Fatigue behaviour of selective-laser-melted nickel-titanium scaffolds

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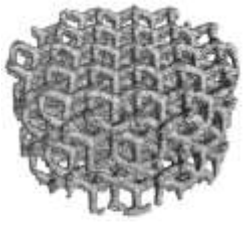
INTRODUCTION

The shape memory alloy nickel-titanium is a promising biomaterial for scaffolds and load-bearing implants. It exhibits pseudo-elastic or pseudo-plastic behaviour that allows mechanically stimulating the adherent cells and the adjacent tissue and, thus, can improve the osseo-integration.[1] Its damping capacity allows for shock absorption.[2] For a metal, NiTi has a low elastic modulus, which facilitates the implant design to avoid stress-shielding.[2]
Selective laser melting (SLM) enabled us to fabricate NiTi scaffolds.[1,3] Such SLM-scaffolds, however, are porous and reveal an irregularly shaped surface owing to partially integrated powder particles. These defects have a significant impact on the mechanical properties of the scaffolds and related future load-bearing implants. A detailed analysis of the fatigue behaviour is, therefore, highly desirable and the focus of this study.

EXPERIMENTAL METHODS

Fig. 1 represents a NiTi scaffold 4 mm high and 8 mm in diameter that we built by means of the SLM-Realizer 100 (SLM-Solutions, Lübeck. Germany) using NiTi powder (Memry GmbH, Weil am Rhein, Germany) with particle sizes between 35 and 75 µm. The scaffolds were designed to match the geometry of our compression bioreactor (CBR). The universal testing machine Zwick-Roell Z100, Ulm, Germany served for static compression loading with a speed of 0.5 mm/s. Uniaxial dynamic compression along the scaffold's cylinder axis was carried out by means of a servo-hydraulic testing machine (walter+bai AG, Löhningen, Switzerland) with a sinusoidal loading profile between 40 and 150 MPa mean stresses and a frequency of 10 Hz.



∅ 8 mm,
strut thickness ~300 µm

Fig. 1: The three-dimensional rendering of the SLM-NiTi scaffold shows the irregular surface topography.

RESULTS AND DISCUSSION

Static compression testing showed the pseudo-elastic response of the SLM-scaffolds, since they recovered up to 7 % of the applied deflection. The overall elastic modulus of the scaffolds was about (1.3 ± 0.3) GPa. The compressive strength referred to about 200 MPa. Cracks, however, were initiated already at deflections exceeding 5 % of the scaffold height, in particular at the hinge positions. From dynamic compression testing, a stress-cycle diagram was derived by counting the number of load cycles until fracture at given loading amplitude, see fig. 2. The endurance limit of the NiTi scaffolds for reaching $5{\cdot}10^5$ cycles was about 50 MPa. Since the lattice-based scaffold geometry comprise of an inhomogeneous cross-section,[4] the calculated stress is based on the minimal cross-sectional area of 7.9 mm². The fatigue performance suits the requirements of the CBR. Further, the formation of a well-defined Woehler-curve demonstrates that the SLM scaffolds exhibit reproducible fatigue behaviour even though the presence of small internal pores and a rough scaffold surface topography.

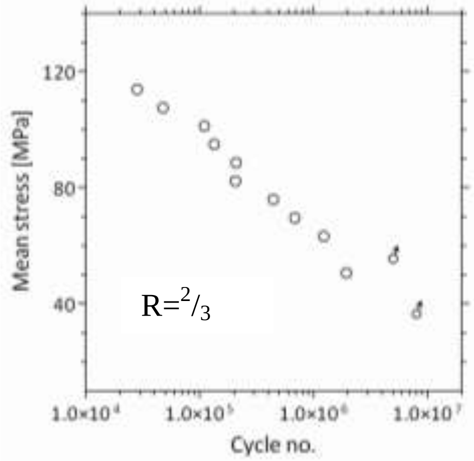


Fig. 2: The Woehler-diagram of the SLM-scaffolds. Run-outs achieving $5{\cdot}10^5$ loading cycles are marked with arrows.

CONCLUSION

The investigated static and dynamic mechanical properties confirm the performance of SLM NiTi scaffolds for load-bearing implants. Since the SLM fabrication process allows dedicated adjustment of the geometry, the mechanical properties such as the elastic modulus can be optimized to match the biomechanical characteristics of the implantation site.

REFERENCES

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