Changing the design paradigm – 3D Printing on molecular texture in plastics

Daniel Pedrosa da Silva

daniel.p.silva@ipleiria.pt

–

João Pinheiro[1]; Saba Abdulghani[1]; Christina Kamma-Lorger[2]; Juan Carlos Martinez[2]; Eduardo Solano[2]; Artur Mateus[1]; Paula Pascoal-Faria[1]; Geoffrey R. Mitchell[1]

1. CDRSP - Centre for Rapid and Sustainable Development, Polytechnic Institute of Leiria, Portugal
2. NCD-SWEET Beamline, ALBA Synchrotron Light Source, Barcelona, Spain

MIT Portugal

2022 Annual Conference

Introduction

Additive manufacturing is now more than a prototyping set of technologies, it is a viable manufacturing methodology that allows mass customization and the achievement of complex shapes **[1]**. The focus of the developments in **3D printing** is often on geometric and dimensional reproduction of the digital form of the product.

In polymer processing technologies, the manufacturing parameters affect the mechanical properties of the final products, and this is also well established in 3D printing **[2]**. It is known that, when polymers with high molecular weight are extruded through a die with an appropriate length-to-diameter ratio, a preferred orientation in the melt can be induced. When the temperature decreases, a highly anisotropic crystalline morphology is formed. Consequently, this morphology unravels different mechanical properties in comparison with the morphology formed from a quiescent melt. In accordance with **[3]**, this can result in a significant increase in the elastic modulus.

The present work shows some results of **morphology analysis** with in situ X-ray scattering, employing a customized 3d printer adapted to an X-ray scattering beamline at the ALBA Synchrotron, correlating the processing parameters with the preferred molecular orientation.

The focus of this project is to explore the scope for depositing materials with different properties by controlling the structure and morphology of the polymers, more than replicating shapes. With new degrees of freedom, the team is working in order to apply this methodology, in non-planar layers of deposited material, in order to obtain new designs of material along a given designed model.

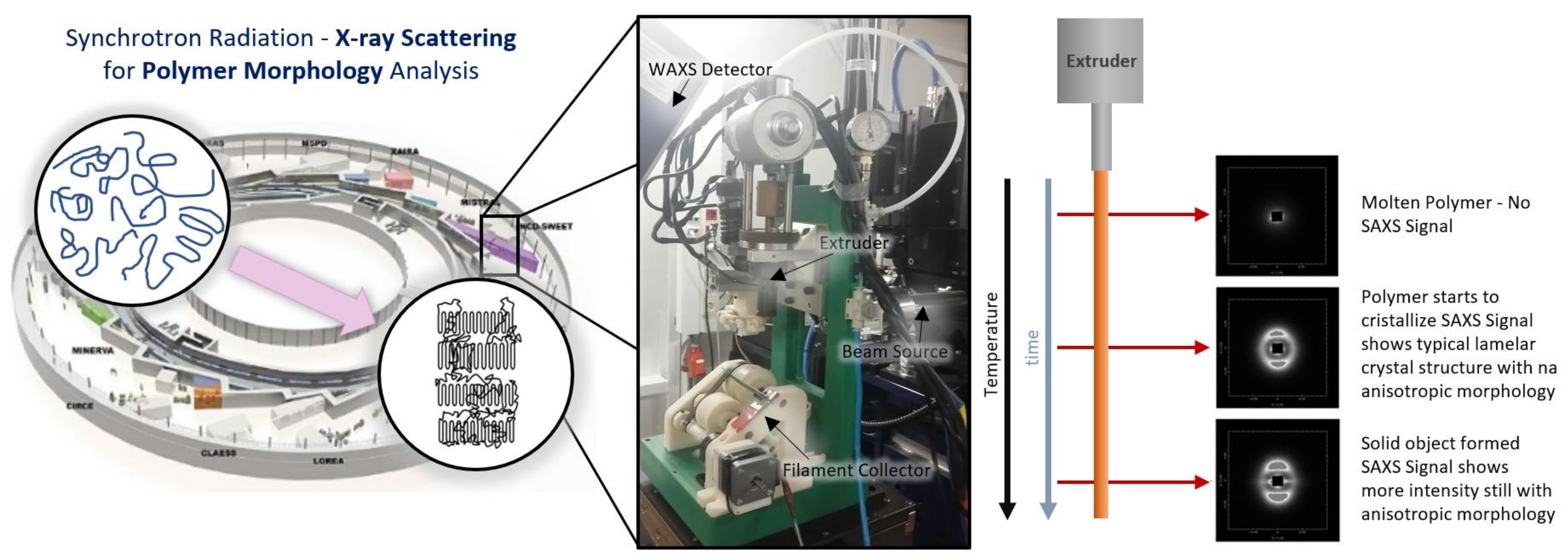

Figure 1 – Left: Schematic of the ALBA Synchrotron and the domain of the analysis. Middle: Photograph of the customized 3D Printer at the NCD-SWEET Beamline. Right: a schematic of the quasi-static state of the extrudate in a constant gradient of temperature. The evolution of the structure can be evaluated by moving the incident X-ray beam down the jet. Adapted from **[4]**.

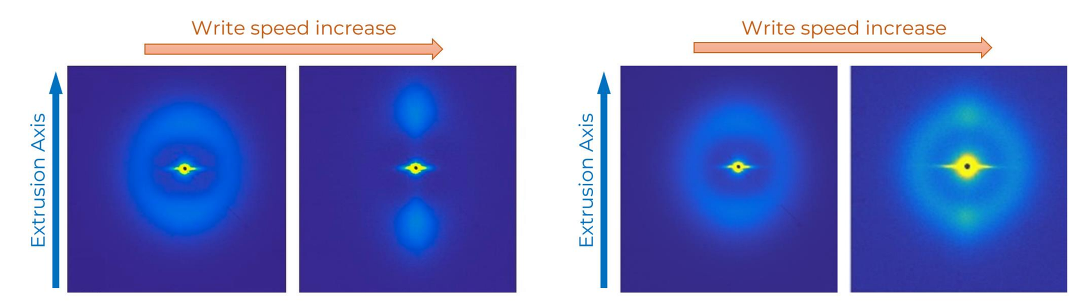

Figure 2 – LDPE (left) and PCL (right) SAXS patterns obtained at different writing speeds.

Morphology Analysis

As previously mentioned, the team used a customized 3D printer to evaluate the morphology control of semi-crystalline polymers during extrusion. This model, mounted on the NCD- SWEET beamline platform, as observed in **Figure 1**, allows the deposition of material onto a rotating platform, resorting to a single extruder with a dual channel screw. Plastic pellets are heated and the melt flows through a 300 μm inner diameter needle with a considerable length-to-diameter ratio (L/D ≈36).

With the configurable heat zones and the remote control of extrusion velocity, and collector velocity (write speed), the team performed printing trials with polycaprolactone (PCL) and low-density polyethylene (LDPE). The extrudates were observed in a quasi-steady state with a constant temperature profile (as represented on the right side of Figure 1). repositioning the incident x-ray beam along the extrusion axis, and moving the platform on the z-axis, scans of 20 steps of 0.1mm with a 1-second data collection period were captured.

In **Figure 2**, an example of the resultant small-angle X-ray scattering (SAXS) patterns, is presented for each material. As it is possible to conclude in these measurements, the filaments (solidified extrudates) produced at a low speed have a broadly isotropic crystal orientation; whereas a higher level of orientation is revealed for a higher write speed (as indicated by the two sharp maxima above and below the zero-angle point). This might be associated with the crystallization occurring before the extended chains have totally or completely relaxed.

Conclusions and Future Work

So far, the morphology analysis in 3D printing has been successful, and it was proven that it is possible to produce extrudates of a polymeric material with different morphologies, by controlling the processing parameters. Some correlations between the printing conditions and the level of preferred orientation in the deposited material have been established. As an output, this strategy of polymer deposition results in a mapping of properties along a printed part.

Future developments are expected, regarding the application of the analysis outputs in a non-planar extrusion-based 3D printer in order to obtain new geometries with distinct layer sections reinforced along the extrusion direction, as represented in **Figure 3**. Moreover, new results are expected in regard to temperature variation and slicing strategies, and the overall mechanical behavior of the manufactured parts; employing the information retrieved by the multiscale modeling of polymer processing, to be developed in partnership with MIT.

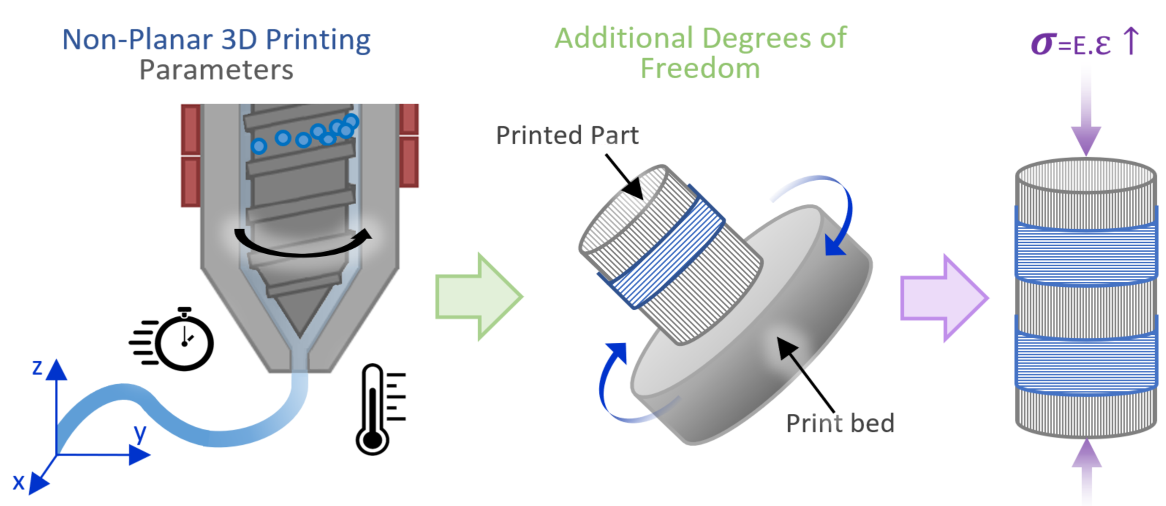

Figure 3 – Solution proposal of non-planar 3D Printing with different properties along the whole part, and with a single material.

References

[1] Gibson, Ian; Rosen, David; Stucker, Brent; Additive Manufacturing Technologies 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing; Springer: Berlin/Heidelberg, Germany, 2015. ISBN 978-1-4939-2113-3.

[2] Kristiawan, R.B.; Imaduddin, F.; Ariawan, D.; Ubaidillah; Arifin, Z. A Review on the Fused Deposition Modelling (FDM) 3D Printing: Filament Processing, Materials, and Printing Parameters. 2021, 11, 639–649, doi:10.1515/eng-2021-0063.

[3] Pinheiro, J.; Abdulghani, S.; Pascoal-Faria, P.; Sousa, D.; Carreira, P.; Viana, T.; Kamma-Lorger, C.S.; Mitchell, G.R. In Proceedings of the 2019 AIP Conference Proceedings 2116, 230003; doi:10.1063/1.5114229.

[4] da Silva, D.P.; Pinheiro, J.; Abdulghani, S.; Lorger, C.K.; Martinez, J.C.; Solano, E.; Mateus, A.; Pascoal-Faria, P.; Mitchell, G.R. Changing the Paradigm-Controlling Polymer Morphology during 3D Printing Defines Properties. MDPI Polym. 2022, 14, 1–14, doi:10.3390/polym14091638.

Acknowledgements:

This work is supported by Fundação para a Ciência e Tecnologia (FCT) through the project references: MIT-EXPL/TDI/0044/2021, UID/Multi/04044/2013; PAMI- ROTEIRO/0328/2013 (N° 022158), Add.Additive - Add additive manufacturing to Portuguese industry PO-CI-01-0247-FEDER-024533 and UC4EP PTDC/CTM-POL/7133/2014). The small-angle x-ray scattering measurements were made on the NCD-Sweet Beamline at the ALBA synchrotron facility in Barcelona with the collaboration of ALBA staff and CALIPSOplus (Grant 730872) funding.

Co-funded by:

POLITÉCNICO DE LEIRIA | CDRSP CENTRE FOR RAPID AND SUSTAINABLE PRODUCT DEVELOPMENT | ALBA | COMPETE 2020 | PORTUGAL 2020 | UNIÃO EUROPEIA Fundo Europeu de Desenvolvimento Regional | FCT Fundação para a Ciência e a Tecnologia | MIT Portugal

under the Exploratory Project: MIT-EXPL/TDI/0044/2021 | MIT Portugal Program – Digital Transformation in Manufacturing