Robustness aspects of the inherent strain method for distortion predictions in additive manufacturing

Etienne Bonnaud*, Fredrik Wredenberg*

* Swedish Research Institute for Materials (SWERIM)
Box 7047, SE-164 07, Kista, Stockholm, Sweden
e-mail: etienne.bonnaud@swerim.se, web page: http://www.swerim.se

ABSTRACT

Additive Manufacturing is an attractive and promising technique. The layer by layer approach makes it possible to build nearly any component of nearly any conceivable shape. Nevertheless, to reach its full potential, the method still needs to cope with distortion and residual stress issues. Very local and quickly moving high heat input leads to high temperature gradients that give rise to residual stresses during solidification and cooling. Due to residual stresses, components can crack already during manufacturing, distortions can develop when components are cut off their build plate and fatigue life is usually shortened as residual stresses add up to external service stresses.

Numerical simulations based on the Finite Element Method are a well-suited tool to predict residual stresses and resulting distortions. Simulations techniques for Additive Manufacturing have been derived from simulation techniques developed for welding with a certain success. Among these, the so-called Inherent Strain Method has, in certain cases, been shown to give very good predictions, see [1,2] for example.

In essence, the Inherent Strain Method aims at strongly reducing the computational effort by running a detailed, elasto-plastic, fully coupled, thermal and mechanical simulation on only a few square millimetres small model (often called the meso model) to extract strains values that are elastically mapped on the full-size component of interest (often called the macro model). Values for the inherent strains usually reduce to two of six possible, namely the two in-plane normal strains (shear strains happen to be one order of magnitude lower and the normal strain in the build direction is not considered as it does not give rise to stress). All material parameters and process parameters reduce therefore to two numerical values, which sets very high precision requirements on their calculation.

Assumptions and parameters for a meso model are unfortunately numerous: how large and thick the model should be, what should the thermal and mechanical boundary conditions be, what plasticity model should be used, how and where should plastic strain be extracted?... Up to now, inherent strains are calculated after deposition of one single layer but in reality, deposition of subsequent layers first partly re-melts this initial layer and then subject it to high temperatures at which plasticity repeatedly occurs, altering the inherent strain initial values.

Here a meso model with several deposited layers on top of each other is set up and the mechanical effect of all subsequent layers on the first layer is investigated. The effect of different cyclic hardening plasticity models is also investigated. The different combinations are then mapped into a full-scale macro model and the resulting deformations are compared with experimental results.

REFERENCES

[1] N. Keller, V. Ploshikhin F. Feuerhahn, H. Koehler, "Multi Scale FEM Simulation for Distortion Calculation in Additive Manufacturing of Hardening Stainless Steel", *International Workshop on Thermal Forming and Welding Distortion, IWOTE 14*, 2014.

[2] J. Ding, P. Colegrove, J. Mehnen, S. Williams, F. Wang, P. Sequeira Almeida, "A computationally efficient finite element model of wire and arc additive manufacture", *International Journal of Advanced Manufacturing Technology,* Vol. 70, pp. 227–236, 2014.