Residual stresses and deformations generated in laser powder bed fusion of thin metallic samples

Pouria Khanbolouki[1], Eann A. Patterson[2a], Chris J. Sutcliffe[3], John Lambros[1]

[1]Department of Aerospace Engineering
University of Illinois, Urbana-Champaign, USA

[2]Department of Mechanical, Materials & Aerospace Engineering
University of Liverpool, UK

[3]Meta Consulting LDA, Portugal

[a]eann.patterson@liverpool.ac.uk

Abstract

Numerical modeling is used to predict residual stresses and deformations in thin metallic components created via laser-powder bed fusion (L-PBF). The focus is on two geometries: a thin horizontal plate for residual force analysis and thin vertical plates for investigating residual deformations and the effects of support removal. Using the ANSYS Additive Suite for weakly coupled thermo-mechanical simulations, the numerical results align qualitatively and quantitatively with experimental observations, both in terms of forces measured during manufacturing and deformations present after manufacturing.

Introduction

In laser powder bed fusion (L-PBF), especially for thin-walled components, parts are prone to defects and potential failure from residual stresses. The L-PBF process involves layering and consolidating metal powder with a high-powered laser, causing local phase changes and mechanical property gradients. Differential cooling rates between liquid and solidified phases create residual tensile stresses, which can cause macroscopic deformations upon detachment from the base plate. While internal residual stresses may not significantly impact large or axisymmetric objects, they can induce out-of-plane deformations and buckling in thin, quasi-two-dimensional structures [1]. Traditional machining of these structures from thicker plates leads to material wastage, positioning additive manufacturing as a preferable method due to its efficiency and the ability to incorporate unique features [2].

In [3,4], aiming to understand stress development during L-PBF, the authors conducted experimental research where in situ forces during the building of a horizontal plate were measured using a custom-made load-cells embedded in the base plate. A matrix of four-by-four force transducer devices was used, with support structures constructed on top of pillars each of which was connected to an individual load cell. In [1], the residual deformation of vertical thin geometrically-reinforced plates was investigated and to mitigate the risk of failure during the manufacturing process, buttresses were used as scaffolding to support the plates.

Methods

The current study examines both these horizontal and vertical plate configurations using detailed numerical simulations. The ANSYS Additive Suite was used for weakly coupled thermo-mechanical simulations and Fig.1 shows an example of a vertical plate as tested in [1]. This involved performing a transient thermal history analysis on an undeformed mesh using a layer lumping technique, the outcomes of which served as input for subsequent static mechanical simulations. Additionally, several physically manufactured layers were lumped into one finite element layer in order to reduce computational costs. Additional static structural steps for sequential removal of support structures were added at the end of cool-down period.

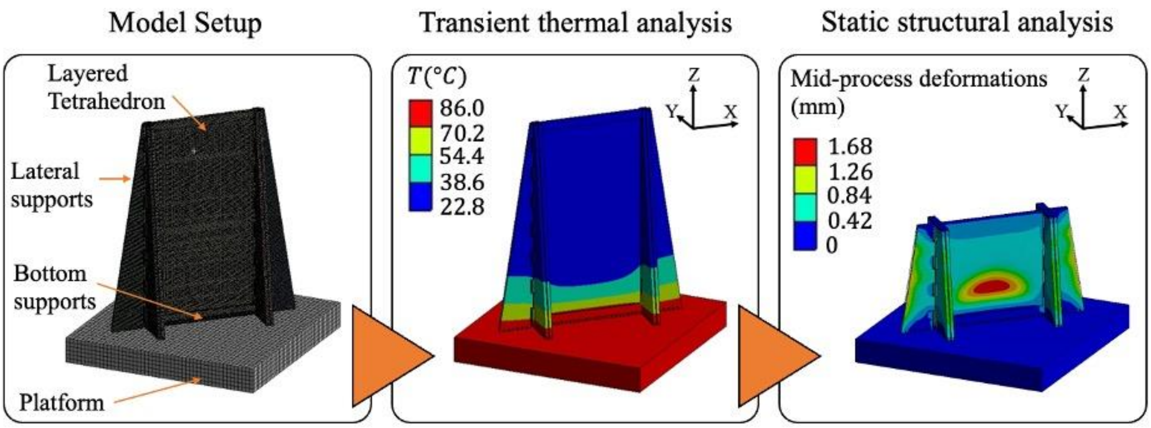

Figure 1 – Plate in portrait orientation meshed with layered tetrahedron elements (left); with transient thermal analysis applied (center); followed by a static structural analysis (right).

Results

The simulations demonstrated the ability to deliver both qualitatively reliable and, to a large extent, quantitatively accurate forecasts of residual forces, deformations, and the ultimate shapes of thin structures. In the horizontal plate configuration, numerically predicted forces were within about 30%, on average, of the experimental values. For the vertical plate, Fig. 2, showing net out-of-plane displacement, illustrates the formation of peaks and valleys in the build plate starting from the fabrication stage to the final support removal. This capability offers a valuable tool for devising strategies aimed at reducing the residual deformations in thin metallic structures produced via L-PBF.

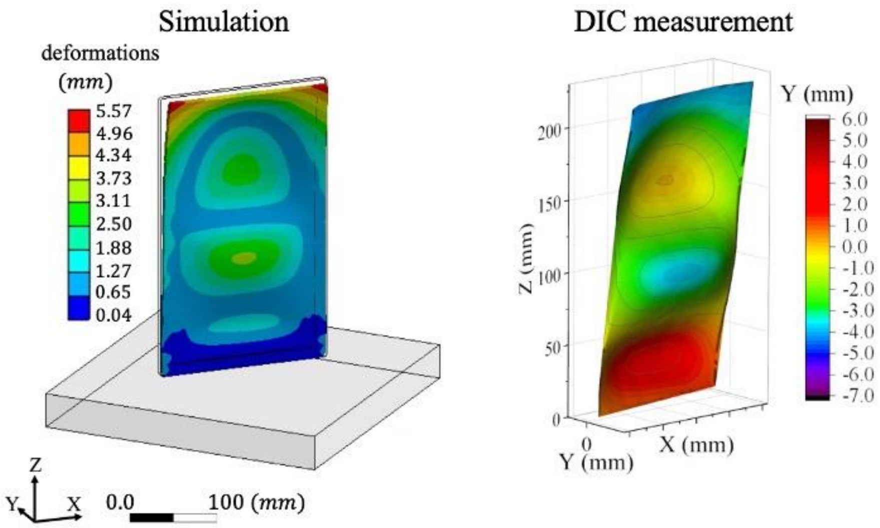

Figure 2 – Comparison between results from simulation (left) and DIC measurements (right) collected from plates manufactured vertically via L-PBF process.

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