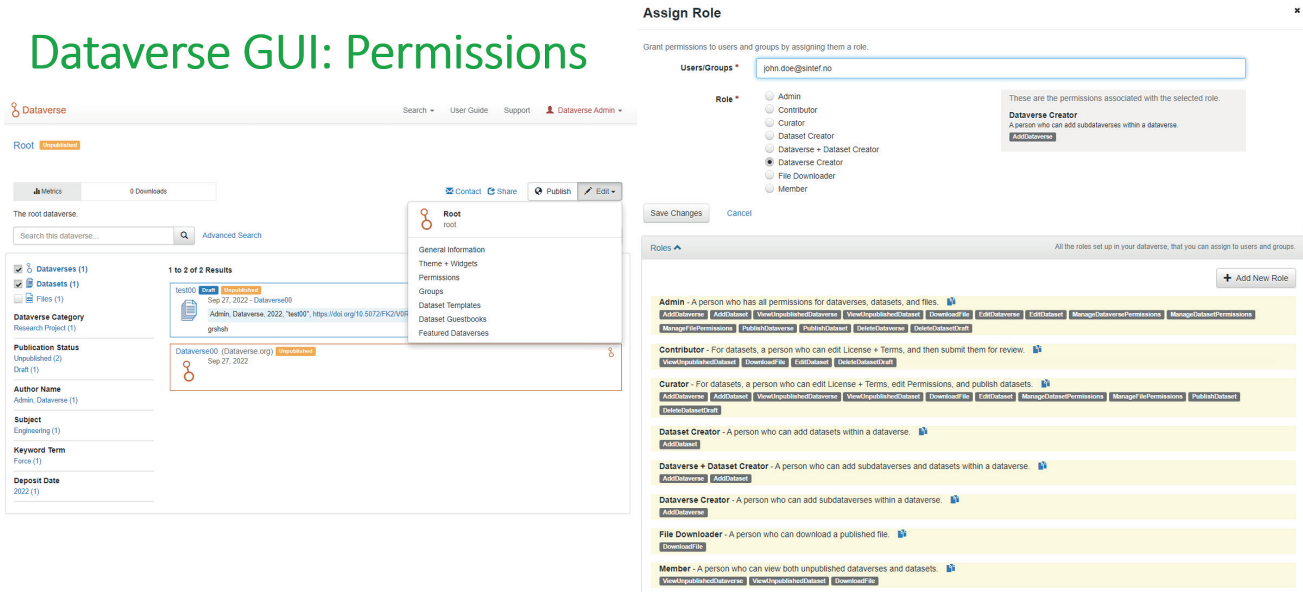


Figure 1. Dataverse roles definitions and user interface

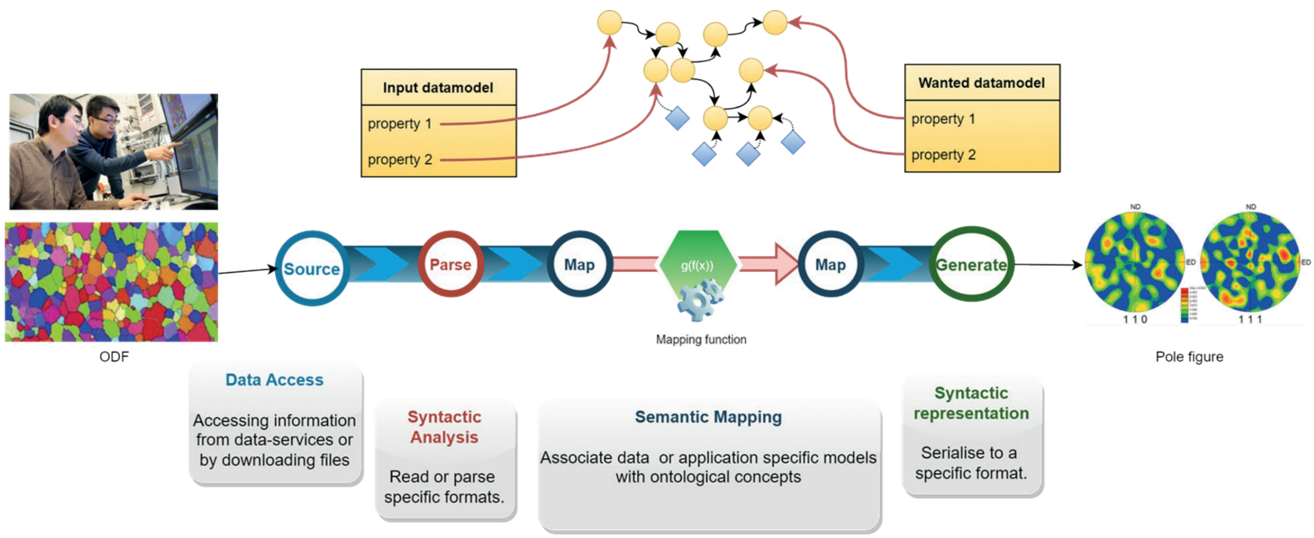


Figure 2. How concepts and technology developed in EU projects can be utilised to set up reusable pipelines for FAIR data handling and seamless connection of instruments, models and tools that have never been designed to communicate with each other.

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.
Activities in 2022:

- Tested Dataverse solution (chosen in Task 5.1) locally out-of-the-box (without new developments).
- Defined metadata fields for simple description of a numerical model and create a database to store and search model information.
- Tested Amazon S3 solution deployed on SINTEF premises as an object store backend.
- Developed and tested data models to store precipitates measurements and simulate the material strength (in collaboration with KSP SumAl)

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 in 2022:

- Promoted the use of the PhysMet Platform to strengthen the metallurgy environment in Norway.
- Gathered and communicated expected usage and requirements of the platform.
- Provided "success stories" demonstrating the platform.
- Organised user meetings.
- Organized a webinar on cyber security in collaboration with SFI Manufacturing and SFI NORCICS
- Presented SFI PhysMet and RA5 results at National and International conferences and meetings:
  - Digital Transformation, May 19, 2022
  - CaNAl workshop, June 14-16, 2022
  - ICAA18, 4-8 Sep, 2022
  - Dierk Raabe seminar, Nov 17, 2022
- Published a selected set of web demos developed in SFI PhysMet on PhysMet RA5's website (Figure 3).
- Implemented a set of demonstrations of technology and concepts:
  - SumAl WebAPP – web application for storing data on precipitate and strength calculation.
  - QRsamples – description of a sample, store the data, and generate a QR code to provide a link to data.
  - Models WebAPP – web application to search microstructure models developed at SINTEF and NTNU and display a short description.

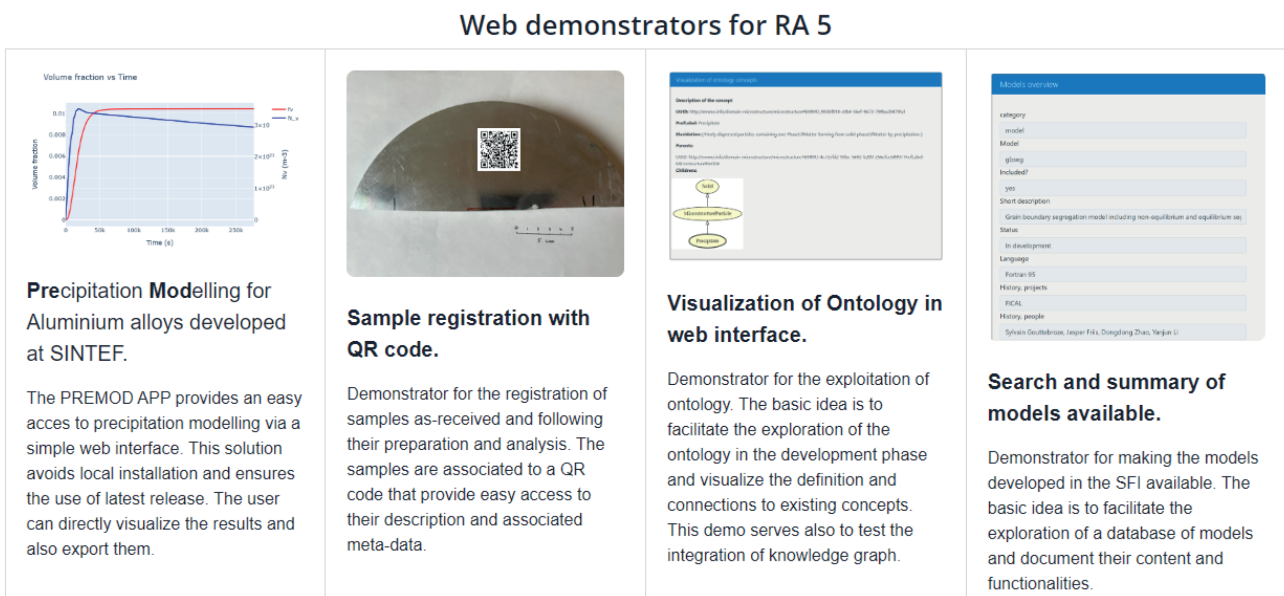


Figure 3. Web demos made available on PhysMet's website (https://folk.ntnu.no/friisj/webdemos/).

OBITUARY - HANS JØRGEN ROVEN

Professor Hans Jørgen Roven, died on 20 September 2022, aged 64, after a long illness.
Hans Jørgen Roven graduated as Master of technology, in physical metallurgy from former NTH in 1982. After graduation he worked one year at Aker Stord, before he came back to SINTEF and he became Dr. Techn. at NTH in 1989. He was employed as associate professor at NTH/NTNU in August 1990, and he was appointed professor at the same place in 1993. His research interests included physical metallurgy of light metals, Severe Plastic Deformation (SPD) nanostructuring of metals, novel forming processes, recycling, fatigue and micro-/nanostructure characterization of materials and their relations to macroscopic mechanical properties.
Throughout his entire academic career, Roven worked closely with Hydro Aluminium and was an active participant in several of Hydro's foreign initiatives to establish contact and enter into formal agreements between Hydro, NTNU and local universities and research institutions. This included cooperation with top universities in India and in the US, and later also China and Qatar. Roven was for a period visiting professor at Shanghai Jiao Tong University and later also at Qatar University. For his long and extensive commitment to internationalization of research and education at NTNU, Roven received the Internationalization Award at NTNU in 2013.

As an employee at NTNU, he was as a very important partner also for Norwegian industry, and with his visions and innovative ideas he helped develop new industrial processes. An example of such an innovation was the development of a so-called screw extruder for metals and in particular aluminium, in a long-lasting collaboration between NTNU and Hydro (patented in 2008). The screw extruder, currently located at NTNU is a second generation, medium scale experimental extruder.
This apparatus has paved the way for a new full scale pilot extruder recently built at Hydro Aluminium at Sunndalsøra and now being tested on an industrial scale.

Hans Jørgen was an active driving force for SFI PhysMet and had many exciting and innovative ideas for material and process development, which he wanted to further develop in the SFI, especially related to the use of screw extrusion, among other things, for solid-state recycling (i.e. recycling without remelting) and for new composite materials with new and improved properties. Unfortunately, due to serious illness over the last years, he never got to realize his ideas.
Colleagues at NTNU and SINTEF have lost an extremely competent and good colleague and Norwegian industry a very important partner. May he rest in peace.

Friends and colleagues at NTNU, SINTEF and Hydro.

EDUCATING THE NEXT GENERATION OF PHYSICAL METALLURGISTS

Education of students is an important ingredient of an SFI centre. A vital part of NTNU's mission is education and training of master and PhD students. SFI PhysMet gives a valuable contribution in this respect. During the eight years centre period, we will recruit and educate numerous PhD candidates, postdoctors and master students. Our students are exposed to scientific questions on topics highly relevant for the industrial partners. In fact, many of the student projects are designed by industrial partners to meet their specific challenges and need for new knowledge. Through the close collaboration between the university, the research institutes and the industry partners, the candidates learn the interplay between solving industrial questions and applied research, as well as formulating basic scientific questions based on industrial needs.

There are multiple opportunities for students to connect to the centre and to our industry partners. Motivated students are invited to complete their master projects in collaboration with the SFI, and some of the projects offer summer job as a kick-start to the project/MSc work.

The project students present their results in a seminar each year. In 2022, we had 19 student presentations related to physical metallurgy and several of them where directly connected to the SFI-PhysMet centre.

We encourage talented and motivated master students to continue their academic career and apply for a PhD position at the SFI. In the fall semester we organized several recruitment meetings to give the master students information on the benefits of having a PhD and the numerous PhD project opportunities.

Master student project presentations 1.12.2022. Photo Marisa Di Sabatino

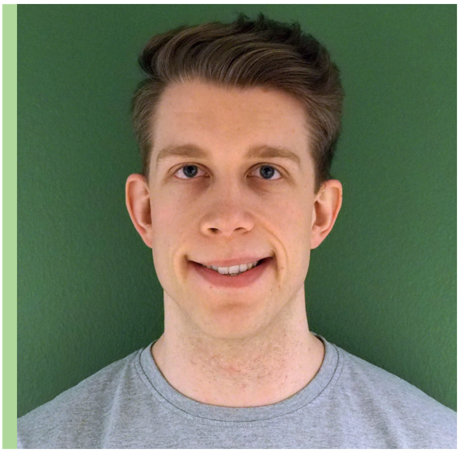
Picture from a recruitment meeting for master students: Why should you get a PhD? Photo: Kari Håland

THE SFI PHYSMET MASTER STUDENTS IN 2022 HAVE BEEN:

Student	Title	Supervisor	Partners involved and co-supervisors	Summer job
Daniel Bojescul Johannessen (Norway)	The effect of solvent on the silicon powder properties	Marisa Di Sabatino	Leander Michels and Kenneth Friestad (ELKEM)	YES
Joshua Kayode Adegbo (Nigeria)	Effect of cooling rate on the microstructure and chemistry of ferrosilicon alloys	Marisa Di Sabatino	Leander Michels and Bjørn Rune Henriksen (ELKEM)	YES
Martin Fast Buen (Norway)	Grain Refinement of Austenitic Steels	Yanjun Li	Leander Michels and Trygve Mauset (ELKEM)	YES
Steffen Samuelsen (Norway)	Production of aluminium nano-composite welding wires	Jens C. Werenskiold	Geir Langelandsvik (SINTEF)	YES
Vegard Bjerve (Norway)	Grain refinement of foundry aluminium alloys	Yanjun Li	Petter Åsholt (HYDRO)	YES
Simen Skurdal (Norway)	Characterization of hybrid-welded metals	Jens C. Werenskiold	Geir Langelandsvik (SINTEF)	YES
Hedda Øye (Norway)	Investigation of the Effects of Additions of Vanadium and Titanium to 6005 and 6008 Aluminium Alloy	Randi Holmestad	Eva Moørtsell (HYDRO), Calin Mariora og Sigurd Wenner (SINTEF)	YES
Martin Lesjø (Norway)	The effect of cooling rate from solution heat treatment on ductility in Al-Mg-Si crash box alloys	Knut Marthinsen	Lars Lodgaard og Yngve Langsrud (BENTELER), Randi Holmestad (NTNU)	
Herman Hansen (Norway)	Development of aluminium alloys with superior properties for additive manufacturing	Yanjun Li	Yijiang Xu og Eivind Øvrelid (SINTEF)	
Lavrans Thorstensen (Norway)	Screw Extrusion technology and Al-alloys	Trond Furu	HYDRO, Bjørn Holmedal and Ole Runar Myhr (NTNU)	
Harald Skar (Norway)	Develop aluminium alloy components with super properties by additive manufacturing process	Yanjun Li	Yijiang Xu og Eivind Øvrelid (SINTEF)	
Kjell M. Kirkbakk (Norway)	Welding thread and screw extrusion	Jens C. Werenskiold	Geir Langelandsvik (SINTEF)	

OUR PHD CANDIDATES

Five talented PhD candidates have been recruited to SFI PhysMet, and more will start in 2023. Four of the PhD candidates are working in the SFI locations in Trondheim and one candidate is an “institute PhD” working at SINTEF in Oslo. We look forward to following their scientific progress in the years to come!

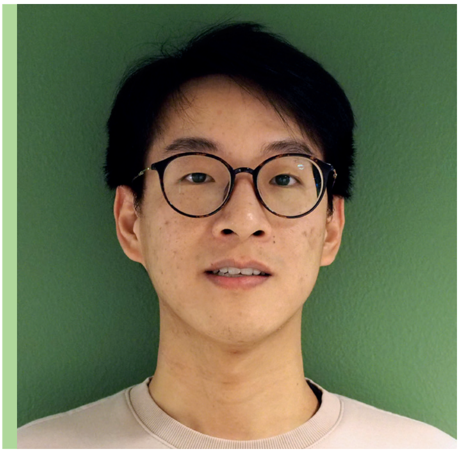


PHD STUDENT
ANDREAS VOLL BUGTEN

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

Short desctiption: To understand the role and effect of trace elements on the microstructure and properties of ductile cast iron as more recycled steel scraps are added in the industry to reduce costs and CO_2 footprint.

Supervisor: Prof. Marisa Di Sabatino



PHD STUDENT
XUEZHOU WANG

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

Short desctiption: Development of an advanced precipitation model for AA6xxx alloys with significantly improved nucleation kinetics of precipitates in both bulk of grains and at grain boundaries. To address the influences of impurity elements and vacancies on the age hardening response of recycling-based aluminium alloys.

Supervisor: Prof. Yanjun Li

PHD STUDENT
TOR INGE THORSEN

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

Short desctiption: TEM studies of aluminium welds where nanoparticles have been added to increase the strength of the welds. The welded regions are the weakest link in the aluminium product. I will add nanoparticles and study how this can improve the material.

Supervisor: Prof. Randi Holmestad

PHD STUDENT
INGVILD RUNNINGEN

Research topic: Development of nanoparticle-containing aluminum filler wires

Short desctiption: Development of nanoparticle-containing aluminum filler wires for fusion welding by molten salt-assisted flux casting, extrusion, and cold drawing. Slimmer and more environmentally friendly structures may be manufactured if the weakest link behavior in aluminum fusion welding can be solved.

Supervisor: Prof. Ida Westermann

PHD STUDENT
MAGNUS REIERSEN

Research topic: Material development and microstructure control for powder based additive manufacturing processes

Short desctiption: To study material development and microstructure control for powder based additive manufacturing (AM) processes with the ambition of expanding the material range for AM including the use of recycled (powder) materials

Supervisor: Prof. Mohammed M'hamdi

PROFESSOR DIERK RAABE APPOINTED HONORARY DOCTOR AT NTNU

Professor Dierk Raabe was appointed Honorary Doctor at NTNU at the NTNU Doctoral Awards Ceremony November 18th. Dierk Raabe is a Director at Max Planck Institute for Iron Research in Düsseldorf, Germany, and he is also a Professor at RWTH Aachen. His interests are in sustainable metallurgy, hydrogen, microstructures, alloy design, computational materials science and atom probe tomography. He has received the Leibniz award and two ERC Advanced Grants. Raabe is also a member of the SFI PhysMet Scientific Advisory Committee.

The appointment of Dr. Raabe as Honorary Doctor will be a valuable asset for NTNU and facilitate and strengthen collaboration with Prof. Raabe and his colleagues at the Max-Planck Institute within areas of great importance to NTNU, SFI PhysMet and our industrial partners.

Dr. Raabe's research combines experiments and simulations to study thermomechanical processes in materials. In recent years, Dr. Raabe has also taken a strong interest in how materials science and technology can contribute to the development of more sustainable metal production and sustainable metal-based materials and products. This includes primary production methods with reduced energy consumption and CO_2 emissions, more recycling, scrap-based alloy development, as well as materials with better properties and a longer service life.
He recently was the prime author of a comprehensive review in Progress in Materials Science: Making sustainable aluminum by recycling scrap: The science of "dirty" alloys, which addresses these issues along the whole process chain.

NTNU Rector Anne Borg, Dr. Raabe and Prof. Knut Marthinsen at the NTNU Doctoral Awards Ceremony November 18th 2022. Photo: Thor Nielsen

NTNU Doctoral Awards Ceremony in Aulaen, November 18th 2022. Photo: Thor Nielsen

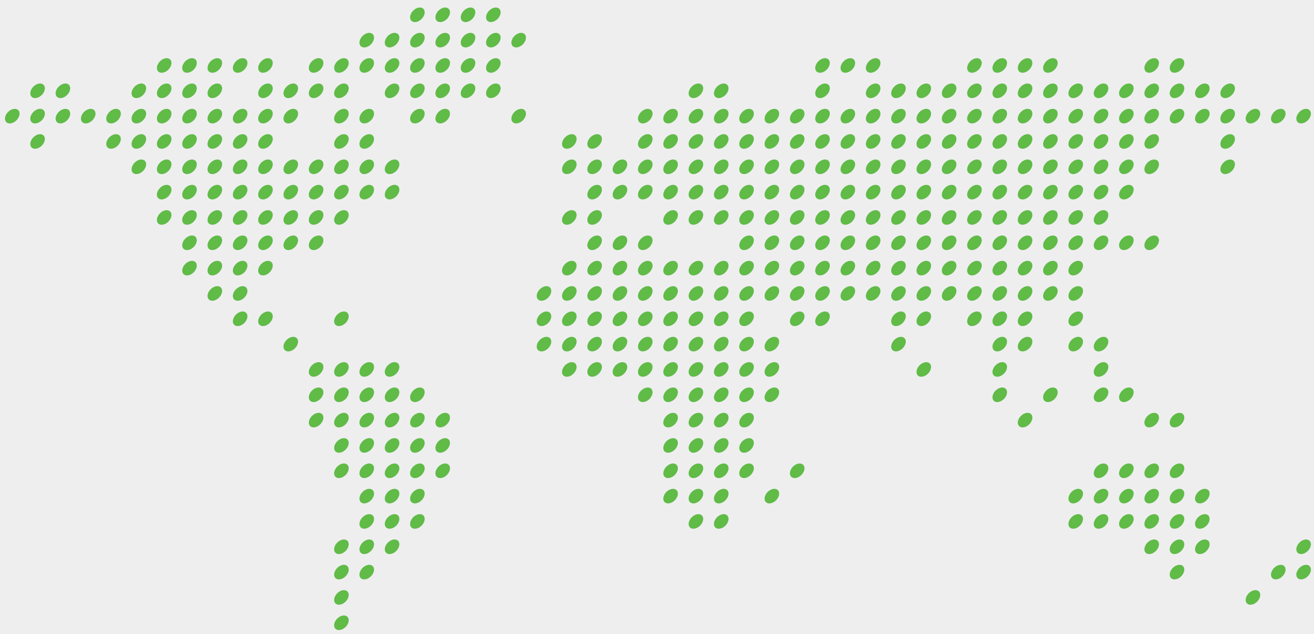
RAABE SEMINAR ON SUSTAINABLE MATERIALS AND MATERIALS PROCESSING

The first day of Professor Raabes visit SFI PhysMet organized an all-day seminar on Sustainable Materials and Materials Processing. The seminar opened with a guest lecture by Dr. Raabe, on the topic 'Sustainable metals', with focus both on steel making and aluminium. This was followed by talks from NTNU and SINTEF researchers within the field of material science and engineering, partially in the context SFI PhysMet, but also a broader presentation of the experimental and modelling activities in the physical metallurgy environment at NTNU and SINTEF, with a special attention to sustainable materials development and processing. The seminar also included a presentation from SFI CASA, in which several of the key researchers in SFI Physmet have been involved. More than 50 researchers, students and industry partners attended the seminar.

We are looking forward to the further collaboration with Professor Dierk Raabe and his colleagues at the Max Planck Institute for Iron Research.

Guest lecture by Dierk Raabe at the seminar November 17. Photo; Kari Håland

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 (keynote/plenary lectures) at major international scientific conferences in our fields.
The academic communities in SFI PhysMet already cooperate with several leading universities and research environments in Europe, Japan, China, and the USA in ongoing border zone projets, as well as in strategic education and research collaboration through several INTPART applications.

INTPART PROJECTS
International Materials Science and Engineering education and research network (IntMat) (2020-2024). Project leader is Prof. Ida Westermann, NTNU. Partners: 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 (Sept. 2021-Aug. 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 joint publications.
Norwegian-Japanese Aluminium alloy Research and Education Collaboration - Phase-2 (2019-2023) Project leader is Prof. Randi Holmestad. Partners: NTNU, SINTEF, Hydro, University of Toyama, Tokyo Tech., Kyushu University, Japanese Aluminium Association, and Toyama Aluminium. Three Japanese students from Tokyo Institute of Technology and Kyushu University have been visiting the Department of Physics this fall for 3.5 and 6 months respectively to do TEM on aluminum alloys, linked to the INTPART project with Japan.

CONFERENCES AND SEMINARS

An important event for many SFI PhysMet researchers during 2022 was the 18th International Conference on Aluminium Alloys (ICAA18) in Toyama, Japan, 4.-8. September 2022. This conference is organized every second year and gather researchers from academia and industry to discuss the latest news related to aluminium alloy development and technology. The SFI PhysMet community was well represented by one plenary lecture, two key-notes as well as several other oral and poster presentations. While most of us only participated online, PhD student Tor Inge Thorsen from SFI PhysMet was present in-person.

On April 26, SFI PhysMet, together with SFI Metal Production and Inst. for Materials Science and Engineering, hosted a one-day seminar with Trade mission 'New metallurgy', a delegation from region Wallonia in Belgium, consisting of several industrial companies, research institutes and universities that visited us to explore the possibility of academic cooperation, and especially with regard to project opportunities within Horizon Europe.

On 14-16 June 2022, SFI PhysMet together with SFI Metal Production, co-organized an aluminum summer school at Gløshaugen (and Zoom). The Summer School was part of the INTPART project CaNAl, with Professor Kristian Etienne Einarsrud as project manager. CanAl aims to promote and facilitate joint research and education related to aluminium between Canada and Norway.

The TEM Gemini Centre (headed by Prof. Randi Holmestad) organized 21-23 June the ESTEEM3 Workshop 2022 *Electron diffraction for solving engineering problems*, with 26 participants from eight different countries – in addition to four invited speakers from abroad. Lectures were held by Paul Midgley, Stefan Zaefferer, Tina Bergh and Magnus Nord. Topics included Introduction to electron diffraction in the (S)TEM, EBSD

PhD students Tor Inge Thorsen and Tina Bergh arriving in Toyoma, Japan, September 2022. Photo: Christoph Hell

PhD Håkon W. Ånes leading coding and microscopy lab on the use of data analysis software HyperSpy, pyxem and kikuchipy. ESTEEM Workshop June 2022. Photo: Randi Holmestad and orientation microscopy. Coding and microscopy labs were organized by locals and others encompassing use of HyperSpy, pyxem and kikuchipy with Python coding on own computers and open-source software/GitHub.

The Kavli prize for 2020 was awarded to four recipients (Harald Rose, Knut Urban, Max Haider and Ondrej Krivanek) for the development of aberration corrected TEM. After the award ceremony in Oslo, they came to Trondheim and gave talks in NTNU Nanolabs seminar. At the invitation of Prof. Randi Holmestad, the laureates agreed to stay one day extra in Trondheim to visit the TEM Gemini Centre, and on Saturday they got a guided tour of the NORTEM Trondheim node and participated in a mini seminar with the members in the TEM Gemini Centre at NTNU and SINTEF.

Prof. Holmestad, Prof. Marthinsen and Senior Research Scientist Marioara, SINTEF, are affiliated with the Center for Advanced Materials Research and International Collaboration (CAMRIC), Univ. Of Toyama, Japan, and are respectively chair (RH) and members of the Advisory Board for International Science Network (i-MSN), in the same place. In the period 24 September – 8 October, all three held lectures at the 7th CAMRIC Forum (with national (Japanese industry and academia) and international participation) and lectures for students in materials science and engineering at the Univ. of Toyama.

Prof. Marthinsen is 'Guest Professor' at the Univ. of Chongqing, China, as part of the Chinese '111' Excellence program. In the autumn of 2022, he has given guest lectures for students and staff at Chingqing University and Nanjing University of Technology, as well as at Jilin University.

Group picture of members of the TEM Gemini Center and the Kavli price winners. Photo: Inger-Emma Nylund

Guest researcher Paul Sanders visited Elkem, Kristiansand, during his stay at SFI PhysMet. From left: Elkem host Leander Michels, Professors Randi Holmestad and Knut Marthinsen, and Paul Sanders. Photo: Leander Michels

Professors Dierk Raabe and Knut Marthinsen at the honorary doctorate award, November 2022. Photo: Thor Nielsen

INTERNATIONAL VISITS AND GUEST RESEARCHERS TO SFI PHYSMET

At the invitation of Hydro Aluminium, Prof. Paul Sanders, Michigan Tech, spent a 6-month research stay at NTNU and Hydro in the fall of 2022. Prof. Sanders is an internationally recognized and well-merited researcher in process and alloy development for aluminum, cast iron and nickel alloys, and aluminum and steel alloys for wire-based additive manufacturing. One goal of this stay is to revitalize the previously institutionalized collaboration between NTNU, Michigan Tech. Hydro Aluminium in the USA (Holland) and Norway, among other things, to ensure recruitment to Hydro's US operations. During his stay in Norway, Prof. Sanders also established good relations with Elkem, Kristiansand, which forms the basis for further cooperation.

Within the production of wire for aluminum welding, SFI PhysMet has established cooperation with Spanish EURECAT. PhD student Alejandra Torres had a 3-month visiting research stay in SFI PhysMet in the spring of 2022 where she studied wear and friction in the production of welding wire containing nanoparticles.

Prof. Dierk Raabe, director of the Max Planck Institute of Iron Research and professor at RWTH Aachen, who is a member of the SFI PhysMet's International Scientific Advisory Board, was officially awarded an honorary doctorate at NTNU on 18 November 2022. In connection with this, we had a full-day academic seminar on 17 November with the theme Sustainable Materials and Materials Processing, with over 50 participants from NTNU, SINTEF and industry.

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 new 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 European Materials Modelling Council (EMMC) and leads the focus area within interoperability.

COMMUNICATION AND DISSEMINATION ACTIVITIES

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

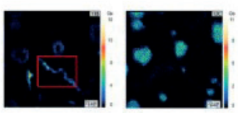
An important arena to reach out to the public and making information easily available is the centre website **www.ntnu.edu/physmet/**

From November 2022 we have published a news feed on the centre website.

News

A common language for data from material science

January 30, 2023 Researchers from SFI PhysMet develop ontologies as a common language for describing and connecting data from different sources. Read more in this article published in Dagsavisen. The article gives a brief historical background to ontologies and points out resent applications for new innovations.



SFI PhysMet Scientific Highlights from 2022

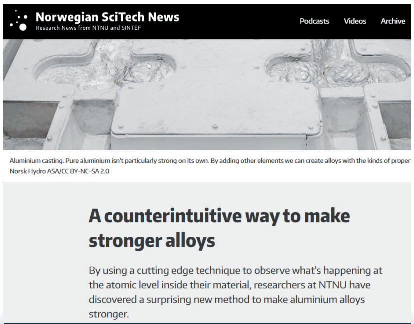
December 19, 2022 2022 was a prosperous year for our centre, in terms of scientific results and potential innovations. We have made short presentations of some of the recent scientific achievements made in the various research areas. Read more here.

Professor Dierk Raabe appointed Honorary Doctor at NTNU

November 30, 2022 Professor Dierk Raabe was appointed Honorary Doctor at NTNU at the NTNU Doctoral Awards Ceremony November 18th. Dierk Raabe is a Director at Max Planck Institute for Iron Research in Düsseldorf, Germany, and he is also a Professor at RWTH Aachen. His interests are in sustainable metallurgy, hydrogen, microstructures, alloy design, computational materials science and atom probe tomography. Read more

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 where researchers from our centre have been interviewed or written popular science articles disseminated in Norwegian newspapers.


Norwegian SciTech News
Research News from NTNU and SINTEF
Podcasts Videos Archive

Aluminium casting. Pure aluminium isn't particularly strong on its own. By adding other elements we can create alloys with the kinds of proper
Norsk Hydro ASA/CC BY-NC-SA 2.0

A counterintuitive way to make stronger alloys

By using a cutting edge technique to observe what's happening at the atomic level inside their material, researchers at NTNU have discovered a surprising new method to make aluminium alloys stronger.

Interview of Professor Yanjun Li (NTNU) in Norwegian SciTech News 9.2.2023


Dagsavisen Nyheter • Debatt • Kultur • Pluss

DEBATT

Nå skaper vi det nye dataspråket

Språklig logikk med utspring i oldtidens filosofi hjelper oss nå i jakten på grønne fremtidsmaterialer.

Chronicle in Dagsavisen 26.11.2022 by Francesca L. Bleken, Jesper Friis and Inga G. Ringdalen (SINTEF)


Innlegg: La lettmetall hjelpe det grønne skiftet

Klimaet fortjener flere konstruksjoner i aluminium. Men da må innkjøperne se forbi anskaffelseskostnader og bry seg om de samlede livsløpskostnadene i stedet.

2 MIN | PUBLISERT: 20.01.22 — 15.57 | OPPDATERT: ETT ÅR SIDEN

Chronicle in Dagens Næringsliv 20.01.2022 by Mohammed M'Hamdi and Geir Ringen (SINTEF).

WEBINAR SERIES

From 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 10-11	*Screw extrusion – a presentation of technology and examples of methods and results*	Professor Hans Jørgen Roven, NTNU
Febr 18 14-15	*Metal powders: how to make them, what we should measure about them and how*	Assistant Professor Christopher Hulme, KTH, Sweden
March 23 10-11	*Glow discharge mass spectrometry (GDMS) and glow discharge optical emission mass spectroscopy (GDOES) - introduction and application examples*	Prof. Marisa di Sabatino and PhD Sergey Khromov, NTNU
April 21 10-11	*Strategies for microstructure control during wire and arc additive manufacturing*	Assoc. Prof. João Pedro Oliveira from Nova University, Lisbon
May 18 15-16	*High Energy x-ray Microscopy Insights into Additive Manufacturing*	Professor Anthony Rollett, Dept. of Materials Science and Engineering, CMU, US
Sept 7 10-11	*Optimization of a nickel-based alloy for improved resistance to weld solidification and strain age cracking using multi-objective Bayesian optimization*	Professor Paul Sanders, Michigan Tech, USA
Sept 21 12-14	*Cybersecurity Seminar*	Organizers: SFI NORCICS, SFI Manufacturing, SFI PhysMet
Sept 30 10-11	*Sustainable aluminium alloys for automotive application*	Professor Stefan Pogatscher, Montanuniversität Leoben, Austria
Nov 25 10-11	*Laser materials processing, en enabler for new solutions and efficient joining*	Prof. Jan Frostevarg, Luleå University
Dec 7 12-13	*Combining structure, chemistry and properties at the nanoscale with correlative tomography approaches*	Prof. Williams Lefebvre, Université de Rouen, INSA de Rouen

RECRUITMENT CAMPAIGN TO ATTRACT PHD CANDIDATES

The last year 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 were made in 2022.

- 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. This year the event was organized on October and 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 secure the students attention on the possibilities to pursue an academic career

Doktorgrad, noe for deg?

Institutt for materialteknologi 19.09.2022 By Kari Håland

Institutt for Materialteknologi inviterer studenter til informasjonsmøte den 21.september:

Vil du vite mer om hva det det innebærer å jobbe som stipendiat og ta en doktorgrad?

Vil du vite mer om mulighetene for å få en stipendiatstilling innen ditt fagområde?

Velkommen til informasjonsmøte **21.sept kl 14:00.**
Sted: Kjemiblokk 2, rom 133

"NTNU-EVENING" AT DOKKHUSET - THE KAVLI PRIZES AWARDED IN NANOSCIENCE

During the Kavli Prize Week 2022 NTNU organized an event at Dokkhuset scene: Presentations of the Kavli Prizes awarded in Nanoscience. The winners if the Kavli Prize in 2020 have succeeded to improve the Transmission Electron Microscopy (TEM) and played an enormous role both in fundamental science and technology. Professor Randi Holmestad from SFI PhysMet gave a presentation on the TEM and explained to the audience why the new knowledge is important and useful to society and humanity.

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

Consortium meetings: We organize bi-annual SFI meetings with participants from all partners. The purpose of these meetings is to exchange information on major results as well as presenting overall thoughts and strategies vital to the centre progress.

In 2022 the first consortium meeting was held in May at a conference hotel in Trondheim. The second meeting was organized in November, at The Catapult Centre at Raufoss. The meeting was hosted by SINTEF Manufacturing. During the two-day meeting there were presentations of scientific highlights from the five research areas as well as discussions on future projects and the possibility of cross-partner industrial business cases. Presentations of the SFI PhysMet partners located at Raufoss – SINTEF Manufacturing, Benteler and Raufoss Technology were also on the agenda, followed by a guided tour to the respective industrial sites as well as the SINTEF facilities. This was a great opportunity to learn more about the manufacturing industry at Raufoss.

Consortium meetings participants at the Norwegian Catapult Centre, Raufoss.

SOCIAL EVENTS AND LUNCH SEMINARS –

BRINGING STAFF MEMBERS TOGETHER

LUNCH SEMINARS

Every second week we organize Lunch Seminar. One staff member is responsible for a short presentation of results, a scientific challenge, a dilemma or a specific problem he or she wants to discuss with the other members of the group. This is an informal event where we also enjoy freshly made waffles.

INTERNATIONAL LUNCH

Our staff is international, and many countries, languages and cultures are represented in the group. In 2022 we invited for international lunch where everyone brought a (favorite) dish from their country.

CHRISTMAS EVENT

BOWLING AND POOL

It is nice to meet outside the office from time to time. The SFI PhysMet social committee invited all staff members to bowling and pool, and this was a great way to socialize and get to know each other outside of work.

PERSONELL SFI PHYSMET

CENTRE ADMINISTRATION

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

KEY RESEARCHERS

RESEARCH AREA 1. MULTI-SCALE MATERIAL ANALYSES

Randi Holmestad	NTNU	Multi-scale material analyses
Ida Westermann	NTNU	Thermo-mechanical processing, microstructure and mechanical properties (steel and aluminium)
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
Mohammed M'hamdi	SINTEF Industry	Sustainable and high-performance material development
Stephane Dumoulin	SINTEF Industry	Materials modelling
Ole Martin Løvvik	SINTEF Industry	Atomic scale modelling
Yijang Xu	SINTEF Industry	Materials modelling

RESEARCH AREA 3. SUSTAINABLE AND HIGH-PERFORMANCE MATERIAL DEVELOPMENT

Mohammed M'hamdi	SINTEF Industry	Sustainable and high-performance material development
Even Hovig	SINTEF Industry	Sustainable and high-performance material development
Astrid Mathinsen	SINTEF Industry	Sustainable and high-performance material development
Marisa Di Sabatino	NTNU	Material-processing, properties and characterization
Yanjun Li	NTNU	Scale and process bridging methodologies
Hans Jorgen Roven	NTNU	Thermo-mechanical processing, microstructure and mechanical properties (steel and aluminium)
Hanne Flåten Andersen	IFE	Powder synthesis and characterization
David Wragg	IFE	Powder synthesis and characterization
Morten Onsøien	SINTEF Industry	Sustainable and high-performance material development
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 Langelandsvik	SINTEF Industry	Aluminium alloy process developments and characterisation for welding and AM
Ivan Bunaziv	SINTEF Industry	Laser materials processing; process study and stability, microstructure and properties
Hans Jørgen Roven	NTNU	Alloy-design and process developments (screw extsruion, AM)
Anette B. Hagen	SINTEF Industry	Thermo-mechanical processing, characterisation of microstructure and mechanical properties
Ida Westermann	NTNU	Thermo-mechanical processing, microstructure and mechanical properties
Jens Christofer Werenskiold	NTNU	Thermo-mechanical processing, microstructure and mechanical properties
Siri Marthe Aarbo	SINTEF Manufacturing	Materials, processing and properties
Jon Holmestad	SINTEF Manufacturing	Materials, processing and properties
Xiaobo Ren	SINTEF Industry	Materials, processing and properties
Bård Nyhus	SINTEF Industry	Materials, processing and properties
Ruben Bjørge	SINTEF Industry	Nano-/microstructure characterization (TEM and APT)
Ragnhild Aune	SINTEF Industry	Welding, processing and properties
Morten Høgseth Danielsen	SINTEF Industry	Welding, Laser Arc Hybrid Welding, Processes

RESEARCH AREA 5. DATA, SHARING AND DIGITAL PLATFORMS

Jesper Friis	SINTEF Industry	Data, sharing and digital platforms
Sylvain Gouttebroze	SINTEF Industry	Materials modelling and digital platform
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

VISITING RESEARCHERS

Ruojin Zang	Chongqing University	Intpart project: International Materials science
Fang Han	Chongqing University	Intpart project: International Materials science
Xiaoxi Mi	Chongqing University	Intpart project: International Materials science
Paul Sanders	Michigan Tech	Alloy and process development of Al, cast iron, steel and Ni superalloys
Alejandra Torres	EURECAT	Wear and friction in nanoparticle containing welding wires

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

Rania Hendawi	2020-2023	Structure loss in CZ-silicon
Jochen Busam	2019-2023	Viscosity in Quartz crucibles for PV silicon

PHD STUDENTS WITH FINANCIAL SUPPORT FROM THE CENTRE BUDGET

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

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

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

MASTER STUDENTS

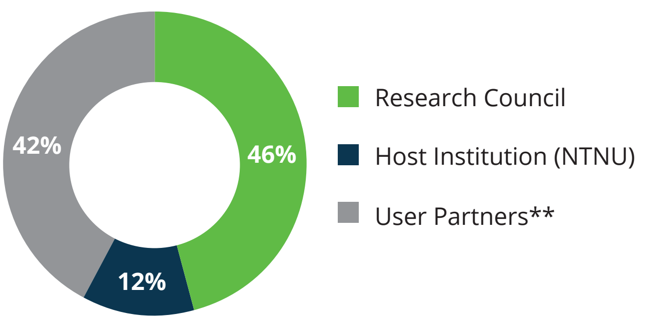
Hedda Øye	Investigation of the Effects of Additions of Vanadium and Titanium to 6005 and 6008 Aluminium Alloy
Martin Lesjø	The effect of cooling rate from solution heat treatment on ductility in Al-Mg-Si crash box alloys
Herman Hansen	Development of aluminium alloys with superior properties for additive manufacturing
Steffen Samuelsen	Production of aluminium nano-composite welding wires
Vegard Bjerve	Grain refinement of foundry aluminium alloys
Joshua Kayode Adegbo	Effect of cooling rate on the microstructure and chemistry of ferrosilicon alloys
Daniel Bojescul Johannessen	The effect of solvent on the silicon powder properties
Martin Fast Buen	Grain Refinement of Austenitic Steels
Simen Skurdal	Characterization of hybrid-welded metals
Lavrans Thorstensen	Screw Extrusion technology and Al-alloys
Harald Skar	Develop aluminium alloy components with super properties by additive manufacturing process
Kjell M.Kirkbakk	Welding thread and screw extrusion

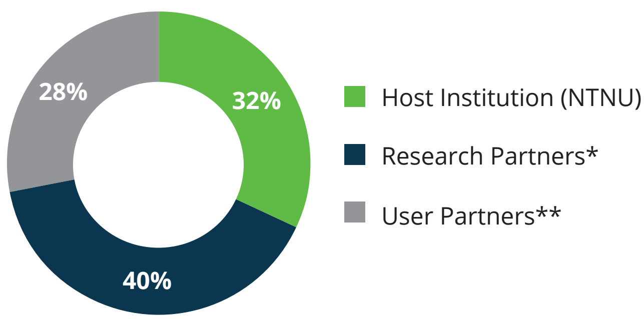
ANNUAL ACCOUNTS 2022

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 2022:

Funding (1000 NOK)	Amount
Research Council	11 416
Host Institution (NTNU)	2 949
Research Partners*	0
User Partners**	10 245
Total	**24 610**

Costs (1000 NOK)	Amount
Host Institution (NTNU)	7 754
Research Partners*	9 961
User Partners**	6 895
Equipment	0
Total	**24 610**





* *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 2022

PUBLICATIONS FUNDED FULLY OR PARTLY BY SFI PHYSMET:

- **Bunaziv, Ivan; Langelandsvik, Geir; Ren, Xiaobo; Westermann, Ida; Rørvik, Gisle; Dørum, Cato; Danielsen, Morten Høgseth; Eriksson, Magnus Carl Fredrik.** *Effect of preheating and preplaced filler wire on microstructure and toughness in laser-arc hybrid welding of thick steel. Journal of Manufacturing Processes 2022*
- **Du, Qiang; M'hamdi, Mohammed.** *Predicting kinetic interface condition for austenite to ferrite transformation by multi-component continuous growth model. Calphad 2022*
- **Du, Qiang; S. Azar, Amin; M'hamdi, Mohammed.** *Kinetic interface condition phase diagram for the rapid solidification of multi-component alloys with an application to additive manufacturing. Calphad 2022*
- **Jin, Shenbao; Su, Haokai; Qian, Feng; Li, Yanjun; Sha, Gang.** *Effects of atom probe analysis parameters on composition measurement of precipitates in an Al-Mg-Si-Cu alloy. Ultramicroscopy 2022*
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