Predicting Hot Cracking in Laser Powder Bed Fusion

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Problem Statement

Background

- The two most common laser-based metal AM processes are directed energy deposition (DED) and laser powder bed fusion (LPBF).
- The LPBF process has two main steps: spreading a thin layer of powder and then rapidly melting the powders with a high-powered laser. As the laser is scanned over the thin layer of powder, the melted powders form a "melt pool" and solidify as a single part. By repeating this melting-solidification cycle a part can be built layer-by-layer.
- There are still many challenges that need to be overcome before AM technologies can be freely used in industry[1]. The most common defects seen in AM are porosity that develops from melt pool boiling and lack of fusion, and delamination caused by hot cracking[2].

Objective

- Create a multi-physics model framework that can assess hot cracking in a Titanium alloy (Ti-6Al-4V) additively manufactured via the laser powder bed fusion process.

Model Framework

Material Properties and LPBF Parameters
- Effective material properties
- Laser power, scan speed, hatch distance

→ **Run SADMAN** →

SADMAN Outputs
- Sector at each time step
- Solid-liquid fraction (enthalpy)
- Temperature at each unit volume

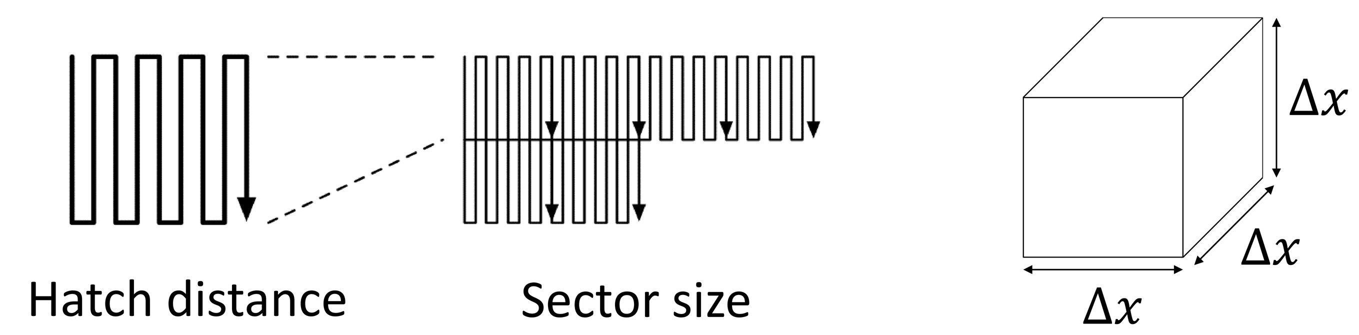
RDG Inputs
- Temperature gradient from SADMAN
- Solid-liquid fraction from Scheil calculation

→ **Run RDG** →

RDG Output
- Pressure drop at each position
- Heat map of propensity to crack

SADMAN Model

$$\frac{\partial\theta}{\partial\tau} = \frac{k}{\rho c_p v \Delta x}\frac{(\theta_i - \theta_{i-1})}{T_m} + \frac{Q\Delta x^3}{\rho c_p v\, \Delta x^2 T_m}$$



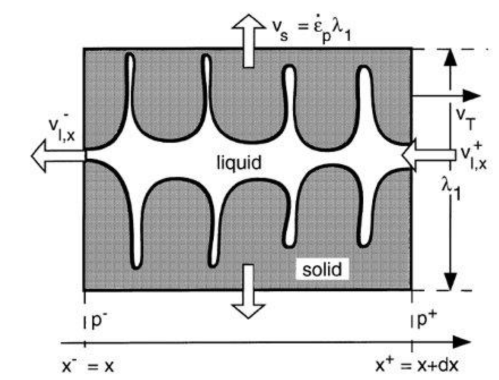
Normalized Thermal Diffusivity, λ — $\frac{k}{\rho c_p v \Delta x}$

Normalized Absorbed Power, π — $\frac{Q\Delta x}{\rho c_p v T_m}$

Normalized Latent Heat, ω — $\frac{L_H}{c_p T_m}$

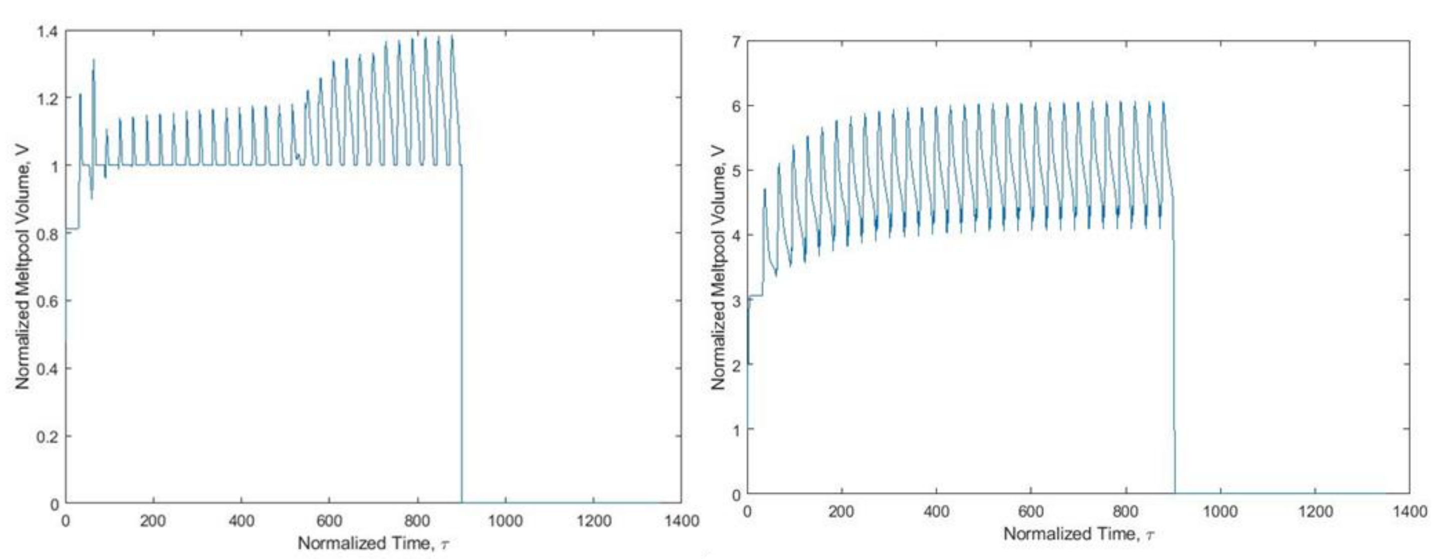
RDG AM Model

$$\Delta P_{max} = \frac{5(1+\beta)\mu}{S_v^{-2} G}\int_{T_S}^{T_L}\frac{E(T) f_s^2}{(1-f_s)^3}dT + \frac{5 v_T \beta \mu}{S_v^{-2} G}\int_{T_S}^{T_L}\frac{f_s^2}{(1-f_s)^2}dT$$

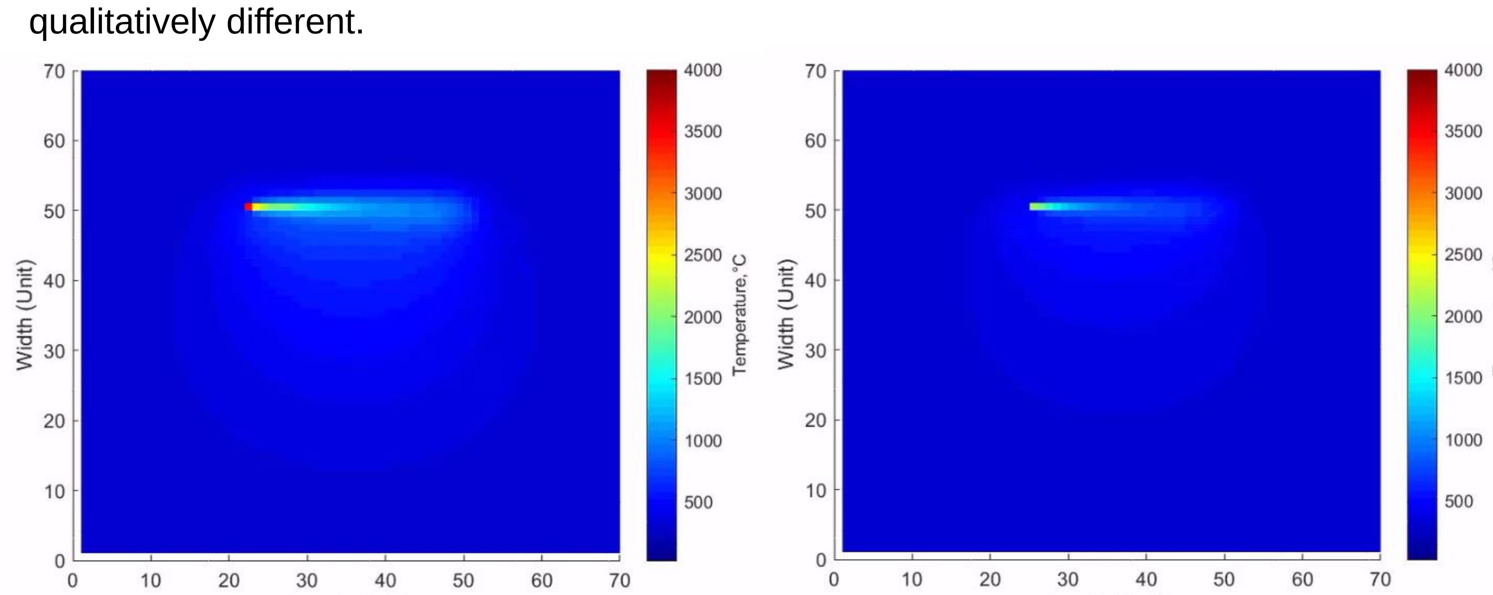


Results

Process Parameter Exploration

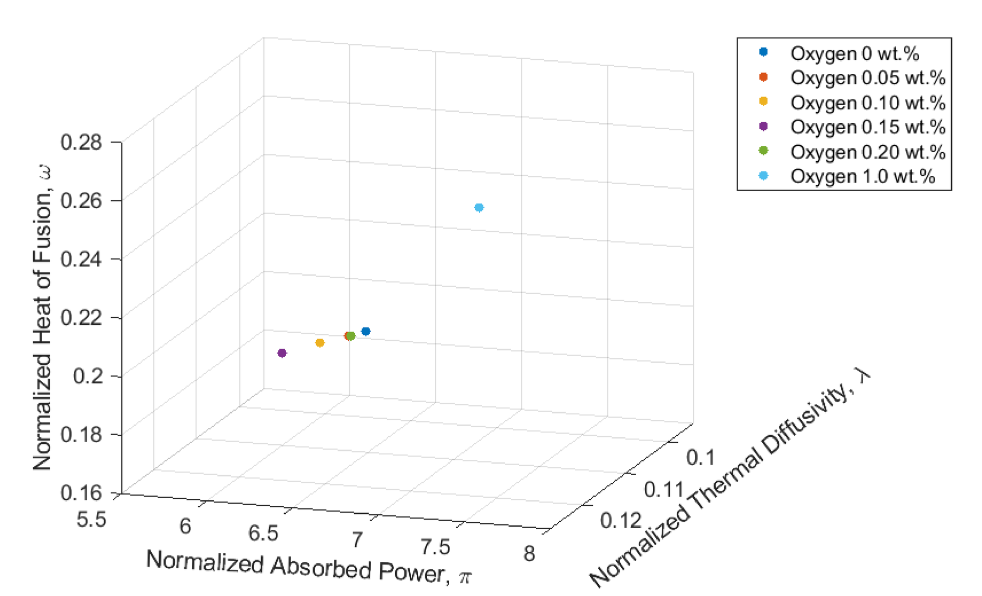


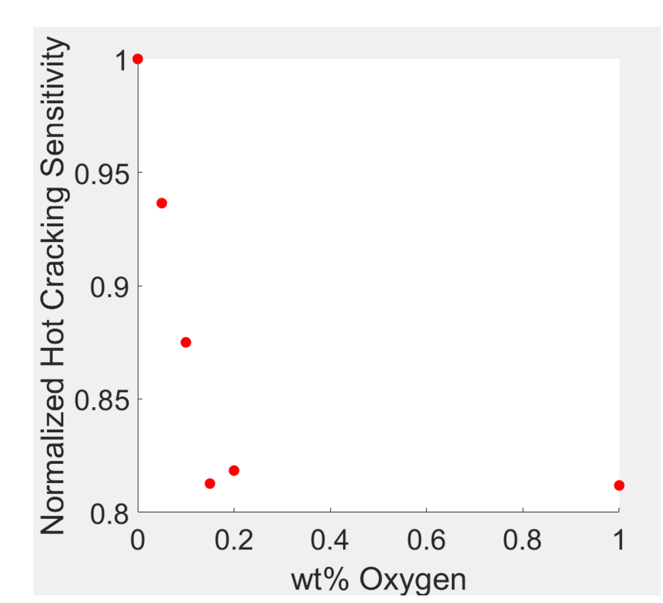
Meltpool volume of different power levels for the reversing lines strategy. Laser power of 60W (left) and laser power of 100 W (right). The meltpool volume throughout the build is qualitatively different.



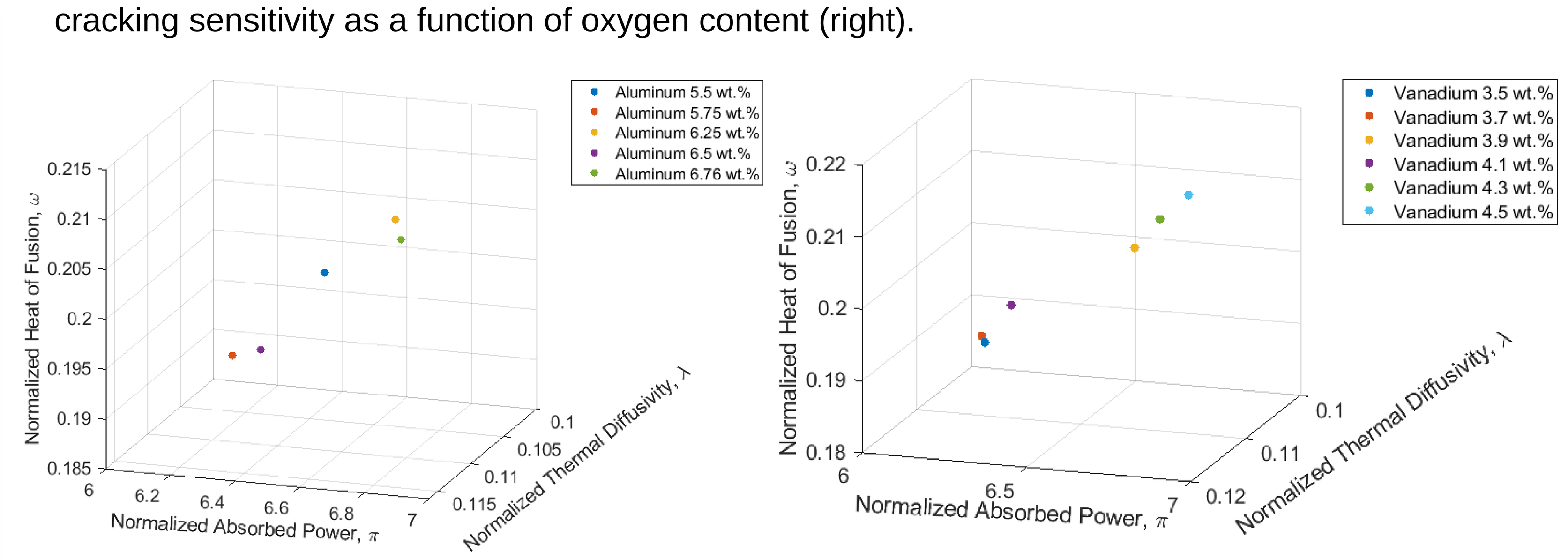
Temperature of top of sector for different power levels for the reversing lines strategy. Laser power of 60W (right) and laser power of 100 W (left). Heat accumulation across the sector is larger at the higher power level.

Composition Variance





Non-dimensional parameters as a function of oxygen content (left) and a normalized hot cracking sensitivity as a function of oxygen content (right).



Non-dimensional parameters as a function of aluminum content (left) and as a function of vanadium content (right).

Conclusions

- Results of oxygen addition to Ti-6Al-4V studied, as well as aluminum and vanadium content.
- Hot cracking sensitivity decreased to a minimum with increasing oxygen content.
- Composition changes are dominated by differences in specific heat.
- Local composition changes are important to hot cracking because the material properties in the heat equation are highly dependent on it.
- Results show that even 0.1wt.% variation in the composition will have an effect on hot cracking likelihood.

References

1. NIST (2018). https://www.nist.gov/ambench/challenges-and-descriptions
2. Debroy, T., Wei, H. L., Zuback, J. S., Mukherjee, T., Elmer, J. W., Milewski, J. O., … Zhang, W. (2018). Progress in Materials Science Additive manufacturing of metallic components – Process, structure and properties. Progress in Materials Science, 92, 112–224. https://doi.org/10.1016/j.pmatsci.2017.10.001