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IMPACT OF DIFFERENT 3D HYDROGEL SCAFFOLD DESIGNS ON THE ISOTROPIC VISCO-HYPERELASTIC BEHAVIOR

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1 INTRODUCTION

Approximately 20% of American adults experience bone injuries and disorders, making it a leading cause of disability [1]. Hydrogel-based scaffolds are one of the most promising additive manufacturing structures in 3D cell cultivation, representing ideal biomaterials for bone plate restoration due to mechanical strength, tissue-resemble elasticity, and self-healing capabilities [2]. This investigation evaluates the isotropic visco-hyperelastic mechanical behavior of fully reticulated 5% (w/v) alginate hydrogel scaffolds and scaffold degradation. Different scaffold geometries and finite element models were developed. A compression setup was created in ABAQUS to simulate the conditions of a mechanical compression test. The forces generated were tracked for each numerical simulation. The degradation of different scaffolds were also investigated.

2 METHODS

In subsection 2.1 the development of different biomechanical models of scaffolds is presented, and in subsection 2.2 the compression numerical setup is described.

2.1 BIOMECHANICAL MODEL OF DIFFERENT SCAFFOLDS

The mechanical response of the scaffolds was defined as isotropic visco-hyperelastic, using the Yeoh constitutive model paired with the generalized Maxwell model for the viscous response [3]. The mechanical properties of all scaffolds were set for the fully reticulated 5% (w/v) alginate hydrogels were obtained (Table 1) [3]. Scaffolds with different geometries were created using a combination of MATLAB and Blender softwares. Finite element meshes for each generated geometry were applied in ABAQUS, using 4-node isoparametric tetrahedral hybrid (C3D4H) finite elements.

Table 1 – Reticulated mechanical parameters [3].

Hyperelastic Behavior	Viscous Behavior
$C_{10} = 15.531e-3$ MPa	$\alpha = 3$ (-)
$C_{10} = 9.3118e-3$ MPa	$\beta_1 = 0.05$ (-)
$C_{10} = 9.879e-3$ MPa	$\tau_1 = 6$ s
	$\beta_2 = 0.16$ (-)
	$\tau_2 = 93$ s
	$\beta_3 = 0.12$ (-)
	$\tau_3 = 262$ s

2.2 COMPRESSION NUMERICAL SETUP

The numerical setup comprises one of the developed finite element scaffold models and two rigid plates (Figure 1). The movement of the orange plate is restricted in all directions, while the blue plate will compress the scaffold 0.2 mm. The compression simulation was divided into two steps: (i) the scaffold was compressed for 10 seconds, applying a displacement of 0.2 mm to the blue plate in Oz direction; (ii) the scaffold was held in the compressed state for an additional 20 seconds.

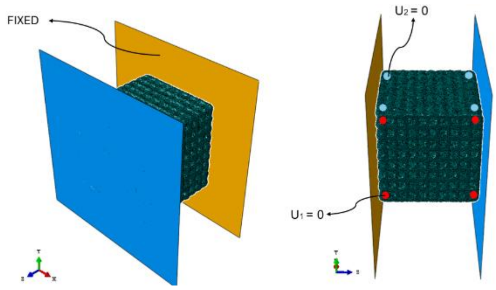

Figure 1 - Compression numerical setup.

3 RESULTS

One of the factors investigated was the staggering effect. Adding staggering to the scaffold design leads to smaller loads generated during the numerical simulation, according to Figure 2. However, no significant differences were observed between different levels of staggering. This suggests that while the mechanical visco-hyperelastic behavior of the scaffold is affected by the presence of staggered layers, the extent of staggering does not lead to significant differences in performance.

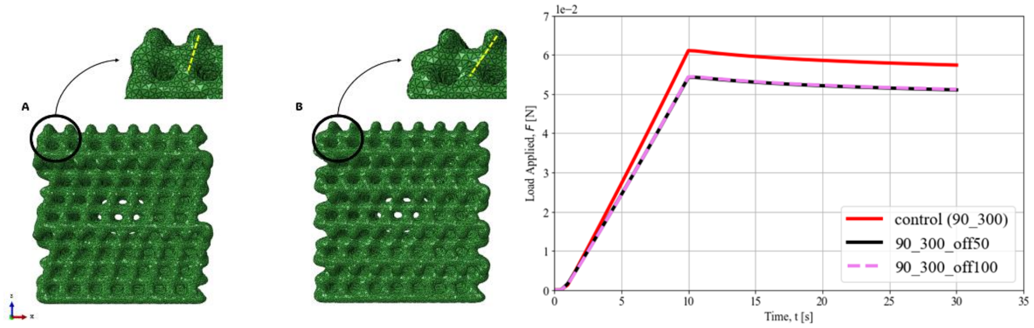

Figure 2 – Loads generated during the numerical simulation for scaffolds with varying staggering levels.

4 DISCUSSION AND CONCLUSION

The scaffold printing parameters, including staggering, pore size, and the relative orientation of consecutive layers, influence the relaxation period during compression. This conclusion carries significant implications for scaffold implantation in the human body, providing valuable insights into the relationship between various scaffold geometries and their visco-hyperelastic behavior, showing that the scaffold design may impact its performance as the tissue regenerates.

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