HIGH SCHOOL INTERNSHIP PROGRAM

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Mechanisms of Gamma Prime Cracking in LPBF

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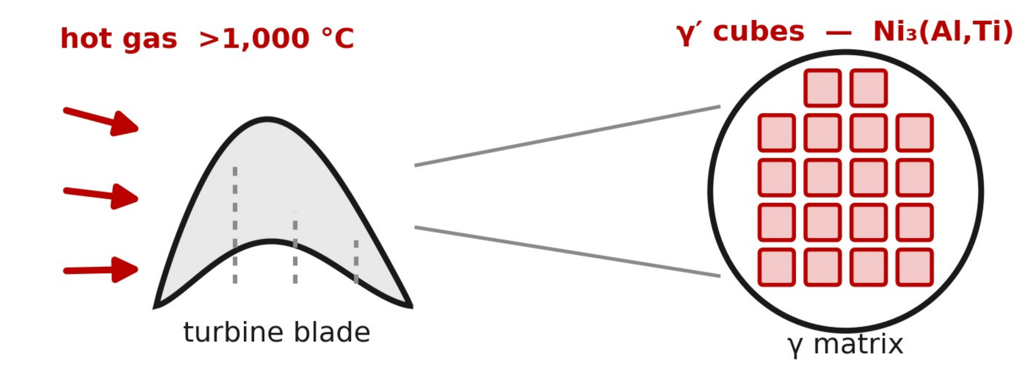
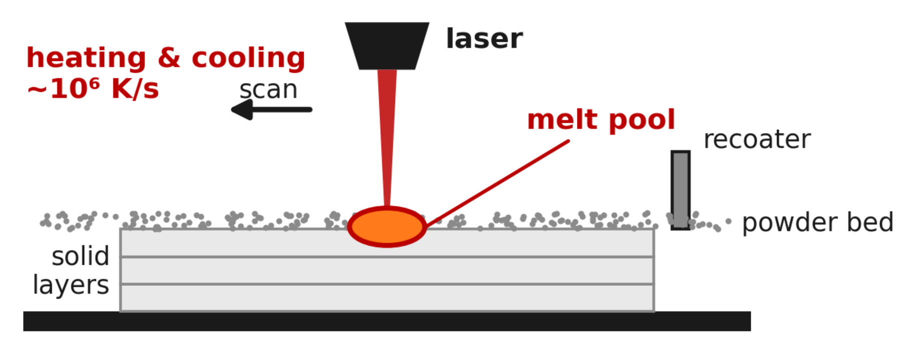
Background

THE MATERIAL



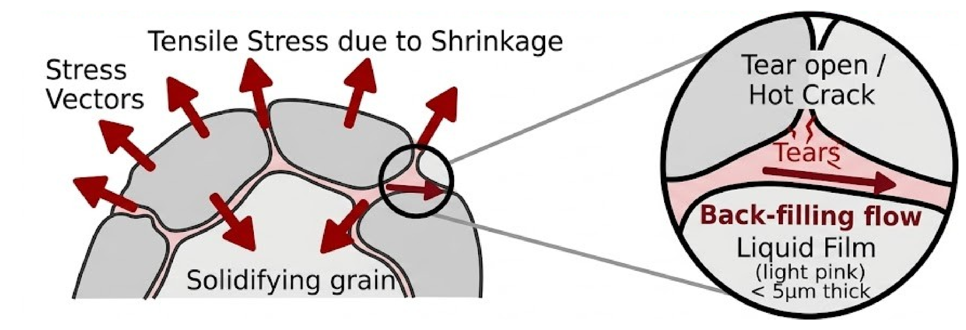
Nickel based superalloys hold their strength at temperatures that soften conventional alloys, so they are used for turbine blades and other components under extreme heat. That strength comes from the gamma prime phase, an ordered precipitate of nickel with aluminum and titanium in a fixed 3:1 ratio. The same additions also widen the solidification temperature range, leaving the alloy prone to cracking as it solidifies.

THE PROCESS



Laser powder bed fusion (LPBF) builds a part by fusing successive layers of metal powder with a scanning laser. The laser creates a localized melt pool that solidifies as the beam moves on, and each new layer reheats the material printed beneath it. Cooling is fast enough to hold the microstructure far from equilibrium, and the repeated thermal cycling and steep gradients leave residual stress along the weld path.

THE PROBLEM



As the melt pool solidifies, thermal contraction opens narrow channels between the growing dendrites. Remaining liquid must flow into them to keep them filled, and when it cannot, the film separates and a solidification crack forms. The Flow Resistance Index (FRI) measures the pressure, in kPa, needed to feed liquid through this network. A higher FRI means the alloy cracks more readily.

Motivation

Nickel superalloys are among the most difficult materials to print without cracking, and every failed build carries the cost of powder, machine time, and inspection. Simulation identifies problem compositions before any metal is melted. The existing FRI model developed at The Ohio State University returns a value for a fixed composition but cannot vary individual elements. That limitation matters because commercial alloys are specified over a range of weight percent for every element, and because the influence of any single element is otherwise invisible. Calculating weld pool dimensions alongside the FRI supplies the geometry that process simulation software such as Simufact Welding requires, which in turn resolves stress concentration and therefore predicts where cracking is likely.

Objectives & Approach

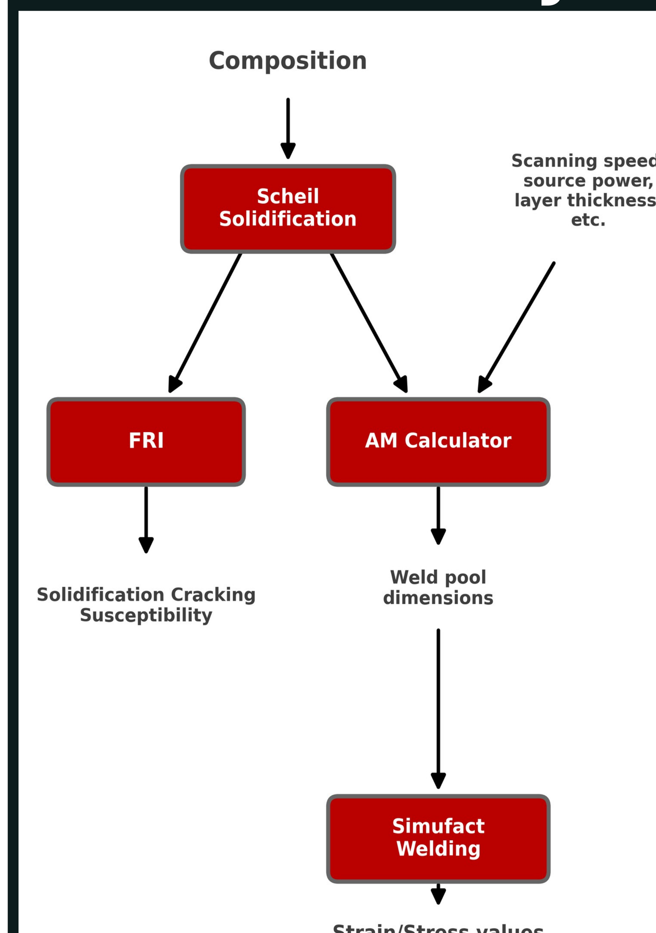


Figure 1. Workflow of the combined FRI and AM melt pool calculator.

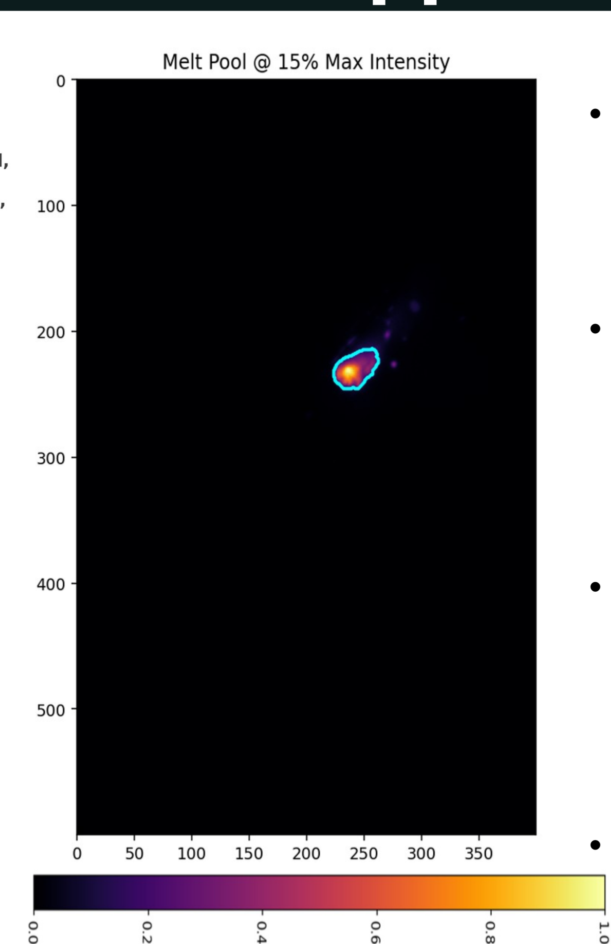


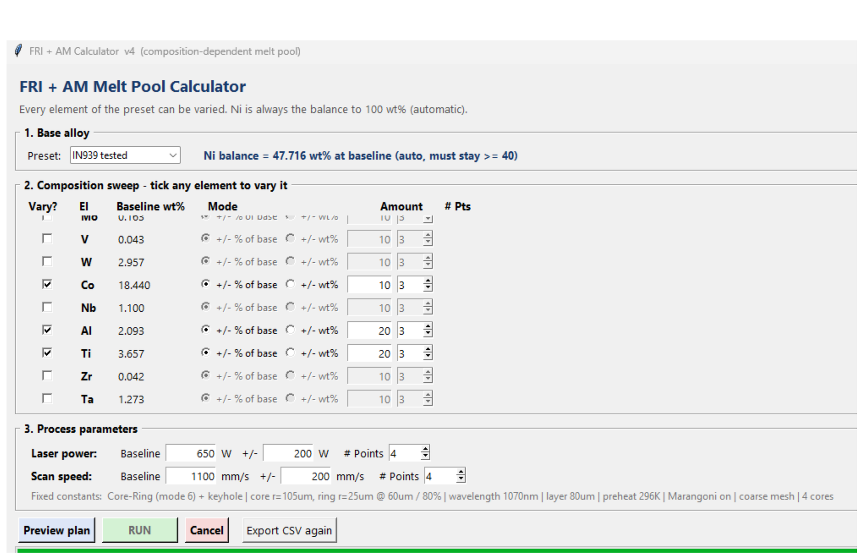
Figure 2. Simulated melt pool thermal intensity map, with the melt pool boundary taken at a 15% maximum intensity threshold.

- Create an automated pipeline that predicts solidification cracking in Ni-based superalloys
- Rebuild the FRI model on an updated calculation engine, enable batch processing, and add weld pool output
- Integrate the new FRI model with process simulation software to predict stress and strain on any print
- Automate the simulation inputs so batches of compositions can be run without manual setup

Conclusions

This project delivered a working automated application that returns FRI values and melt pool dimensions for any varied inputs, and lets the user adjust AM parameters such as source power and scan speed. Aluminum and titanium had the strongest influence on solidification cracking.

FRI + AM Melt Pool User Interface



Future Work

- Expand the user interface so more model and process parameters can be varied
- Connect the FRI and melt pool calculator to Simufact Welding so that a custom material card is generated automatically for every composition in a batch
- Extend the pipeline to CALPHAD databases beyond nickel based superalloys
- Implement additional cracking criteria, including the Crack Susceptibility Index (CSI) and the Hot Cracking Susceptibility criterion (HCS)

Results & Discussion

TESTING THE MODEL

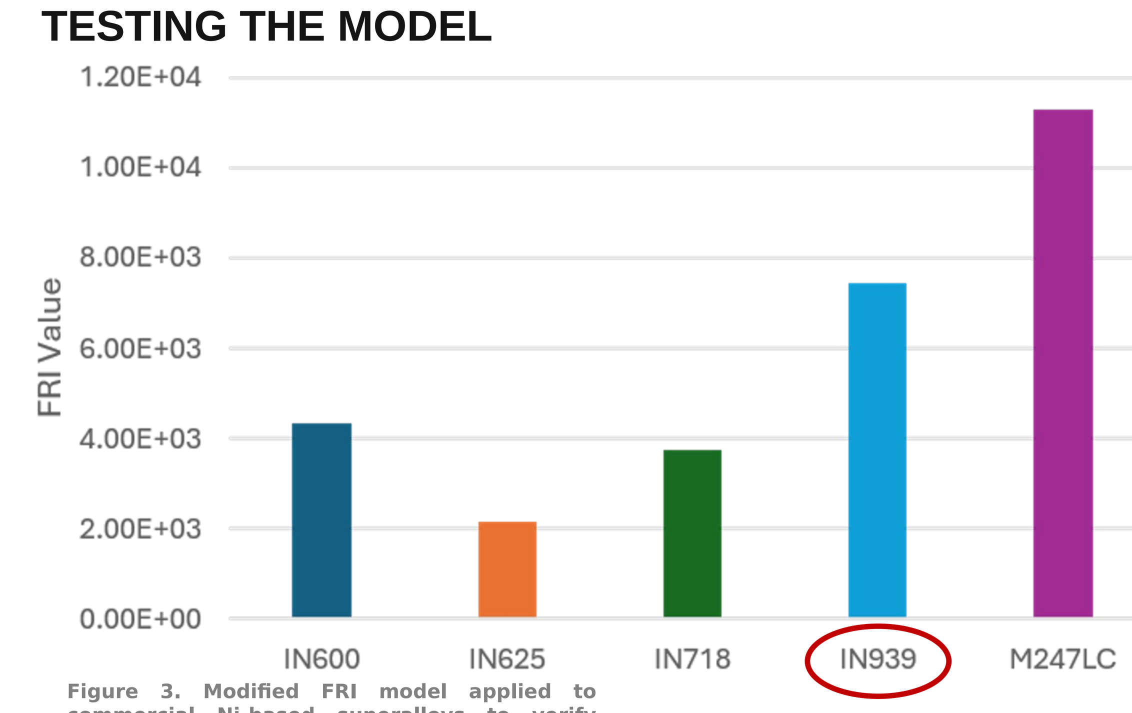


Figure 3. Modified FRI model applied to commercial Ni-based superalloys to verify accuracy.

Alloys of known behavior were simulated first to baseline the model. The crack resistant grades IN625 and IN718 rank lowest, IN939 carries roughly 3.5 times the flow resistance of IN625, and M247LC, a known crack prone benchmark, ranks

TARGET ALLOY: IN939

An aerospace superalloy that industry wants to print and repair. Its position in the ranking sets the reference point for every composition tested in this work.

WHAT DRIVES THE RISK?

- Aluminum, zirconium, and titanium are the most sensitive elements, with aluminum alone spanning 1,146 kPa
- Vanadium, tantalum, and silicon are the least sensitive, spanning under 380 kPa each
- Aluminum and titanium form the gamma prime phase, tying strength to cracking risk
- The model varies each element independently and ignores cross correlations

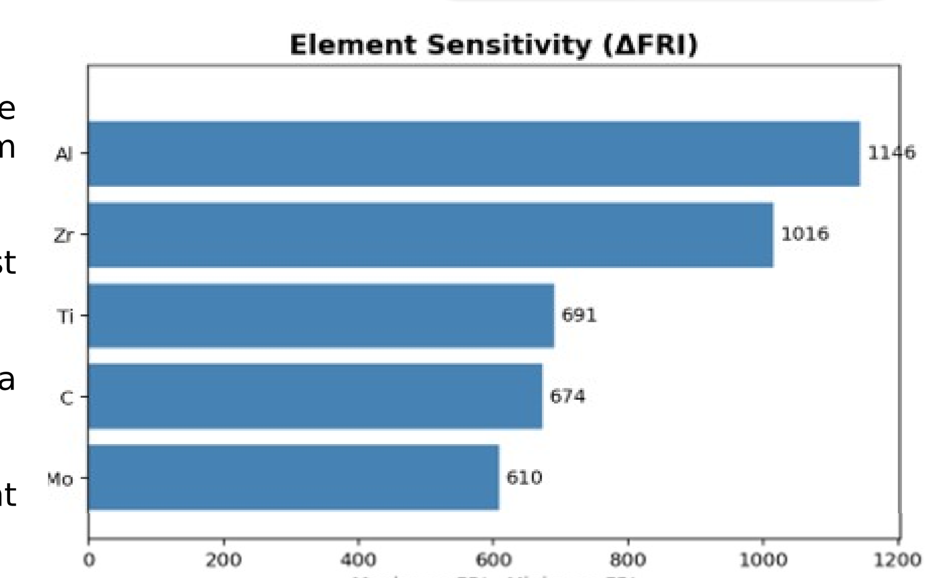


Figure 4. Element sensitivity, defined as the change in FRI produced by a ±10% variation in wt.% of each element in IN939. 100 samples were run through the model.

SIMULATING WELD POOL DIMENSIONS

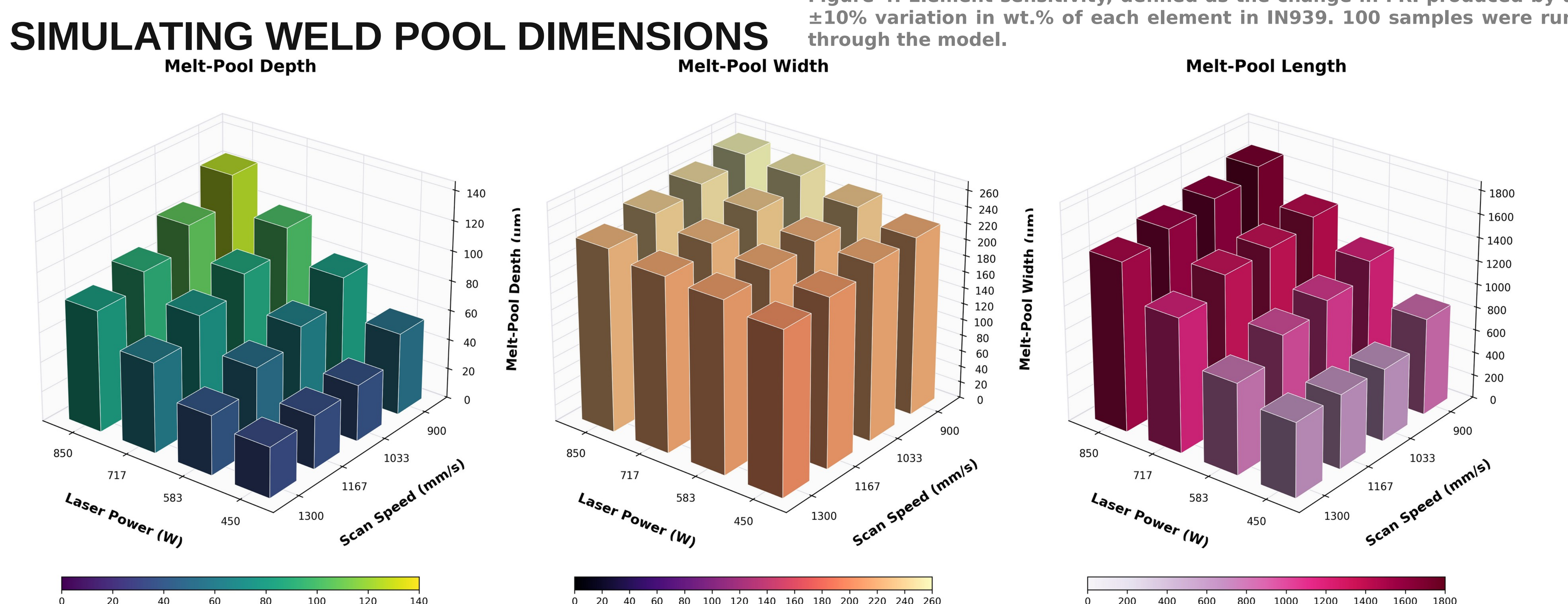


Figure 5. Change in weld pool dimensions with scanning speed and laser power. 100 samples were run through the model.

STRESS FOLLOWS THE WELD PATH

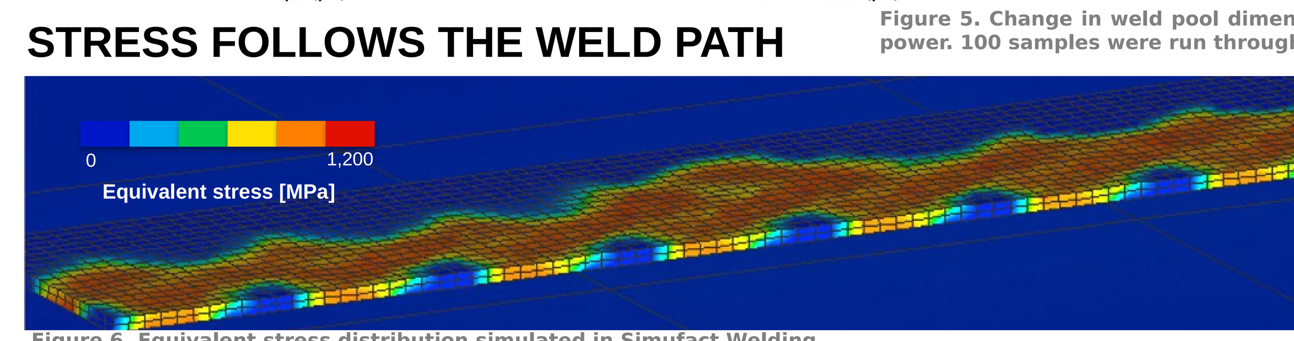


Figure 6. Equivalent stress distribution simulated in Simufact Welding.

Equivalent stress peaks near 1,200 MPa along the solidifying weld path. The gaps between high stress bands are a rendering limitation, not a physical result.

Sources

References

Kou, S. (2015). A criterion for cracking during solidification. *Acta Materialia*, 88, 366-374.

Rappaz, M., Drezet, J.-M., & Gremaud, M. (1999). A new hot-tearing criterion. *Metallurgical and Materials Transactions A*, 30(2), 449-455.

Guzman, J., Riffel, K. C., et al. (2025). Weldability study of alloys 625 and 718 fabricated by laser-based additive manufacturing. *Journal of Manufacturing Processes*.

Schanz, J., Islam, N., Kolb, D., et al. (2022). Individual process development of single and multi-material laser melting in a novel modular laser powder bed fusion system. *Progress in Additive Manufacturing*, 7, 1025-1040.

Software

Thermo-Calc 2026b with TC-Python, Thermo-Calc Software AB, Stockholm, Sweden. QuesTek ICMD, QuesTek Innovations LLC, Evanston, IL, USA. Simufact Welding, Hexagon Manufacturing Intelligence. Visual Studio Code, Microsoft Corporation.

Data, Models, and Images

Flow Resistance Index (FRI) model provided by Prof. Antonio Ramirez, Department of Welding Engineering, The Ohio State University. Figures 2, 3 and 4 courtesy of Austin Tiley.

THE OHIO STATE UNIVERSITY

This program is proudly sponsored by the American Welding Society Foundation.