
NASJONAL KONFERANSE FOR MATERIALTEKNOLOGI

28.-29. AUGUST 2024

Scandic Lerkendal Hotel, Trondheim

**Marisa Di Sabatino**
*NTNU*

**Ida Westermann**
*NTNU*

**Marianne Videm**
*Force Technology*

**Trond Furu**
*Hydro*

**Jorun Zahl Albertsen**
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**Bjørn Holmedal**
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*DNV*

## Program: Materialer for det grønne skiftet: utfordringer og muligheter

**Wednesday Aug. 28th**

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| 08:15 | **Registration** |

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| | **Plenary Session** | Room: Messanin 1 | Chair: **Marisa Di Sabatino** |
| 09:00 | **Welcome** | **Marisa Di Sabatino,** professor at NTNU | |
| 09:10 | An example of a heavy industry for mass application: Building thermal management, thermal efficiency, electrification, decarbonation | **Yves Brechet**, Scientific director of Saint Gobain (France) and professor at Monash University (Australia) | |
| 09:40 | Green aluminium constructions: Opportunities and challenges | **Trond Furu**, Research Manager at Norsk Hydro ASA, professor II at NTNU | |
| 10:10 | **Pause** | | |
| 10:30 | Critical raw materials for Net-Zero: The influence of technological and societal paths to meet global material demand | **Moana Silva Simas**, Research Scientist at Sintef Industry | |
| 11:00 | Challenges with well-established metallic materials applied for the green shift | **Gotthard Mälzer**, Leading Advisor Materials Technology - Metallic Materials & Welding, Equinor ASA | |

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| 11:30 | **Lunch** |

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| | **Parallell session 1** | Room: Messanin 1 | **Parallell session 2** | Room: Nils Arne |
| | **Material Processing 1** | | **Data Management, Modelling and Characterization** | |
| | Chair: **Marisa Di Sabatino** (NTNU) and **Morten Onsøien** (SINTEF) | | Chair: **Ida Westermann** (NTNU) and **Bjørn Holmedal** (NTNU) | |
| 13:00 | Increased raw material utilisation not trivial but by necessity in the future | **Maria Wallin, keynote** | Data sharing for cross-disciplinary green solutions | **Jesper Friis, keynote** |
| 13:20 | Additive manufacturing of a high temperature coating for aero-engine applications | **Ingrid Bergheim** | Data documentation and storage for advanced materials development | **Tor S. Haugland** |
| 13:35 | Aluminothermic reduction: a sustainable method for producing Fe65Si26B9 phase change material | **Jianmeng Jiao** | Crystal plasticity finite element method, implementation, and applications | **Hassan Moradi Asadkandi** |
| 13:50 | 3D-printing og Støping – Venner eller konkurrenter? | **Morten Onsøien** | Do we need crystal plasticity theory in metal forming simulations? | **Bjørn Holmedal** |
| 14:05 | **Pause** | | **Pause** | |
| 14:25 | Hydrogen reduction of ilmenite: Comparing two ores | **Tristan Petrus Maria Van Kaam** | Indexing of Electron Backscatter Patterns using EBSP Indexer software | **Yingda Yu** |
| 14:40 | Implementing Pre-Reduction in Mn-Alloy Production: A Case Study at Eramet Porsgrunn | **Vincent Canaguier** | Flux-Assisted Sessile Drop Method on the Stability and Wettability of the 1xxx/TiC system | **Ingvild Runningen** |
| 14:55 | Removal of Zn and other volatile elements from molten Al by vacuum refining | **Sarina Bao** | Morphology and refractive index characterization of subsurface ultrashort pulsed laser modifications in ZnS | **Eskil Einmo** |
| 15:10 | A Short Review of Metal Additive Manufacturing by Laser Powder Bed Fusion | **Kai Zhang** | Recycling of B-added Steel Scrap Into Spheroidal Graphite Iron: Microstructural Analysis | **Andreas Bugten** |
| 15:25 | Quality requirements for 3D printed parts | **Stian Gurrik, keynote** | The NorFab Infrastructure - opportunities for materials research in Norway, the Nordics and beyond | **Peter Andreas Köllensperger, keynote** |
| 15:45 | **End of Day 1** | | | |

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| 18:30 | **Dinner at Rockheim Panorama** |

**Thursday Aug. 29th**

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| | **Material Processing 2** | Room: Messanin 1 | **Corrosion and off-shore materials** | Room: Nils Arne |
| | Chair: **Merete Tangstad** (NTNU) | | Chair: **Marianne Videm** (Force Technology) | |
| 09:00 | SFI PhysMet – Status and recent research highlights | **Knut Marthinsen, keynote** | Material challenges in the ocean industry, from a regulators perspective | **Morten Langøy, keynote** |
| 09:20 | Atomization of silicide powders for Additive Manufacturing | **Kristina Dyrli Log** | Development of a Welding Procedure for High Strength Steel Armour Wires for Subsea cables | **Jonas Larsson** |
| 09:35 | Modular semi-industrial scale Liquid Metal Loop with MHD pumping | **Robert Fritzsch** | Hydrogen assisted cracks in jack-up rigs | **Marianne Videm** |
| 09:50 | **Pause** | | **Pause** | |
| 10:20 | SiO reduction using hydrogen: Exploring reaction conditions | **Liya Jacob** | Corrosion of Steel Wires in Musical Instruments due to Emissions from Cellulose Nitrate | **Vera de Bruyn-Ouboter** |
| 10:35 | Slag flow into coke beds in Mn-furnaces | **Vishal Rimal** | Effekt av økt Fe, Zn og Cu innhold i Aluminiums-legeringer på mekaniske egenskaper og korrosjon | **Ola Jensrud** |
| 10:50 | Utilization of biochar in Mn-sinter production | **Yu Han** | | |
| 11:05 | Lab scale to pilot scale pelletization; bauxite residue agglomerates for H2 reduction | **Frida Vollan** | | |

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| 11:30 | **Lunch** |

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| | **Al and light alloys** | Room: Messanin 1 | **Energy materials** | Room: Nils Arne |
| | Chair: **Trond Furu** (Hydro) | | Chair: **Gabriela K. Warden** (NTNU) | |
| 13:00 | Effect of impurity elements on the recycled HPDC aluminium alloys: a literature study | **Supreet Kaur** | Fused Quartz Crucibles for Czochralski Silicon Production | **Gabriela Kazimiera Warden** |
| 13:15 | Effect of Trace Elements in Recycled Aluminium Alloys for Extrusion | **Eva Mørtsell** | Hydrogen storage properties of Nb-rich alloys of the Nb-Cr-Mn system | **Bruno Hessel Silva** |
| 13:30 | Effekt av bråkjølingshastighet på mekaniske egenskaper og restspenninger i Aluminiumsblokker for maskinering | **Stanka Tomovic-Petrovic** | Investigations of gas flow in charge materials with biocarbon | **Frida Vollan** |
| 13:45 | **Pause** | | **Pause** | |
| 14:05 | Misconceptions about the Beta to Alpha Transformation in 6xxx Aluminium Alloys | **Jostein Røyset** | Metallic phase change materials for high temperature latent heat thermal energy storage applications | **Paolo Lai Zhong Lo Biundo** |
| 14:20 | Multi-billet extrusion of aluminium for large section panels | **Kristian Grøtta Skorpen** | Optimisation of the formulation of silicon anodes for lithium-ion batteries | **Alberto Olivo** |
| 14:35 | Optimizing the Mn and Cr content in fibrous 6005A Aluminium alloys | **Jostein Røyset** | Revolutionizing Lithium-Ion Batteries: Sustainable Silicon Waste Transformation into High-Performance Anode Materials | **Kai Tang** |

14:50 **End of Conference**

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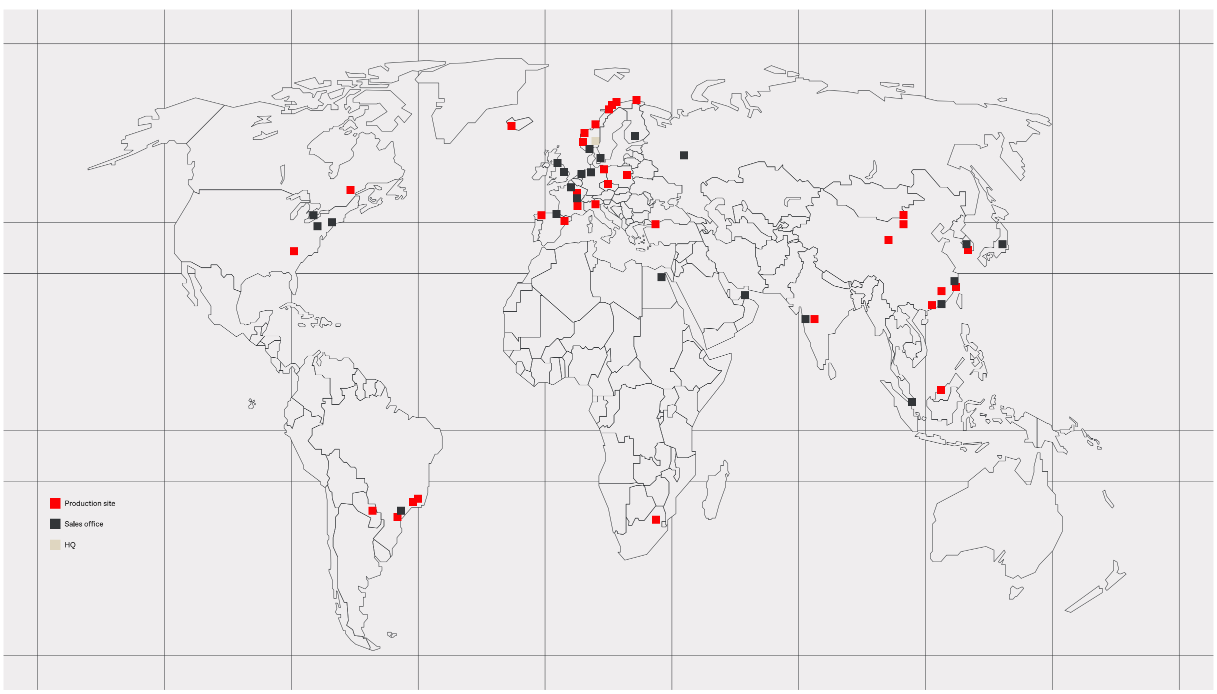


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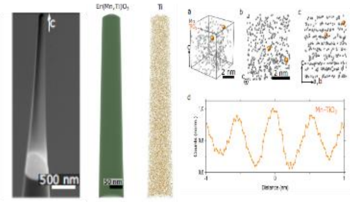


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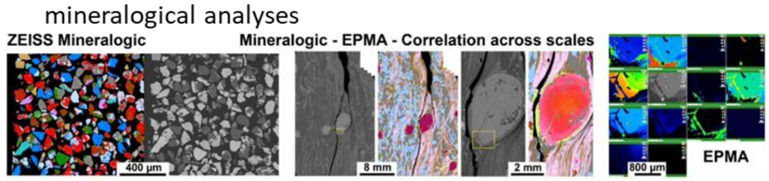


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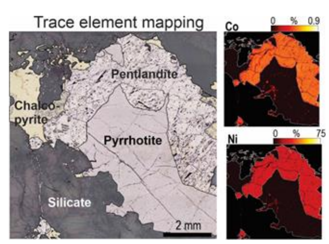


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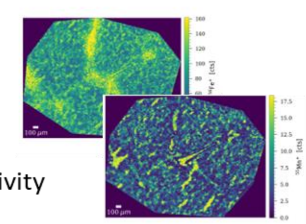
- Measure and investigate trace element concentrations with micro-metre resolution and ppb-level sensitivity



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# KONFERANSEBIDRAG/ ABSTRACTS

Saint Gobain

Yves Brechet,

## An example of decarbonation of a heavy industry for mass application: Building thermal management, thermal efficiency, electrification, decarbonation

*Y. Brechet*
*Saint Gobain, France*

Building is a key contributor the emission of CO2 in our industry, and is a basic need for society. As a result, it plays a key role in the necessary transitions to fight global warming. The materials involved have a huge variety and they come in large quantities. The presentation will illustrate the various strategies implemented industrially to decarbonize the operation of buildings, to decarbonize materials production processes, and to build a circular economy recycling wastes as much as possible. The achievements to date, the roadmap, and the challenges will be presented.

Sustainable Energy Technologies, SINTEF Industri

Moana Simas, moana.simas@sintef.no

# Critical raw materials for Net-Zero: The influence of technological and societal paths to meet global material demand

M. Simas

SINTEF Industry, Trondheim

The transition towards a net-zero economy will require a large-scale implementation of low-carbon technologies. Concerns have been raised whether the availability of minerals will be a bottleneck for the green transition, with special focus on critical and strategic raw materials. Critical raw materials (CRM) are those that have a significant economic importance and that have risks to their supply, for which many low-carbon technologies currently depend on. The total demand for CRM and whether they will become a challenge for the green transition depending on the path we take. The technological choices for decarbonisation in the coming decades are highly uncertain and depend on a wide range of factors such as prices, resource constraints, social and environmental standards, and innovation and technological development. How each of these factors will develop in the medium and long term and how they will interact with each other cannot be predicted.

We look at the CRM demand for a net-zero emissions energy system, based on the technological decarbonisation path of the *Net Zero by 2050* scenario developed by the International Energy Agency. It focuses on seven critical and strategic minerals for the green transition: lithium, cobalt, nickel, manganese, rare earth elements, platinum and copper. We answer the following question: How can different technological choices alleviate mineral demand? While the broad technological background (such as total installed capacity of wind power and number of electric vehicles on the road) follow that described in the *Net Zero by 2050* scenario, the technological choices refer to the specific technologies used, such as different types of wind turbines and chemistries for rechargeable batteries. We then investigate four technology scenarios: current technology mix; business-as-usual which follows current technological patterns, learning curves, and industry signals; resource constraint scenario; and advanced technology scenario, where new technologies low in CRM take off and become a larger share of the market share of annual installed capacity by 2050.

We show that technological choices make a significant difference for future mineral demand. Shifting to new technologies with less CRM can reduce total demand for the seven minerals by 30%. The adoption of different chemistries for electric vehicle batteries and moving away from lithium-ion batteries for stationary applications could reduce the total demand for cobalt, nickel, and manganese by 40-50% of cumulative demand between 2022 and 2050 compared to current technologies and business-as-usual scenarios. Also, increasing the use of electric traction motors and wind turbine generators with low or no rare earth elements could cut the cumulative demand of these minerals demand by 20%.

Nasjonal konferanse for Materialteknologi 2024

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## Additive manufacturing of a high temperature coating for aero-engine applications

I. Bergheim, K. Christofidou, R. Holmestad, P. Kontis

NTNU, Dept. of Materials Science and Engineering, Trondheim

University of Sheffield, Dept. of Materials Science and Engineering, Sheffield

Abstract

Traditionally, metallic overlay and bond coatings for high temperature applications, such as nickel-based superalloy blades, in aero-engines are produced by thermal spraying processes. In this study, we investigate the potential to produce such coatings by additive manufacturing processes that will allow the repair of such components. In particular, the well-known overlay coating with NiCrAlY composition was produced by the directed energy deposition (DED) process directly on a nickel-based superalloy substrate. The primary aim is to investigate the microstructure in the as-built condition after the deposition. As such coatings have not been produced by additive manufacturing processes before, a multi-scale analysis was deployed to investigate the produced microstructure. Electron backscatter diffraction (EBSD) revealed the presence of columnar grains along the building direction, as shown in Figure 1. Scanning electron microscopy (SEM) and electron probe microanalysis (EPMA) has shown that micro-segregation of Y and Al exists between the dendritic and interdendritic regions. Besides, no cracks were observed between the deposited coating and the superalloys substrate. Finally, atom probe tomography (APT) provided compositional information at near atomic-scale for various phases forming during processing.

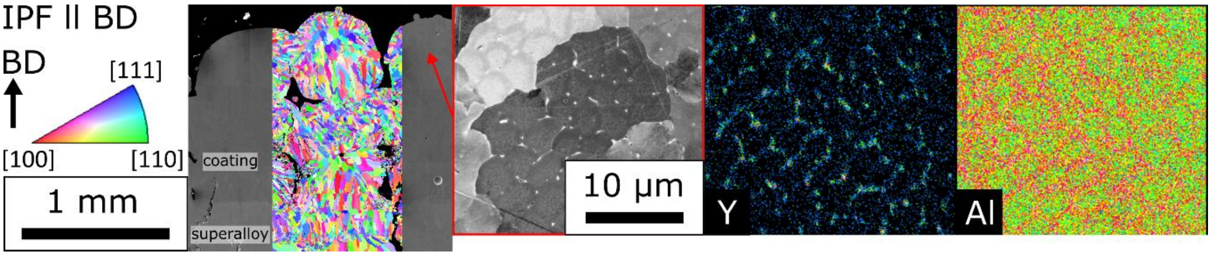


*Figure 1: Secondary electron SEM image with superimposed inverse pole figure plotted along the build direction (BD) from the NiCrAlY coating in the as-built condition, with backscatter image and EPMA maps showing Y and Al distributions at greater magnification.*

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# Aluminothermic reduction: a sustainable method for producing Fe65Si26B9 phase change material

Jianmeng Jiao*, Maria Wallin, Merete Tangstad

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Abstract

Fe65Si26B9 (wt.%) is proposed to be a high-temperature phase change material (PCM) for a thermal energy storage system, due to its high latent heat of fusion and minimal volume change during solidification. Currently, the production of Fe65Si26B9 alloy involves mixing FeSi alloys with either pure boron (B) or FeB alloys. The use of pure boron is high cost, while the carbothermic reduction of FeB alloy results in significant greenhouse gas emissions and high energy consumption. In this regard, the aluminothermic reduction is proposed to use FeSi alloys, aluminum and iron metals, and calcinated colemanite for producing this FeSiB PCM. According to the experimental results, the equilibrium is achieved after 3h holding at temperatures range from 1550°C to 1650°C. By varying the slag/metal (S/M) ratio from 0.6 to 1.4, the boron content in the FeSiB alloys can be increased from 5.2wt.% to 15wt.% after 3h holding at 1650°C. Maintaining the S/M ratio at 1, the produced FeSiB alloys exhibit a B content between 9-13 wt.%, Si and Fe ranging in 24-30wt.% and 61-64wt.%, respectively. The energy consumption is estimated to be around 1182kWh/t metal. Therefore, aluminothermic reduction is an efficient and sustainable method for producing FeSiB alloys.

Key words: FeSiB, $B_2O_3$, Aluminothermic, PCM, Thermal Energy Storage

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## 3D-printing og Støping – Venner eller konkurrenter?

Morten Onsøien

SINTEF Industry, Trondheim

3D-printing har gått fra å være en "rapid prototying" teknologi til å bli en "additive manufacturing" teknologi. Veien har vært lang fra den første kommersialisering på 80-tallet til dagens bruk i industri og akademia. Fortsatt er det slik at 3D-printing sliter med å være et godt nok alternativ til andre produksjonsteknikker når det gjelder masseproduksjon, med kan være et utmerket alternativ når det gjelder produksjon av mindre serier og serier med vanskelig geometri. 3D-printing kjennetegnes gjerne med at det er kort tid fra tegnebrettet til produksjon, mens selve produksjonen kan være svært tidkrevende. Støping av metaller har en flere tusen år lang historie. Denne framstillingsprosessen er svært god egnet til produksjon av store serier med mer eller mindre kompleks geometri. En av utfordringene med støping er design og tilvirkning av fysiske modeller og former. Modellene må tilvirkes med korrekt løpsystem for å gjøre det mulig å fylle formene med metall på en effektiv og skånsom måte. I tillegg må modellene ved behov være utstyrt med matere for å ettermate metall til støpestykket for å motvirke støpedefekter relatert til krymping av metallet ved størkning. Når den fysiske modellen er laget, vil selve støpingen av metalldelen typisk gå veldig raskt. 3D-printing og støping kan sies å fylle et behov på hver sin ende av seriestørrelsesskalaen. Når det gjelder fysisk størrelse på komponenten som skal lages vil støping normalt være fordelaktig på store komponenter. Tilvirkning av modell og form vil riktig nok være tid og kostnadskrevende, men for store komponenter med kompleks geometri finnes det ingen reelle alternativer. Så på en strørrelsesskala vil støping være enerådende på store komponenter, mens det kan være overlapp i metode på mindre komponenter. Når det gjelder kompleksitet i geometri vil 3D-printing normalt være fordelaktig, både for utvendig og eventuell innvendig geometri på komponenten som skal tilvirkes. Støping av komponenter med kompleks innvendig geometri vil kreve bruk av kjerner. For små innvendige geometrier, f.eks. små kjølekanaler vil det være svært vanskelig eller umulig å tilvirke komponenter med støping. 3D-printere for plastmaterialer har blitt svært billige og lett tilgjengelige og nesten allemannseie. Dette gir støpere og støperier et godt verktøy for å prøve ut sin fysiske støpemodell for å se etter design-problemer før den virkelige støpemodellen settes i produksjon. Så konklusjonen på spørsmålet i tittelen er vel at 3D-printing og støping på mange måter og områder utfyller hverandre og således er venner, mens de på noen områder overlapper hverandre og er konkurrenter.

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## Hydrogen reduction of ilmenite: Comparing two ores

T. P. M.V. Kaam, M. Tangstad, S. C. Lobo

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Hydrogen reduction is used as a reducing agent for ferrous ores. The use of hydrogen as a reducing agent for ilmenite pre-reduction has potential. By switching out the use of carbon during pre-reduction, the overall process's environmental footprint will be lower. The process should be better understood before switching the reducing agent to hydrogen. This study will focus on the differences between reducing synthetic ilmenite and South African Ilmenite. By synthesizing ilmenite, one can have greater control over the iron and impurities content in the sample. Previous experiments show this can affect the phases present after oxidation and the subsequent reduction progress. To investigate these differences in weight change, X-ray diffraction, and secondary electron microscopy will be used for classification.

**Nasjonal konferanse for Materialteknologi 2024**

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# Implementing Pre-Reduction in Mn-Alloy Production: A Case Study at Eramet Porsgrunn

V.Canaguier, M. Duchamp
SINTEF Industry, Trondheim

Abstract

Applying and implementing research work to industrial practice is a difficult yet essential task to reach $CO_2$ emissions reduction targets, especially due to the urgency of the matter. In the present work, the deployment of a new separate pre-reduction unit upstream of a HC FeMn furnace at Eramet Porsgrunn is considered. This is done both by evaluating the consequences for the process itself but also on the practical requirements of such installation at the plant. For the former, several charge and process conditions cases have been considered to evaluate the effect that pre-reduction would have at this specific site. The simulation work carried out in HSC Sim resulted in more precise data regarding carbon and energy consumption, but also on exhaust gas composition. In parallel, technical constraints have been listed regarding the plant's arrangement, the furnace's construction, and the overall safety and environment concerns. The integration of this new equipment in an existing process and presented additional challenges.

Summary

The modular liquid metal loop with magneto hydrodynamic pumping (MHD) at the IMA at NTNU is a new equipment for the REM group, designed for optimization, testing and development of industrial scale casting processes, such as filtration, degassing, but also remelting and alloying, but also allows operation for melt transfer. The loop modules for circulation have been installed in the 1 quarter of 2024, together with the validation and construction of the permanent magnetic pump required for the circulation of the metal in the loop. The presentation at the conference shows the performance of the new equipment at IMA, NTNU.

The direct implementation of new technology is an urgent need for the shift towards a sustainable and green economy. The liquid metal loop can act as a bridge between academic level research and industrial scale implementation. It contains up to 65 liters (~150kg) of liquid aluminium. The metal will be circulated by an electromagnetic (EMP) or permanent magnetic pump (PMP), where the flow velocity can be adjusted by a programable wave shape generator, as for the EMP's or inverters for the PMP's. The loop maintains the process temperature by SiC and immersion heating elements in the lid sections. The loop has two modular units that can be exchanged with testing units, depending on the scope of the ongoing project. The goal of this project is to establish stable operation of a liquid metal loop, gathering initial process data and the validation of the EMP and PMP.

SINTEF Industry

Kai Zhang

# A Short Review of Metal Additive Manufacturing by Laser Powder Bed Fusion

K. Zhang, M.I. Onsøien, K.G. Skorpen, M. Reiersen, Q. Du

SINTEF Industry, Trondheim

T. Manik, YJ. Li, K. Marthinsen

Department of Materials Science and Engineering, NTNU, Trondheim

Abstract

Metal additive manufacturing (AM) has emerged from lab development into wide industrial applications. The laser powder bed fusion (LPBF) technology is currently one of the most widely applied AM technology in the industry. This contribution aims to give a short review of the LPBF from the material technology aspect, especially based on research work using the LPBF printer sponsored by the Manulab infrastructure project. The LPBF technology and its common workflow will be first introduced with illustrations from real 3D printers and jobs. Common challenges when applying LPBF will then be introduced and discussed. Developing new AM-oriented alloys can be a solution for those challenges. AM of high strength aluminium alloys by alloying and by addition of nanoparticles will be presented. The correlations between alloying, processing parameters, microstructure and properties will then be discussed.

SINTEF Industry

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## Data documentation and storage for advanced materials development

S. Gouttebroze, D. Marchand, F. L. Bleken, D.R. Småbråten

SINTEF Industry, Oslo

C.W. Andersen, T.S. Haugland, S. Clark, S. Krishnamurthi, J. Friis

SINTEF Industry, Trondheim

T.R. Joseph, T. Hagelien

SINTEF Ocean, Trondheim

Material innovation stands as the bedrock of the green transition, with energy storage solutions and fuel cells emerging as pivotal pillars for sustainable mobility. Central to enhancing system performance in both arenas, material innovation not only plays a critical role but also offers a competitive advantage.

The process of material development is multifaceted, often weaving together theoretical analysis, experimental work, characterization, online measurements, and complex numerical simulations. The resulting data spans a broad spectrum of expertise and necessitating an inter-disciplinary, concerted effort for effective utilization. Ensuring meticulous data documentation and systematic storage is fundamental for the efficient advancement of materials and processes.

The OntoTrans project has pioneered an approach that leverages semantic descriptions and the application of data models to guarantee the integrity of data quality. This methodology has been instrumental in refining data management within the MEDIATE and BATMACHINE projects, focusing on Solid Oxide Fuel Cell and battery production, respectively.

The presentation will outline the methodology for data documentation and structuring. It will then delve into the specifications and practicalities of deploying a database and software infrastructure tailored to these needs. To concretely demonstrate the utility of this dataspace solution, we will provide straightforward examples showcasing the ease of data search, retrieval, and reuse.

**Nasjonal konferanse for Materialteknologi 2024**

NTNU, Dept. of Materials Science and Engineering

Hassan Moradi Asadkandi, hassan.m.asadkandi.ntnu.no

## Crystal plasticity finite element method, implementation, and applications

Hassan M. Asadkandi [1], Tomáš Mánik [1], Bjørn Holmedal [1], Odd Sture Hopperstad [2]

[1] NTNU, Department of Materials Science and Engineering, Trondheim, Norway

[2] NTNU, Department of Structural Engineering, Trondheim, Norway

Abstract

The mechanical response of crystalline materials during plastic deformation significantly depends on the crystallographic texture. Crystal plasticity models are capable of accounting for crystallographic anisotropy and capturing the underlying physics of deformation mechanisms at the single crystal level but are not generally available in commercial finite element softwares like Abaqus. The standard continuum-based material models cannot directly capture the influence of crystallographic texture on the mechanical response of materials, but the initial anisotropy can be calibrated to virtual experiments by experiments or crystal plasticity simulations. Crystal plasticity simulations have been enabled in this work by the implementation of material user-subroutines. The complex plastic deformation is modeled using crystal plasticity theory, accounting for interactions within a polycrystalline aggregate.

The drawback is that such implementations are computationally very expensive. In this study, two state-of-the-art user-implementations of the rate-dependent Crystal Plasticity Finite Element Method (CPFEM) as user material subroutines in the finite element solvers Abaqus/Explicit and Abaqus/Standard (Implicit) are presented. Simulation results and efficiency are evaluated for both implementations. The routine for applying the implemented subroutines for generating yield surfaces is discussed. Furthermore, it is investigated how the predictions of the elasto-plastic transition are fundamentally different when using the crystal plasticity approach, which is of importance for the predictions of flow instabilities.

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# Do we need crystal plasticity theory in metal forming simulations?

Bjørn Holmedal, Hassan Moradi Asadkandi, Tomas Manik

NTNU, Dept. of Materials Science and Engineering, Trondheim

Abstract

Industrial simulations of metal forming or plastic deformation during crash behavior is today performed by continuum plasticity simulations using FEM software. Metal parts typically contain billons of grains, for which detailed crystal plasticity simulations are not feasible. The continuum models are less accurate but for many purposes their estimates are good enough. However, it is important to know where the estimates are least accurate and to have an idea of how far off the simulations are. The crystal plasticity simulations can provide virtual experiments that can be used to calibrate and further develop the simpler continuum models. In this talk the spin model will be assessed. In crystal plasticity, the constitutive spin is uniquely given, leading to a unique evolution of plastic anisotropy. In continuum plasticity, the model for the spin and the model for the stress anisotropy plays together. If another spin model is chosen, the response will develop differently. The evolution of the yield surface is computed during deformation by crystal plasticity. In the continuum plasticity model, a spin is sought that results in plastic anisotropy which is in best agreement with the crystal plasticity results.

**Indexing of Electron Backscatter Patterns using EBSP Indexer software**


Abstact:

Characterization of the microstructure of metals and alloys is often carried out in scanning electron microscopes (SEM) by use of electron backscatter diffraction (EBSD). The crystallographic orientations and phases are most often determined by Hough indexing (HI). HI is based on detection of some of the brightest bands in the diffraction pattern by use of the Hough transform. Recently, a new EBSD pattern indexing method has been introduced, so-called dictionary indexing (DI). DI compares each experimental pattern to some hundred thousand theoretically constructed patterns in a dictionary. The orientation/phase of the best fit pattern is selected as the solution. DI is a more time-consuming process than HI, but DI is more reliable when it comes to indexing of noisy patterns and overlapping patterns close to grain boundaries.

In this work, comparisons between DI and HI have been performed from the same datasets collected from microstructures in different alloys. The EBSD analyses were performed in both conventional tungsten and field emission SEMs equipped with a NORDIF EBSD detectors.The patterns were acquired and streamed to a hard disk drive using the NORDIF N3 acquisition software. The pattern indexings were executed off-line by commercial EDAX/TSL and EBSP Indexer, an open source Python software based on kikuchipy. The results show that misindexing of overlapping patterns close to grain boundaries are significantly reduced by DI compared to HI.

SFI PhysMet

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# Flux-Assisted Sessile Drop Method on the Stability and Wettability of the 1xxx/TiC system

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Abstract

The ceramic particles ' wettability and thermodynamic stability are critical when synthesizing aluminum matrix composites reinforced by premade particles. The high oxygen affinity of the system results in enclosing oxide films that inhibit intrinsic or "true" contact. Thus, the Al/TiC system is held at a high temperature for an extended period with low oxygen partial pressure to disrupt the oxide film, which affects the system's thermodynamic stability. Thus, the formation of $Al_4C_3$ at the interface drives the spreading, a hygroscopic brittle interfacial reaction product. Intrinsic wetting could be observed at lower temperatures at shorter exposure by rapidly chemically disrupting the oxide films using fluxing agents. Hence, flux-assisted spreading gives valuable insight into the 1xxx/TiC wettability and stability at processing parameters similar to the molten-salt-assisted stir casting method.

This study investigates the influence of two fluxing agents, $KAlF_4$ and $K_2TiF_6$, on the wettability and stability of the 1xxx/TiC system at different temperatures and exposure. Coating the TiC substrate with 5 and 10 mg/cm$^2$ of $KAlF_4$ flux initiated rapid wetting at 632℃ and 692℃, respectively. $Al_4C_3$ formed in varying degrees at the interface, depending on the exposure at 750℃ and 850℃, respectively. When coating the substrate with 8 mg/cm$^2$ $K_2TiF_6$, the flux facilitated instantaneous, complete wetting with an $Al_4C_3$-free interface after 5- and 30 minutes at 850℃.

**The National Materials Science Conference 2024**

NTNU, Department of Materials Science and Engineering

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# Morphology and refractive index characterization of subsurface ultrashort pulsed laser modifications in ZnS

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Abstract

Subsurface ultrashort pulsed laser processing of dielectrics and semiconductors is a promising technique in various materials, including materials for energy applications, laser technology, photonics, optical sensing, in-chip micro structuring, microfluidics and optical storage. Precise confinement of highly intense pulses allows fine subsurface 3D-micro-modification of transparent materials, changing their molecular structure and optical properties in a controllable fashion. The refractive index depression that is realized in the core of the focal volume in crystalline materials, such as ZnS and Si, enable waveguiding geometries. A study on such modifications in ZnS and their dependence on the average laser power, writing speed, and depth is reported, with an emphasis on cross-sectional morphology and induced refractive index changes, Δn.

Morphological features are found to strongly depend on laser parameters such as the average power, laser scanning speed and processing depth. With severe pulse overlap, which is contingent upon low writing speed, even minor increases in processing depth were proven to adversely affect the modification morphology by elongation along the axial direction of the laser. The lateral refractive index contrasts of the induced modifications were measured using quantitative phase microscopy and shows a profile distortion in the form of oscillatory variations in the plane perpendicular to the inducing laser beam. Higher average powers diminish the localization of the energy deposition, and instead spreads radially outwards, leading to a lower refractive index contrast in the center of the modification. The highest refractive index change, |Δn|, is found to be $(3.88 \pm 0.18) \cdot 10^{-2}$.

Such parametric insight is critical for understanding and optimizing the fabrication process and for realizing compact 3D geometries for photonic and energy applications in the bulk of semiconductor materials in a reproducible manner.

# Recycling of B-added Steel Scrap into Spheroidal Graphite Iron: Microstructural Analysis

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**Keywords:** boron, ferrite, pearlite, cast iron, graphite

The production of cast iron generally includes adding 10 to 50 wt% steel scrap to the iron charge in order to reduce the environmental footprint and lower the cost of the cast iron. Presently, B-added steels are frequently used in automobiles, a trend which is predicted to increase in the coming years. When such automobiles reach their end of use, the boron-added steels will end up in scrap yards. It is thus inevitable that the modern cast iron foundries must adapt to the changing chemistry of the available steel scrap. In this study the effect of boron (B) on spheroidal graphite iron (SGI) is investigated. It is found that B has a detrimental effect on the ferrite/pearlite ratio of the matrix, which is unfavorable for cast iron components that are mainly used in as-cast state. Furthermore, B is observed to have a detrimental effect on the graphite shape, which might decrease the fatigue life of components made of cast iron contaminated by B.

NTNU, Department of Materials Science and Engineering

Knut Marthinsen

# SFI PhysMet – Status and recent research highlights

K. Marthinsen

NTNU, Dept. of Materials Science and Engineering and SFI PhysMet, Trondheim

## Abstract

SFI PhysMet - Centre for Sustainable and Competitive Metallurgical and Manufacturing Industry, is a so-called Centre for Research Driven Innovation, co-funded by the Research Council of Norway (RCN) with the research partners: NTNU, SINTEF and IFE, and the user partners: Hydro, Elkem, Equinor, Benteler, Raufoss Technology, and Thermo-Calc. The project period is from 2020-2028, and the objective of SFI PhysMet is the development of cutting-edge expertise, contributing to national competence building within five main areas: i) Development of new and recycle-friendly materials and alloys, enabling significantly more recycling in the metal-based value chains; ii) solid-state recycling and mechanical alloying, with the prospect of new alloys and composites with improved properties; iii) rapid solidification, with prospects of development new feedstock materials for additive manufacturing; and iv) welding and joining methods, with prospects of new material- and processing solutions for large scale structures (bridges, off-shore wind installations etc) and iv) development of a Digital Platform, providing efficient and flexible access to through-process and through-scale workflows combining advanced scientific models, experimental data and expertise to support the industry in accelerated innovation. The centre combines advanced characterization with materials modelling and simulations at all length scales, as basis for process and material developments relevant for the green shift. The presentation will briefly present the centre – who we are and what we are doing, as well as presenting examples and highlights of recent and ongoing research activities.

Elkem ASA, Elkem Silicon Products, Kristiansand

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# Atomization of silicide powders for Additive Manufacturing

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Abstract

To support the green energy transition, technologies like additive manufacturing are important contributions. An additive manufacturing process introduces several advantages compared to a conventional subtractive manufacturing, such as less waste, prolonged lifetime of parts and the possibility to create more complex geometries. These processes do however demand a certain flowability of the metal powders, which can be obtained by utilizing gas atomization.

A gas atomizer installed at the Elkem facilities in Kristiansand have been used to produce several different silicide powders for additive manufacturing, all with an increased silicon content compared to their respective conventional alloys. Work has mainly been done on FeSi, AlSi and NiSi alloys for applications in soft magnetics, construction, and coating, respectively. The increased silicon content in these silicide powders give increased strength and excellent wear- and corrosion resistance for the printed parts. For soft magnetic purposes, the increased silicon content also gives improved magnetic properties. Some initial results on material properties of printed parts will be presented for all the mentioned silicides.

The increasing interest for low carbon footprint for these types of materials have been addressed. Work is currently being done on introducing recycled material in these alloys, where the main challenges are related to the purity and the pre-processing of the recycled material. Experiences with this will be presented at the conference.

# Removal of Zn and other volatile elements from molten Al by vacuum refining

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With increasing aluminium (Al) recycling, the minor element composition in recycled Al fluctuates considerably. Further, trace elements in Al alloys can cause serious defects. For instance, combination of Cu and Zn can cause corrosion issue even if the alloy produced with recycled scrap are according to specifications. However, it is challenging to remove tramp elements from Al scrap. The main goal in this work is to remove impurity elements from Al by utilising the high vapour pressure of the elements above the vapour pressure of molten Al. Lab experiments show that 11 % Zn can be 100 % removed holding 15 min at 900 °C or 120 min at 700 °C in 0.1mbar vacuum. Kinetics and thermodynamics of vacuum refining will also be discussed.

**SiO reduction using hydrogen: Exploring reaction conditions**

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**Abstract**

The reduction of silicon oxide (SiO) is a fundamental process in various industrial applications, especially in the production of silicon for electronics and solar cells. Traditional reduction methods often involve high temperatures and carbon emissions. In recent years, the use of hydrogen ($H_2$) as a reducing agent has emerged as a sustainable and efficient alternative for metal reduction. We are studying the potential of using hydrogen as a reductant in the SiO process. Even though, thermodynamically tricky, as the SiO generation takes place in 1700 ºC and the SiO reaction with hydrogen takes place below 800 ºC, we are exploring temperature ranges where both reactions could coexist. As a preliminary study, we are using a furnace where temperatures can be controlled in two different stages, where the lower part of the furnace would be used for generating SiO at high temperatures and the upper part of the furnace would be used for hydrogen and SiO reaction at lower temperatures. The reaction products are analysed using X Ray Diffraction and Scanning Electron Microscopy. The off gas is analysed using a Gas chromatography to better understand the reaction mechanism.

*Key words*:
SiO reactivity, Two zone furnace, Hydrogen, Si+$SiO_2$ pellets

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# Slag flow into coke beds in Mn-furnaces

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Abstract

The knowledge of fluid flow through the coke bed is crucial for the smooth operation of a submerged arc furnace. The present study aims to find the relationship between basicity, reduction rate, and their overall effect on slag flow. Thermogravimetric analysis indicates that the reduction pathway is characteristic of basicity, most particularly for 0.6 basicity when compared to higher basicities. During the processing of ores, the reduction rate would peak to a certain value and decrease gradually. Despite the different rates, the total duration for feasible reduction is typically close. The results from flow measurements conclude that the flow rate has a constant value for a fixed void size and does not depend on the basicity. A fixed flow rate implies that the reduction proceeds at a constant rate enabling the flow of different phases. The inferences obtained from flow experiments outweigh other results in the study since here the reduction and fluid flow occur simultaneously as in an industrial setting.

**Nasjonal konferanse for Materialteknologi 2024**

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## Utilization of biochar in Mn-sinters production

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Abstract

Charcoal, coke, and high-grade manganese ore (Comilog) have been used to investigate the impact of replacing coke with charcoal on manganese sinters (Mn-sinters) properties. The results demonstrate that substituting specific quantities of coke with charcoal can yield sinters of high quality and process efficiency compared to using only coke breeze. The value of O/Mn ratio is around 1.17 – 1.24, indicating that manganese exists in the forms of $Mn_3O_4$ and MnO. Besides the high Mn content, the sinters are primarily composed of $Al_2O_3$ and $SiO_2$, which is attributed to the corresponding content in Comilog ore. Regarding phase characterization, three distinct phases can be classified based on different morphology features. A high degree of miscibility for iron into manganese-bearing phases was observed. The first phase contains (Mn, Fe)O and $(Mn, Fe)_3O_4$ , the second phase is the $Al_2O_3$-rich phase, while the third phase is manganese containing silicate ($(Mn, Fe)_2SiO_4$).

SINTEF

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**Lab scale to pilot scale pelletizing; bauxite residue agglomerates for $H_2$ reduction**

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Finding ways of valorizing waste materials in the metal industry is very important for a sustainable industry. Waste materials are often fine powder materials with substantial amounts of metals which could be utilized. One example is bauxite residue, which is rich in iron oxides and other valuable metals and minerals. The iron from the bauxite residue can be recovered. Reducing the iron oxides in bauxite residue with $H_2$ instead of with fossil carbon eliminates $CO_2$ emissions from the process.

Bauxite residue has a $d_{90}$ of about 12 microns, and that makes it unfit to be used in conventional metallurgical reduction processes. It is therefore necessary to agglomerate the materials. Many methods of agglomerating finish off with sintering to improve pellet strength. Skipping the sintering step and producing usable self-hardening pellets will eliminate this energy consuming step.

The process of pelletizing bauxite residue was designed for lab scale and were further upscaled pilot scale. The pellets' mechanical strength and endurance were tested in all steps to ensure the right pellet quality for planned reduction experiments in a pilot Plasma Rotary Furnace.

A lab scale Eirich Mixer (Eirich EL01, 1L) was used to develop the pelletizing procedure while a larger mixer (Eirich R08W, 75L) was used for the pilot campaigns. Two batches of 400 and 550 kg pellets were produced in two campaigns. The mechanical strength and endurance of the pellets were measured by testing abrasion, drop strength and cold compression strength after two weeks of drying and after four weeks of drying.

Two pilot reduction experiments in the Plasma Rotary Furnace were successful. The pellets have been analyzed with XRF, XRD and LECO both before and after the reduction experiments.

Nexans Norway AS

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# Development of a Welding Procedure for High Strength Steel Armour Wires for Subsea cables

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The galvanized steel armour wires of a subsea cables armouring layer absorbs the tensile load during the cable installation from an installation vessel to the seabed. The complexity of the installation of subsea interconnector cables increases with increased water depth. The subsea cable, including all its cable materials, needs to be jointed, and the cable joint needs to withstand the installation along with the cable. This presentation describes the development of a welding procedure for high strength steel armour wires. The armour wire weld had to be made under several constraints such as no possibility for post weld heat treatment, among other contrains.Several welding trials and small-scale test evaluations of welded samples as well as full-scale tensile-bending tests of cable were made. The main conclusion is that it is possible to TIG-weld armour wire up to Grade 90 (specified minimum tensile strength of 900 MPa) without performing post weld heat treatment.

FORCE Technology
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## Hydrogen assisted cracks in jack-up rigs

Marianne Videm and Ditte Bilgrav Bangsgaard

FORCE Technology Norway and Denmark

Following the recent observation of relatively long cracks in the lower part of the legs of a jack-up rig in the Norwegian sector, we have on behalf of Havtil performed a study of hydrogen-related cracks in the legs of jack-up installations. The cracks were located at the welds connecting the spudcan to the chords and were determined to be hydrogen cracks.

The legs of a jack-up platform are constructed from high strength steel (500 – 690 MPa). The failures are most likely caused by a combination of fabrication flaws and crack growth due to ingress of hydrogen from cathodic protection into the steel, i.e., hydrogen assisted cold cracking (HACC) resulting from welding and crack propagation by hydrogen induced stress cracking (HISC) in service.

The experience is that the cracking is more related to lack of effective QA-QC during fabrication, rather than to deficiencies in the steel, the welding consumables or the structural design. It is emphasised that there is no experience of fast propagating brittle cracks or situations close to collapse.

The development of the observed cracks is described by the following sequence:

- The welding process provides a susceptible microstructure and residual stress enabling initiation of HACC due to hydrogen uptake during welding.
- In service hydrogen charging through bare steel surfaces due to cathodic protection triggers further growth of preexisting cracks by HISC.
- Structural stresses composed of weld residual stresses, service and environmental loads drive the crack growth due to stress concentration at the crack tip.

The main conclusions derived from the study are:

- Although cathodic protection contributed to cracking, the root cause is usually linked to the presence of undetected fabrication defects.
- Coating prevents bulk hydrogen charging of the steel thereby reduce the damaging effect of hydrogen from cathodic protection.
- The 690 MPa structural steels can retain structural integrity under hydrogen charging provided coated structures free of welding defects.

Referanse:

[Hydrogenassistert oppsprekking av oppjekkbare innretninger (havtil.no)]

**Nasjonal konferanse for Materialteknologi 2024**

Ringve Music Museum / Rockheim (Museums in Sør-Trøndelag), Trondheim
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## Corrosion of Steel Wires in Musical Instruments due to Emissions from Cellulose Nitrate

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A recurring development of local contact corrosion and atmospheric corrosion has been observed on historic musical instruments in museum collections. Metal parts, such as steel strings, corrode when mounted in contact with other materials of the sounding body.
One of the critical material combinations found during a survey of 12 large musical instrument collections in Europe was steel strings mounted close to Cellulose nitrate (CN). Consequently, this combination was the focus of further analysis.

Using scanning electron microscopy with Energy Dispersive X-ray Spectroscopy (SEM–EDS) and inductively coupled plasma-mass spectrometry (ICP-MS), different types of steel strings were investigated to detect their microstructure and elemental composition. Evident variations in the elemental composition were detected. All strings have a fine lamellar microstructure and a low degree of impurities to provide the desired tuning stability and tone response properties.
On a bass sitar produced around 1960 in India, the presence of a decorative part made of CN was confirmed by infrared spectroscopy (IR). The volatile compounds emitted were captured by solid-phase-microextraction (SPME) and analysed by gas chromatography-mass spectrometry (GC-MS). The findings include camphor, sulphur- and nitrogen-containing compounds and different carboxylic acids.
The respective corrosion product on one of the steel strings mounted close to the CN was investigated by SEM-EDS, Raman and IR spectroscopy and pointed to iron(III) nitrate nonahydrate $Fe(NO_3)_3 \cdot 9H_2O$ and iron(III) oxyhydroxide FeO(OH) (goethite). The presence of nitrous compounds in the corrosion product indicates the involvement of $NO_x$ emitted from CN.

Summarising, the findings confirm an interaction between steel strings and CN by the integration of nitric compounds inside the corrosion product.

**Nasjonal konferanse for Materialteknologi 2024**

SINTEF Manufacturing

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# Effekt av økt Fe, Zn og Cu innhold i Aluminiumslegeringer på mekaniske egenskaper og korrosjon.

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SINTEF Manufacturing, Raufoss

## Abstract

Aluminium er mye brukt i bil- og byggindustrien på grunn av gode egenskaper slik som høy styrke, lav vekt, god formbarhet og god korrosjonsmotstand. I tillegg har aluminium høy resirkulerbarhet. Siden det er forventet at innholdet av noen uønskede elementer kan øke i forbindelse med resirkulering har vi undersøkt effekten økt innhold av Fe, Zn og Cu (kun i 6082) har på mekaniske egenskapene og motstand mot intergranulær korrosjon.

I 6005 Aluminium er det ingen endring i mekaniske egenskaper ved økte nivåer av Fe og Zn. Økningen av Cu i 6082 Aluminium fører derimot til en økning i flytspenning og strekkfasthet i forhold til legeringene uten Cu. Ingen av legeringstypene viser noen endringer i duktilitet ved økt legeringsinnhold.

I 6005-legeringen er det økt intergranulær korrosjon ved økende legeringsinnhold. Vi observerer en kombinasjon av intergranulær korrosjon og gropkorrosjon. Korrosjonen trenger ikke gjennom det rekrystalliserte laget i overflaten.

Økende korrosjon observeres også i 6082-legeringen med økende innhold av legeringselementene. I denne legeringen er det intergranulær korrosjon som observeres, og angrepene blir dypere og mer utbredt med økt innhold av legeringselementer.

# Nasjonal konferanse for Materialteknologi 2024

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## Effect of impurity elements on the recycled HPDC aluminium alloys: a literature study

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### Abstract

Recycling of materials plays a crucial role to tackle the current environmental and energy challenges, as it contributes to reduce waste in landfills and energy consumption, thereby reducing the carbon footprints. Large amount of scrap is created by transportation industry. Aluminium alloys are used widely in the automotive industry because of their light weight, low energy consumption and corrosion resistance. The majority of the aluminium components used in the automotive industry are produced by the high-pressure die casting (HPDC) process. HPDC is a cost-effective process for the production of high-quality castings in large quantities. As the percentage of recycled Al alloys is increasing, the amount and type of impurities may vary. Thus, the purpose of the study is to look at the effect of different impurity elements such as iron (Fe), zinc (Zn), copper (Cu) etc on the microstructural and mechanical properties of the Al HPDC alloys. For example, increased Fe (1-2 wt%) content in recycled HPDC alloys can induce corrosion and can be a barrier to widespread use in casting applications which require high ductility. While addition of manganese (Mn) can counteract the negative effects of iron. Thus, in this way a deeper understanding of the effect of these impurities on key properties such as tensile strength, yield strength, hardness, and elongation can be achieved and used to develop better recycled alloys. In this work, an extensive review on the effects of different impurity elements on the microstructures and properties of HPDC aluminium alloys is made.

**Nasjonal konferanse for Materialteknologi 2024**

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## Effect of Trace Elements in Recycled Aluminium Alloys for Extrusion

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Abstract

The green shift has led to a growing demand for recycled materials and products with a low $CO_2$ footprint. Being an infinitely recyclable metal, which also maintains its good material properties through this process, Aluminium is a perfect candidate for recycling purposes. It is, however, well-known that recycling of Aluminium introduces trace elements like Fe, Zn and Cu into the final products which in turn can affect the final material properties. It is crucial to understand and document any effects that may arise from using recycled- instead of primary Aluminium.

The main strength contribution in 6xxx alloys comes from small additions of Si, Mg and Cu. But increased levels of Fe, Zn and Cu may alter the mechanical properties of the alloy in addition to its corrosion resistance.

In this work, the effect of Zn and Cu up to 0.05 weight % each in 6063 and up to 0.20 weight % each in 6082 have been investigated. Hardness- and tensile testing, light microscopy (LOM), scanning electron microscopy (SEM), energy dispersive electron spectroscopy (EDS) and glow discharge optical emission spectroscopy (GD-OES) have been used to document the material properties.

Based on the results in this study, it was concluded that these trace element amounts exhibited low- to no measurable effect on the mechanical properties in these alloys. This in turn implies that the present alloys can be used for the same mechanical applications as Cu/Zn-free alloys.

# Effekt av bråkjølingshastighet på mekaniske egenskaper og restspenninger i Aluminiumsblokker for maskinering

J.Holmestad, S. Petrovic Tomovic, K. Aamot, H. Lange, O. Jensrud

Aluminium er et materiale med mange gode egenskaper som lav vekt, høy styrke, god korrosjonsmotstand og god maskinerbarhet. En utfordring med maskinering av store Aluminiumsblokker etter utherding er introduksjonen av restspenninger i løpet av produksjonsprosessen.

Vi har undersøkt effekten av bråkjølingshastigheten på mekaniske egenskaper og restspenninger etter utherding i valsede Aluminiumsblokker. Mindre biter av blokkene ble saget ut symmetrisk fra topp og bunn av blokkene for å se effekten på restspennningene. Blokkene ble innherdet, bråkjølt i ulike kjølemedier før romtemperaturlagring og utherding. Kjølemediene som ble undersøkt var romtemperert vann, olje, polymer, blåsende luft og stillestående luft. Restspenningene ble målt i to posisjoner ved hjelp av hullborring og påmonterte strekklapper. Runde strekkstaver ble maskinert ut og brukt til å måle de mekaniske egenskapene.

Det er en stor effekt av bråkjølingshastighet på både de mekaniske egenskapene og restspenningene. De mekaniske egenskapene blir redusert kraftig med kjøling i blåsende luft og stillestående luft, men har liten reduksjon ved kjøling i polymer eller olje i forhold til i vann. Reduksjonen i kjølehastighet fører også til en reduksjon i restspenninger i materialet, med en reduksjon for alle kjølemetodene i forhold til kjøling i vann.

Resultatene viser at avkjøling i polymer eller olje kan gi svært liten reduksjon i mekaniske egenskaper, samtidig som restspenningene i materialet blir kraftig redusert i forhold til kjøling i vann. Bruk av et annet kjølemedium enn vann vil derfor kunne redusere risikoen for at materialet slår seg under maskineringen, samtidig som de mekaniske egenskapene opprettholdes.

**Nasjonal konferanse for Materialteknologi 2024**

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## Misconceptions about the β to α Transformation in 6xxx Aluminium Alloys

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Abstract

In the lean AlMgSi alloys, such as the extrusion alloys 6060 and 6063, the main part of the Fe in the alloy forms elongated particles of β-AlFeSi, during solidification. During homogenization, a transformation towards the α-AlFeSi, takes place, and these particles are considerably less elongated than the particles found after casting. It is a common perception that it is beneficial for extrudability and surface quality of the profiles to have a high degree of transformation from the β-AlFeSi to the α-AlFeSi particles. Thus, many extrusion billet customers have requirements on the degree of transformation that should be achieved during homogenization.

The common way of determining the degree of transformation is to make a metallographic sample, etch it in HF and examine it in the light microscope. The etch gives a difference in colour tone between the two particle types, making it easy to determine the percentage transformed. It would, however, be convenient if one could just determine the particle type just from the morphology. The sample preparation would be easier, and it would be simple to use image analysis for determining the percentage transformed. This does of course require that, as commonly assumed in the literature, the β-AlFeSi particles are more elongated than the α-AlFeSi particles after homogenization.

In this study, three 6060 alloys were cast as Ø203mm extrusion billets. Samples from the billets were subjected to 3 different homogenization procedures and the transformation degree was measured manually on HF-etched samples using light microscopy. In addition, image analysis was performed on the same samples. By thresholding the particles on their greyness, it was possible to replicate the manual count. This yielded a substantial data set on morphology for both particle types. Contrary to the common assumption, the non-transformed β-AlFeSi gets more spheroidized than the transformed α-AlFeSi particles. This indicates that the approach of using shape for determining the transformation degree can give misleading results.

SINTEF Industry

Kristian Grøtta Skorpen

## Multi-billet extrusion of aluminium for large section panels

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### Abstract

There are increasing demands for complex, wide aluminum profiles in many industries, for weight saving in big structures. However, conventionally extruding wide profiles is very challenging as it is limited by billet diameter. Further, the bigger the billet diameter, the more costly and higher energy consumption to produce the billet and to extrude into profiles. The current work aims to validate a new approach using multiple billet extrusion. This includes development of a new container and die solution. Important factors to understand in this setup is material flow and seam welding so that the extruded profile is free from defect (from improper welding or inflow of billet inverse segregation zone). Work utilizing FEM structural and process simulations to evaluate suitable designs is ongoing. Process simulation using modelling clay in a benchtop model is also contributing to increased process understanding. The presented work will lead to new capability to extrude wide profiles in the extrusion press at SINTEF, where extrusion of relevant profiles from multiple billets will be demonstrated.

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Hydro Aluminium AS

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# Optimizing the Mn and Cr content in fibrous 6005A Aluminium alloys

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Abstract

For some applications, for instance extrusions for the construction of railway wagons, it is desirable to use 6005A alloys with a fibrous microstructure. Such extrusions usually have a large circumference and a complex geometry, making them challenging to extrude. Many of the larger extrusion presses in Europe are delivering 6005A extrusions for such purposes.

To achieve a fibrous microstructure, one adds Mn and Cr to the alloy for the purpose of forming dispersoids during homogenization of the extrusion billets. These dispersoids then largely prevent the recrystallization of the extruded profile. A recrystallized layer at the surface is inevitable, however. The main drawback of adding Mn and Cr to the alloy is that it gets much harder to extrude. Therefore, one should seek to add only as much Mn and/or Cr as necessary to achieve the desired microstructure and with an acceptable thickness of the recrystallized layer. Also, the effects of Mn and Cr are not identic, and it is not straightforward to determine whether to use Mn, Cr, or a combination of the two. It is therefore worthwhile to perform a study on how to optimize alloys for this purpose.

In the present study, 6 alloys with identic contents of Mg, Si, Cu and Fe and various contents of Mn and/or Cr were studied. The alloys were cast as Ø95mm extrusion billets and homogenized. Dispersoid densities in the billets were measured in a scanning electron microscope. Extrusion was done at the SINTEF laboratory press in Trondheim. Two profiles were extruded, a round-bar profile with ribs for comparing the maximum extrusion speed before tearing, and a flat-bar profile for determining mechanical properties. The grain structure was examined by light microscopy for both profile types.

The results indicate that the best combination of extrudability, grain structure and mechanical properties is achieved when Mn is used as the main dispersoid former, and with a small addition of Cr.

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## Fused quartz crucibles for Czochralski silicon ingot production

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Abstract

In the recent years, solar cells have proven to be one of the most efficient and promising green energy sources in the fight against climate change. The solar cell market is currently dominated by monocrystalline silicon-based cells, leading to increased demand for higher production yield. Monocrystalline silicon is usually produced in the Czochralski process, where molten silicon is held in a fused quartz crucible for several hundred hours. The crucible must have high purity and have great mechanical stability to withstand temperatures around 1500 °C. During the process, the crucible will undergo a phase transition, in which cristobalite will grow on the crucible surface. To meet the growing demand for monocrystalline silicon, there is a need to improve our knowledge and understanding of fused quartz crucibles, that play a crucial role in the Czochralski process. As of today, the crucibles are being disposed of after one heating cycle, and there exist no recycling process for this product.

This work will highlight the recent findings in the field of fused quartz crucibles, including studies investigating crucibles mechanical properties, the above-mentioned phase transformation, the bubble content, the impurity concentration and more. It will also investigate the correlation between the different properties.

The properties of the crucibles are important factors affecting the production yield. Therefore, understanding the importance of those is a key to further optimization of the Czochralski process, making the crucibles more durable and thus making the process more environmentally friendly.

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## Hydrogen storage properties of Nb-rich alloys of the Nb-Cr-Mn system

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Metal hydrides are potential candidates for stationary hydrogen storage applications such as in tanks and compressors. Body-centered cubic (BCC) multicomponent alloys attract the attention of the scientific community due to their rapid hydrogen absorption/desorption kinetics and the ability to absorb hydrogen without the need of activation treatments. Another interesting feature of BCC alloy systems is the possibility of optimizing hydrogen storage properties (such as the thermodynamic stability of their hydrides) through compositional balance of hydride-forming and non-hydride-forming elements in solid solution. Nb-rich BCC alloys have been showing promising performance for hydrogen storage at room temperature. Within this context, this work investigates hydrogen storage properties of Nb-rich alloys of the Nb-Cr-Mn system, focusing on compositions that can absorb/desorb hydrogen under moderate pressure and temperature conditions. Chemical compositions were selected using the CALPHAD method with the aim of achieving BCC solid solutions with substantial contents of Cr and Mn (non-hydride forming elements). Two alloys containing Nb with an atomic ratio greater than 60% were selected. The alloys were 1) produced via electric arc melting; 2) characterized via X-ray diffraction and scanning electron microscopy 3) investigated regarding hydrogen storage properties via Sieverts volumetric measurements. Both alloys showed major amounts of BCC solid solution phases with minor fractions of a eutectic microconstituent composed of BCC + Intermetallic Laves C14 phases, as predicted via CALPHAD. Both alloys were easily hydrogenated, without the need of activation treatments, reaching storage capacities between 1.4 and 2 wt.% of hydrogen. The hydrogenation process led to the formation of Face-centered cubic hydrides. Moreover, measurements of Pressure-Composition-Isotherms (PCIs) demonstrated plateau equilibrium pressures for the BCC ↔ FCC reaction greater than 0.8 bar at 30 ºC, demonstrating reversible hydrogen absorption/desorption capacity at room temperature. Cycling measurements at room temperature confirmed the reversibility of 0.7-1.2 wt.% of hydrogen for the alloys. These results demonstrate the potential of Nb-rich alloys for hydrogen storage applications.

SINTEF

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**Investigations of gas flow in charge materials with biocarbon**

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The FeMn and FeSi Industries are transitioning along the lines of green metal and alloy production. A possibility to reduce $CO_2$ emissions in FeMn and FeSi production is to substitute fossil carbon consumption with renewable carbon sources such as charcoal i.e. This change invites new challenges due to the different nature of the two carbon sources. Generally, biocarbon have lower mechanical strength and generate more fines than traditional carbon sources. This will affect the gas permeability of the charge, and in turn the furnace operation.

An apparatus, the pressure drop apparatus, examines the various contributions which influence the pressure drop in a packed bed has been developed and will be described together with the methodology for the investigations. The apparatus is a slim packed bed that provides visibility to phenomenon such as channel formation, segregation, and other movement in the charge in addition to the pressure drop measurements. Each material charge is 18.8 L and gas with velocities in the range 0 m/s to 2.6 m/s can be tested. Gas is blown through each charge bed twice to both simulate the gas permeability of an undisturbed bed, and later to give understanding of the pressure drop in a bed with potential segregation and channeling.

Results from earlier and new investigations of pressure drop in various industrial Si and Mn charges including both fossil carbon and biocarbon, and with some variations in particle sizes of both carbon source and ore will be presented. Different charge compositions and various particle size distributions of the input materials are tested to investigate their effect of particle size on the pressure drop.

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# Metallic phase change materials for high temperature latent heat thermal energy storage applications

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Abstract

Latent heat thermal energy storage systems (LHTES) play a crucial role in enhancing the availability and stability of intermittent renewable energy sources such as solar and wind power. As the integration of these renewable sources increases in energy grids, there is a growing demand for transient storage solutions. Through the European Union-funded SUNSON project, we aim to explore the potential of using silicon-based phase change materials (PCMs) for LHTES applications, specifically targeting working temperatures exceeding 1000°C and achieving exceptionally high energy storage densities surpassing 1 MWh/m3.

In this study, we present state-of-the-art metallic PCMs identified through simulations conducted using FactSage 8.2 software. Additionally, we investigate the potential application of solid-state thermophotovoltaic (TPV) energy generators that could benefit from the extremely high phase transition temperatures offered by such PCMs. Specifically, we explore the possible implementation of such systems in concentrated solar power (CSP) energy production.

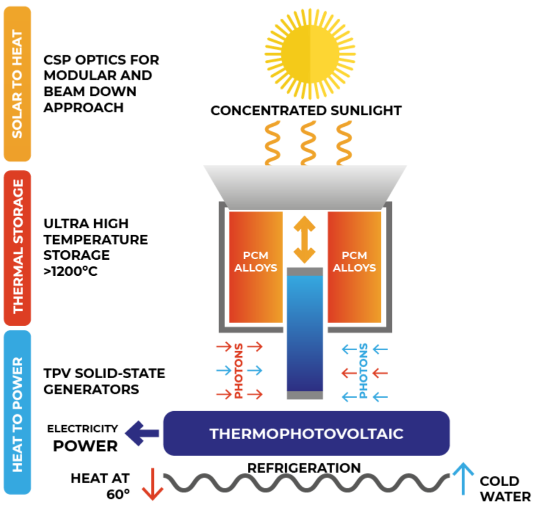


*Figure 1. Schematic of the latent heat thermal energy storage developed in SUNSON.*

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# Optimisation of the formulation of silicon anodes for lithium-ion batteries

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Abstract

Nowadays lithium-ion batteries (LIBs) are a key technology for the transition to a net-zero emission society. Silicon could be used as a main component in LIBs' anodes due to its high capacity to store lithium ions. This feature might improve energy density even further, thus paving the way to new fields of application. Anode formulations have been proposed already, but the understanding of the effect of each component on physical and electrochemical performances is still unclear.

In this work, the formulation of anode slurries was investigated aiming at optimising anodes with high silicon content (> 50 wt. %) and high loading (> 3 mAh/cm$^2$). Materials and synthetic procedure were analysed in depth and key parameters were selected. A $2^{5-1}$ half factorial design of experiment (DOE) was used to investigate all of them. Formulations were prepared and used to cast anodes for coin cell testing.

By means of analysis of variance (ANOVA), models to describe anode slurries, casting and testing were developed. Results indicate that formulation parameters have a clear effect not only on physical properties of slurries and casts, but also on electrochemical performances of coin cells. However, once extra operations occur between slurries preparation and data collection, models become more complicated and interactions between parameters become significant too.

From the interpretation of experimental data, it was possible to develop a model of understanding of the effect of the formulation of Si-based anodes on physical and electrochemical properties of final materials.

# Revolutionizing Lithium-Ion Batteries: Sustainable Silicon Waste Transformation into High-Performance Anode Materials

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## Abstract

Silicon has long been recognized for its high theoretical specific capacity of 4200 mAh/g as a potential anode material for lithium-ion batteries (LIBs). However, its commercial application is hindered by significant volume changes during the charging and discharging processes.

We first explored a yolk-shell structured Si@void@C[1] anode material to tackle this challenge. This material features a silicon nanoparticle 'yolk,' derived from kerf loss (KL) silicon waste produced during the slicing of silicon blocks into wafers for the photovoltaic industry. The 'shell' is made from carbon, synthesized via a hydrothermal method using glucose, while $Al_2O_3$ serves as a sacrificial interlayer. The resulting Si@void@C anode material not only demonstrated enhanced cyclic stability but also showed notable electrochemical reversibility.

Further, we also developed silicon-carbon (Si@C) composites[2] as promising alternatives to commercial graphite for LIB anodes. These composites were produced by extracting purified nanosilicon powder from KL Si wastes, employing a process that integrates ball milling and acid leaching. The Si@C composites were then produced using a novel method that includes glucose coating and freeze-drying, which effectively encases the silicon particles. This encapsulation significantly reduces volume changes during battery operation. Moreover, the freeze-drying method introduces a high level of porosity within the composite, improving lithium-ion diffusion.

These investigations collectively underscore the practicality of repurposing silicon waste into high-performance anode materials, steering the way toward more sustainable and economically feasible battery technologies.

**Keywords:**
Lithium-ion batteries
Anode materials
Silicon waste recycling
Yolk-shell structures
Si@C composites
Electrochemical performance
Sustainable technology

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[1] Ji, H., Liu, Z., Li, X., Li, J., Yan, Z., & Tang, K. (2023). Recycling Silicon Waste from the Photovoltaic Industry to Prepare Yolk–Shell Si@ void@ C Anode Materials for Lithium–Ion Batteries. Processes, 11(6), 1764.
[2] Ji, H., Xu, X., Li, X., Li, K., Yuan, L., Han, Z., & Tang, K. (2024). A low-cost Si@ C composite for lithium-ion batteries anode materials synthesized via freeze-drying process using kerf loss Si waste. Ionics, 1-15.