Fracture and Fatigue of Selective Laser Sintered Polymeric Lattice Structures

Zoltan Major[1], Anna Hössinger-Kalteis[1], Michael Lackner[1], Issam Doghri[2], Darit Hun[2], Thomas Lück[3]

[1] *Johannes Kepler University Linz, Austria,*
[2] *Université Catholique de Louvain, Belgium*
[3] *cirp GmbH, Germany*
* *Presenting Author email: Zoltan.major@jku.at*

Abstract

Designed cellular lattice structures can be used in many engineering applications. While typically the viscoelastic deformation behavior (stiffness and damping) is utilized in many of these applications, the strength and the fatigue behavior plays an important role for components which are exposed to long-term cyclic loading. Selective laser sintered (SLS) polyamide 12 (PA12) and thermoplastic polyurethane (TPU) materials were investigated in two various lattice structures. A bistable structure based on curved bending beams (BB) and another structure with the combination of bending and torque of the trusses (USF) was designed and produced. To cope with the complexity of the SLS generated structure, three specimen configurations with different printing directions (0° and 90°) were used. To study the bulk behavior cylindrical hollow and notched round-bar specimens, to study the cellular behavior specimens consist of single trusses and knots and specimens contain multiple lattice cells were investigated under both uniaxial and axial/torsional, monotonic and cyclic loading conditions. The monotonic tests provided not only the strength values but relevant material models for subsequent simulations. The cyclic tests were performed at low strains for a comprehensive viscoelastic characterization and at higher strains for fatigue characterization in terms of conventional and strain based S-N curves.

1. Basic Considerations

Selective laser sintering (SLS) is a productive and powerfull additive manufacturing process for producing high quality components. The resolution allows the production of tiny structures, hence complex lattice structures in the sub mm range can also be produced. A slight anisotropy and a distinct porosity induced by the SLS process is expected in these components and structures. Lattice structures inherently involves a high number of stress concentrations at the vicinity of the knots. A higher density of defects and imperfections is also is assumed around these knots. Preliminary investigations have shown that the majority of the fracture was observed at the vicinity of the knots. Our experimental strategy considers both the investigations of the bulk material behavior and the investigation of these local sites. The experiments also provides the necessary material parameters for material models used in various accompanying conventional and novel micromechanics based simulations of the failure and fatigue behavior of the lattices. This paper provides a short overview about the entire experimental methodology with some selected results.

2. Experimental and Results

Two selective laser sinter grade polymeric materials have been used in our investigation (i) PA12 and (ii) thermoplastic polyurethane (TPU). Two different type of lattice structures have been investigated: (i) USF cell, combination of bending and torque of the truss elements of the cell and (ii) A curved beam bending cell (BB), which can reveal bistable or conventional behavior depending on the ratio of the height of the cell and the thickness of the trusses. The characterization was performed in three different test configurations:

- Cyclindrical hollow and bulk notched specimens were manufactured at two different position, layer orientation relative to the loading (0° and 90°)
- The cells are multiplied in structures and integrated in test specimens
- The single knots were investigated with 3, 4 and sich 6 trusses

All specimens and lattice structures have been manufactured at the company parner cirp (Heimsheim, D) under controlled process conditions. Monotonic and cyclic loading was applied under axial and axial/torsional loading conditions. Monotonic uniaxial force-displacement curves for both lattice cells (BB and USF) are shown in Fig. 1 for comparison. The significantly different deformation behavior of these cell types is clearly visible.

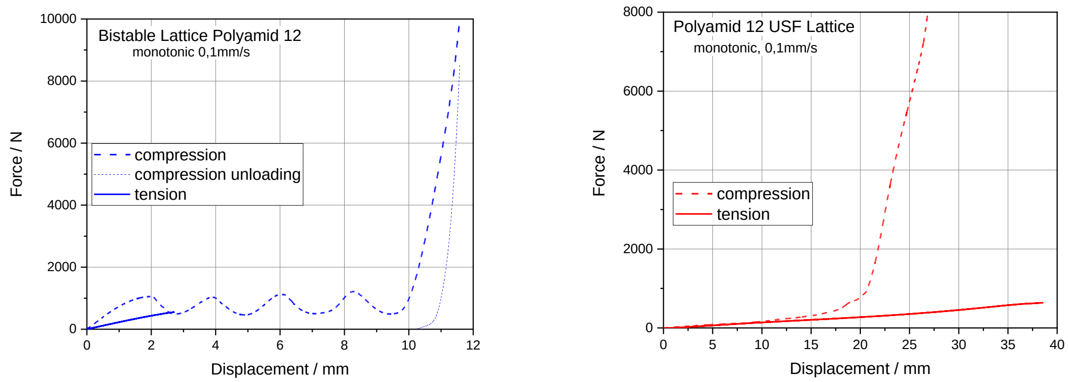

Fig.1 – Monotonic uniaxial force-displacement curves for both lattice cells (BB and USF)

While conventional load controlled experiments were performed for bulk PA12 for constructing of conventional Wöhler curves, displacement controlled experiments were carried out for bulk TPU and both lattice structures, and displacement as well as local strain based Wöhler curves were constructed as it is shown in Fig. 2.

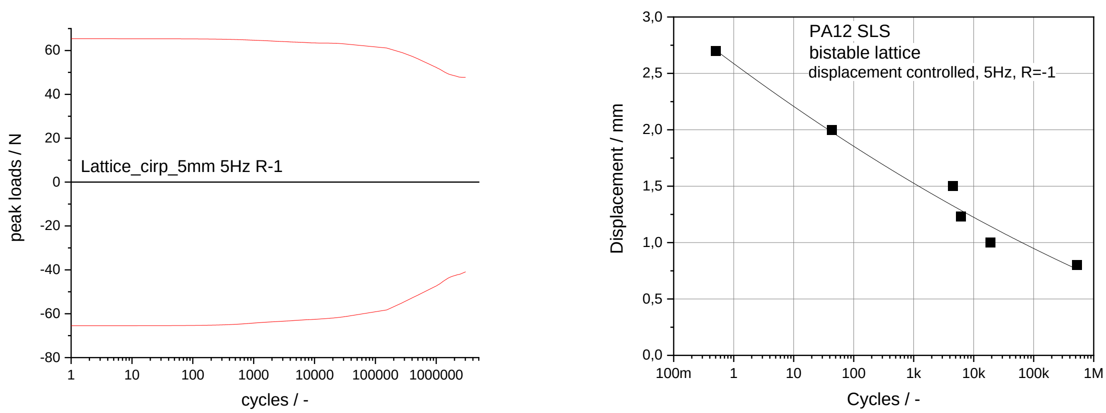

Fig.2 – Fatigue tests of USF lattice cells

3. Summary and Conclusions

An extensive experimental program is ongoing for characterizing the fatigue behavior of SLS lattice structures of two polymers and two different lattice cells under uniaxial and multiaxial cyclic loading conditions. In addition, material models considering the viscoelasticity, viscoplasticity and failure of these materials are developed and used in subsequent simulations.

Acknowledgements

These experiments have been performed in the Multi-scale Optimisation for Additive Manufacturing of fatigue resistant shock-absorbing MetaMaterials (MOAMMM) project. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 862015.