Light-weight construction: Robust simulation of complex loaded cellular structures

Currently, one of the main challenges in industry is the reduction of the energy consumption of moving parts as well as of the total amount of the materials used. In order to meet the demand for optimized light-weight parts, the development of load adapted structures has begun to play a key role in today's research. One approach is the employment of low density materials, such as the well-known aluminum foams. However, on small scale, these foam structures are stochastic and therefore not load optimized. At this point, additive manufacturing becomes highly beneficial as it enables for an unprecedented design freedom. By the application of additively manufactured non-stochastic cellular structures, which can be locally adapted to the prevailing stresses, an optimized relative loading capacity becomes feasible.

1. Objectives

The first focal objective of this project is the creation of a robust Finite Element Analysis (FEA) model for complex loaded cellular light-weight structures. Based on of a previously generated linear elastic simulation, the examinations will be extended to linear-plastic deformation behavior including several materials e.g., metals as 316L stainless steel (ductile) and Ti-6Al-4V alloy (brittle) and plastics as PA12. The second focal objective of the project addresses the experimental verification of the generated FEA model. Therefore, cellular structures will be additively manufactured by employing Laser Sintering (LS) as well as selective laser melting (SLM) and subsequently uniaxial and bending tests will be conducted.

2. Procedure

In the first step, two different types of base-cells for a verification of the mechanical behavior and the simulation were designed. Both geometries were then employed for compressive and four-point bending tests. In addition to the latter mechanical analysis, the local strain distribution throughout the specimen was analyzed by means of digital image correlation (DIC). This software tool enables to achieve profound insights into the local loads of single struts and thus were crucial to evaluate the accordance of simulated and actual stress distributions for both metallic and plastic additively generated specimens. During the entire duration of the project the proceedings were reported at regular intervals.

3. Latest results

Previous investigations have shown that the deformation behavior of lattice structures depend on the heat-treatment, cell-structure, microstructure and load type. For a FE-analysis, the struts' diameter is as important as the tensile strength of the material to simulate the mechanical behavior. In Fig. 36, the simulation of compressive and tensile tests is displayed and compared to the experimentally tested specimens. The main challenge was to identify the average strut-diameter of the specimens. Therefore, the compressive and tensile tests were simulated with various strut-diameters.

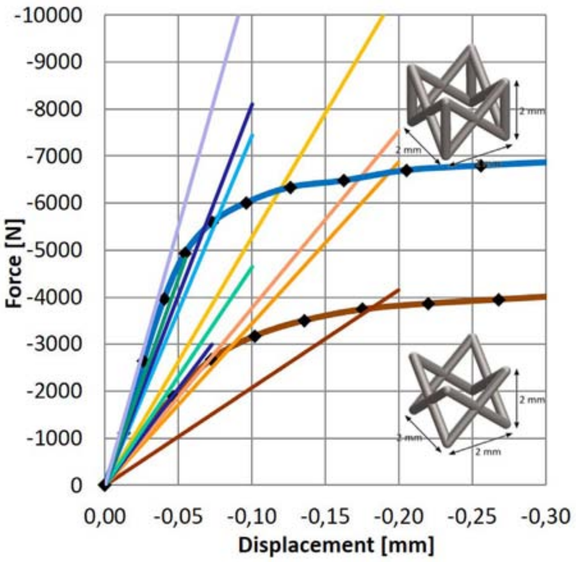

Figure 36: Comparison of the mechanical behavior of the fcc- as well as for the fccz- structured specimen with the FE-analyses (Ti-6Al-4V)

These investigations are in alignment with the SEM analyses, since a precise prediction about the diameter for the struts in different directions is not feasible. Despite the deviations in the lattice structure diameters, the data in Fig. 37 reveals that the inhomogeneous struts, however, can still be employed for the FE-Analyses.

With the information from tensile tests and simulation according to the average strut–diameter, FE-analyses were conducted and compared to the mechanically tested lattice structures during compressive (Fig. 37) and tensile tests. The comparison of both lattice structures has shown that the results of the FE-analyses are very similar to the digital image correlation in the linear-elastic range.

Project Manager	*Prof. Dr.-Ing. Mirko Schaper*
Scientific Associate/s	*Alexander Taube, M.Sc., Stefan Josupeit, M.Sc.*

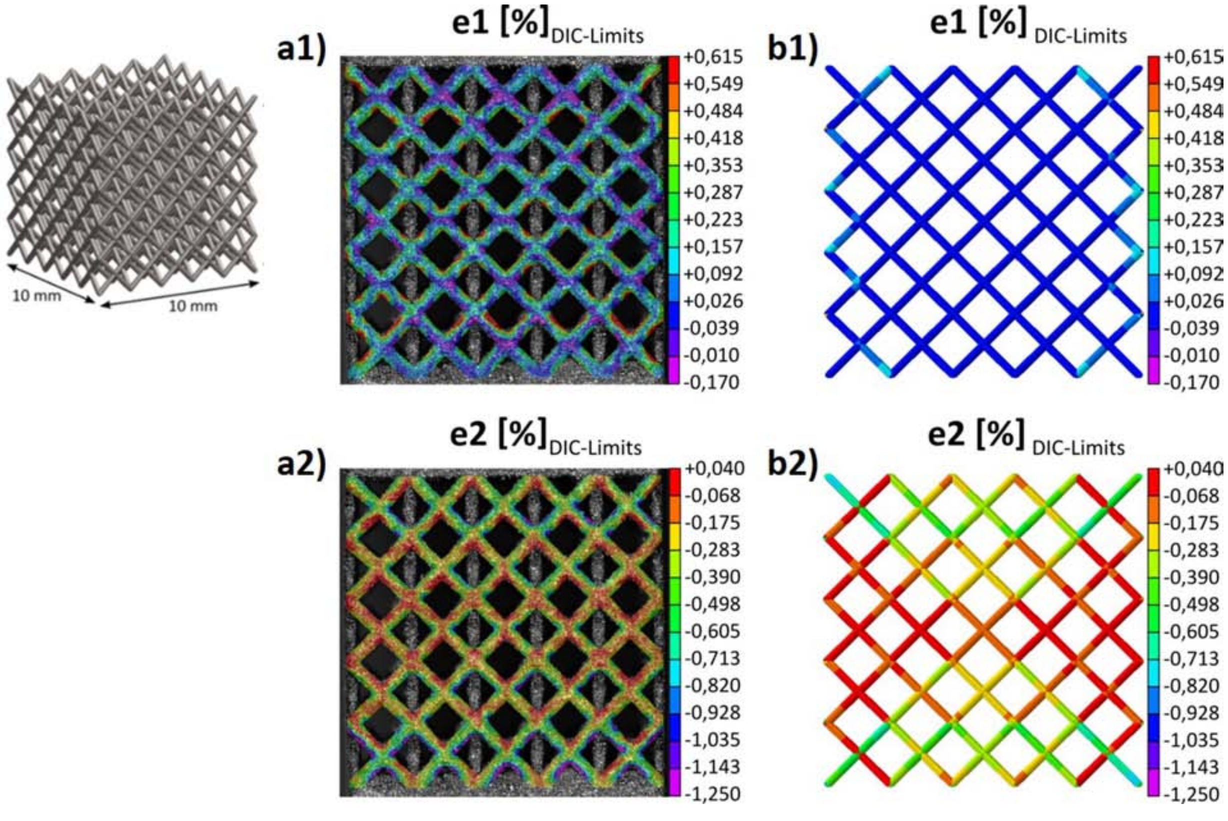

Figure 37: Local strain distribution of the fcc lattice structure under compressive load (a) maximum principal strain e1 and minimum principal strain e2 for the DIC; b) Simulation