SEES HÖSTMÖTE | 17-18 OKTOBER 2023 | FINSPÅNG

Corrosion-Fatigue interaction on 3D-Printed (L-PBF) AlSi10Mg

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Erik Dartfeldt

- MSc in Mechanical Engineering (Chalmers)
- PhD in Solid and Structural Mechanics (Chalmers)
- Started at SP in 2014 (now RISE)
  - Dept. Chemistry & Applied Mechanics
- Involved in commission work and research projects
  - Experimental mechanics
  - Computational mechanics
  - Model validation
- Coordinator for a research group (Mechanics and Reliability)

Background - Timeline

- Interaction between mechanical loading and corrosion?
- Primary vs. secondary alloy?
- Impact of surface treatment?
- Electrification > Aluminium

2020
CorrAl

- How does the test mode affect the identified fatigue performance?
- As-print vs. machined
- Axial loading
- RISE internal method development
- SK-funding
- Nominal – Sequential - Combined

2021
CorrFat

- How do different alloys respond to corrosion-fatigue?
- Research project
- Bending fatigue
- Nominal – Sequential - Combined

2022-2025
EICAL

- Can we use DIC to identify fracture initiation?
- RISE internal method development

2023
BendFat

- Model quality vs. need for prototypes?
- Research project
- Model validation
- Predictive capability assessment

2022-2025
EVIDENT

- Impact of gradient effects on fatigue performance?
- Stress gradient
- Residual stress
- Heterogeneity e.g. coatings
- Linking modelling and experiments

2024 (?)
GRADIENT

RI.
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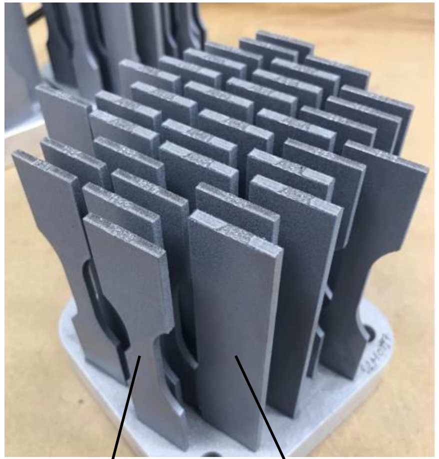
CorrFat

- WHAT: Develop capacity to be able to study combined effect of mechanical fatigue and corrosion.
- WHY: Electrification in the automotive industry > structural aluminium components subjected to harsh environments.
- HOW: Testing of 3D-printed aluminium specimens subjected to both mechanical loads and corrosion.
- RESULTS: Wöhler curves for three different test sequences and two surface states (as-print and machined)

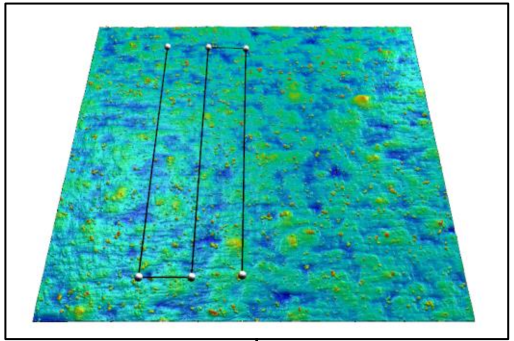
Method - Printing

SLM 125HL

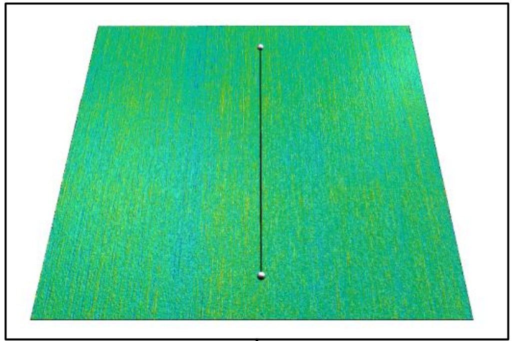


As-print

To be machined



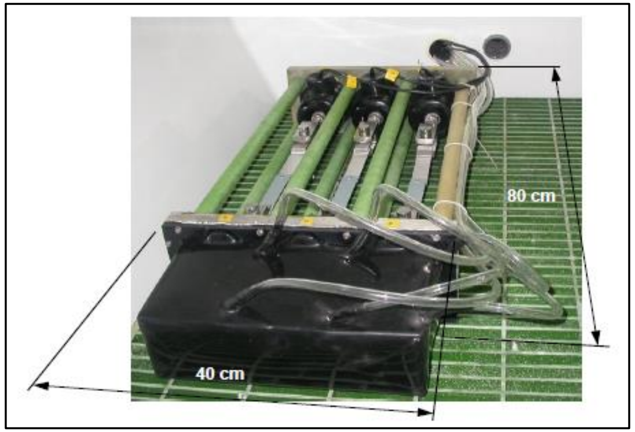
As-print
Ra=4.01 μm



Machined
Ra=0.5 μm

Method - Corrosion

- Accelerated corrosion testing using the VDA 233-102 cycle (6 weeks)
  - Temperature
  - Humidity
  - Salt spray
- Effect of corrosion is analysed in terms of pit depths



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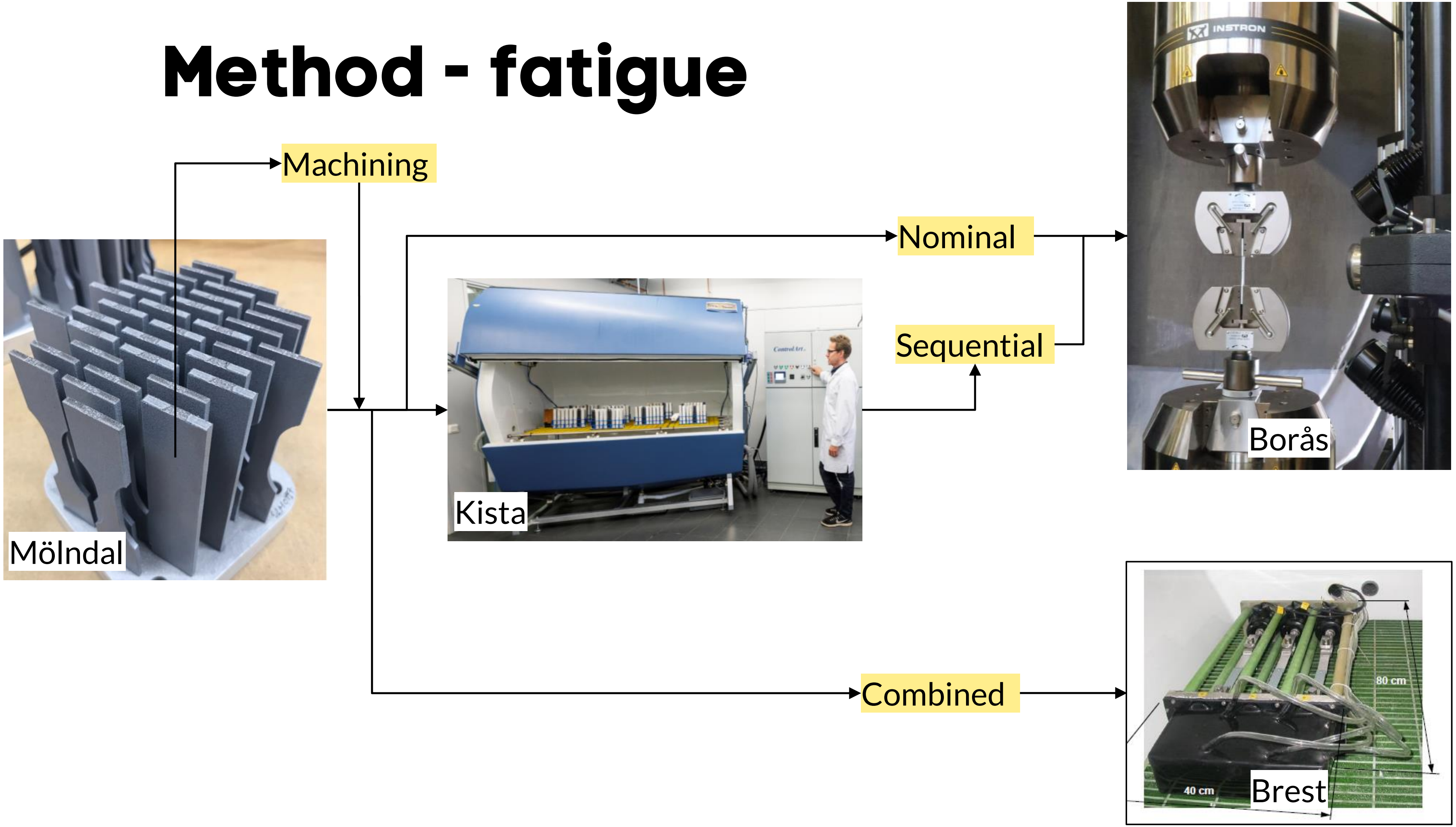
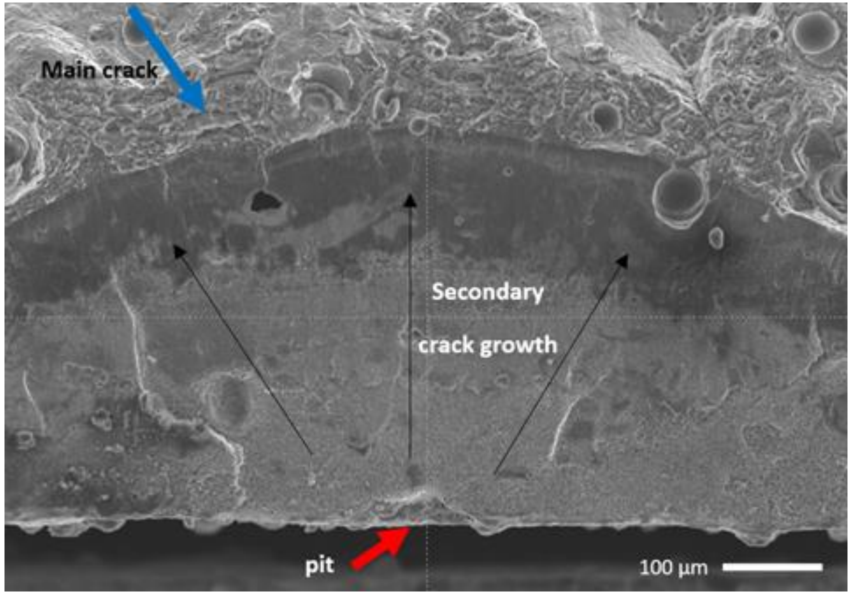
Method - fatigue

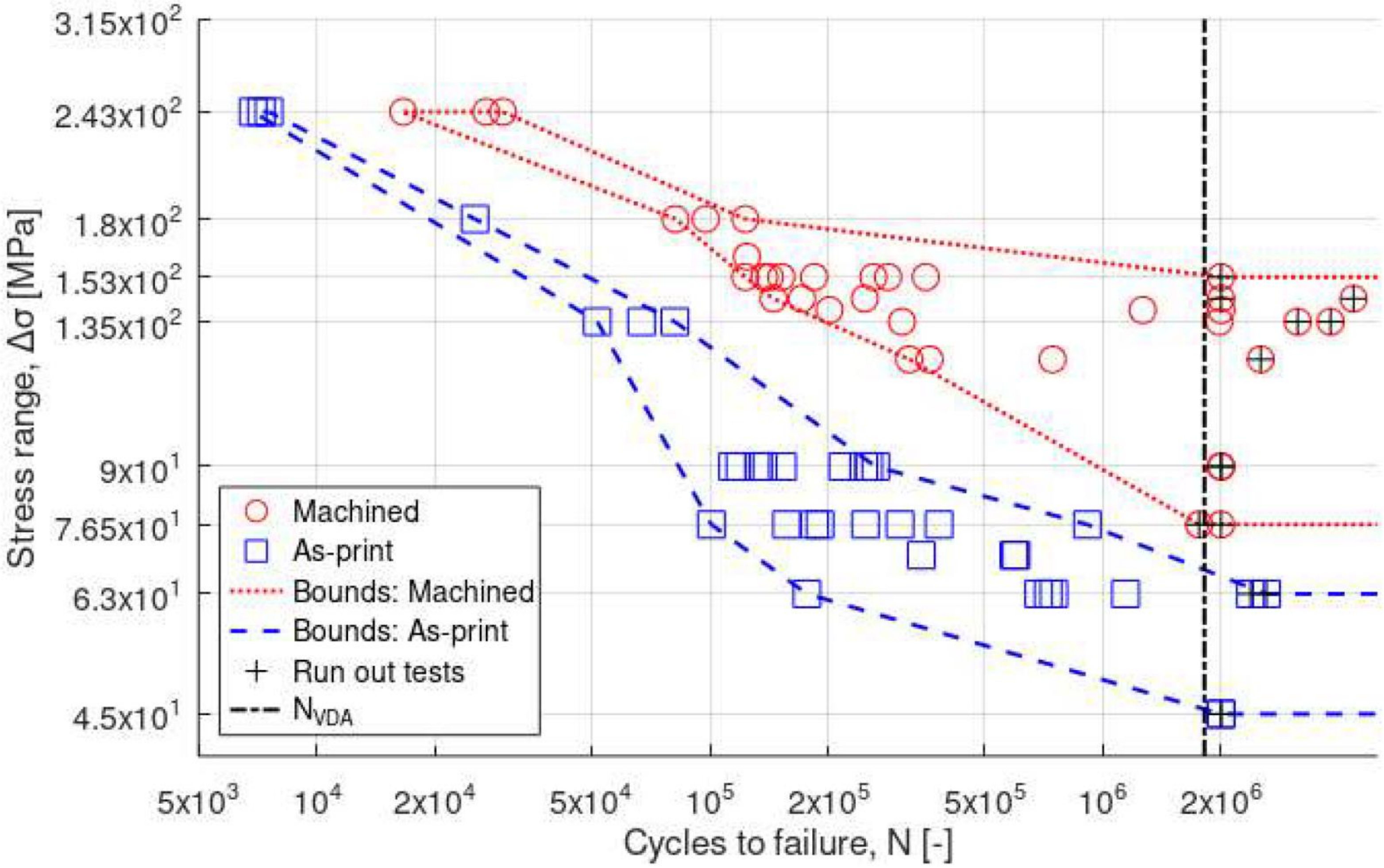


Results - Corrosion

- Crack initiation in pits for both sequential and combined loading mode
- Average pit depth
  - As-printed: 50 µm
  - Machined: 11 µm



Results - Fatigue



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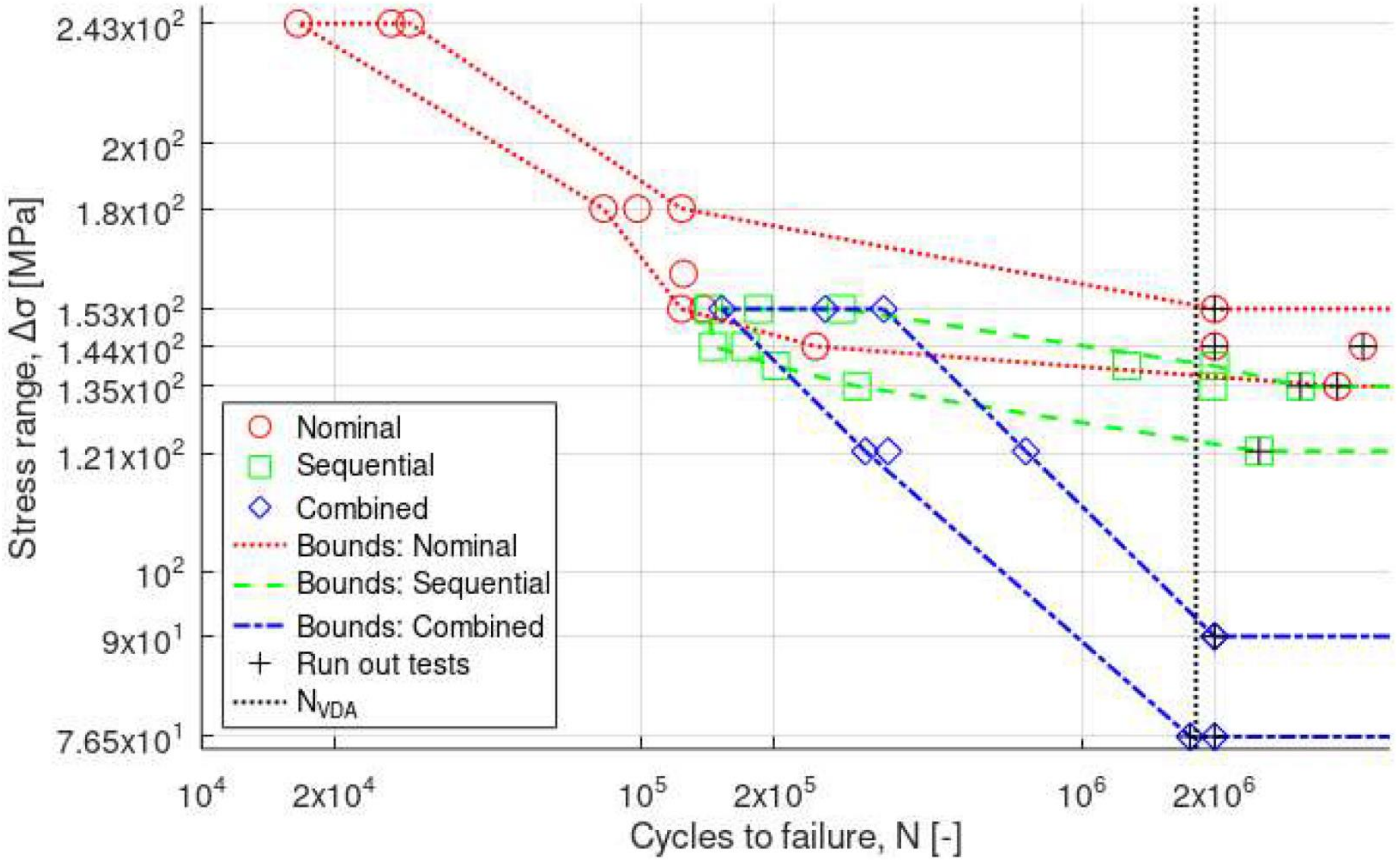
Results – Fatigue (machined)



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CorrFat – Further reading

- The work is published in MDPI Materials [link]
- The methods and workflow is now used in EICAL

materials MDPI

Article

Corrosion-Fatigue Performance of 3D-Printed (L-PBF) AlSi10Mg

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Abstract: Additive manufacturing (AM) allows for optimized part design, reducing weight compared to conventional manufacturing. However, the microstructure, surface state, distribution, and size of internal defects (e.g., porosities) are very closely related to the AM fabrication process and post-treatment operations. All these parameters can have a strong impact on the corrosion and fatigue performance of the final component. Thus, the fatigue-corrosion behavior of the 3D-printed (L-PBF) AlSi10Mg aluminum alloy has been investigated. The influence of load sequence (sequential vs. combined) was explored using Wöhler diagrams. Surface roughness and defects in AM materials were examined, and surface treatment was applied to improve surface quality. The machined specimens showed the highest fatigue properties regardless of load sequence by improving both the roughness and removing the contour layer containing the highest density of defect. The impact of corrosion was more pronounced for as-printed specimens as slightly deeper pits were formed, which lowered the fatigue-corrosion life. As discussed, the corrosion, fatigue and fatigue-corrosion mechanisms were strongly related to the local microstructure and existing defects in the AM sample.

Keywords: atmospheric corrosion; fatigue; additive manufacturing; 3D printing; aluminum alloys; AlSi10Mg

check for updates

Citation: Linder, C.; Vucko, F.; Ma, T.; Proper, S.; Dartfeldt, E. Corrosion-Fatigue Performance of 3D-Printed (L-PBF) AlSi10Mg. *Materials* **2023**, *16*, 5964. https://doi.org/10.3390/ma16175964

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1. Introduction

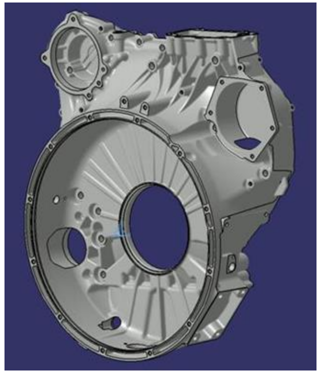
Lightweight structures and materials are nowadays considered the most effective solutions to decrease energy consumption in the automotive sector [1,2]. Aluminum alloys have been recognized as a viable lightweight alternative to steel because of their good performance and low cost [3]. In the global automotive market, approximately 60% of aluminum components are produced by die-casting. The demand for aluminum die casting is increasing due to both the trend of replacing steel with aluminum and due to the change from forging to casting in vehicle parts [4]. This could potentially lead to new possibilities for additive-manufactured (AM) aluminum components.

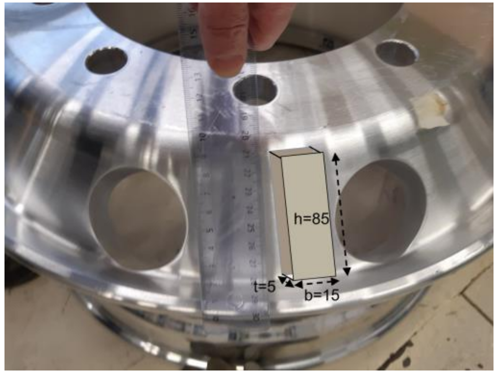
AM materials with optimized part design enable further weight reduction compared to conventional manufacturing techniques. The most prevalent AM process techniques for metallic 3D printing are Laser Powder Bed Fusion (L-PBF), Electron Beam Powder Bed Fusion and Direct Energy Deposition [5,6]. The L-PBF process is comparatively robust, productive, cost-effective and provides fine surface finishes [7].

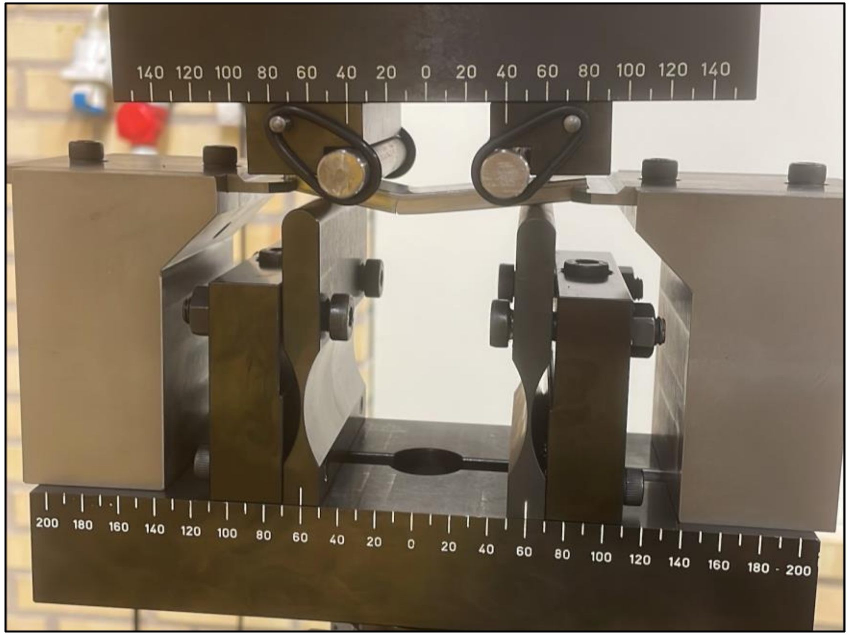
Aluminum alloys with silicon and magnesium as major alloying elements, in particular AlSi10Mg, exhibit moderate mechanical properties, low density and good corrosion performance [8,9]. Mechanical properties obtained by AM processes are similar to cast AlSi10Mg after adapted thermal treatments [10–12]. However, the size of Si particles was found to be finer in the case of AM materials. In particular, the morphology and size of eutectic silicon and intermetallic compounds were different, which can greatly impact the mechanical properties of the final products [13]. Fatigue crack initiation is, for example,

EICAL

- WHAT: Increased understanding for environmentally induced crack initiation in aluminium.
- WHY: Electrification of heavy trucks leads to new structural components of aluminium. These components must be able to withstand the operating conditions.
- HOW: Fatigue testing of corroded specimens (sequential and combined). Testing is carried out in bending using as-cast specimens.
- RESULTS: Quantified impact on fatigue life of combined corrosion and mechanical degradation.



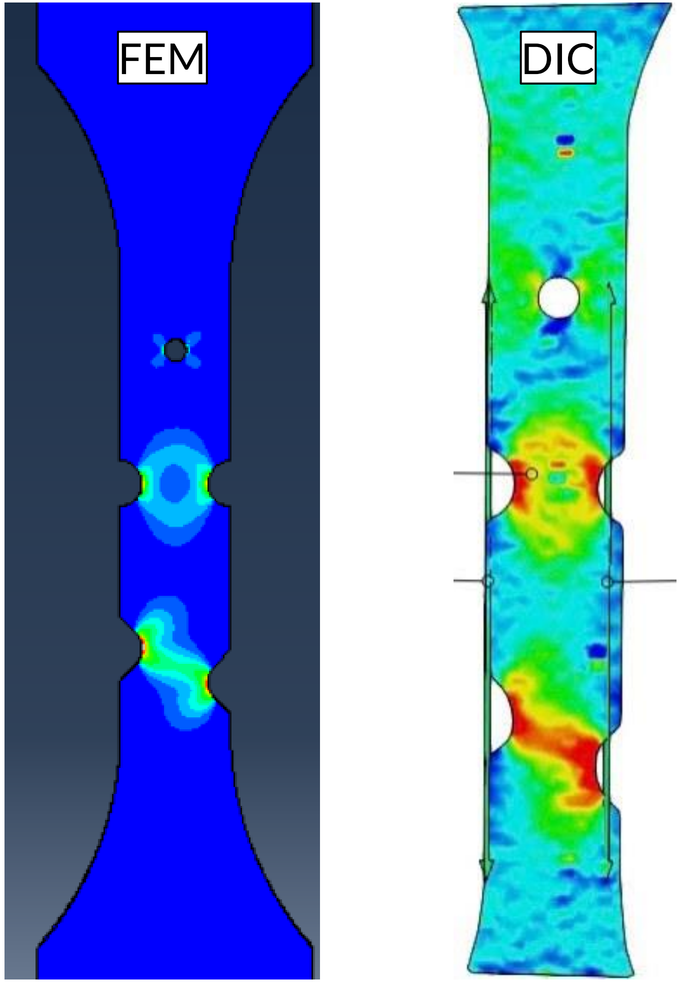




SCANIA GJUTERIFÖRENINGEN Swedish Foundry Association Ljunghäll Energimyndigheten SWERIM JÖNKÖPING UNIVERSITY RISE

EVIDENT

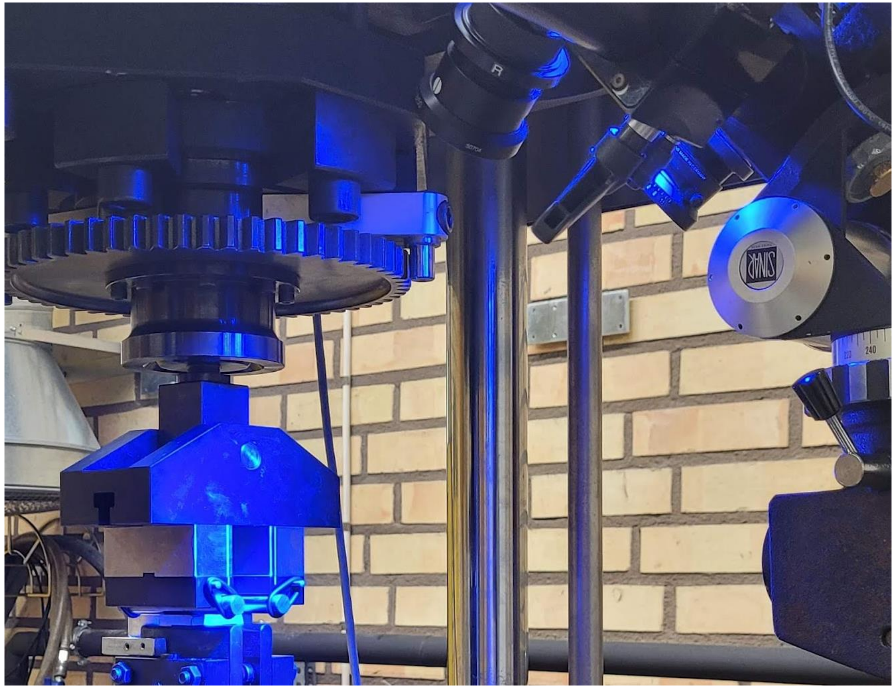
- WHAT: Quantify agreement between FE based predictions and experimental results.
- WHY: Quantified prediction capability of a FE model can be used to guide further model development or to evaluate modeling guidelines.
- HOW: Experiments are designed based on the intended use of the modeling tool to be evaluated. Tests are then carried out both physically and virtually. The predictive capability is quantified by comparing quantities of interest.
- RESULTS: Quantitative and qualitative assessment of agreement between model and experiments.

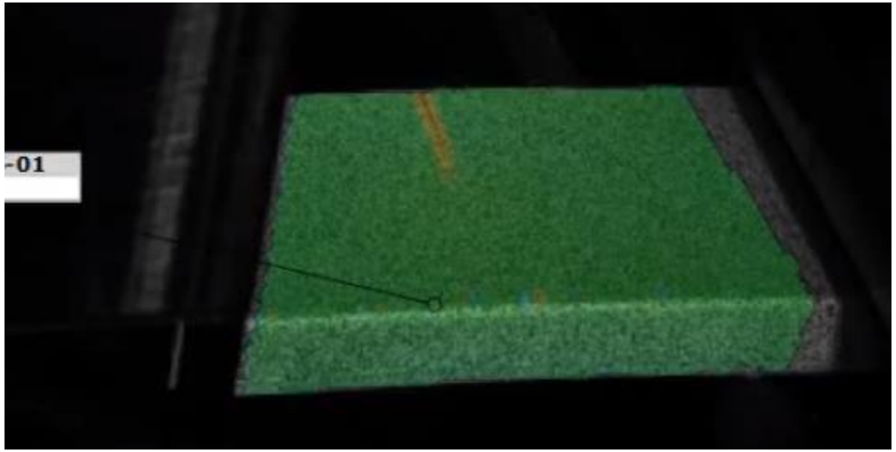


LIGHTer VINNOVA Sweden's Innovation Agency SCANIA VOLVO Husqvarna JÖNKÖPING UNIVERSITY RISE

Fatigue testing with DIC

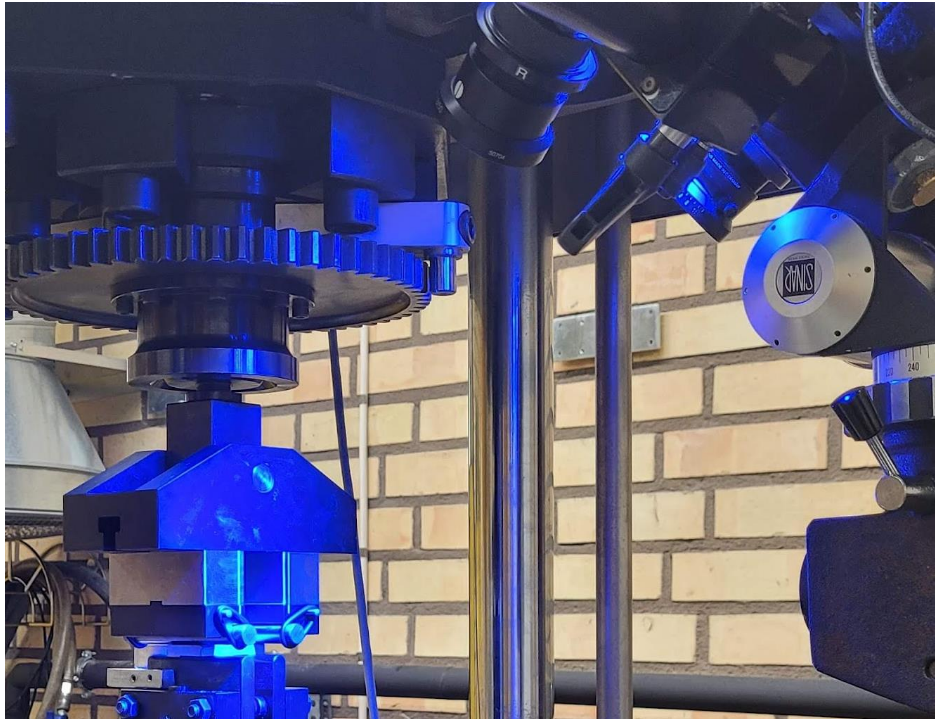
- WHAT: RISE-internal project focusing on the use of DIC in fatigue testing.
- WHY: For some applications the function is lost when a crack initates (e.g. coating). Therefore, the time of crack initiation is of interest.
- HOW: Fatigue testing is carried out while acquiring DIC images which can be used to measure displacements and strains.
- RESULTS: Images showing the strain evolution which can be used to identify the time of crack initiation.

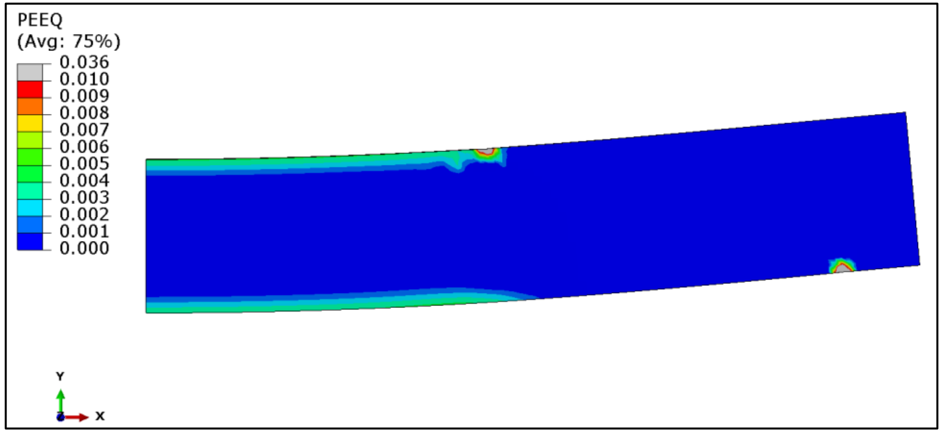




GRADIENT

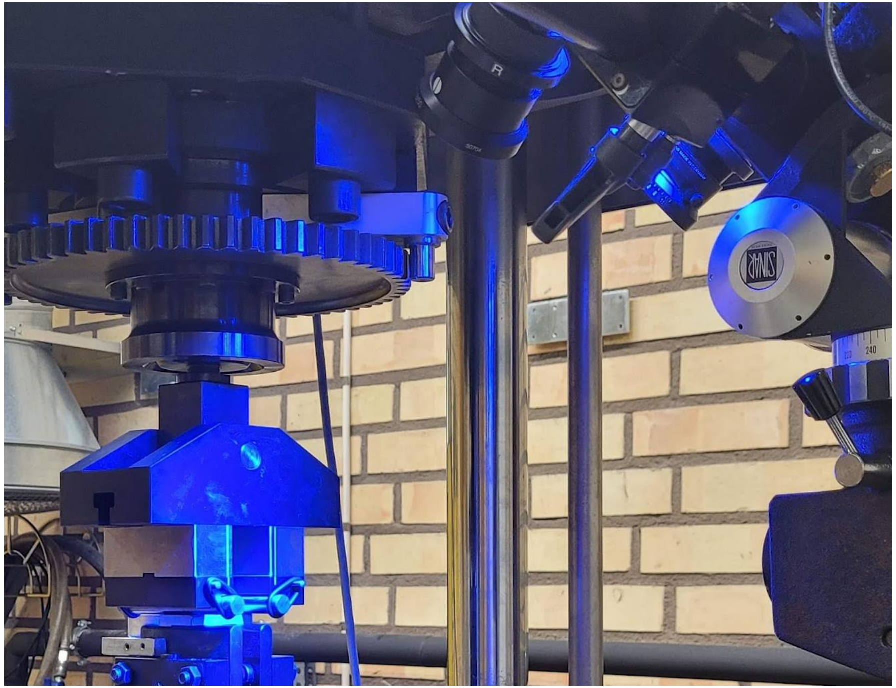
- WHAT: Increased understanding of gradient effects using a combination of modelling and experimental techniques.
- WHY: Estimating the actuals stress state in bending can be non-trivial e.g. when local surface plasticity occurs.
- HOW: By combining testing (using DIC) and model calibration approaches.
- RESULTS: Calibrated FE models and more detailed information about the actual stress state (including gradient effects).

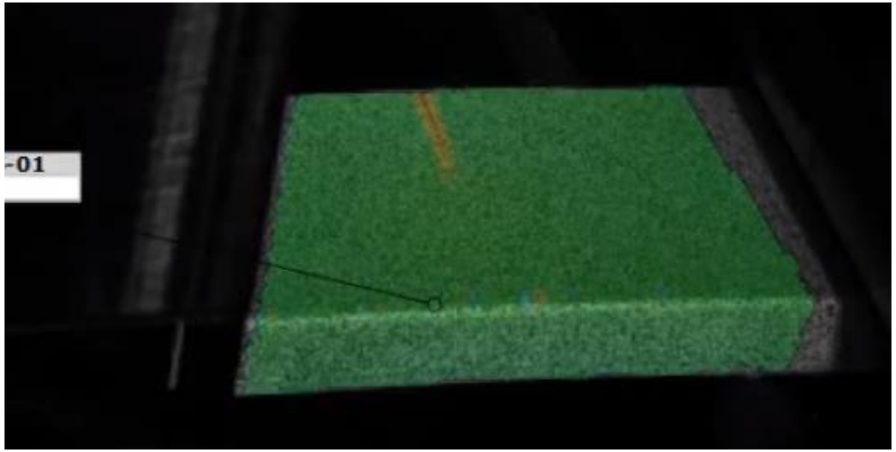




Summary

- CorrAl > CorrFat
- EICAL
- EVIDENT
- Fatigue testing with DIC
- GRADIENT: project proposal
- Thanks for listening!
- Questions?





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