Computationally efficient thermo-mechanical modelling in metal additive manufacturing

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Selective laser melting (SLM) is one of the main additive manufacturing methods suitable for metallic parts. Although SLM has nearly no limitation for geometrical complexity of the parts, undesired deformations and residual stresses are detrimental for the quality of the product. Appropriate process parameters and the scanning strategy need to be selected carefully to minimize deformations and residual stresses, but experimental trial and error is expensive and time consuming. Therefore, we present a computationally efficient thermo-mechanical model to investigate the influence of these parameters on the deformations and residual stresses of the SLM product. A semi-analytical thermal model is first established, in which an analytical solution for heat sources in semi-infinite space is utilised to capture the steep temperature gradient in the vicinity of the laser, and the boundary conditions are accounted for by finite element method (FEM). The temperature field is then used to calculate the thermal strain induced on the SLM product. This thermal strain, comprise of elastic and plastic deformations which satisfies the compatibility. A temperature dependent elastic-plastic model with kinematic hardening rule is used to determine the stress field. Since the material bears no stress when it is melted, the stress/strain of the material point is reset to zero and becomes temporarily deactivated when the temperature is above the melting point. The mechanical analysis is assumed to have no effect on the temperature field, thus the thermal and mechanical models are one way coupled. Several case studies are investigated by the proposed model. The residual stresses and part deformations are investigated as a function of different scanning strategies and number of layers. The accuracy of the model is validated by experimental findings from literature [1]. The results prove that the scanning strategy is essential for the final shape of the product and hence should be accounted for in the process modelling.

References

[1] Vrancken, Bey. (2016) Study of Residual Stresses in Selective Laser Melting. PhD Thesis, KU Leuven, Leuven.