Virtual testing of additively manufactured grid structures

Ulrike Gebhardt1,∗, Roland Gärtner2, Matthias Berner2, Stefan Holtzhausen3, Julia Kristin Hufenbach4, Uta Kühn4, and Markus Kästner1,5

1 Institute of Solid Mechanics, TU Dresden, Dresden, Germany
2 Leichtbauzentrum Sachsen GmbH, Dresden, Germany
3 Institute of Machine Elements and Machine Design, TU Dresden, Dresden, Germany
4 Leibniz Institute for Solid State and Materials Research Dresden, Germany
5 Dresden Center for Computational Materials Science (DCMS), TU Dresden, Dresden, Germany

Additive manufacturing lifts the restrictions of classical manufacturing methods and enables us to produce lattice structures within otherwise massive bulk material to increase the lightweight potential of technical components.

In this contribution we present a multiscale approach to characterise additively manufactured lattice structures. Tensile tests provide the properties of the bulk material and are input for a homogenisation scheme and a detailed numerical model to perform virtual experiments. The virtual experiments are compared to actual experiments on test specimen to validate the modelling approach.

Process parameters strongly influence the overall mechanical behaviour of additively manufactured lattice structures and are cause for macroscopic deviations of the geometry. Those deviations can be additional material at the struts or an inner porosity of the structure. They are identified, quantified and a first numerical analysis of their influence is presented.

© 2019 The Authors Proceedings in Applied Mathematics & Mechanics published by Wiley-VCH Verlag GmbH & Co. KGaA Weinheim

1 Introduction

With selective laser melting, topology optimised support structures as seen in Fig. 1a can be produced. To further increase the lightweight potential, lattice structures can be included to create a stiff core-shell structure. Designing such components for technical applications requires a reliable prediction of the material properties. It is known that the process parameters of additively manufactured components strongly influence their mechanical behaviour. Thermal cycles are cause for residual stresses and distortion and a high energy input can cause porosity within the material and adhesion of additionally melted powder. To consider these effects in a modelling approach the following multiscale approach is presented.

Fig. 1: Lattice structure and it’s characterisation on three scales: (a) Additively manufactured support structure filled with lattice structure, (b) tensile tests of bulk material, (c) unit cell for homogenisation scheme, (d) test specimen for compression test.

2 Multiscale approach and virtual testing

To characterise the presented lattice structure three scales are considered: Tensile tests of the bulk material in three directions – vertical, parallel and at an angle of 45° to the build direction with as built as well as heat treated test specimens, see Fig. 1b – are performed to determine the material parameters Young’s modulus, yield strength and the flow curve. The flow curve

\[ k = (1 - \alpha) \cdot k_v + \alpha \cdot k_s \]  

is extrapolated using a combination of the hardening laws

\[ k_s = A \cdot (\varepsilon_p + \varepsilon_0)^n \]

and

\[ k_v = k_0 + Q \cdot (1 - e^{-\beta \varepsilon_p}) \]
$k_s$ by Swift [1] and $k_v$ by Voce [2], where $\alpha$ is a factor to combine both equations, $\varepsilon_p$ is the plastic strain and $A, \varepsilon_0, n, k_0, Q$ and $\beta$ are parameters to fit the equations to the actual data from the experiments. Those material parameters are input variables for modelling on the other scales.

To identify effective material parameters for the homogeneous effective material (HEM), a homogenisation scheme is performed on a unit cell for the used rhombic dodecahedron (Fig. 1c). The modelling approach is validated by performing virtual tests on a compression test specimen (Fig. 1d) with the HEM as well as a detailed FE-model. Those virtual tests are compared to experiments. At this point, process induced imperfections are not considered in the model, which is why model and experiment are not in agreement yet. (see graphs HEM, FEM and experiment in Fig. 2c)

### 3 Imperfections

Thermal cycles during production can cause residual stresses and global distortions in additively manufactured components. Due to heat treatment after production residual stresses cannot be the source of the discrepancy in the validation. Also global distortions can be ruled out, since process simulation with AMPHYON showed only slight deviations with the given process parameters.

CT scans of a test specimen show local deviations of the geometry due to powder quality and high energy input during manufacturing. The high energy input can lead to the melting of too much powder which will stick to the surface of the component as seen in Fig. 2a and b.

Storm et al. [3] show that geometric deviations in foam structures can lower the effective Young’s modulus up to 15%. Geometric deviations as considered in Liu et al. [4] reduce the Young’s modulus up to 30%. To capture that effect, Young’s modulus can be reduced in our simulation which minimises the gap between simulation and experiments as seen in Fig. 2c.

High energy input during production and the powder quality also lead to an inner porosity of the component. Amani et al. [5] suggest using a modified Gurson-Tvergaard-Needleman model to account for the influence of porosity in damage behaviour.

#### 4 Outlook

In further research the quantified geometric deviation of the rhombic dodecahedron will be considered to improve the elastic as well as the damage behaviour of the model. The influence of those deviations in the homogenisation scheme will result in the presentation of effective material parameters to reliably predict the overall mechanical behaviour of the lattice structure.

### References

[1] H. W. Swift, J Mech Phys Solids 1, 1 – 18 (1952)
[2] R. W. Swindeman, J Eng Mater-T ASME 97, 98 – 106 (1975)
[3] J. Storm, M. Abendroth and M. Kuna, Mech Mater 86, 1 – 10, (2015)
[4] L. Liu, P. Kamm, F. García-Moreno, J. Banhart and D. Pasini, J Mech Phys Solids 107, 160 – 184 (2017)
[5] Y. Amani, S. Dancette, P. Delroisse, A. Simar and E. Maire, Acta Mater 159, 395 – 407 (2018)