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IMAGE-BASED MECHANICAL MODELLING OF AN ELECTROSPUN SCAFFOLD

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SUMMARY

The relationship between the microstructure of an electrospun scaffold and its mechanical behavior was investigated using an imaged-based finite element (FE) model. The scaffold was first imaged using a Nanotom M microCT. Based on the images, the microstructure of the scaffold was characterized (i.e. fibers thickness and orientation) and the individual fibers were segmented for the creation of a representative volume element (RVE) used in the FE model. Secondly, a virtual uniaxial tensile test was simulated on the RVE and the virtual stress-stretch curve was compared to the actual experimental stretch-stress curve of the scaffold.

Key words: *microCT imaging, representative volume element, electrospun scaffold*

1 INTRODUCTION

Electrospun scaffolds are very promising for cardiovascular tissue engineering applications as they offer a high porosity for cell migration and an adequate mechanical support for tissue regeneration. These scaffolds are characterized by a complex microstructural organization, which defines their macro-mechanical behavior. The aim of this research is to investigate how the microstructure of the scaffold influences the macro-mechanical properties by combining high-resolution X-ray microfocus computed tomography (HR-XCT) imaging with uniaxial tensile testing and microscale modeling.

2 MATERIALS AND METHODS

Imaging: A RestoreXTM scaffold (Xeltis BV [1]) was imaged using a Nanotom M microCT at a resolution of 0.67m. The individuals fibers were identified and segmented using Avizo (ThermoFisher Scientific). Then, a representative volume element (RVE) of the scaffold was selected (cube with edge length 150m). Within this RVE, the fiber density, fiber orientation and thickness distribution were analyzed.

Modeling: Next, the fibers in the RVE were traced and meshed into C3D4H linear tetrahedral elements for virtual mechanical testing using the finite element software Abaqus 2021 (Simulia). Boundary conditions and a displacement were applied to simulate two ideal uniaxial tensile tests of 20% engineering strain along the circumferential and axial direction of the graft, respectively. Neohookean material properties were assigned to the elements.

Mechanical Tests: To calibrate the shear and bulk modulus, the stress-stretch curves of the virtual uniaxial tensile test were iteratively compared to actual uniaxial tensile tests on the same material, performed on a Zwick/Roll tensile testing device.

3 PRELIMINARY RESULTS AND CONCLUSIONS

The RVE had a fiber volume fraction of 21.3%, with an average fiber thickness of 3.75μm. One preferred in-plane orientations was identified symmetrically at 100° and 280° w.r.t. the circumferential direction towards the axial direction (figure 1), which corresponds to a single fiber family oriented almost along the axial direction. The scaffold contained almost no out of plane oriented fibers (figure 1).

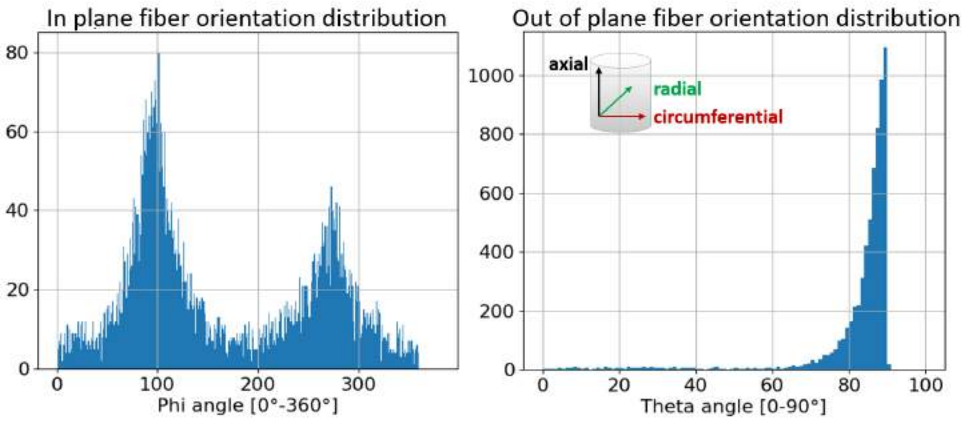

Figure 1: In plane and out of plane scaffold orientation distribution represented in a cylindrical coordinate system.

Figure 2 shows the deformed and undeformed state of the RVE in the circumferential direction. Figure 3 shows the output of Avizo for the RVE fiber tracing and the comparison of the experimental and virtual stress-stretch curves of the virtual uniaxial tensile test, for a scaffold fiber shear modulus of 1.2MPa.

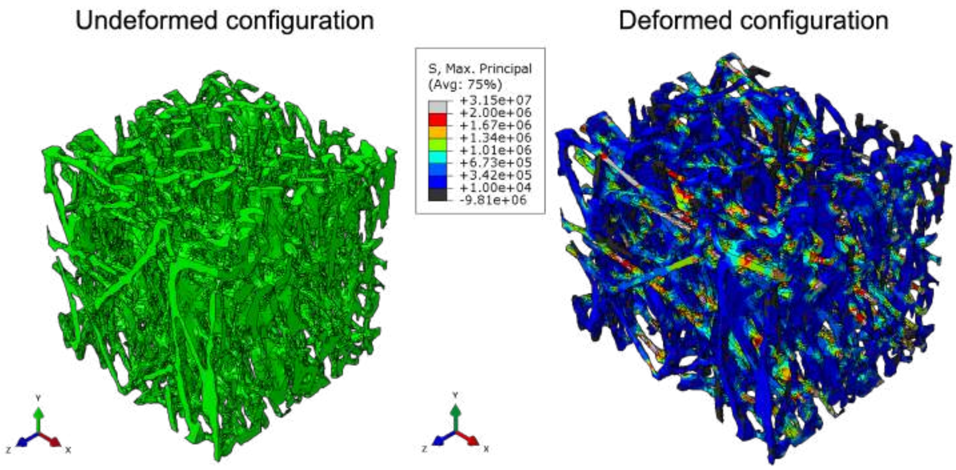

Figure 2: Undeformed and deformed configuration of the RVE. Min and max principal stress equal -9.8MPa and 31.5 MPa, respectively.

By applying an isotropic material to the RVE model, an anisotropic material response was obtained, where the axial direction is stiffer than the circumferential direction. This corresponds to the experimental behavior obtained and is confirmed by the microstructural analysis of the fibers, which are mainly aligned axially. Future work will also include a more thorough comparison with experimental stress-stretch curves and further optimization of the material properties of the scaffold. This proof of concept for the image-based modelling of a complex microstructure can be used to further optimize scaffold design parameters such as volume fraction, orientation, and thickness in an in silico setting, with the aim of achieving the optimal mechanical behavior.

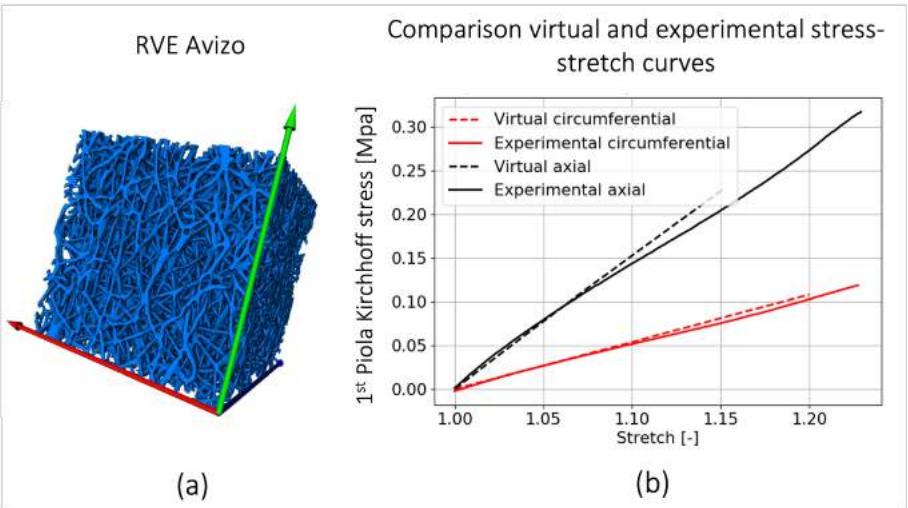

Figure 3: (a) Output of Avizo fiber tracing module and (b) comparison between virtual and experimental stress-stretch curves.

REFERENCES

[1] Xeltis, Restorative cardiovascular devices, `https://xeltis.com/xeltis-initiates-first-ever-pivotal-trial-of-a-synthetic-restorative-pulmonary-heart-valve/`.