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STRESS-RELAXATION IN TPMS SCAFFOLDS FOR TISSUE ENGINEERING

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1 INTRODUCTION

In this work, the triply periodic minimal surfaces (TPMS) method is utilized for scaffold design for tissue engineering (TE) [1]. Given that biological tissues exhibit viscoelastic properties, scaffolds might be analysed considering viscoelastic material properties [2]. The primary aim of this study is to understand the influence of different porosity levels and TPMS geometries on the viscoelastic response of the scaffolds, and potentially contribute to characterize and parameterize the viscoelastic behaviour of various TPMS scaffolds [3]. Different testing condition were designed to better understand the influence of material aging time, and different compression rates on the viscoelastic response in order to establish a more feasible protocol for testing.

2 METHODOLOGY

Three geometries: Schwarz Primitive (SP), Gyroid (SG), and Schwarz Diamond (SD), were generated with 60%, 70%, and 80% porosity. Viscoelastic behaviour was analysed through linear elastic, displacement-controlled compression, maintained for at least 2 hours to assess relaxation. The focus was on peak stress, long-term relaxation stress, and the relaxation gap. An initial assessment of 70% and 80% porosity scaffolds was conducted to determine the influence of the three TPMS geometries on viscoelastic responses, followed by a deeper investigation of the SD and SG geometries. The impact of the printing material's aging time was evaluated for both the solid samples and TPMS geometries at three curing time points: 2, 5 and 8 weeks, while the 60% porosity configuration was included for a comprehensive overview. Finally, the effects of compression rates at 0.9 mm/min, 1.8 mm/min, and 3.6 mm/min were analysed.

3 RESULTS AND DISCUSSION

The first study confirmed differences in the viscoelastic response of various TPMS geometries and porosities, linked to a non-linear viscoelastic microstructural response with distinct microscopic strain occurrences. The SP model exhibited the highest relaxation response, making it a less appealing scaffold choice, prompting deeper analysis of SG and SD geometries. In terms of material aging, solid samples showed a predominance of the viscous component over the elastic one from 2 to 8 weeks, with an increasing stress gap and decreasing elastic modulus. Conversely, SD70 and SD80 scaffolds stabilized their relaxation response after 5 weeks, enhancing the elastic component and increasing Young's modulus while decreasing the stress gap. The subsequent analysis examined the influence of TPMS geometry and porosity on viscoelastic response. Increasing porosity in both SG and SD geometries led to decreased peak stress and Young's modulus, reducing elastic performance. For relaxation response, the SG geometry displayed a linear increase in the stress gap with porosity, as shown in Figure 1.

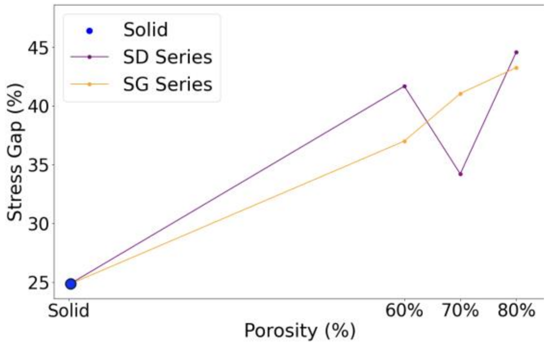

Figure 1: Stress relaxation gap trend for SD and SG geometries when increasing porosity.

The third analysis reports that different compression rates influence the viscoelastic response of the scaffolds. In particular, it was observed that the higher the porosity, the less perturbation there is on the relaxation curve when increasing the compression rate. As shown in Figure 1, scaffolds with 80% porosity present the highest relaxation gap, indicating a greater expression of the viscous component. However, higher compression rates may obscure the viscous expression and enhance the elastic component's response. At this stage, a three-parameter Prony series model was employed to fit the experimental results and characterize the viscoelastic response of SD and SG geometries at 70% and 80% porosity. For SG, a system of equations for the Prony series coefficients was developed based on porosity and compression rate, but an analogous method was not applicable in SD scaffolds.

4 CONCLUSIONS

This study highlights the influence of TPMS geometry and porosity on the viscoelastic response of scaffolds for TE. The findings provide valuable insights for optimising scaffold design and suggest that careful consideration of geometry, material aging time, and testing setup is essential to enhance mechanical performance for specific applications.

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