AMC TRR277

A06

Laser Powder Bed Fusion (LPBF) of Steel Elements for Construction – Basics of Design and Mechanical Resilience

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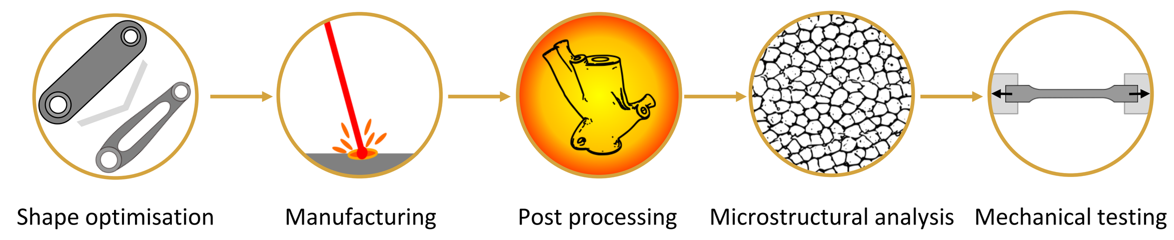
Project summary:

This project explores and evaluates the factors influencing the manufacturing of safe and durable structural steel elements by LPBF. The 1st funding period focuses on the effect of the process parameters, the post-treatment, and the geometrical aspects on the microstructure and mechanical properties to meet the construction industry standards.

Workflow:



Main outcome of 1st funding period

Process investigations

- The cooling rate highly affects the mechanical properties.
- Pores and surface roughness can be classified by artificial intelligence using µCT.

Mechanical resilience

- LPBF-manufactured 316L shows softening behaviour during cyclic plastic deformation, whereas hot-rolled 316L shows hardening behaviour.
- Hot isostatic pressing reduces the fatigue resistance due to larger grain sizes.
- Vibratory polishing reduces the fatigue resistance in comparison to manual polishing due to low surface residual stresses and opening of surface near pores.

AM design and large-scale part testing

- Successful implementation of the LPBF process into the construction design and execution planning

Key collaborations in 1st funding period

C01
- Simulation of pores and the resulting stress intensity
- Development of optimised lattice structures for damping

C02
- Optimisation of tensegrity nodes using vertex morphing
- Optimisation of the support structure

A07
- Multi-process additive manufacturing of 316L using WAAM and LPBF
- Microstructural investigation of graded 316L

Project status – process investigations

- The cooling rate decreases as heat accumulation occurs.
- The cooling rate and the hardness of 316L were correlated using estimated cell sizes and a Hall-Petch type relationship.
- Cooling rates change locally depending on the scanning pattern of the laser.
- A process parameter window was developed for 316L with low porosity.
- Correlations between the process parameters, the cooling rates, and the tensile properties were established.

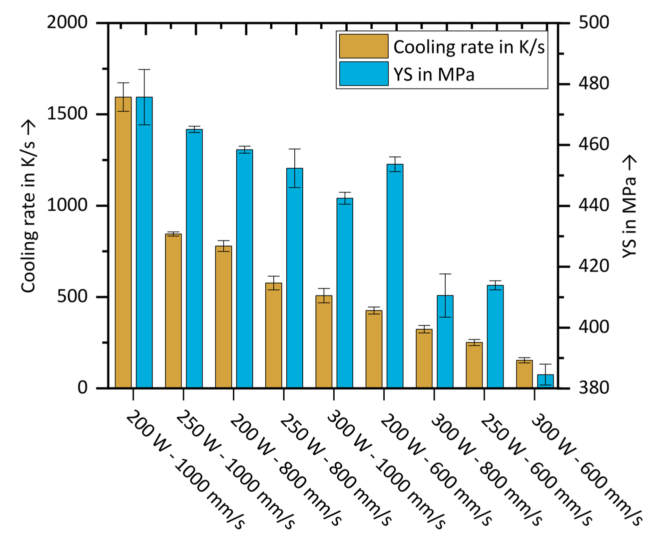


Fig 4: Correlation between the cooling rate, the process parameters and the yield strength (YS)

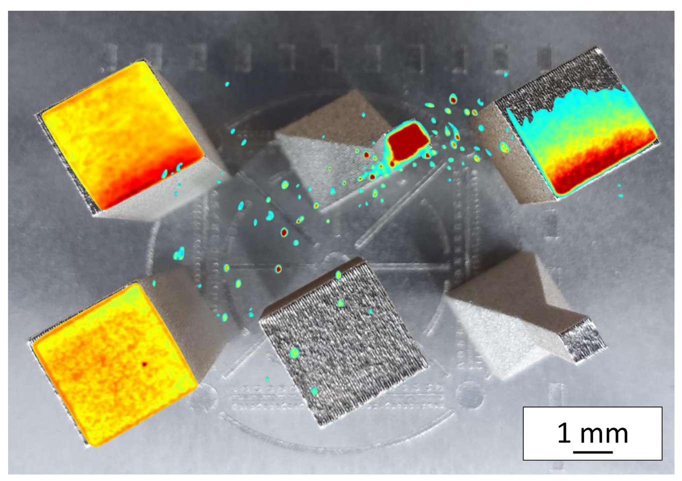


Fig 5: LPBF-manufactured specimen on the build platform with thermography data

Project status – mechanical resilience

- LPBF-manufactured 316L exhibits higher initial maximum stresses, followed by a cyclic softening behaviour, in contrast to hot-rolled 316L (hardening).
- LPBF-manufactured 316L has a higher fatigue life in comparison to hot-rolled 316L.
- Surface residual stresses and grain sizes greatly influence the fatigue resistance.
- Vibratory grinding opens the surface near pores, which leads to lower high-cycle fatigue resistance, whereas manual grinding introduces surface residual stresses that increase the fatigue resistance.
- The surface roughness can be measured automatically from µCT-imaging.
- Pores can be classified by a k-nearest-neighbour machine learning algorithm.
- Critical layers can be detected using stress intensity factors and neural networks.

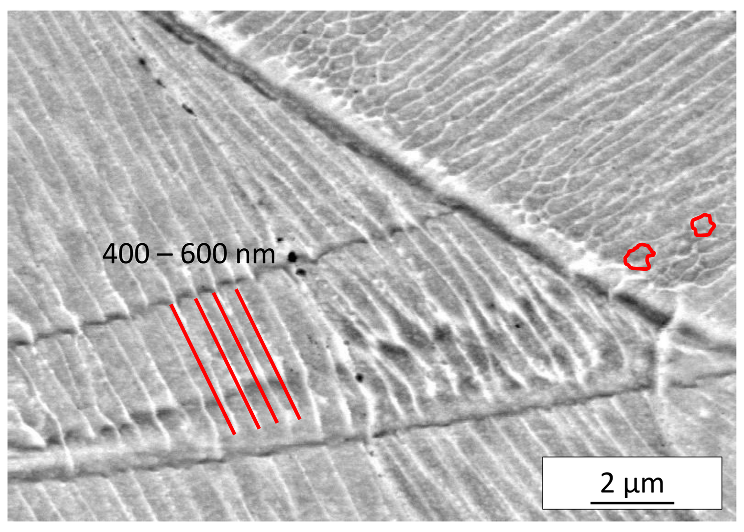


Fig 1: Microstructure of LPBF-manufactured 316L with sub-grain cell boundaries (red)

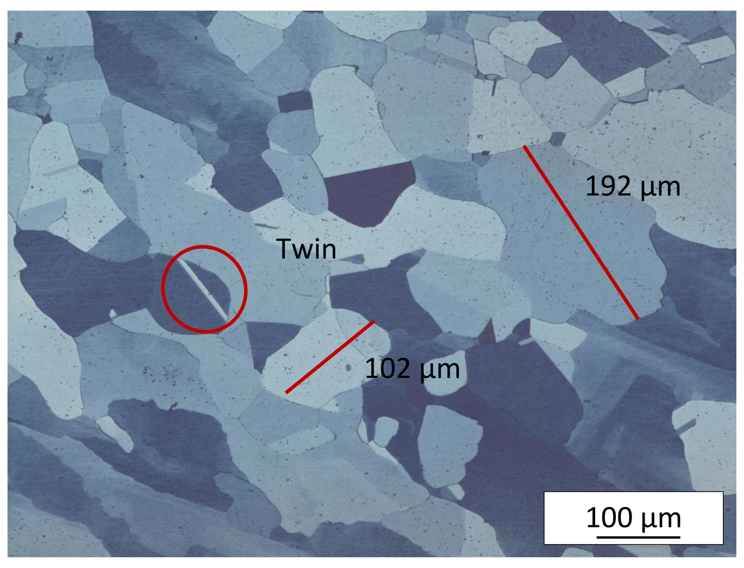


Fig 2: Microstructure of hot-rolled 316L

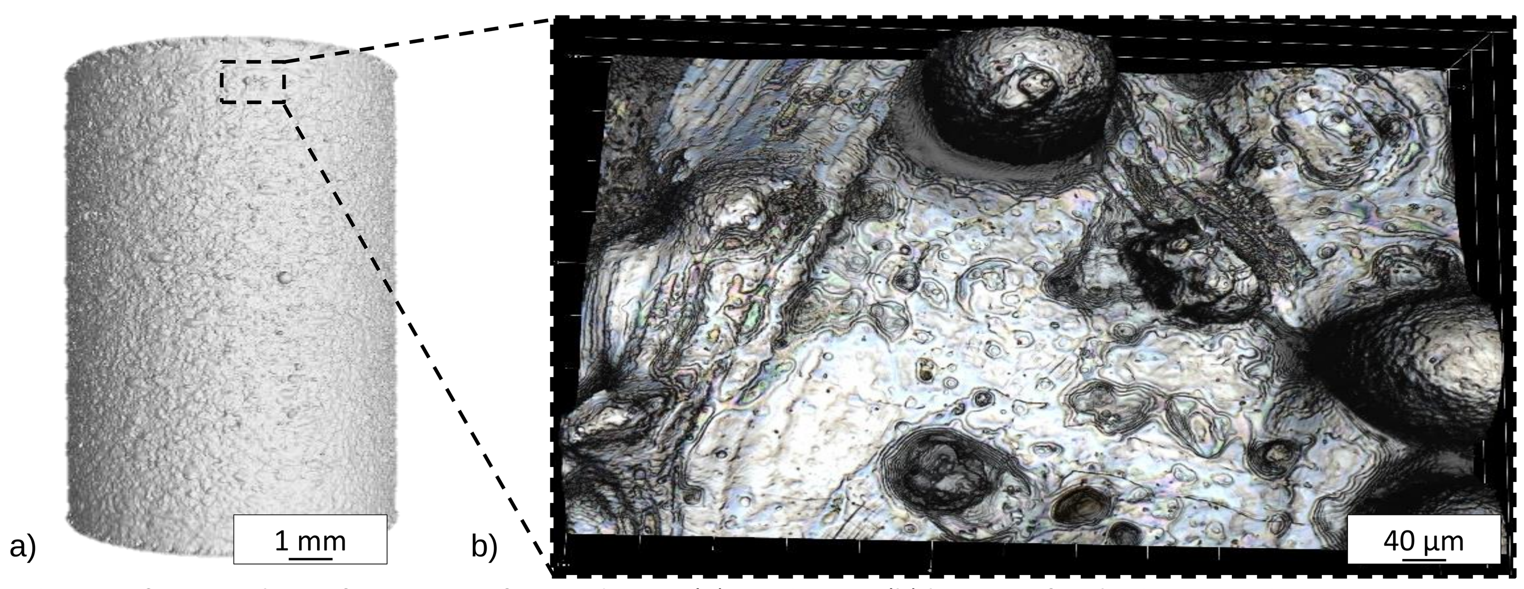


Fig 3: Surface topology of LPBF-manufactured 316L, (a) µCT image, (b) laser-confocal-microscope image

Large-scale demonstrator

- A tensegrity tower with shape-optimised connection nodes was designed and built. It is now exhibited in the Deutsches Museum.
- The tensegrity nodes, shape-optimised by vertex morphing, were subjected to tensile loading in a fully hinged testing set-up.
- The threads were tested dynamically up to 10^7 cycles.

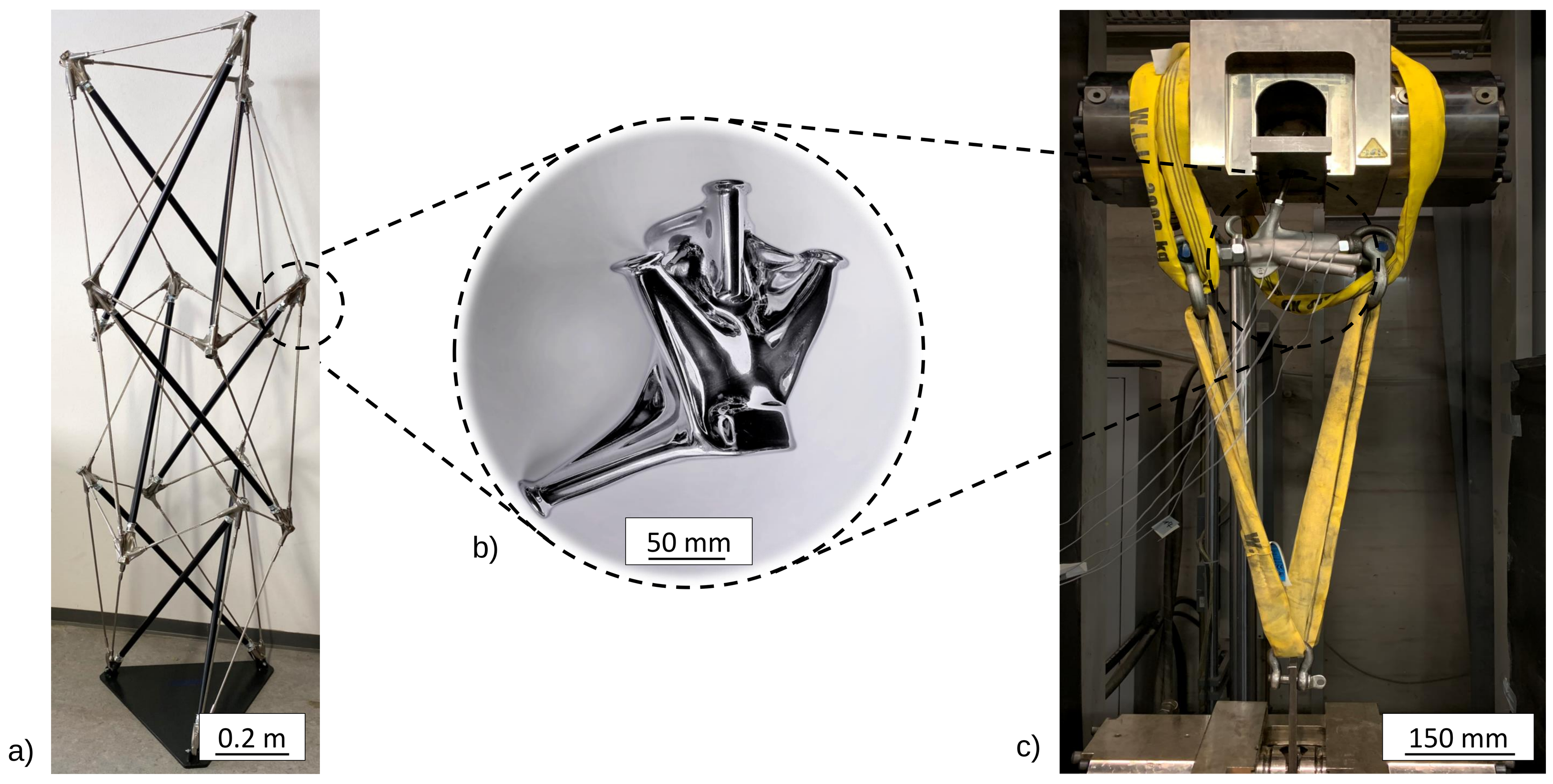


Fig 6: (a) Tensegrity tower demonstrator, (b) shape-optimised tensegrity node with surface polishing, (c) mechanical testing

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