UNIVERSITÄT SIEGEN

PD Dr.-Ing. habil. B. Eidel
Heisenberg-Fellow (DFG)
Chair of Computational Mechanics
Department of Mechanical Engineering

Heisenberg-Programm
Deutsche Forschungsgemeinschaft

Optimization of Lightweight Metallic SLμM Microlattices by Finite Element Modeling and by Mechanical Testing

• Motivation

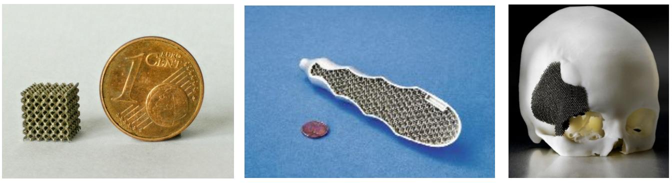

Fig. 1. SLμM-lattice (present work). Applications: surgeon tool (Fraunhofer), skull implant (Hanlon, 2006).

Main Aims

Optimized design and fabrication of metallic microlattices by Selective Laser Micro Melting (SLμM) for lightweight structures. Requires a joint research effort with an interplay of fabrication, modeling, characterization and testing disciplines.

Unique properties of SLμM lattices

1. Non-stochastic, almost deterministic cellular materials:
   → Effective optimization of stiffness and strength,
   → Unambiguous model reduction to a unit cell,
   → Tailored design of gradient materials.
2. Optimization in the numerical lab to narrow down the 'configuration space' of favorable lattice cells.
3. Optimized, reliable fabrication by SLμM by virtue of its high resolution.

Current and Future Applications

Lightweight structures in aerospace and automotive industries; bone replacement in orthopedic surgery; acoustic, vibration, or shock energy damping.

• Characterization and Mechanical Tests

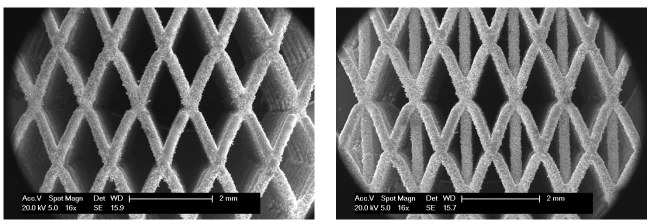

Fig. 2. SLμM-BCC and BCC-Z lattice (stainless steel), strut length to diameter $l/t = 4/0.3$ mm.

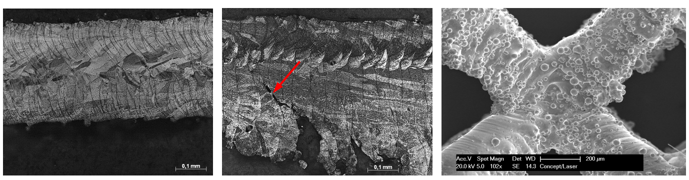

Fig. 3. Grinded cross sections of (left) a vertical strut and (centre) a diagonal, 45°-strut with melting deposit and cracks at the lower strut side. (Right) BCC-node from top.

• Finite-Element Analysis (FEA)

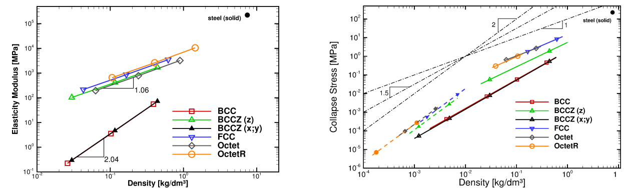

Fig. 4. Scaling laws and Ashby-diagrams for the elastic stiffness $\bar{E} = C\,\rho^n$ and strength $\bar{\sigma} = D\,\rho^m$ of various lattice types.

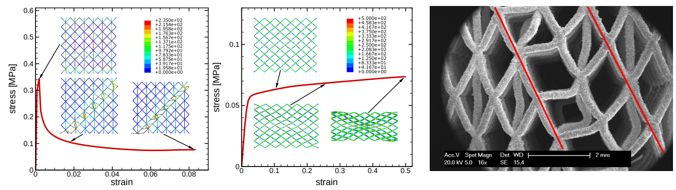

Fig. 5. Plastic localization in shear-bands for (left) a BCCZ- and (centre) a BCC-lattice along with von-Mises stress. (Right) SEM micrograph of a shear band in a BCCZ-60°-lattice.

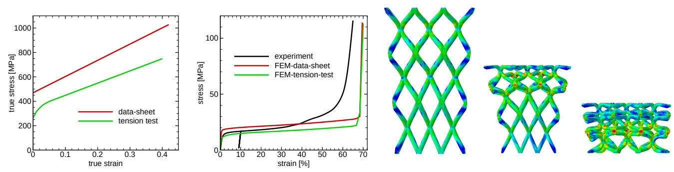

Fig. 6. (From left to right:) Hardening curves of elasto-plastic tension tests for parameter identification (present work vs. data of manufacturer). Stress-strain curves for the compression simulation of a BCC-45° lattice and the experiment. Deformation states with von-Mises stress for a BCCZ-lattice simulated with 3d 8-node solid finite elements.

• Issues, Challenges and Future Directions

- **Modeling:** Material's anisotropy, damage accumulation. Two-scale finite element modeling for the homogenization of large lattices. Analysis of the influence of various types of boundary conditions.
- **Characterization and Mechanical Tests:** Parameter identification on small scales. Surface postprocessing.
- **Optimized design and product properties**:
  (i) lattices with designed gradients in stiffness,
  (ii) increasing the lifetime for cyclic loading,
  (iii) maximization of dissipation for impact loading.

References

[1] L. J. Gibson, M. F. Ashby, Cellular Solids, Cambridge University Press, (1999).
[2] R. Gümrük, R.A.W. Mines, *Int. J. Mech. Sci.* 68 (2013).
[3] S. Didam, B. Eidel, A. Ohrndorf, H.-J. Christ, PAMM (2015).

PD Dr. B. Eidel
Institut für Mechanik
Universität Siegen

Dr. A. Ohrndorf, Prof. Dr. H.-J. Christ
Institut für Werkstofftechnik
Universität Siegen