On the size effect of prototypes fabricated by electron beam melting. An experimental-simulation study

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ABSTRACT

Rapid prototyping technologies allow to reduce the design time and the overall cost of new prosthesis, in addition to offer a unique alternative for the development of patient specific implants. In this regard, one of the more significant added value of the 3D printing technologies is the ability to design almost arbitrary geometries incorporating specific features as graded trabecular structures favouring osteointegration and lowering the overall weight of the implant.

In this work, mechanical characterization and numerical models to study the size effect on Ti6Al4V ELI (grade 23) specimens fabricated with Electron Beam Melting (EBM) were performed. Mechanical characterization has been performed at the macroscale and the mesoscale (trabecula). These results were used to determine effective material properties of the trabecular structure by means of the Asymptotic Expansion Homogenization (AEH) theory which accounts for the periodicity of the underlying structure of the material [1,2].

Experimental results showed a linear response of the material at the macro- and meso-scales up to failure, therefore supporting the use of linear elastic models for simulation. However, the results indicate a reduction of an 80% in the elastic modulus and of a 50% in the yield stress at the mesoscale with respect to the macroscale indicating a clear size-effect associated with components fabricated by means of EBM. In addition, a morphological analysis at the mesoscale found the final dimensions of the trabecula to be larger than the nominal size specified in the CAD model, indicating that dimensional accuracy is not guaranteed when working close to machine resolution. The elastic modulus and yield stress reported for the bulk material (macroscale) is in line with previous literature, for the bulk material printed with EBM technology along the printing direction [3]. On the other hand, reduction of the elastic modulus and yield stress are consistent with reported values for PEEK samples fabricated with selective laser sintering (SLS). Effective mechanical properties of the trabeculated structure obtained by means of AEH showed excellent agreement with compression pin-loaded experiments on trabeculated samples. However, the homogenization process needs to take into account for size-effects.

In conclusion, accounting for scale effects is crucial in order to accurately describe the macroscopic mechanical response of trabeculated components. This work also demonstrates that effective mechanical properties of trabeculated components can be obtained using the asymptotic theory of homogenization as long as scale effects are accounted for in the model.

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