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Name: Kevin Cole
Organization: University of Nebraska

Abstract Title: Reduced-order thermal models in additive manufacturing: toward design and process optimization

Authors: Kevin D. Cole

Introduction. In metal additive manufacturing, deleterious heat buildup and uneven temperature histories are the root causes of inconsistent part quality and flaw formation [1]. Thermal models can reduce the need for expensive build-and-test empirical studies for process optimization [2]. Long computation time for thermal models is a challenge, however, especially for thin struts and supports, as these require dense grids and high node counts.

Objective. The objective of this study is to reduce model computation times by replacing thin struts and supports by a reduced order model. The target process is laser powder bed fusion (LPBF).

Methods. The procedure is demonstrated on a C-shaped part with supports, where a full-geometry simulation of one thermal cycle from an additive manufacturing process provides simulated data. Calibration of the reduced-order model, in which the supports are replaced by a region with effective thermal properties and low node counts, is carried out with a parameter estimation procedure.

Results. The calibrated reduced-order model, applied to a NIST overhang geometry, agrees with the full-geometry simulation within 6% and runs 85 times faster. Refer to Fig. 1. The present study investigates a single thermal cycle; future work will encompass repeated thermal cycles in a many-layer additive manufacturing process. Calibration of the reduced-order model with experimental data is also planned.

Significance. The reduced order model will dramatically speed up thermal simulations of the laser powder bed fusion (LPBF) process for parts with thin struts and supports. Calibration on a single test part will provide rough-and-rapid simulation for parts of varying shapes to provide for design optimization (i.e. placement of supports) and process optimization (i.e. setting machine parameters).

References

1. R. Yavari, Z. Smoqi, et al., Part-scale thermal simulation of laser powder bed fusion using graph theory: Effect of thermal history on porosity, microstructure evolution, and recoater crash, Materials & Design, Vol. 204, 2021, 109685.
2. A. Riensche, B. Bevans, et al., DynamicPrint: A physics-guided feedforward model predictive process control approach for defect mitigation in laser powder bed fusion additive manufacturing, Additive Manufacturing, Vol 97, 2025, 104592.

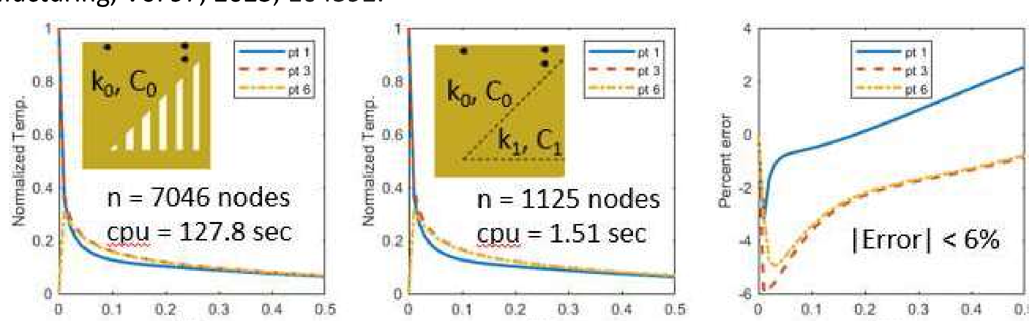

Figure 1. Simulated temperature histories from one LPBF thermal cycle for (a) NIST part with supports (b) calibrated reduced-order model with effective thermal properties (c) error between them.