POLY(ETHYLENE GLYCOL) - NANOSILICATE SACRIFICIAL INK FOR CERAMIC MATERIAL EXTRUSION ADDITIVE MANUFACTURING

Karina Feliciano Santos [1]
Fabiana Cunha Giora [2]
Ana Beatriz Girassol de Carvalho Pereira [3]
José Luis Dávila [4]
Andrea Cecilia Dorión Rodas [5]
Jorge Vicente Lopes da Silva [6]
Juliana Kelmy Macário Barboza Daguano [7]

SUMMARY

There are many techniques to produce ceramic and bioglass scaffolds, each one with advantages and limitations. Among them, Additive Manufacturing (AM), foam replica and freeze-drying are widely used. Despite previous works investigating the fabrication of bioceramic scaffolds, some gaps still need to be fulfilled to establish cost-effectivity routes with satisfactory reproducibility and accuracy [1–3]. As an alternative, the use of AM techniques to construct three-dimensional (3D) structures has been widely explored, considering the fabrication of complex structures as the main advantage. However, the massive search for ink formulations that are easy to obtain, low cost and suitable for AM technologies remains a challenge [4,5]. Sacrificial inks from biomaterials can be 3D printed, resulting in biocompatible 3D structures that can be leached or dissolved after fulfilling their function without changing the medium after their degradation [6]. These materials are commonly transformed in gel or liquid under mechanical, physical or chemical stimuli. Its application has been used basically in two ways: in creating free spaces within 3D structures of complex geometry, as the creation of internal channels (fugitive), or as support materials [7]. In this way, poly(ethylene

[1]Mestrando do Curso de Engenharia Biomédica da Universidade Federal do ABC – UFABC, karina.feliciano@ufabc.edu.br;
[2]Graduado pelo Curso de Ciências Biológicas da Pontifícia Universidade Católica de Campinas – PUC, fabiana.giora@cti.gov.br;
[3]Graduado pelo Curso de Biomedicina da Universidade Tuiuti do Paraná - UTP, anabgirassol@gmail.com;
[4]Doutor, Centro de Tecnologia da Informação Renato Archer - SP, jose.davila@cti.gov.br;
[5]Professor Doutor pelo Curso de Engenharia Biomédica da Universidade Federal do ABC - SP, andrea.rodas@ufabc.edu.br;
[6]Doutor, Centro de Tecnologia da Informação Renato Archer - SP, Jorge.silva@cti.gov.br;
[7]Doutor pelo Curso de Engenharia do Materiais da Universidade Estadual de São Paulo - USP, jdaguano@cti.gov.br.

glycol) (PEG) hydrogels arise as an interesting alternative for sacrificial ink formulation to design ceramic scaffolds, based on their shear-thinning behavior, which is essential for material AM. In this study, sacrificial inks based on PEG-400 and Laponite nanosilicate were obtained and characterized. Initially, the rheological properties of different Laponite concentrations (5, 7.5, and 10% w/w) were evaluated to establish their influence over the PEG viscosity profile. As a result, the viscosity of the PEG-400 solution increased dramatically as a function of the addition of Laponite, characterizing a strong shear-thinning and solid-like rheological behavior, ideal for material extrusion AM. Also, the shape of the ink at the nozzle tip was observed to verify the extrusion of filaments. Then, multi-layer pentagram tube-like structures were designed for printability evaluation. The morphological feature of these structures was investigated and imaged with a stereomicroscope; as observed, tailored rheological properties enabled the material deposition of these multi-layer samples, which could retain their shape in the construction platform. The latter allowed the development of Biosilicate® (BioS) scaffolds comprising 70% (v/v) of ceramic filler. The green samples showed good reproducibility in the deposition of the extruded filaments and the adhesion points between the layers. They do not present defects and pores after the sintering post-processing step. Finally, the chemical composition was analyzed by FTIR and the thermal stability by TGA; as observed, the sacrificial ink was removed through heat treatment, which does not compromise the structure nor change the final composition of the original ceramic material. In conclusion, bearing in mind the increasing demand for inks with excellent printability to generate shape fidelity, the formulated PEG-Laponite ink presents rheological properties that make it promising for extrusion-based 3D printing of BioS scaffolds, where the main target are bone tissue regeneration applications.

REFERENCES

[1] R.G. Ribas, V.M. Schatkoski, T.L. do A. Montanheiro, B.R.C. de Menezes, C. Stegemann, D.M.G. Leite, G.P. Thim, Current advances in bone tissue engineering concerning ceramic and bioglass scaffolds: A review, Ceram. Int. 45 (2019) 21051–21061. https://doi.org/10.1016/j.ceramint.2019.07.096.

[2] D. Desimone, W. Li, J.A. Roether, D.W. Schubert, M.C. Crovace, A.C.M. Rodrigues, E.D. Zanotto, A.R. Boccaccini, Biosilicate ® –gelatine bone scaffolds by the foam replica technique: development and characterization, Sci. Technol. Adv. Mater. 14 (2013) 045008. https://doi.org/10.1088/1468-6996/14/4/045008.

[3] D.A.L.V. Da Cunha, P. Inforçatti Neto, K.C. Micocci, C.F. Bellani, H.S. Selistre-de-Araujo, Z.C. Silveira, M.C. Branciforti, Fabrication and Characterization of Scaffolds of Poly(ε -caprolactone)/Biosilicate® Biocomposites Prepared by Generative Manufacturing Process, Int. J. Biomater. 2019 (2019) 1–11. https://doi.org/10.1155/2019/2131467.

[4] E. Feilden, E.G.T. Blanca, F. Giuliani, E. Saiz, L. Vandeperre, Robocasting of

structural ceramic parts with hydrogel inks, J. Eur. Ceram. Soc. 36 (2016) 2525–2533. https://doi.org/10.1016/j.jeurceramsoc.2016.03.001.

[5] J.K.M.B. Daguano, C. Santos, M.F.R.P. Alves, J.V. Lopes da Silva, M.T. Souza, M.H.F.V. Fernandes, State of the art in the use of bioceramics to elaborate 3D structures using robocasting, Int. J. Adv. Med. Biotechnol. - IJAMB. 2 (2019) 55. https://doi.org/10.25061/2595-3931/IJAMB/2019.v2i1.28.

[6] C.S. O'Bryan, T. Bhattacharjee, S.R. Niemi, S. Balachandar, N. Baldwin, S.T. Ellison, C.R. Taylor, W.G. Sawyer, T.E. Angelini, Three-dimensional printing with sacrificial materials for soft matter manufacturing, MRS Bull. 42 (2017) 571–577. https://doi.org/10.1557/mrs.2017.167.

[7] S. Li, K. Wang, Q. Hu, C. Zhang, B. Wang, Direct-write and sacrifice-based techniques for vasculatures, Mater. Sci. Eng. C. 104 (2019) 109936. https://doi.org/10.1016/j.msec.2019.109936.

[8] C.W. Peak, J. Stein, K.A. Gold, A.K. Gaharwar, Nanoengineered Colloidal Inks for 3D Bioprinting, Langmuir. 34 (2018) 917–925. https://doi.org/10.1021/acs.langmuir.7b02540.