Mechanical evaluation of 3D-printed scaffolds: A 3^3 full-factorial analysis of geometrical parameters

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Summary

In a full-factorial experiment, the effect of height, porosity and pore size at three levels on the structural stiffness of 3D-printed, polylactic acid (PLA) scaffolds was investigated. The porosity and structural properties of the scaffolds were measured. The principal finding was that all three factors affected the structural stiffness of the scaffolds in a manner that was not expected.

Introduction

3D printing is a technique that allows joining materials and creating objects with intricate geometry from 3D geometrical data [1]. Within the limitations of manufacturing process of 3D scaffolding, the internal and external architectural design can be a significant determinant of the mechanical integrity of the scaffold [2]. In this study polylactic acid (PLA) was used, since it is widely studied in tissue engineering [3]. Samples were chosen using a design of experiment (DoE) taking into account three basic factors and three levels for each factor (Figure 1 inset) influencing internal and external architecture.

Methods

The diameter of the scaffolds was constant (10 mm) and six specimens were tested for each condition. The scaffolds were designed with CAD (Inventor) and fabricated by a desktop FDM 3D printing (Makerbot). The porosity of the pieces was measured with a buoyant scale following the Archimedes method. Compression tests were performed on a universal materials testing machine at 1.3 mm/min, room temperature, and dry conditions. Stress and strain were calculated assuming Hooke's Law and measured bulk dimensions. Apparent Young's modulus, **E-mod**, was found by linear regression of stress-strain data between 0 and 2% strain. ANOVA was performed considering a 95% confidence level ($p < 0.05$).

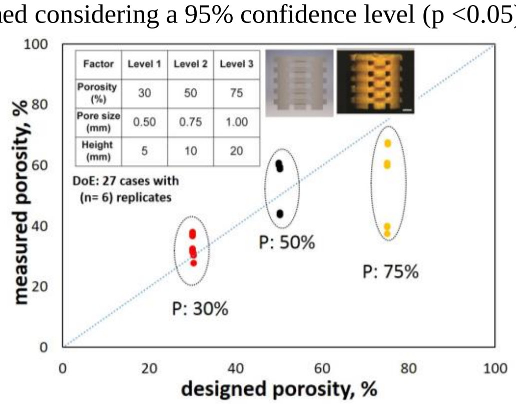

Figure 1: Porosity variation. Inset shows Design of experiment (DoE) and representative images of designed and built PLA scaffold (scale bar represents 2 mm).

Results and Discussion

It was observed on average that the height of 20 mm had the highest E-mod, followed by the 10 mm and finally, the 5 mm heights. Therefore, unexpectedly, as the height increased, so did the E-mod. Pore size did not have a significant effect on E-mod while at the highest levels of porosity the E-mod decreased as expected in porous structures (Figure 2).

Large error were found at high level of porosity (75%) ranging in 10-47% and 10-50% between the measured and theoretical porosity and pore sizes, respectively. The 2 mm diameter nozzle of the 3D printer prevented the resolution required to obtain the target porosity and pore sizes. The nozzle diameter is a critical parameter, since it affects in a pyramidal way the geometry and structural properties of the 3D printed scaffolds.

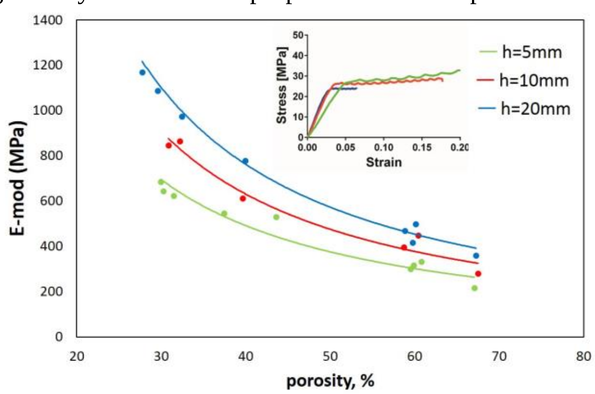

Figure 2: Elastic Modulus of PLA scaffolds as a function of porosity for different height levels; combined pore size values (0.5, 0.75, and 1 mm). Inset shows a representative stress-strain curve obtaining for the different fabrication parameters.

Conclusions

Only height and porosity level had significant effects on the structural stiffness of the scaffolds. The apparent Young's modulus of the scaffold structures were inversely related to the specimen height and porosity. Second, 3D printing brings limiting aspects for their manufacturing. When reporting mechanical properties of 3D printed scaffold structures, the effect of factors relating scaffold architecture, including their interactions on the mechanical properties, should be taken into account and will be further analysed.

Acknowledgments

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References

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