Improved laser-welded joints in Li-Ion batteries through material design

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**University West

THE SWEDISH
Manufacturing
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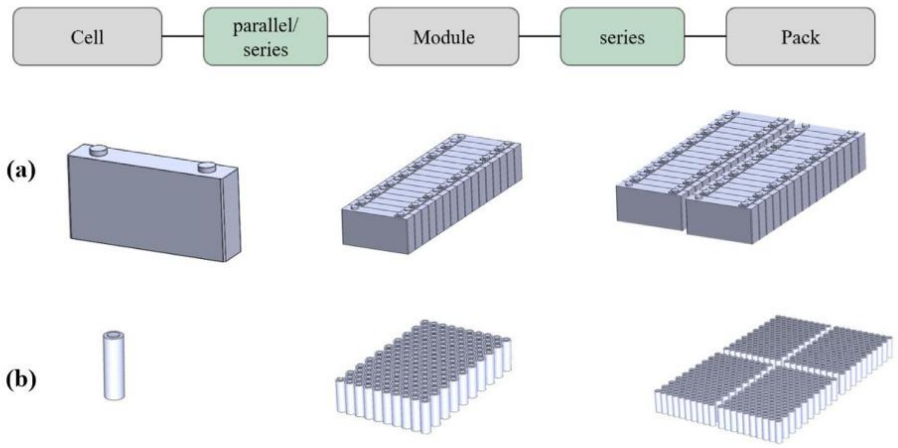
Cluster Conference, May 22-23 2024

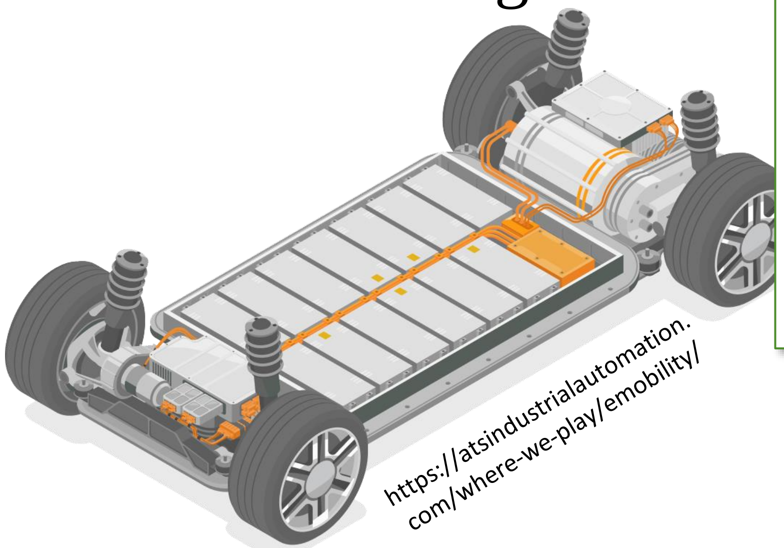
Project EMPIRE - Enhanced material properties in joints in Li-Ion Batteries

- **Scope and objective**
  To improve laser-welded joints in Li-Ion batteries through material design
- **Partners**
  University West was the project coordinator and, together with Swerim, independent research executor. Industrial partners were Scania CV AB, Trumpf Maskin AB, Polarium Energy Solutions AB, Gränges AB, and Materion Corp who contributed with in-kind.
- **Financing**
  This study was funded by Vinnova, the Energy Authority and Formas through the strategic innovation program for Metallic material.
- **Project duration:** 2021-04-05 - 2023-12-31

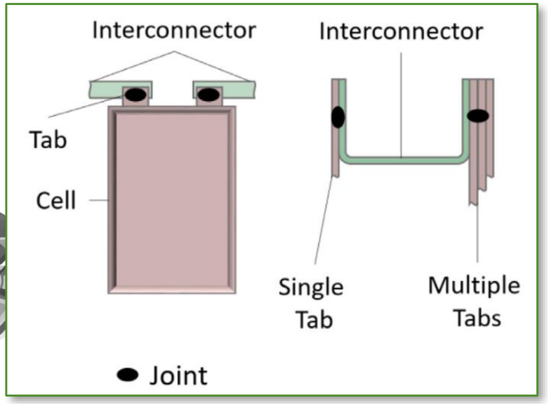
Current challenges

The connections in EV batteries between cell-terminals to busbars or busbars to module terminals are extremely important. Failures in these connections can lead to unplanned downtime or, in worst cases, fires. Moreover, fast charging with very high current has just recently been possible and will be standard for utility vehicles. Fast charging results in significant thermal stresses in the joints, increasing the risk of thermal fatigue.





https://atsindustrialautomation.com/where-we-play/emobility/



M. F. R. Zwicker, M. Moghadam, W. Zhang, and C. V. Nielsen, “Automotive battery pack manufacturing – a review of battery to tab joining,” *Journal of Advanced Joining Processes*, vol. 1, p. 100017, Mar. 2020, doi: 10.1016/j.jajp.2020.100017.

Current challenges

A fault in a battery joint can lead to elevated temperature which in turn leads to further heat generation due to chemical reactions in the battery, which can lead to an uncontrolled temperature rise and battery fire.

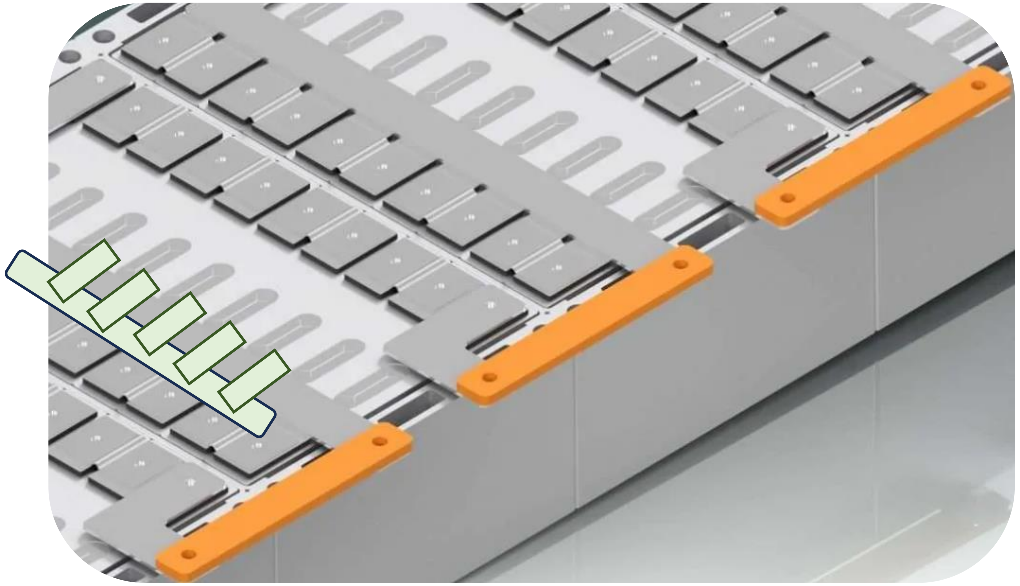
Since there are many battery cells that are connected in series, and thus many battery joints in series, the reliability requirements become very high. Somewhat simplified, if a failure in 10,000 vehicles is an acceptable level, and there are 250 cells in series, the acceptable failure rate of a battery joint is one in five million.

The very high demands on the quality of the laser-welded joints in combination with very large production volumes is a challenge. In this study, new material concepts have been proposed and evaluated to facilitate the battery production.

Novel material concepts for increasing joint quality in Li-ion batteries

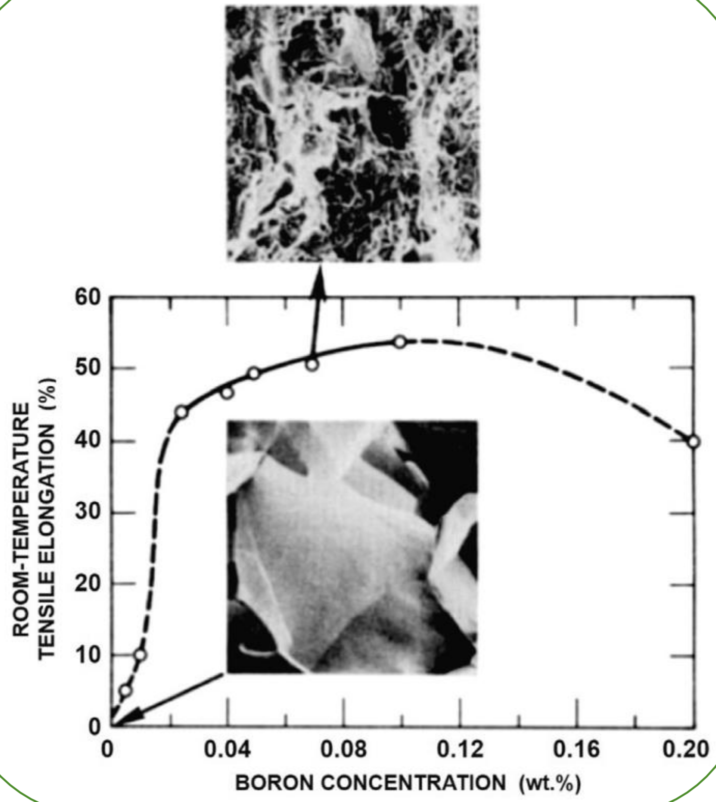
Proposed concept	Purpose
Boron-doped nickel foils	Minimize brittle intermetallic compound formation
Aluminium-copper dovetail	Avoid fusion-based joining for joining copper busbar to aluminium tabs
Aluminium-silicon filler foil with built-in flux	Reduce solidification cracking and porosity in Al-Al joints

Small additions of boron can potentially increase the ductility of the brittle Ni_3Al intermetallic compound



https://www.batterydesign.net/aluminium-busbar-products/

Ni foils can be welded to the terminals for voltage drop measurement



Z.B. Jiao, J.H. Luan, C.T. Liu, “Strategies for improving ductility of ordered intermetallics”, Progress in Natural Science: Materials International, Volume 26, Issue 1, 2016, Pages 1-12, ISSN 1002-0071

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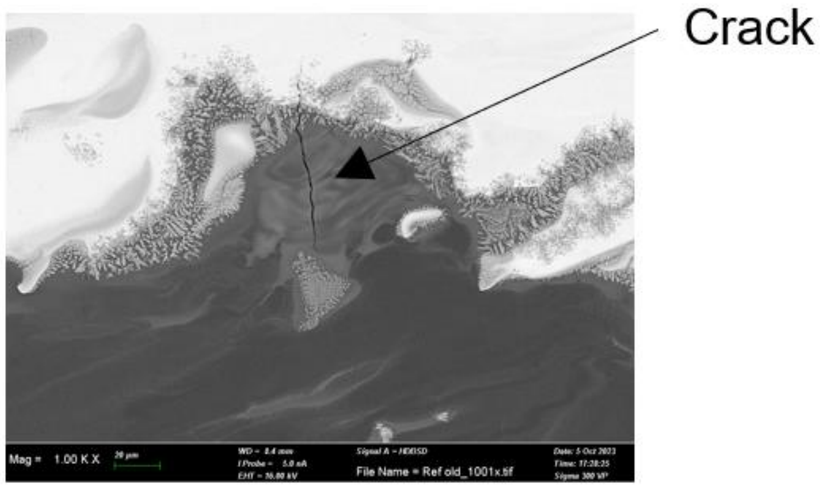
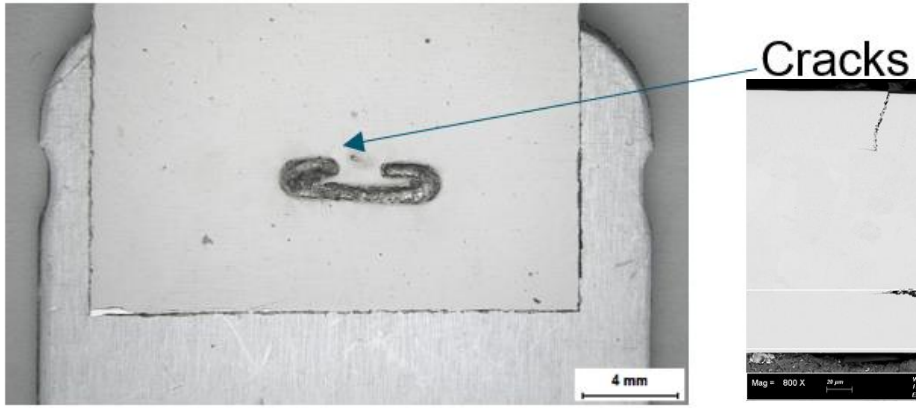
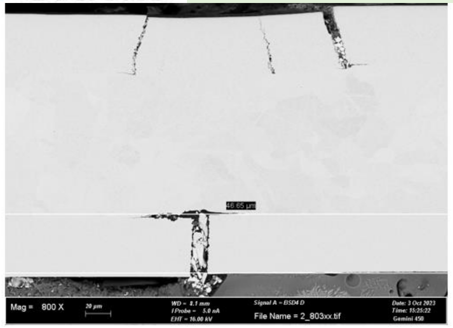
Experiments with electroless Ni-B plated Ni foils laser welded to 1050 Al. The Ni-B coating produced a hard and brittle Ni-B layer that did not alleviate the cracking problem

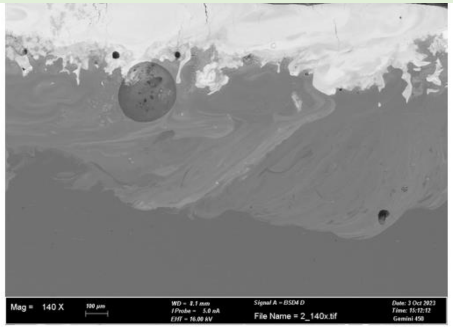


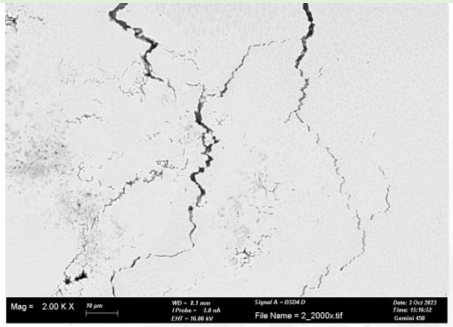
99% Ni foil

B-doped Ni foil, Ni, <1% B

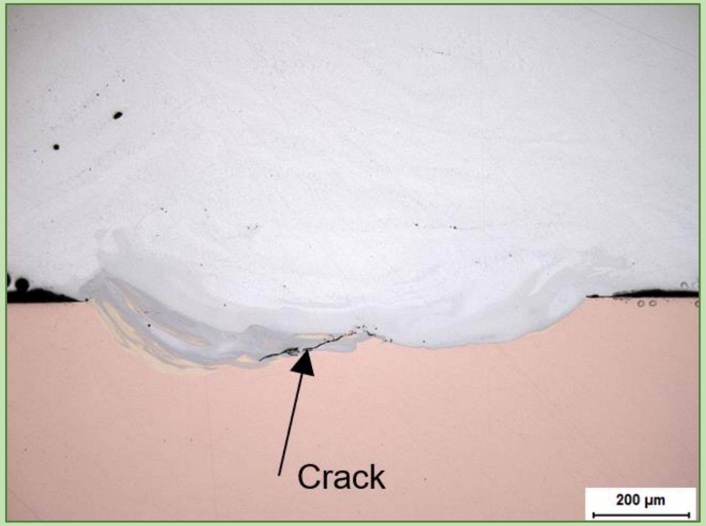






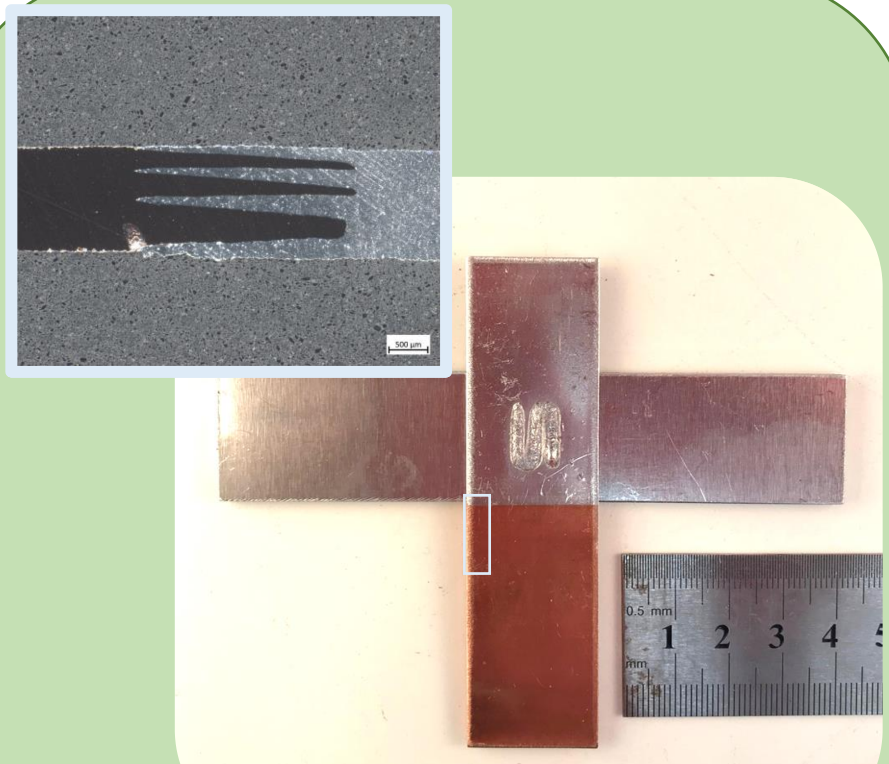


Some battery designs necessitate joining of copper busbars to aluminium battery tabs. Welding of Al to Cu results in a brittle intermetallic compound that can be detrimental to joint strength and fatigue life

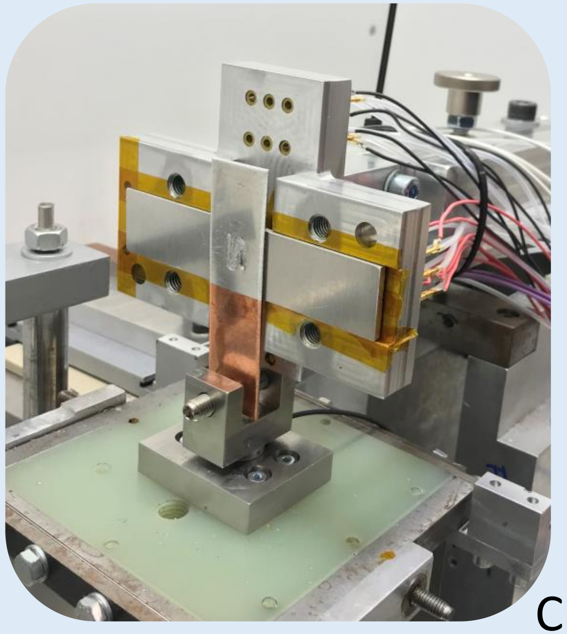


Copper busbar laser welded to 1050 aluminium battery tabs (this work)

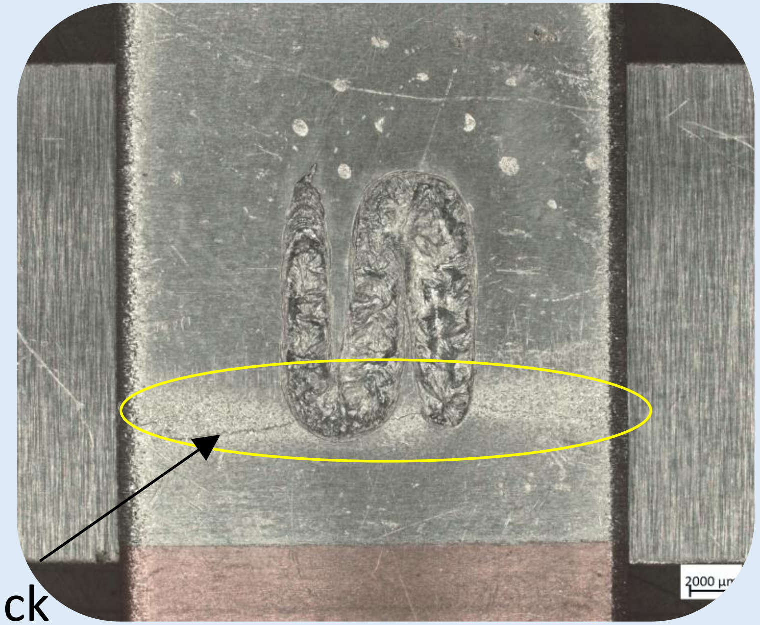
Dovetail-rolling of the Cu-Al allows for similar or better fatigue strength while maintaining the benefits of Cu in the busbar design



Dovetail-rolling of Cu to Al allows for welding of Al directly to Al

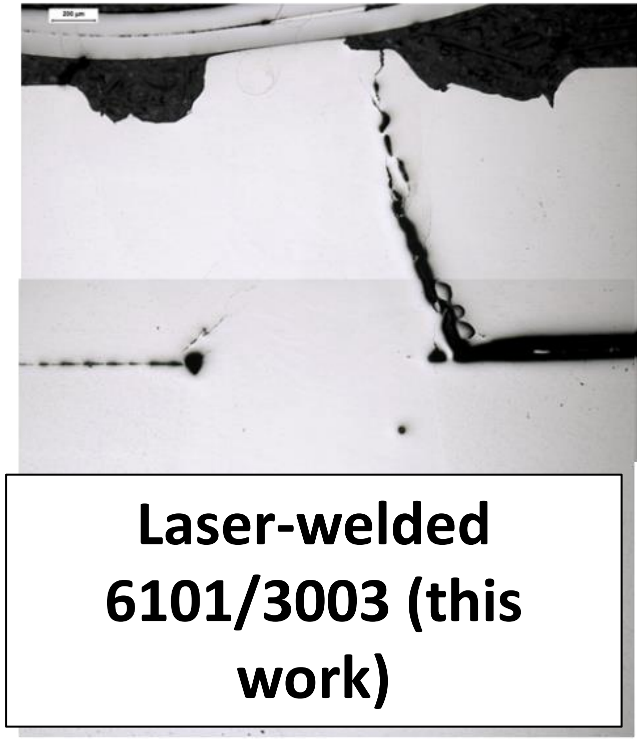


Crack



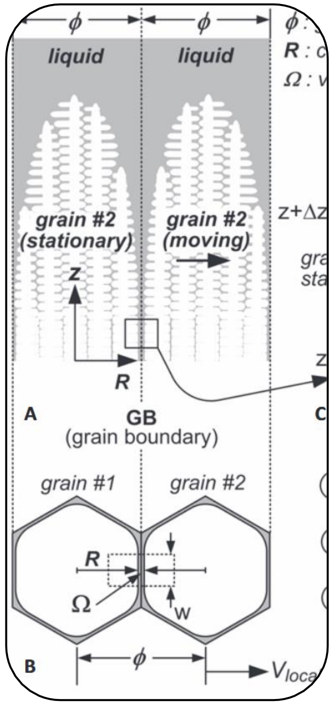
Dovetail samples were as strong or stronger than base aluminium when subjected to fatigue

Laser welding of high-strength aluminium can lead to solidification cracking and reduced joint quality. Experiments with and without filler foil and three different laser powers were performed.



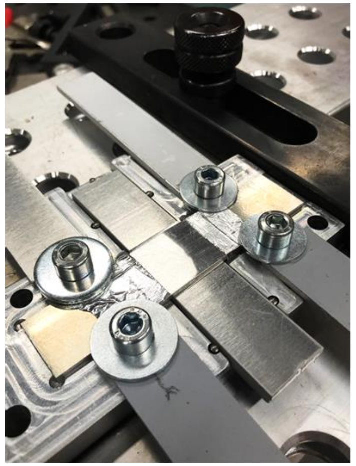
Laser-welded 6101/3003 (this work)

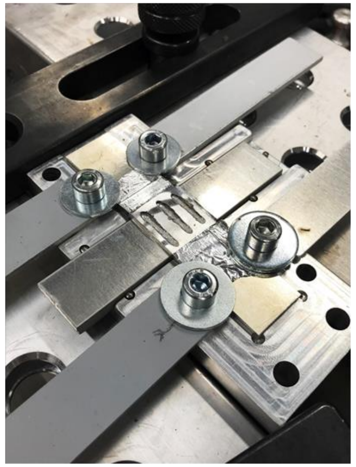
6xxx aluminium provides higher strength-to-conductivity for more demanding busbar designs, but suffers from solidification cracking

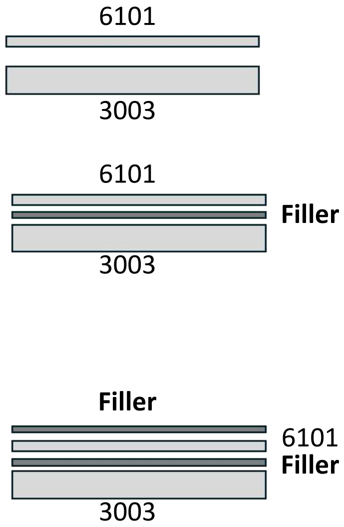


S. Kou, *Welding J.* 2015

J. Liu and S. Kou, “Susceptibility of ternary aluminum alloys to cracking during solidification,” Acta Materialia, vol. 125, pp. 513–523, Feb. 2017, doi: 10.1016/j.actamat.2016.12.028.



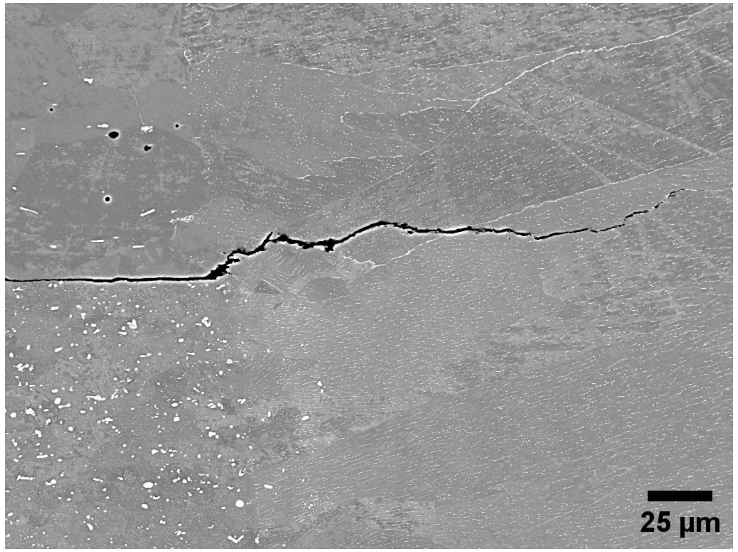


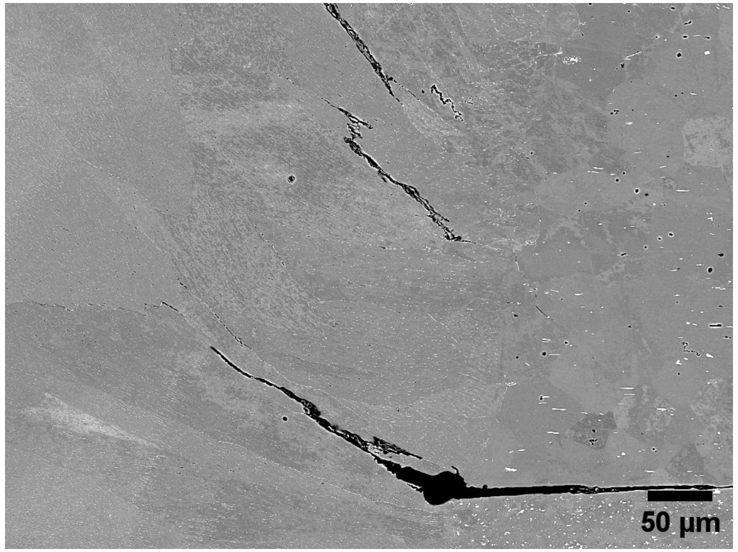


Sample	Aluminium alloy	Size
Lower strip	3003	114 x 24 x 3.2 mm
Upper strip	6101	114 x 24 x 1.2 mm
Filler foil	Al-Si alloy w/ built-in flux	160 micrometre thick foil

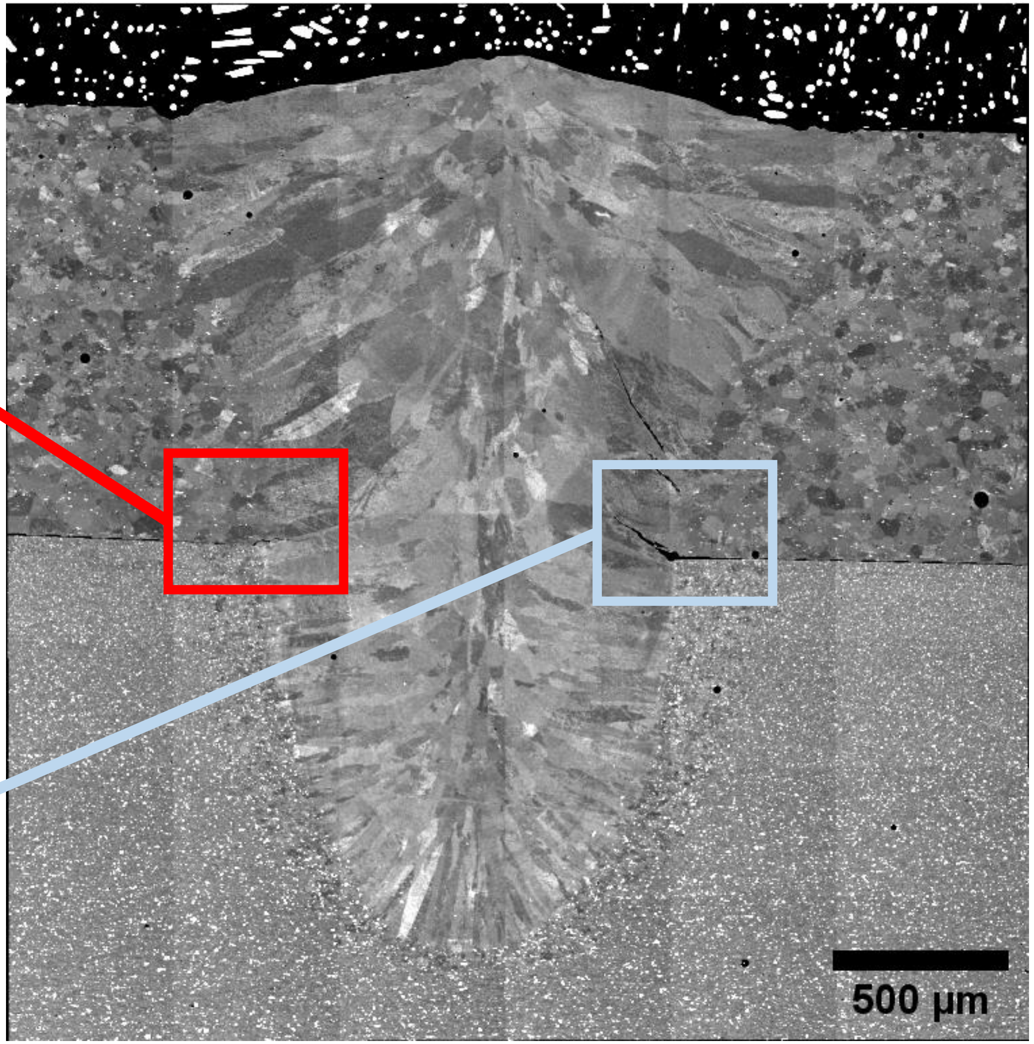
1) Adding a filler material will shift the composition away from the crack-susceptible regime
2) Built-in flux will reduce the amount of oxides and reduce porosity

No foil; laser power 3.5 kW



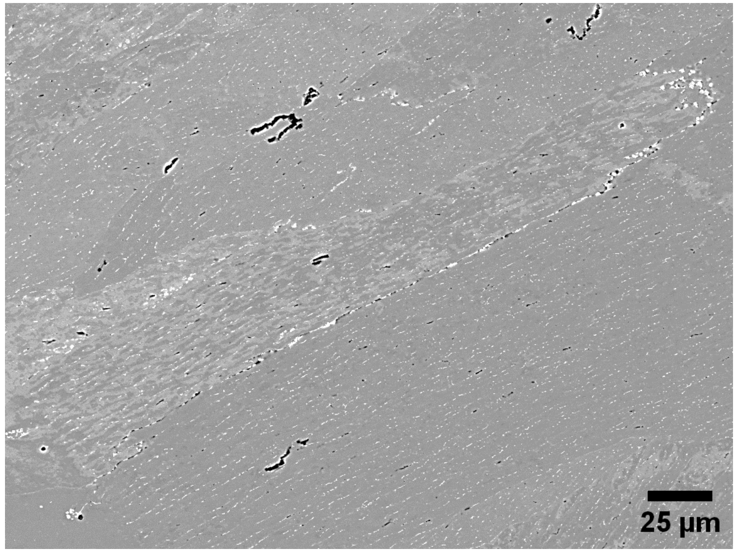


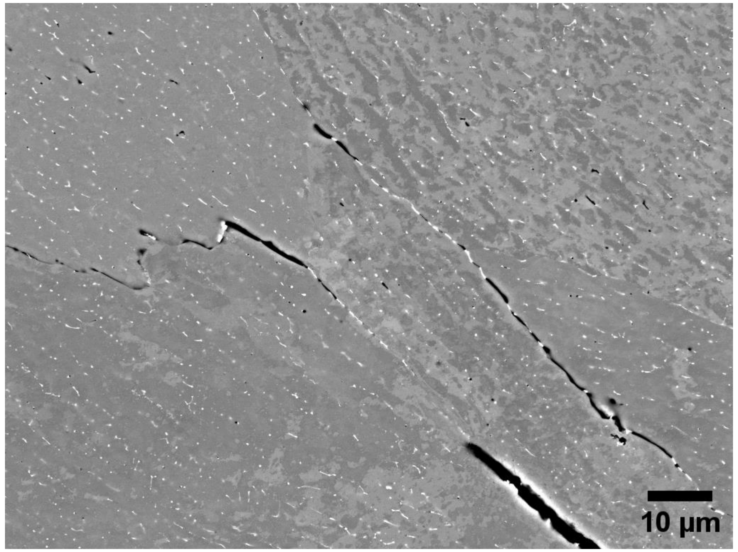
Deep cracks. Cracks forms along the grain boundaries

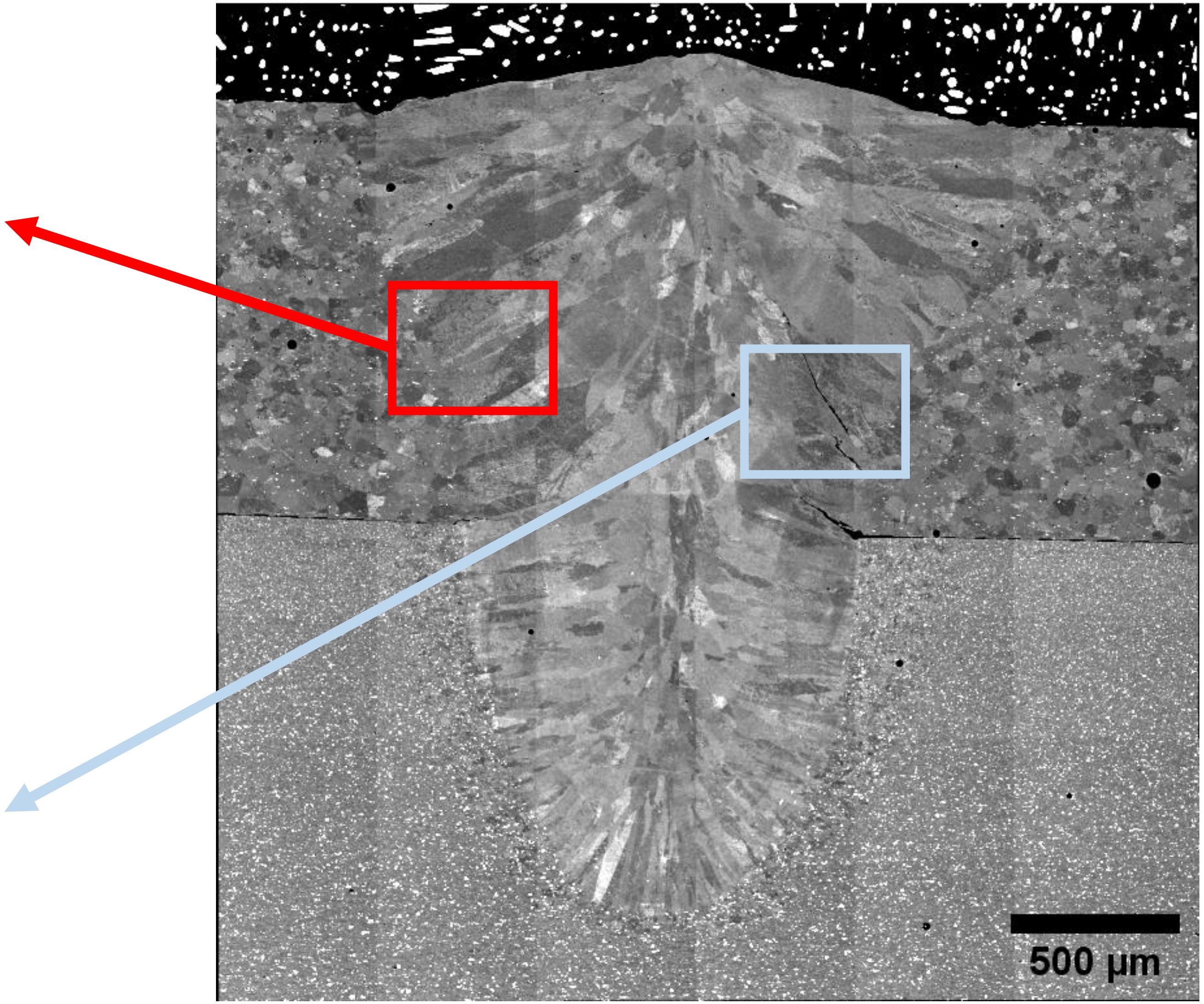


No foil; laser power 4 kW

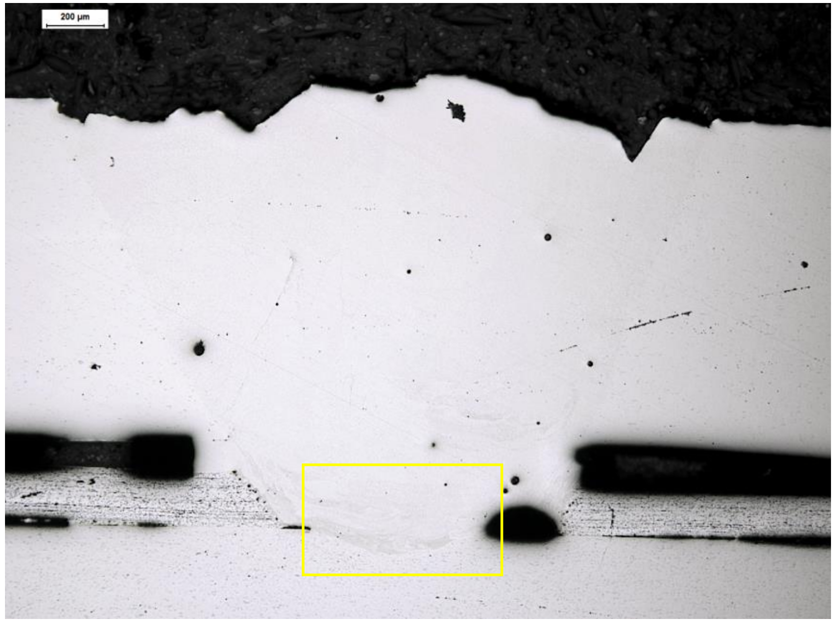
Beginning of crack formation along grain boundaries



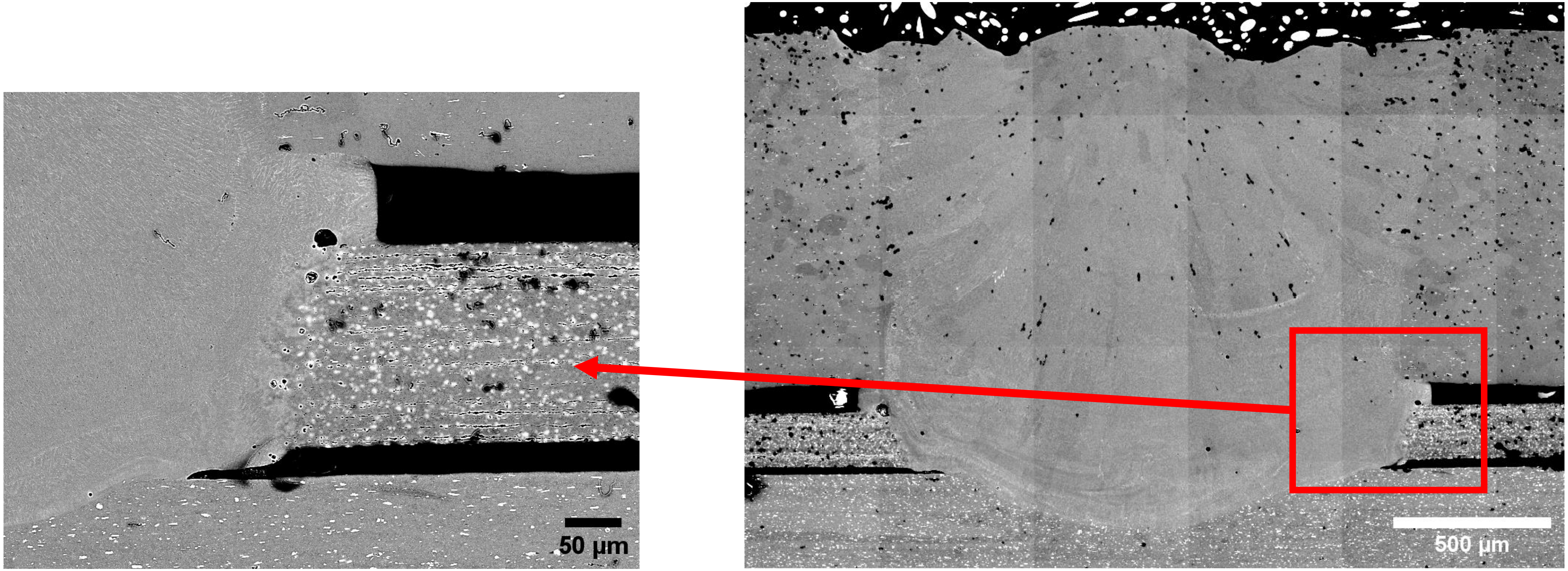




1 foil, laser power 3.5 kW



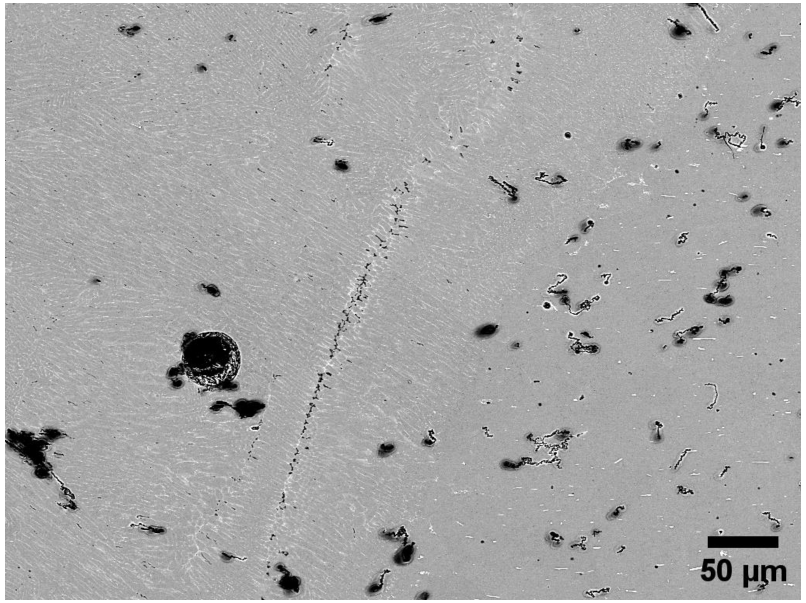
1 foil; laser power 4 kW

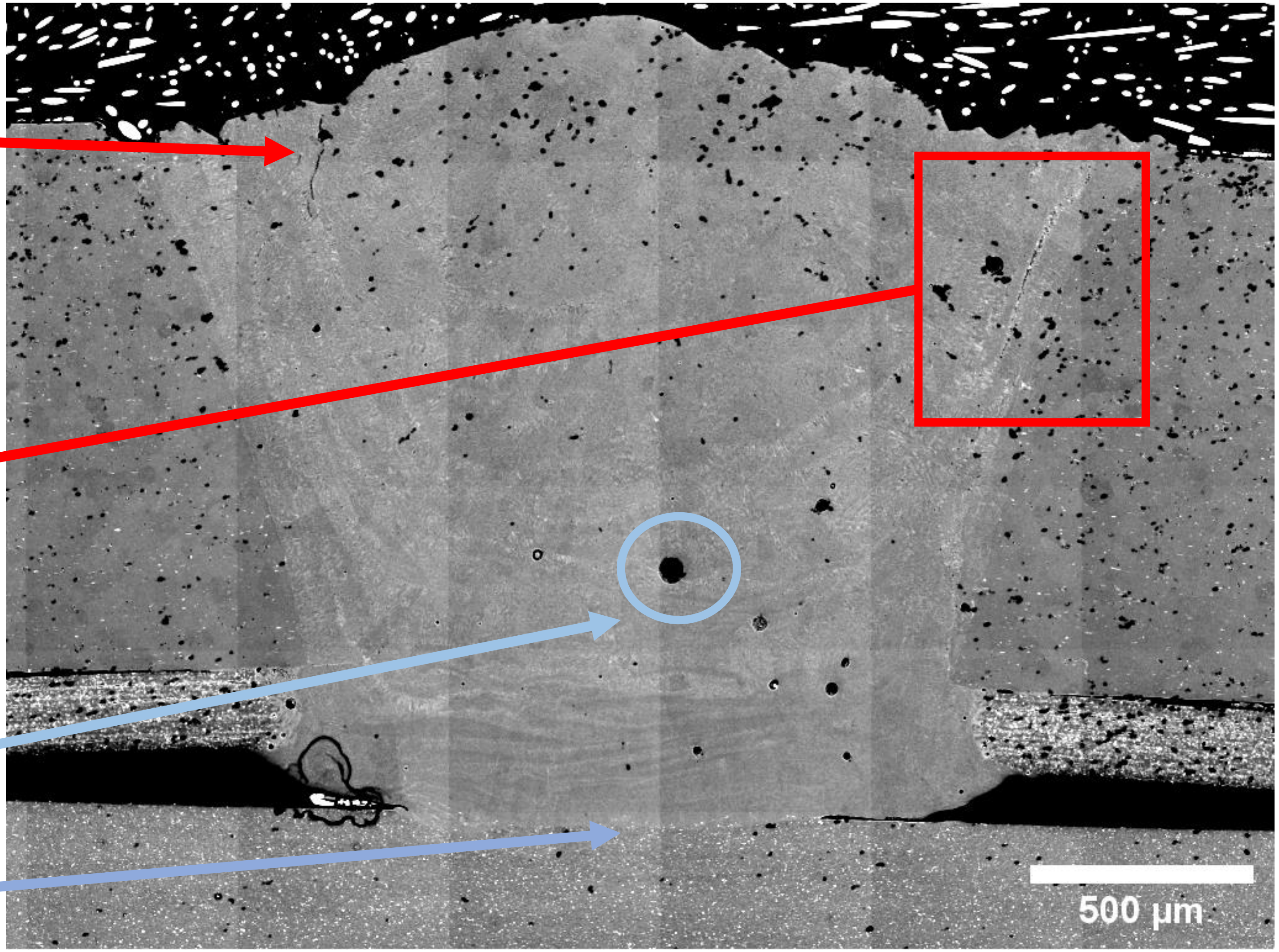


Contact between the substrates and the foil was incomplete and left a big gap once the welding was performed

2 foils; laser power 4 kW

Crack formation

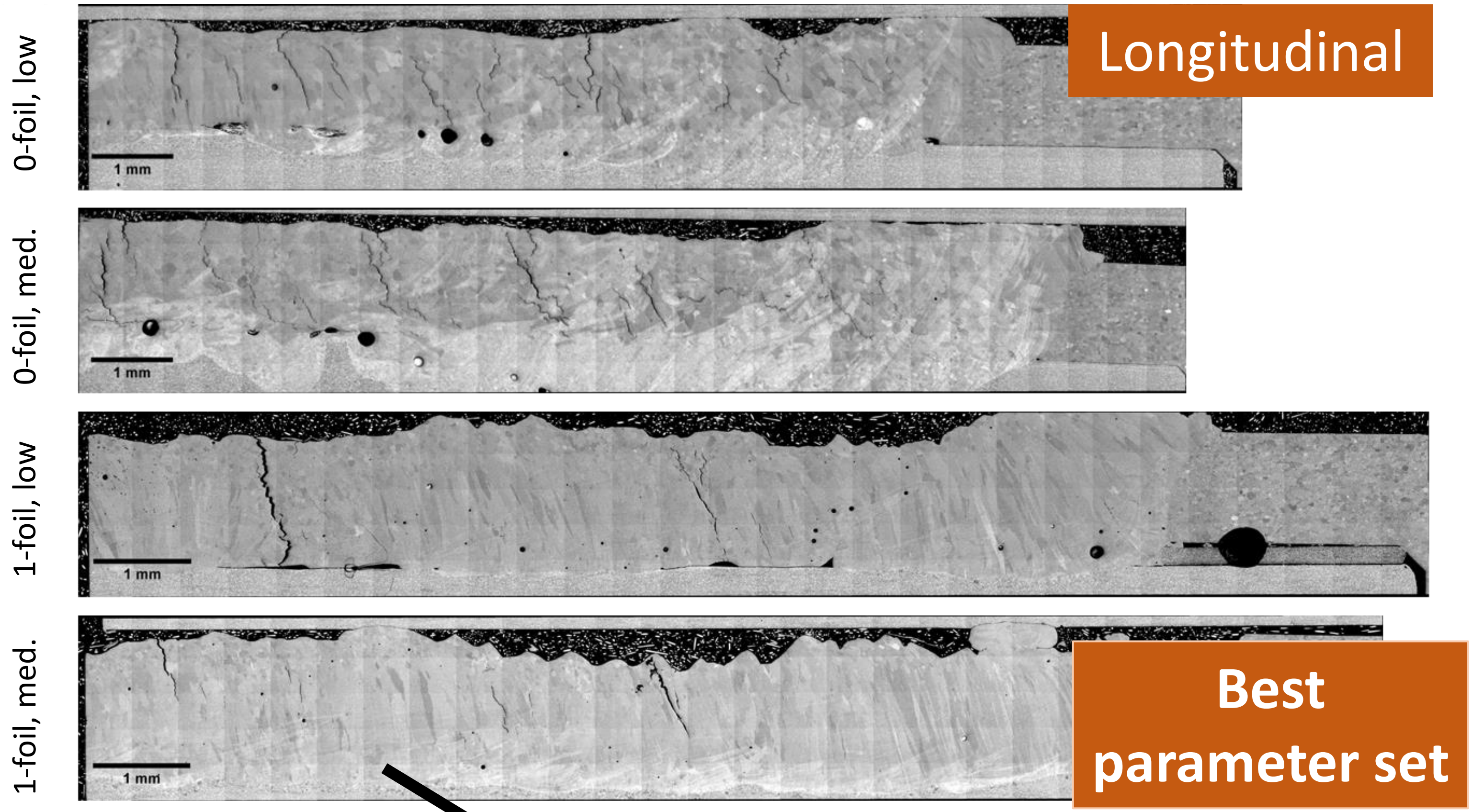


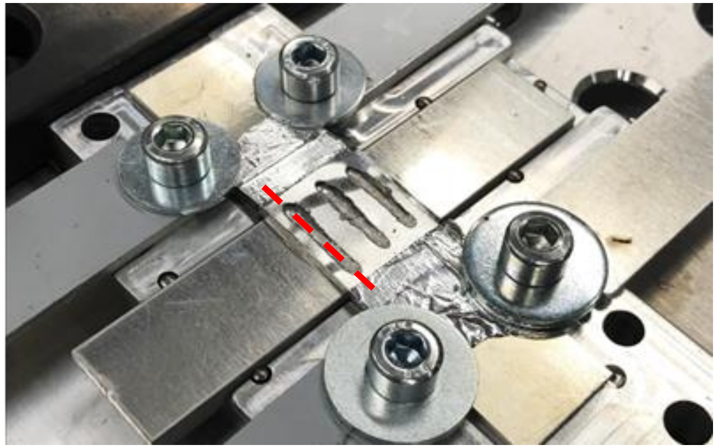


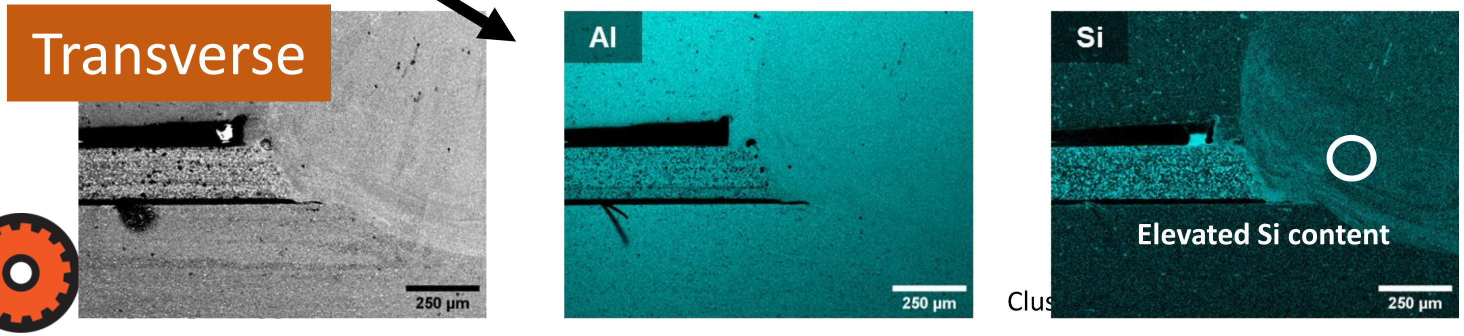
Porosity

Very shallow penetration

One foil with a medium laser power reduce the frequency of solidification cracks and reduced porosity





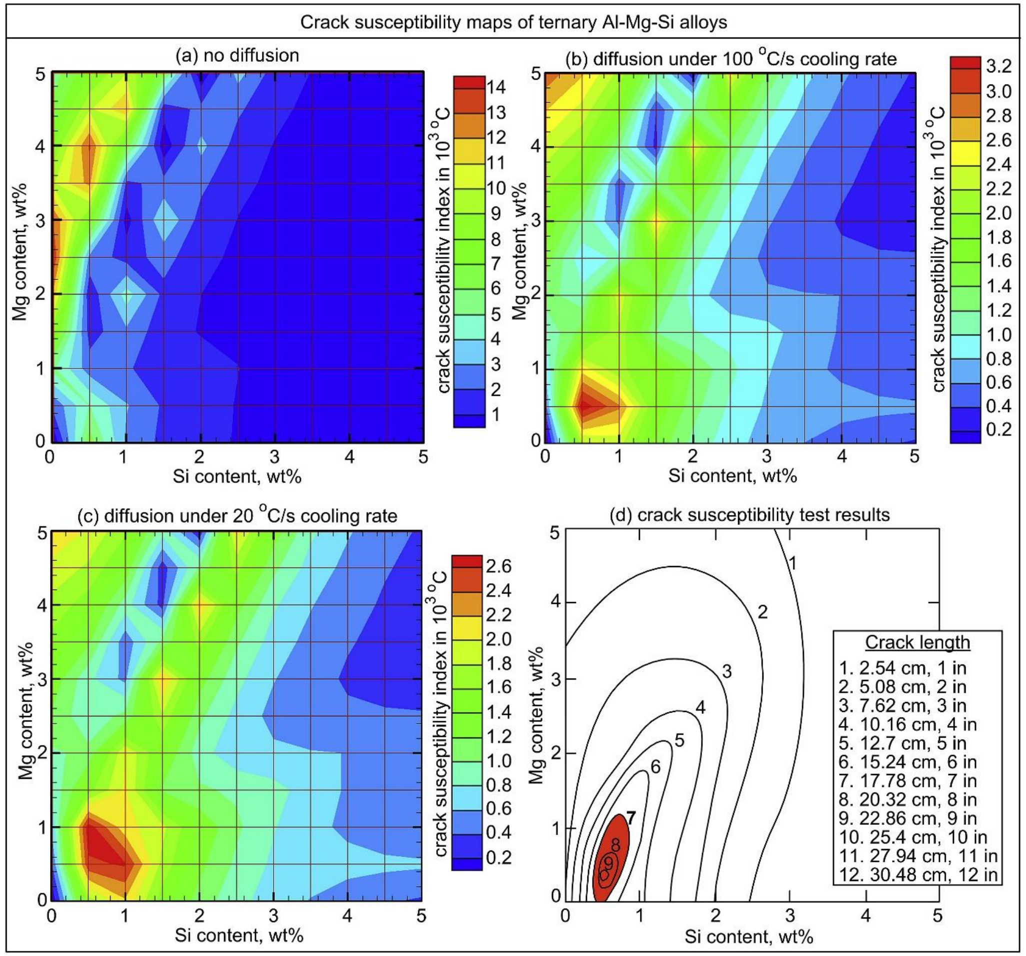


Laser oscillation could further improve Si-mixing and reduce occurrence of solidification cracks

The filler foil can be roll-bonded to the aluminium strip for scaling up production to industrial levels

Discussions – filler foils with built-in flux

By increasing the Si content in the melt pool through the use of filler foils, the composition of the melt is shifted away from the susceptible composition regime, and the severity and extent of solidification cracking in the weld metal is clearly reduced. Additionally, the occurrence of large gas pores in the weld root was minimized.



- Diagrams showing the crack susceptibility in Al-Mg-Si with respect to Mg and Si content. Adapted from J. Liu and S. Kou, "Susceptibility of ternary aluminum alloys to cracking during solidification," Acta Materialia, vol. 125, pp. 513–523, Feb. 2017, doi: 10.1016/j.actamat.2016.12.028.

Summary

Proposed concept	Summary
Boron-doped nickel foils	Brittleness of the coating hindered this approach as a solution for intermetallic formation and cracking
Aluminium-copper dovetail	Avoid fusion-based joining for joining copper busbar to aluminium tabs. **Al – Cu dovetail results in equal or better fatigue strength achieved than Al**
Aluminium-silicon filler foil with built-in flux	**Reduced solidification cracking and porosity in 6XXX Al-Al joints**

Acknowledgments

This study was funded by Vinnova, the Energy Authority and Formas through the strategic innovation programme for Metallic material. Industrial partners were Scania CV AB, Trumpf Maskin AB, Polarium Energy Solutions AB, Gränges AB, and Materion Corp who contributed with in-kind.
The industrial members of the research committee were:

Name	Organization
Therese Källgren	Scania
Richard Westergård	Gränges
Andreas Frehn	Materion
Anssi Jansson	Trumpf
Craig Jones	Polarium

Thank you for the attention!