SWEDEN'S KEY AM RESEARCH CENTRES IN THE ARENA

Compentence

JÖNKÖPING UNIVERSITY

- Design modularization
- Process optimization
- Materials characterization
- Materials testing

ÖREBRO UNIVERSITY

- Advanced materials in design and manufacturing
- Design analysis and optimization
- Experimental mechanics in design and manufacturing
- Characterization of materials
- Design and manufacturing case studies
- Digitalization and digital twins

LULEÅ UNIVERSITY OF TECHNOLOGY

- Design for AM (DfAM)
- Numerical simulation
- Process optimization and high-speed imaging
- Material characterization

DALARNA UNIVERSITY

- Powder characterization
- Material testing and characterization
- Tribological performance

RISE

- Powder material
- Process development
- Production system
- Process stability
- Design

MID SWEDEN UNIVERSITY

- Process and material development for E-PBF
- Post-processing
- Material and surface functionalization
- In-situ monitoring
- Applied industrial applications
- Biomaterials/implants

UPPSALA UNIVERSITY

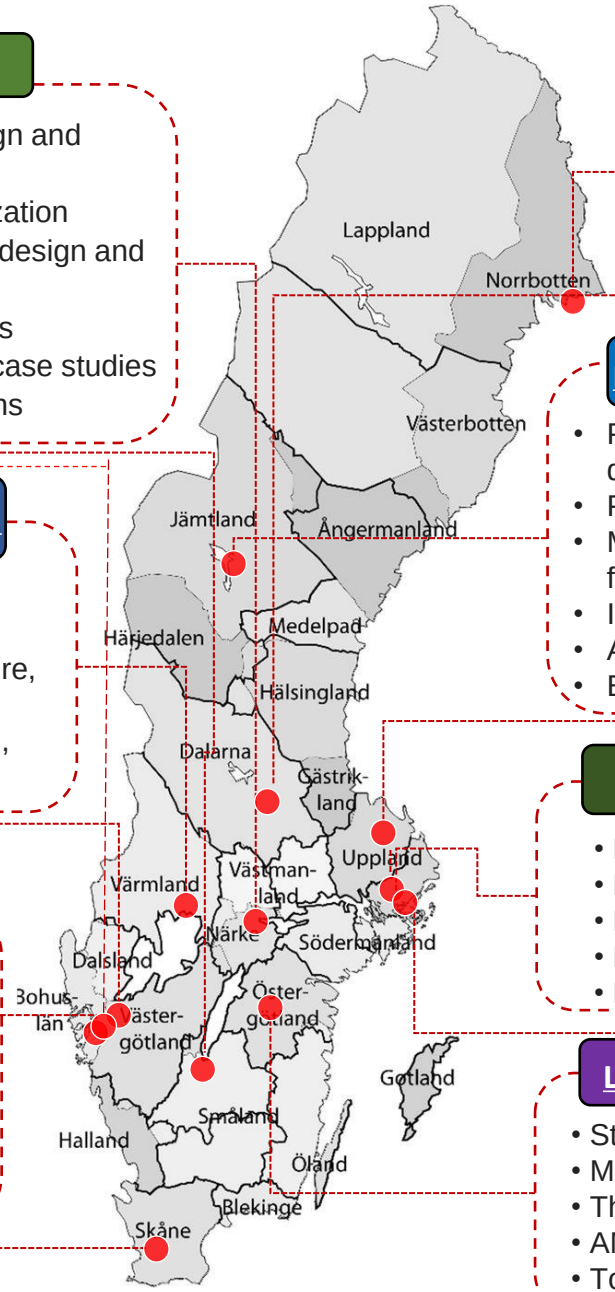
- New materials for AM
- AM for life sciences (includes the Vinnova competence centre AM4Life)
- Microstructure design
- Metastructure design / mechanics (applied mechanics)
- Development and implementation of new technologies in society (Industrial Engineering and Management)

KARLSTAD UNIVERSITY

- LPBF, process, monitoring, advanced materials
- In-situ alloying, microstructure, new materuals
- Mechanical characterization, tribology, UHCF

UNIVERSITY WEST

- Directed energy deposition
- Powder bed fusion, electron and laser beam melting
- Process development/control
- Mechanical and corrosion performance
- Computed tomography
- Non-destructive testing



SWERIM

- Powder material
- Process development
- Powder characterization
- Material testing
- Material development

KTH ROYAL INSTITUTE OF TECHNOLOGY

- AM processing and characterization
- Integrated computational materials engineering (ICME)
- Powder production and characterization
- AM education

CHALMERS UNIVERSITY OF TECHNOLOGY

- Powder metallurgy
- Laser powder bed fusion
- Materials Development
- Powder Development
- Sintering
- In-situ monitoring
- Characterization
- AM education

LUND UNIVERSITY

- Design for AM
- Light-weighting
- Topology optimization
- Economics of AM
- AM Education

LINKÖPING UNIVERSITY

- Structure-property relations
- Material characterization
- Thermal mechanical testing
- AM alloy design
- Topology optimization

Prepared by Emmy Yu Cao
Annika Strondl
Esmaeil Sadeghi

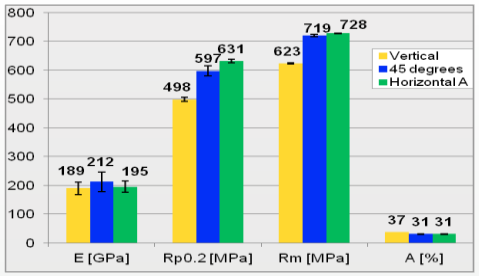
The Swedish Arena for Additive Manufacturing of Metals

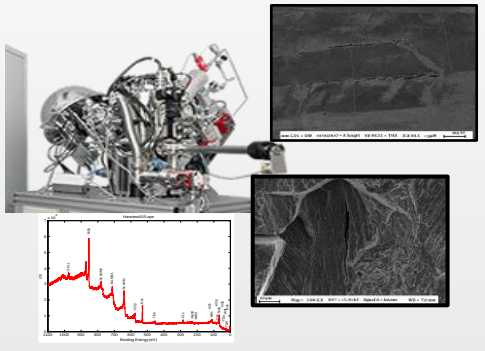
Chalmers University of Technology

Lars Nyborg, lars.nyborg@chalmers.se

Powder-based additive manufacturing

- Powder development with respect to powder properties and surface chemistry control in metal additive manufacturing (PBF-LB, PBF-EB, DED and BJ)
- Process monitoring and process development with particular reference to laser-based powder bed fusion (PBF-LB)
- Materials development taking advantage of inherent characteristics like rapid cooling in metal additive manufacturing
- Powder recycling and its optimisation
- Sintering of binder-jet processed materials/components





Publications, examples

A neural network for identification and classification of systematic internal flaws in laser powder bed fusion C Schwerz, L Nyborg, CIRP Journal of Manufacturing Science and Technology 37, 312-318

Study of defects in directed energy deposited Vanadis 4 Extra tool steel M Yuan, S Karamchedu, Y Fan, L Liu, L Nyborg, Y Cao, Journal of Manufacturing Processes 76, 419-427

The effect of boron and zirconium on the microcracking susceptibility of IN-738LC derivatives in laser powder bed fusion H Gruber, E Hryha, K Lindgren, Y Cao, M Rashidi, L Nyborg, Applied Surface Science 573, 151541

Effect of part thickness on the microstructure and tensile properties of 316L parts produced by laser powder bed fusion A Leicht, C Pauzon, M Rashidi, U Klement, L Nyborg, E Hryha, Advances in Industrial and Manufacturing Engineering 2, 100037

Increasing the productivity of laser powder bed fusion for stainless steel 316L through increased layer thickness A Leicht, M Fischer, U Klement, L Nyborg, E Hryha, Journal of Materials Engineering and Performance 30 (1), 575-584

Powder Assessment and Materials Development

Surface Science

Process development/monitoring

Methods

Advanced characterisation:

XPS, Auger, SEM/ESEM, Dil/TG/DSC

Laser-based powder bed fusion:

One EOSM290 for Ni- nad Fe-alloys

One M290 for Al- and Ti-alloys

One M100 for materials development (all materials expect pure Cu)

Software

Magics, Simufact, Thermo-Calc, JMatPro, HSC Chemistry, Deform, Ansys, etc. (applied use)

Sample preparation and treatment

Glove-box, ball milling, rotation drum testing

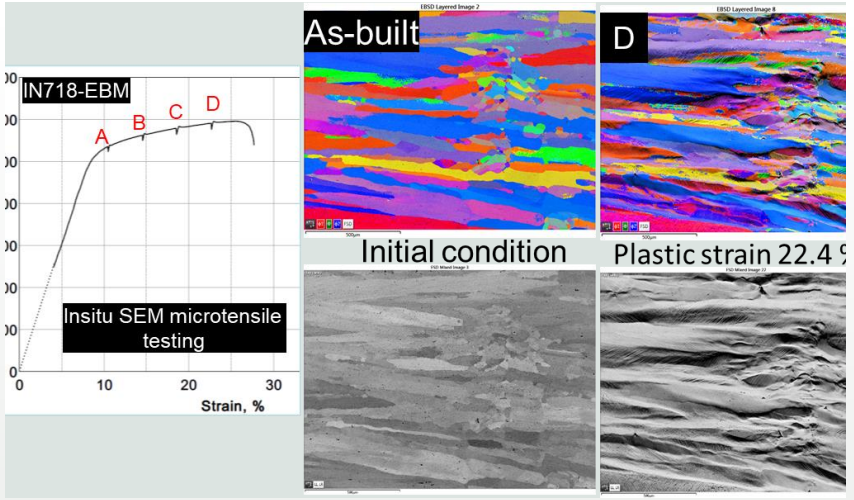
Furnace laboratory for different heat treatments

Metallography and optical microscopy

Mechanical testing (various kind)

Dalarna University

Kumar Babu Surreddi, kbs@du.se



- Characterization of powders for AM processes
- Microstructure – Property relationship of AM products
- Tribological performance of AM products
- Corrosion studies of AM products
- Insitu SEM micromechanical characterization – microtensile, compression, bending, and cyclic loading testing (low cycle fatigue).

Industry collaborations / Needs (in order to develop the research within the area) (Optional)

Siemens-Energy AB

Sandvik AB

Sandvik Coromant

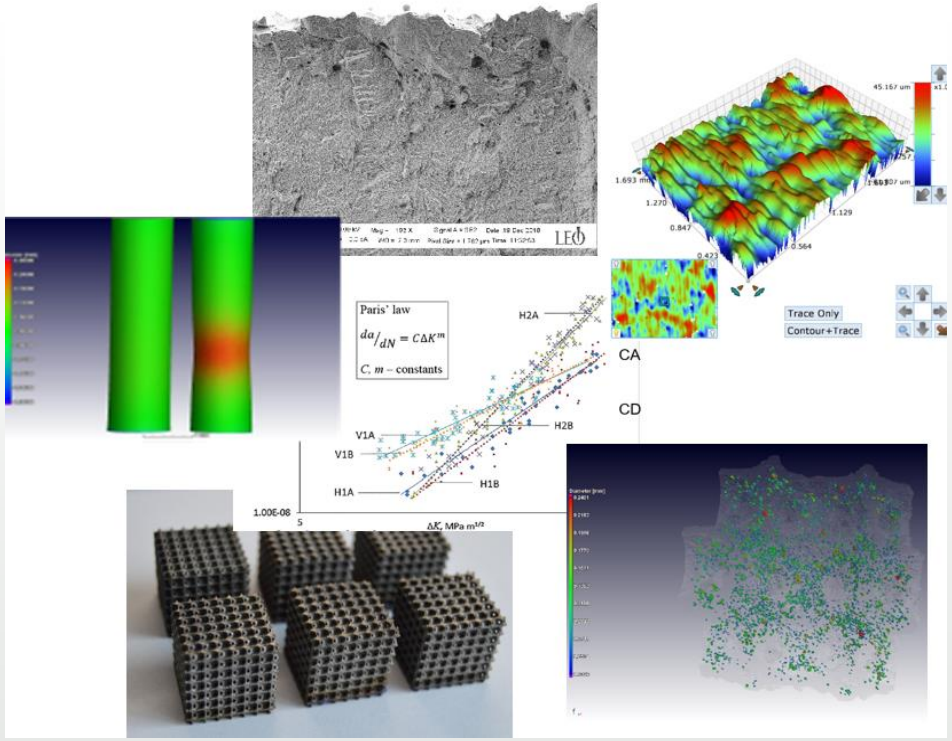
VBN components AB

Infrastructure / Technical platforms / relevant methods / Web etc.

- Microstructure characterization using optical and electron microscopy
- SEM-EDX and EBSD
- Auger Electron Spectroscopy
- Time of Flight – Secondary Ion Mass Spectroscopy
- Microtesting stage – Insitu SEM microtensile, compression, bending and cyclic loading testing is possible
- Tribological performance
- Corrosion studies on AM products

Karlstad University

Pavel Krakhmalev, pavel.krakhmalev@kau.se



- LPBF manufacturing, in-situ alloying, process development/optimization
- Advanced materials (steels, Ti alloys, new materials)
- Microstructure characterization (LPBF, EPBF, DED)
- Materials testing (static mechanical, fatigue, UHCF, tribology)
- Process monitoring for process/material quality assessment

Industry collaborations

Uddeholms AB, Epiroc Rock Drills, Siemens-Energy AB, SECO Tools AB, Sandvik Materials Technology, Curtiss-Wright Engineering, Swerim AB, Scania AB.

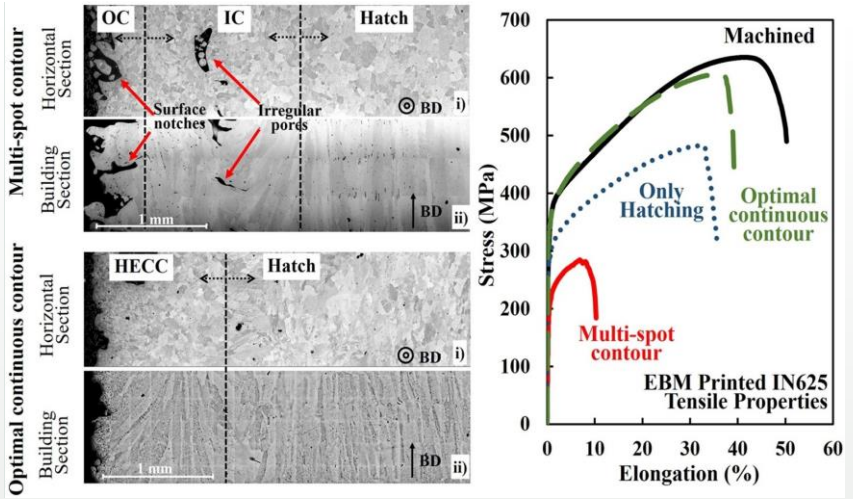
Infrastructure / Technical platforms

- Equipment - L-PBF Renishaw AM400
- Characterization - SEM EDX, EBSD, TEM, TEM EDX, XRD, tensile/compression/bending tests, fatigue tests including high-temperature fatigue, UHCF (20 kHz), tribo-tests
- In-house acoustic- and video-monitoring system

29 peer-review journal publications,
3 book chapters,
ca 50 international conferences

KTH Royal Institute of Technology

Sasan Dadbakhsh; sdad@kth.se



- Metal powder production and powder characterisation
- Alloy design for AM
- AM of metal alloys and functional/advanced materials
- AM process optimisation and modification
- Material characterisation and property control
- AM monitoring
- AM part design and performance

Industry collaborations / Needs (in order to develop the research within the area) (Optional)

Material providers and metal powder producers to design material for AM and evaluate/engineer the material properties
Machine manufacturer and end users to improve/modify AM processes and techniques
Users to reach the requested function of the parts and materials
Software and software-based companies (CFD, physical modelling, design for AM…) to validate and accelerate the AM software commercialisation and solve research questions
Industrial in-kind contributions for projects and thesis works

Infrastructure / Technical platforms / relevant methods / Web etc.

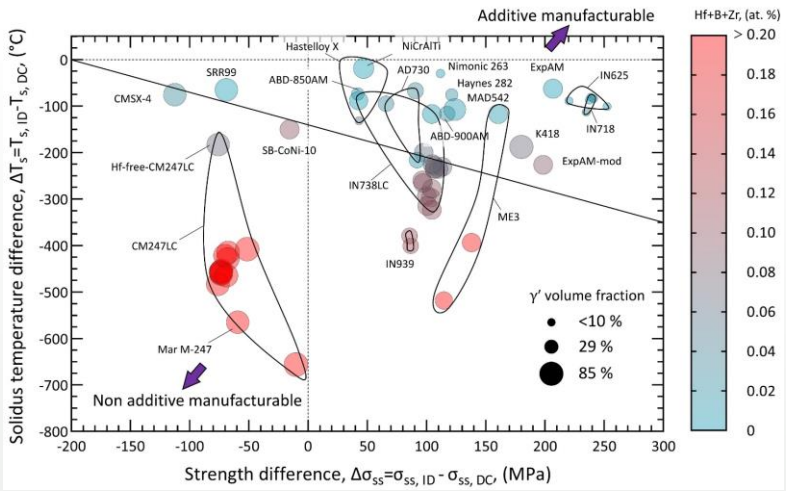
- AM machines: EBM ARCAM A2X, EBM freemelt 1
- Software: Thermo-Calc, Materialise magics, Siemens NX, Ansys, Simufact….
- Powder characterisation lab (Rheometry, Spreadability, Sample division, flowmeter, sieving, AoR…)
- CFD, thermodyamic modelling, numerical modelling, Water lab to test fluid
- Metal AM supporting machines (EDM, metrology, surface measurement, milling/grinding…)
- Metallurgical and mechanical characterisation tools/equipment
- Heat treatment furnaces

For AM related journal publications, please follow this link
https://drive.google.com/file/d/1p0NLCS-HjifYE5Jtxeld2clpXXwQBESB/view?usp=sharing

Linköping University

Johan Moverare: johan.moverare@liu.se

Process – Structure – Properties relationships



The AM group at LiU is strongly involved in the development and characterization of new metallic materials adapted for AM. The relationships between process, microstructure and properties are often in focus. Properties are often evaluated from a component point of view with focus on e.g. fatigue or creep. Ongoing projects includes material development of new nickel and aluminium alloys tailored for AM. Other projects are focusing on optimization of heat treatments and surface post-processing treatments. For the characterization of microstructures, high resolution microscopy and large-scale facilities such as Neutron diffraction is often used.

Research is also conducted at other divisions in the field of structural integrity and topology optimization av AM components as well as Design for AM (DfAM).

LiU is currently in the process of procuring an E-PBF system to be installed during early 2022

Infrastructure / Technical platforms / relevant methods / Web etc.

- Microstructure: LOM, SEM, TEM
- Residual stress: XRD
- Properties: Tensile, Fatigue, Creep, crack propagation, fracture toughness, oxidation
- ICME: ThermoCalc, TC Prisma, Dictra
- E-PBF system

Publications

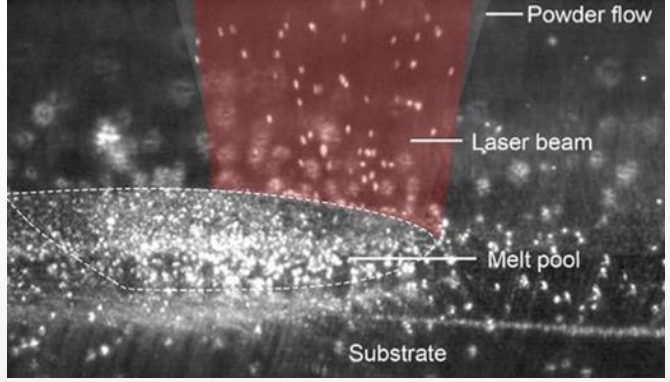
Diva - LiU - Division of Enginnering materials

Google Scholar - Johan Moverare

The Swedish Arena for Additive Manufacturing of Metals

Luleå University of Technology

Jörg Volpp (jorg.volpp@ltu.se)



Research focus

- Design for AM (DfAM)
- Modelling and simulation of AM (DED and PBF) with the finite element method, with focus on residual stresses and deformations, temperature fields, microstructure, physically based material models
- Laser process optimization and high-speed imaging
- Material characterization

Infrastructure

- Aconity Mini (PBF-LB/M machine)
- Laser-DED equipment (wire and powder)
- WAAM and hybrid-laser processes
- High-speed and thermal imaging
- Thermal analysis, Gleeble thermomechanical system
- SEM/EBSD; Micro-CT
- Several 3D printers for prototyping
- FE-software (MSC Marc, Simufact, LS-Dyna, in-house thermo-mechanical FE-software)
- Models for microstructure evolution (Ti64, alloy 625/718, Steel)
- Physically based material models (Ti64, Nickel based alloys, Aluminum, Stainless steel)

Industry collaborations (Selection)

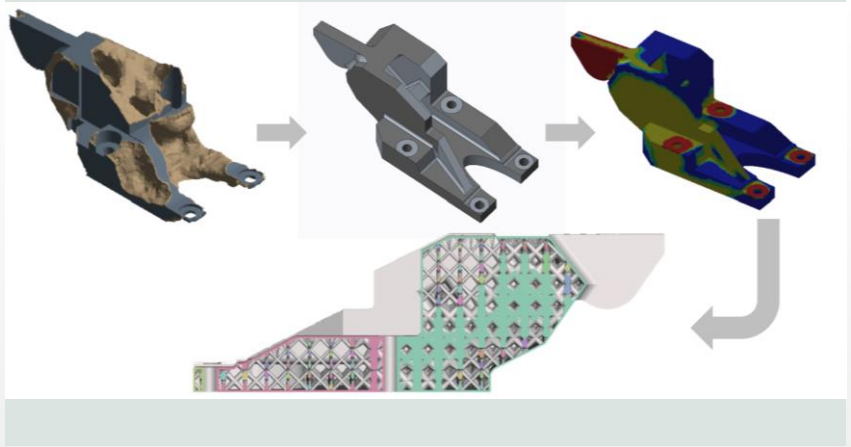
GKN Aerospace, Sandvik, Duroc, Termisk Systemteknik, Cavitar, Höganäs, Siemens, IMR, Sidenor, Magnetto Automotive, Fiat,…

Publications

- https://www.ltu.se/research/subjects/Produktionsutveckling/Publikationer
- https://www.ltu.se/research/subjects/Hallfasthetslara/Publikationer?l=en
- https://www.ltu.se/org/tvm/Avdelningar/Materialvetenskap/Publikationer?l=en
- https://www.ltu.se/org/etks/Avdelningar/human-and-tech?l=en

Lund university/LTH

Axel Nordin: axel.nordin@design.lth.se



Design for Additive Manufacturing

- Design for AM
- Light-weighting
- Topology optimization
- Economics of AM
- AM Education

Infrastructure / Technical platforms / relevant methods / Web etc.

- 3D Systems ProX DMP 320
- CNC Turning, Milling
- Materialise Magics, 3D Systems 3DXpert, Autodesk Netfabb Ultimate, Simufact

Industry collaborations / Needs (in order to develop the research within the area) (Optional)

Alfa Laval
Axis
Tetra Pak
Digital Metal

Tavcar, J., & Nordin, A. (2021). MULTI-CRITERIA ASSESSMENT AND PROCESS SELECTION MODEL FOR ADDITIVE MANUFACTURING IN THE CONCEPTUAL PHASE OF DESIGN. *Proceedings of the Design Society*, *1*, 2197-2206.

Nordin, A. (2020, May). An Approach for Topology Optimization-Driven Design for Additive Manufacturing. In *Proceedings of the Design Society: DESIGN Conference* (Vol. 1, pp. 325-334). Cambridge University Press.

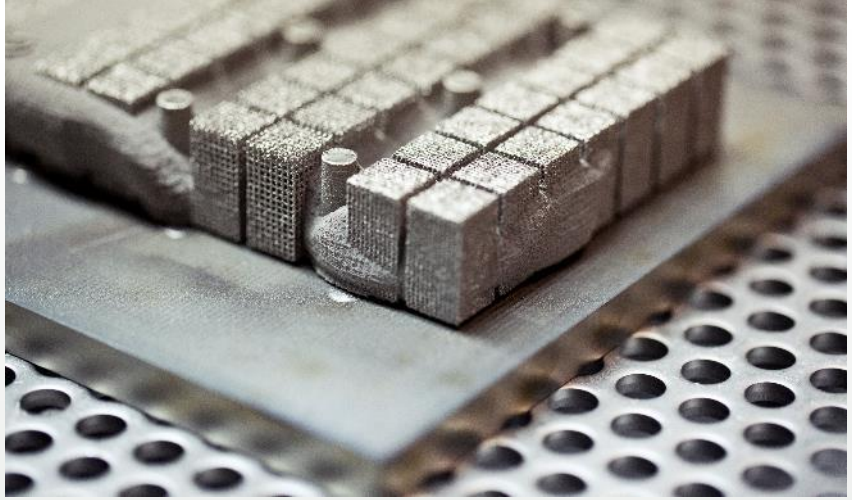
Valjak, F., Bojčetić, N., Nordin, A., & Godec, D. (2020, May). Conceptual Design for Additive Manufacturing: An Explorative Study. In *Proceedings of the Design Society: DESIGN Conference* (Vol. 1, pp. 441-450). Cambridge University Press.

Diegel, O., Nordin, A., & Motte, D. (2019). *A Practical Guide to Design for Additive Manufacturing* (pp. 978-981). Singapore: Springer Singapore.

Diegel, O., Nordin, A., & Motte, D. (2019). Teaching Design for Additive Manufacturing Through Problem-Based Learning. In *Additive Manufacturing–Developments in Training and Education* (pp. 139-149). Springer, Cham.

MID SWEDEN UNIVERSITY

Lars-Erik Rännar: lars-erik.rannar@miun.se



Sports Tech Research Centre
PART OF MID SWEDEN UNIVERSITY

- Process and material development for E-PBF
- Post-processing
- Material and surface functionalization
- In-situ monitoring
- Applied industrial applications
- Biomaterials/implants

Industry collaborations / ongoing projects

AMPeRE – Evaluation of electrochemical post-processing (Metalliska mater)
MaSAM – Development of courses in AM at advanced level (KK)
AMSUSS – Development of super-duplex stainless steel for E-PBF (KK)
FRAMGRAF – Functionalization of AM powders using graphene (SIO Grafen)

Infrastructure / Technical platforms / relevant methods / Web etc.

- Arcam A2 – modified for small powder batches + energy monitoring
- Arcam A2X
- Metallography, LOM, SEM, EDS, XRD, profilometry

https://www.miun.se/en/Research/research-centers/sports-tech-research-centre/publikationer/

Swerim AB

Annika Strondl, annika.strondl@swerim.se

- Powder material development
- Powder manufacturing and characterisation
- Process development
- Post treatment
- Verification of material properties (microstructure, mechanical, physical, corrosion, surface,…)

Infrastructure / Technical platforms / relevant methods / Web etc.

ICME, VIGA Gasatomizer (12 litre), Powder characerisation lab, HIP, PBF-EB, PBF-LB (Exmet), DED-L/W, WAAM, 3D-scanner, Alicona InfiniteFocusSL, Metallography, Mechanical testing, Corrosion, Laser flash, Gleeble, etc.

https://www.swerim.se/en/areas-of-expertise/manufacturing-processes/3d-printing

Industry collaborations / Needs (in order to develop the research within the area) (Optional)

- Research projects with different industries around common challenges, e.g., powder qualification, material development, EHS
- Research program MRC Powder Metallurgy with 12 companies
- Confidential bilateral work with industry

Effect of post-processing on microstructure and mechanical properties of Alloy 718 fabricated using powder bed fusion additive manufacturing processes (https://doi.org/10.1108/RPJ-12-2019-0310)

Surface pick-up of argon during hot isostatic pressing of material built by laser powder bed fusion (https://doi.org/10.1016/j.addma.2020.101763) as examples

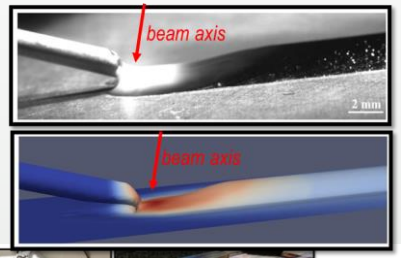
The Swedish Arena for Additive Manufacturing of Metals

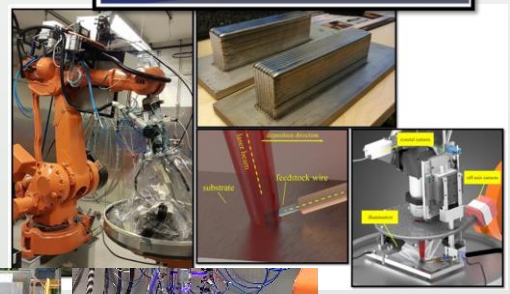
University West

contact: robert.pederson@hv.se

Research Focus

- **Automation/Process control**
  - Resistance/Temperature
  - Vision/Geometry
  - NDT/NDE
- **Simulation**
  - Microstructure
  - Melt pool
  - OLP
- **Materials**
  - Steels
  - Ni-based alloys
  - Ti-alloys
  - Al alloys





Infrastructure / Technical platforms / relevant methods

- EB-PBF and LB-PBF (in 2022) systems.
- 12kW fiber laser system with wire and powder deposition.
- Welding based additive manufacturing systems with both wire & powder deposition (WAAM).
- Material testing capability (tensile, fatigue, varestraint (LBW, TIG), NDT (incl. X-CT), Lab furnaces (<1200C), vacuum furnace, local HT, Gleeble 3800D system.
- SEM-EDX/EBSD, optical microscopy, GOM measurement.
- Simulation: OpenFoam, JMatPro, Thermocalc, Simufact Welding, COMSOL, MSC Marc, Simufact additive, MSC fluid etc, LS-Dyna.

Uppsala university

Activities coordinated through **The additive manufacturing initiative at the Ångström laboratory**
additive@angstrom.uu.se

Director of initiative: Erik Lewin erik.lewin@kemi.uu.se

UPPSALA UNIVERSITET

Research themes

Research is conducted within several research groups at several departments, with different focus. The main themes of research are:

- New materials for AM
- AM for life sciences (includes the Vinnova competence centre AM4Life)
- Microstructure design
- Metastructure design / mechanics (applied mechanics)
- Development and implementation of new technologies in society (Industrial Engineering and Management)

Most of our **research publications** can be found through the university's publication database Diva, using the key words "additive manufacturing".

Collaborations

Active collaborations with several industrial (e.g. *Cytiva, Kanthal, VBN components, Exmet, Erasteel, Sandvik additive, Graphmatech, Add:north*) and academic partners (e.g. *Luleå university, KTH, Mittuniversitetet, RISE, SWERIM*)

We are open for new collaborations with industry and academia in fields matching our interest, in particular if it includes new joint funding applications for new projects.

Infrastructure

Common AM-lab being built up, and will include:

- Shared equipment for metal AM using powder bed
  - Aconity Midi LPBF printer
  - EOS M100 LPBF printer
  - ExOne Lab X-1 binderjet printer
- Equipment belonging to different research groups (not shared) for ceramics, polymers, and composites using FDM, SLS, SLA, and BJ printers.
- Extensive materials characterisation, synthesis, and manufacturing capabilities through other common resources, e.g. µFAB Uppsala, Tandem laboratory, X-ray laboratory, Furnace lab, and the Ångström workshop

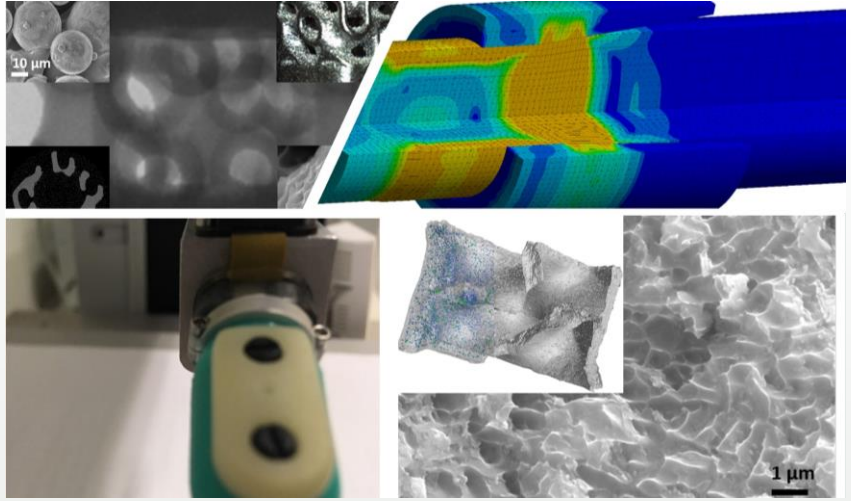
Web pages

- AM initiative home page: www.additivemanufacturing.se
- Vinnova competence centre home page: https://www.uu.se/en/research/am4life/

The Swedish Arena for Additive Manufacturing of Metals

Örebro University

Patrik Karlsson, patrik.karlsson@oru.se



- Advanced materials in design and manufacturing
- Design analysis and optimization
- Experimental mechanics in design and manufacturing
- Characterization of materials
- Design and manufacturing case studies
- Digitalization and digital twins

Examples of research topics of interest

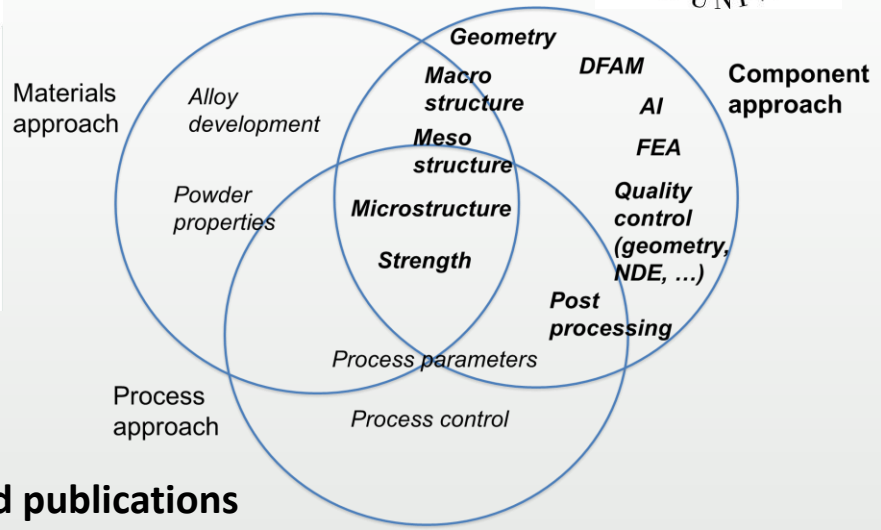
- Advanced materials in design and manufacturing
- Design analysis and optimization
- Experimental mechanics in design and manufacturing
- Characterization of materials
- Design and manufacturing case studies
- Digitalization and digital twins

Methods

- Microscopy (SEM, OM etc.)
- Micro computed tomography
- Characterization of materials
- Metallography
- Mechanical testing

Examples of ongoing research

- Characterization of materials in AM
- Design optimization for AM
- Experimental mechanics and analysis of paperboard
- Experimental mechanics and analysis of wire drawing
- Cyber-physically controlled systems



Selected publications

Pejryd, L. et al. (2016). Non-destructive evaluation of internal defects in additive manufactured aluminium. Konferensbidrag vid World PM 2016, Powder Metallurgy World Congress, Hamburg, Germany, October 9-13, 2016.

Jansson, A. & Pejryd, L. (2016). Characterisation of carbon fibre-reinforced polyamide manufactured by selective laser sintering. *Additive Manufacturing*, 9, 7-13.

Karlsson, P. et al. (2017). Factors Influencing Mechanical Properties of Additive Manufactured Thin-Walled Parts. I: *Euro PM2017 Congress Proceedings*. Konferensbidrag vid Euro PM2017 Congress & Exhibition, Milan, Italy, October 1-5, 2017. European Powder Metallurgy Association (EPMA).

Surreddi, K. B. et al. (2018). In-situ micro-tensile testing of additive manufactured maraging steels in the SEM: Influence of build orientation, thickness and roughness on the resulting mechanical properties. *La Metallurgia Italiana* (3), 27-33.

Karlsson, P. et al.(2020). Generative Design Optimization and Characterization of Triple Periodic Lattice Structures in AlSi10Mg. I: Mirko Meboldt, Christoph Klahn, *Industrializing Additive Manufacturing* Proceedings of AMPA2020. Konferensbidrag vid 2nd International Conference on Additive Manufacturing for Products and Applications (AMPA 2020), Zürich, Switzerland, September 1-3, 2020 (ss. 3-16). Cham: Springer.

Asnafi, N. (2021). Application of Laser-Based Powder Bed Fusion for Direct Metal Tooling. *Metals*, 11 (3).

Asnafi, N. (2021). Metal Additive Manufacturing—State of the Art 2020. *Metals*, 11 (6).

Asnafi, N. Tool and Die Making, Surface Treatment, and Repair by Laser-based Additive Processes. *Berg Huettenmaenn Monatsh* **166,** 225–236 (2021).