Geometry and material optimization of bioscaffolds with use of multiscale modelling and parallel evolutionary algorithm

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ABSTRACT

The bioscaffolds play important role in nowadays medicine. The part of the injured or unhealthy bone need to be removed during the surgery. In many cases, the area of removed bone heals faster when the bone scaffold is implanted. The bone scaffolds are made of biocompatible and biodegradable materials. It is important to implant bioscaffold with orthotropic material properties as close to the real bone as possible. The optimization of bioscaffold geometry and material is proposed in the paper. The bioscaffold is modelled as a hierarchical structure fabricated with use of Fused Deposition Moldeing (FDM). The macro scale parameters of the scaffold should be close to the bones material properties and are used in objective function formulation. The norm of differences between orthotropic material properties of bone and bio scaffold is used as a objective function during optimization. The meso scale Representative Volume Element (RVE) of bone scaffold is used in homogenization procedure to obtain macro scale material properties [3]. The design variables describes the RVE on the meso level. The RVE is described by number of struts in three planes and square struts side size. 6 design parameters are used for geometry creation of RVE. The material properties of struts in meso scale are defined with use of numerical homogenization by micro scale RVE model taking into account the FDM process. The PLGA with hydroxyapatite (HA) [2] is used as a material in micro model. The amount of HA in material is described by seventh design variable. The numerical homogenization [4] in micro and meso levels is conducted with use of periodic boundary conditions assuming periodicity of the structures. The Finite Element Method (FEM) is used to solve direct problems of elasticity, and the homogenization procedure is based on the results of analyses. The optimization in multiscale problem is performed with use of Evolutionary Algorithm (EA) [1]. Each chromosome contain seven design variables describing material and geometry properties of the bone scaffold. The genes code parameters directly due to floating point representation used in EA. The fitness function evaluation for chromosomes is conducted in parallel way, allowing to reduce overall wall time of computations. The full paper contains detailed description of models in micro, meso and macro scales, also the numerical examples of patient oriented optimization of bone scaffold are given.

REFERENCES

[1] T. Burczyński, W. Kuś, "Microstructure Optimization and Identification in Multi-scale Modelling", *Eccomas Multidisciplinary Jubilee Symposium*, **14**, 169-181, (2009).

[2] J. B. Lee, S. H. Lee, S. M. Yu, J.-C. Park, J. B. Choi, J. K. Kim, "PLGA scaffold incorporated with hydroxyapatite for cartilage regeneration", *Surface & Coatings Technology*, **202**, 5757–5761, (2008).

[3] P. Makowski, W. Kuś, "Trabecular bone numerical homogenization with the use of buffer zone", *Computer Assisted Methods in Engineering and Science*, (in print) (2014).

[4] K. Terada, M. Hori, T. Kyoya, N. Kikuchi, "Simulation of the multi-scale convergence in computational homogenization approaches", *International Journal of Solids and Structures*, **37,** 2285-2311, (2000).