MORPHOLOGICAL AND MATERIAL CHARACTERIZATION OF SLM TI6AL4V THIN SAMPLES FOR ORTHOPEDIC IMPLANTS

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Introduction

The advantages of Additive Manufacturing (AM) in orthopedics are nowadays recognized. A new generation of devices mimicking bone is an example: lattice structures characterized by thin struts (in the order of hundreds of μm) are conceived to resemble bone trabeculae. Contrary to traditional manufacturing processes, AM allows to produce custom devices fitting complex anatomies. Unlike mass-production devices, there are no defined methodologies to assess safety and quality of custom implants, given their unique shape and dimension. Finite Element (FE) modeling of implantable devices can be a valid option, as long as the model reliability is verified, in terms of geometry and material description. As for the latter, the characterization of thin struts involved in bone implants is an open issue: their final geometry and mechanical properties are affected by their dimensions approaching AM accuracy, as suggested by [1,2]. Thus, morphology and mechanical behavior of AM struts should be investigated together. The current study aims to provide an exhaustive morphological and material characterization of Ti6Al4V thin struts produced by Selective Laser Melting (SLM), coupling a pure experimental approach adopted in literature with FE analyses. The results will be used to design a safe and efficient device for talus substitution, as discussed in [3].

Materials and Methods

(i) AM production. Cylindrical samples (0.6 mm of diameter, approaching the thickness of bone trabeculae) were manufactured (SLM technique and Ti6Al4V ELI powder) in three different directions w.r.t. the build plane (45°, 60°, 90°), chosen based on the struts inclinations of the trabecular cells commonly used for orthopedic devices and compatibly with AM limits (Fig. 1a). **(ii) Morphological characterization**. The quality of the as-built samples was investigated by performing: 1) density analysis to assess the presence of internal pores w.r.t. a machined Ti6Al4V, 2) global geometry evaluation to assess mismatches of AM samples from the nominal ones (Fig. 1b), 3) local geometry evaluation of the surface texture. **(iii) Material characterization**. Static uniaxial tensile tests were performed under displacement control on three samples for each batch (Fig. 1c). To measure strains, extensometers could not be applied, given the samples small dimensions. Thus, experiments were coupled with FE analyses: samples FE models were developed considering the actual cross-section areas derived from the morphological characterization. Finally, fatigue tests were performed under force control (stress ratio 0.1, mean force 40 N) until either sample failure or runout ($5 \cdot 10^5$ cycles). To date, three load levels were considered and five samples for each level and for 60°- and 90°- batches were tested (Fig. 1d). The runout was chosen based on the final application of the talus prosthesis. Considering the walk activity as a cycling load and assuming an average of 10^6 steps/year, the time to guarantee an osseointegrated implant is about half a year ($5 \cdot 10^5$ cycles), during which the device is the only element bearing the body weight.

Results

The underrated cross-section area (5%-20% difference w.r.t. the nominal one, Fig. 1b) and the surface roughness led to a reduction in the effective load-bearing section. In the static tests, a decrease of about 40% and 7% was found for the elastic modulus and for the yield stress, respectively. In the fatigue tests, a 20%-40% reduction of the limit stress within the cycles range $4 \cdot 10^4$-10^5 was observed w.r.t. to the literature results for bulk Ti6Al4V samples (diameter 3-6 mm, [4]) (Fig. 1d). The introduced parameters were not affected by the print direction, with the exception of the cross-section area.

Discussions

AM peculiarities in the production of thin struts are currently an open issue. A deep insight into their morphological and material properties is fundamental in view of correctly describing and predicting the mechanical behavior of AM lattice-based prostheses exploiting a FE approach.

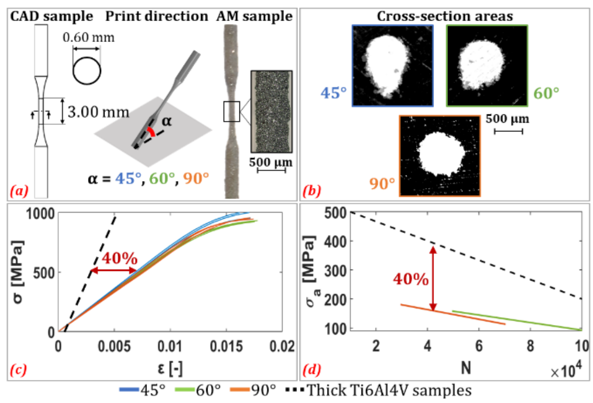

Figure 1: a) SLM-manufacture of Ti6Al4V samples, b) Cross-sections of the samples, c) Stress-Strain curves from static tests, d) Stress-Number of cycles curves from fatigue tests.

References

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2. Hossain et al, Addit Manuf, 2021.
3. Danielli et al, J Mech Sci, 2023.
4. Pegues et al, Int J fatigue, 2018.