# In-situ fracture analysis of 3D-printed structures

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**INTRODUCTION:** Patient-specific titanium implants can be manufactured using additive manufacturing techniques (SLM, Selective Laser Melting). In this study, the mechanical limits of simple and complex-shaped structures were systematically investigated microscopically as well as macroscopically.

**METHODS:** For strain measurements, micro samples were investigated in-situ in a scanning electron microscope (SEM) while applying increasing mechanical load. The deformation behaviour, the strain fields, the crack propagation and the failure mechanism were evaluated using DIC (Digital Image Correlation) on a sequence of SEM images. The micro specimens were produced from titanium grade 4 by Selective Laser Melting on a SLM-125 system (DMG Mori, Germany) in a vertical orientation. Various specimen geometries with 300 µm nominal thickness were designed: dog bone samples ($l_0$ = 500 µm, $d_0$ = 500 µm), diamond ($s_0$ = 1.4 mm, $d_0$ = 300 µm), single and double strut structures ($l_0$ = 3.6 mm, $d_0$ = 500 µm), see Fig. 1. In-situ tensile tests were performed in a SEM (TM3030Plus, Hitachi, BSE detector) strain-controlled with a speed of 100 µm/min up to failure using a tensile test table (Deben, UK, 300 N load-cell with 1% resolution, linear inductive displacement sensor with a resolution of 3 µm) while imaging the specimen and recording the stress-strain curve. The strain field is obtained and quantified from a series of SEM images at different applied forces by *Ncorr*, an open-source 2D digital image correlation software [1].

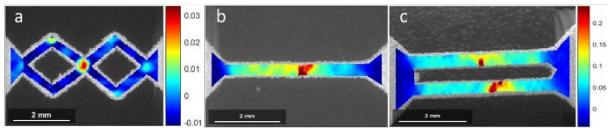


*Fig. 1: Optical Eulerian strain fields $\varepsilon_{xx}$ by SEM-DIC while tensile testing a) a diamond, b) a single and c) a double strut structure before fracturing. Scale bars indicate 2 mm.*

**RESULTS:** The DIC overlays in Fig. 2a-h show the zoned deformation behaviour and peak stress of a dog bone specimen when loaded up to 105 N. The samples produced show approximately 40% smaller cross-sectional area than originally designed by CAD, see Fig. 3.

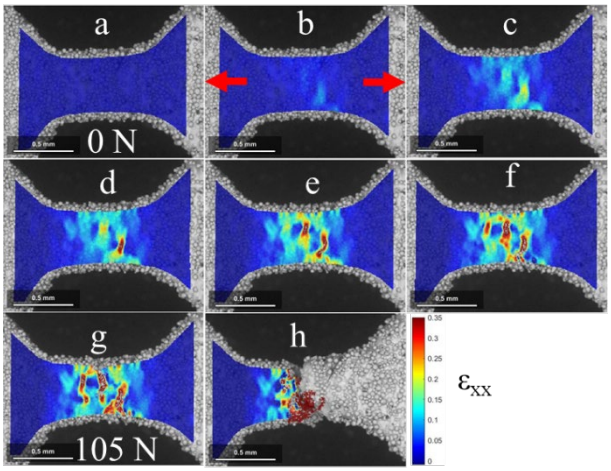


*Fig. 2a-h: Plastic deformation bands perpendicular to the tensile loading direction (red arrows in b) are observed in the DIC analysis of an SLM micro specimen mechanically stressed in the SEM even before surface cracks occur. Scale bars indicate 500 µm.*

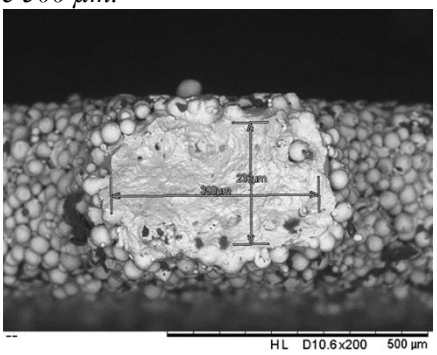


*Fig. 3: Geometrically determined area of fracture with Ti particles sintered to the surface.*

**DISCUSSION & CONCLUSIONS:** Zonal deformation $\varepsilon_{xx}$ is much higher than the overall strain observed before fracture [2]. The SLM-related decoration-particles can be used as reference points so the SEM-DIC can thus be performed directly on untreated SLM samples. However, these spherical particles may occasionally cause slippage within the fixture.

**REFERENCES:** [1] www.ncorr.com. [2] P. Schüler, S.F. Fischer, A. Bührig-Polaczek, C. Fleck (2013) *Mat Sci Eng A* **587**:250-261.