What matters the most in 3D printing is to be connected: proof from the simulation

†*Sofiane Guessasma[1], Sofiane Belhabib[2], and Hedi Nouri[3,4]

[1]INRA, Research Unit BIA UR1268, Rue Geraudiere, F-44316 Nantes, France.
[2]LUNAM University of Nantes Angers Le Mans, CNRS, GEPEA, UMR 6144, IUT de Nantes, 2 avenue du Professeur Jean Rouxel, 44475 Carquefou Cédex, France
[3]Department of Polymers and Composites Technology & Mechanical Engineering, School of Mines Douai, 941 rue Charles Bourseul, CS 10838, F-59508 Douai, France
[4]Ecole Nationale d'Ingénieurs de Sfax, Laboratoire des Systèmes ElectroMécaniques, Route de Soukra Km 3,5 Sfax, Tunisia

*Presenting author: sofiane.guessasma@nantes.inra.fr
†Corresponding author: sofiane.guessasma@nantes.inra.fr

Extended abstract

Some may call 3D printing the next industrial revolution and some would fear it because it places innovation in the hand of anybody [1]. Whether it is a threat or an opportunity, 3D printing assuredly gives off a vibe along its pathway of industrial conquest. It has generated such a noise in the scientific community that this started tickling the intellect of many people including us. One can foresee the added-value that 3D printing would offer: design in multiple ways with a higher degree of freedom and under the shortest fabrication cycle. Increasing the functionalities 3D printed materials comes at a legitimate cost of knowing better the technology and its limits.
In this research work, we are able to address the nature and extent of defects inferred to particular 3D printing process based on fused deposition modelling (FDM). Three-dimensional imaging, mechanical testing and numerical modelling are all combined to draw a clearer picture of FDM capabilities and boundaries.
Virtual design of randomly positioned voids in porous blocks is achieved thanks to reverse engineering procedure described in [2]. Optimal designs are determined based on a precise control of stiffness and porosity content as illustrated in Figure 1.

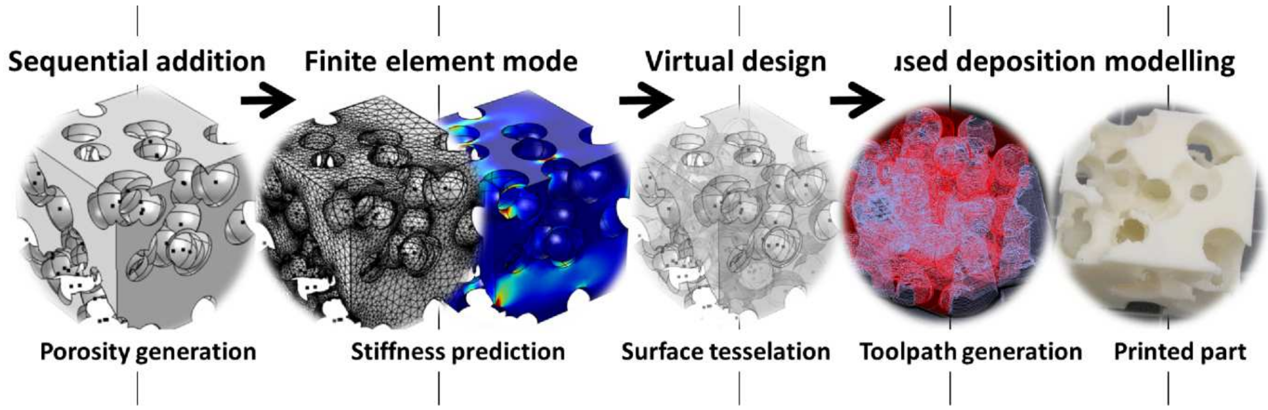

Figure 1. Reverse engineering process to generate porous blocks.

Sequential addition of soft overlapping spherical voids is used to generate the porous medium. The achieved geometry is converted into a finite element model to predict its elasticity behavior. An optimization routine is used to obtain optimal virtual designs with porosity and stiffness control over a large interval of porosity content (up to 60%).
Processing of dense and porous polymeric (acrylonitrile butadiene styrene or ABS) blocks is undertaken under different operating and geometrical conditions including printing angle and porosity content. X-ray micro-tomography is used to assess microstructural defects induced by processing. Our microstructural investigation shows three main sources of defects: presence of support material in airy blocks, process-induced porosity and residual roughness (Figure 2). All

these defects are, to some extent, documented in the literature. The most remarkable result highlighted here is that the porous network induced by 3D printing has a high rate of connectivity (up to 85% of the porosities are connected) despite the relative small porosity level (only 6%).

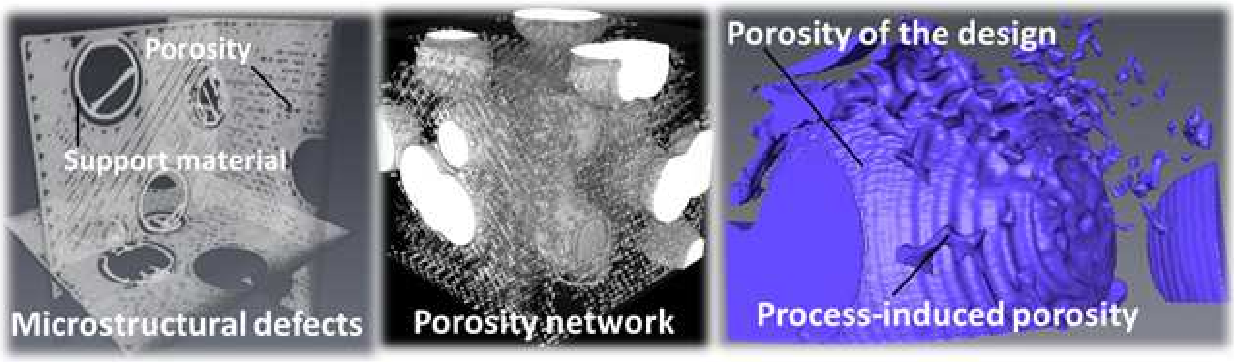

Figure 2. Significance of porous network and microstructural defects in 3D printed ABS.

Porous designs are loaded in compression in order to correlate identified microstructural defects to all engineering constants describing the macroscopic behavior up to densification. Preliminary experimental results show significant anisotropic behavior detectable in the plasticity stage of dense samples. These results make little sense if reported to commonly accepted view of the weak anisotropy of printed features under compression.

Finite element computation is used to assess the source of anisotropy based on conversion of 3D images of printed blocks into finite element models (Figure 3). Investigation of elasticity behavior confirmed a slight transverse isotropy, which is justified by the differences between the building direction and the laying down plane of fused filaments [3]. Finite element results indicate also that loss of stiffness generally reported in the literature (of the order of 20%) is underestimated in the simulation. Finite element predictions reflect simply the effect of a low porosity level, which means that the loss of stiffness goes elsewhere. It appears that the source of discrepancy is probably the perfect bonding hypothesis assumed between filaments. This pushes the investigation further towards the implementation of a 2D finite element model, which handles the filament arrangement and the degradation of the inter-filament connection as function of loading. Damage modelling is then attempted by considering a spatially varied stiffness that follows the filament arrangement (Figure 4). Damage kinetics assumes a sigmoid decay function of stiffness subject to the availability of positive strain. This criterion may appear irrelevant under compression loading but it proves to be the unique possibility that explains porosity percolation and filament decohesion under compressive loading. This criterion works here because Poisson's expansion allows further opening of porosities and percolation along the paths of positive strain as shown in Figure 5. These paths are the size of inter-filament decohesion. Depending on the printing angle, different damage kinetics are predicted. In

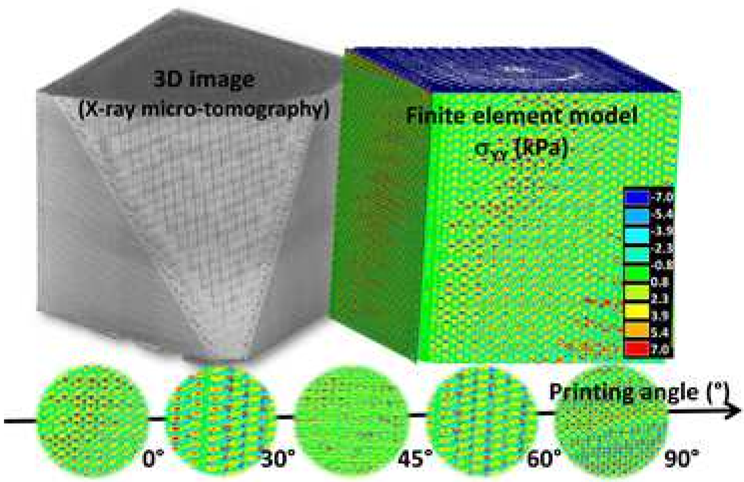

Figure 3. Finite element modelling based on explicit implementation of microstructural defects.

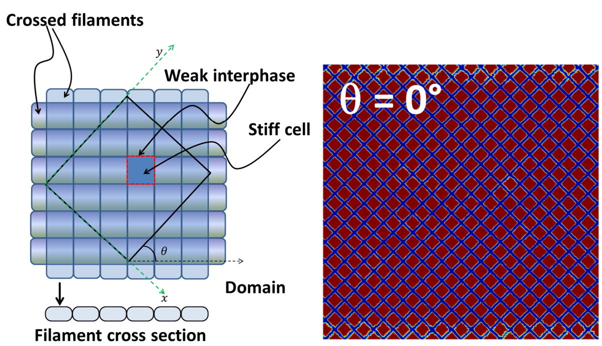

Figure 4. Damage modeling based on varied stiffness distribution and inter-filament decohesion.

particular, finite element results demonstrate that shearing bands develop at the particular printing angle of 0° (Figure 5). This kind of damage is responsible for the force drop at the plasticity stage and fully explains the severe anisotropy discussed earlier.

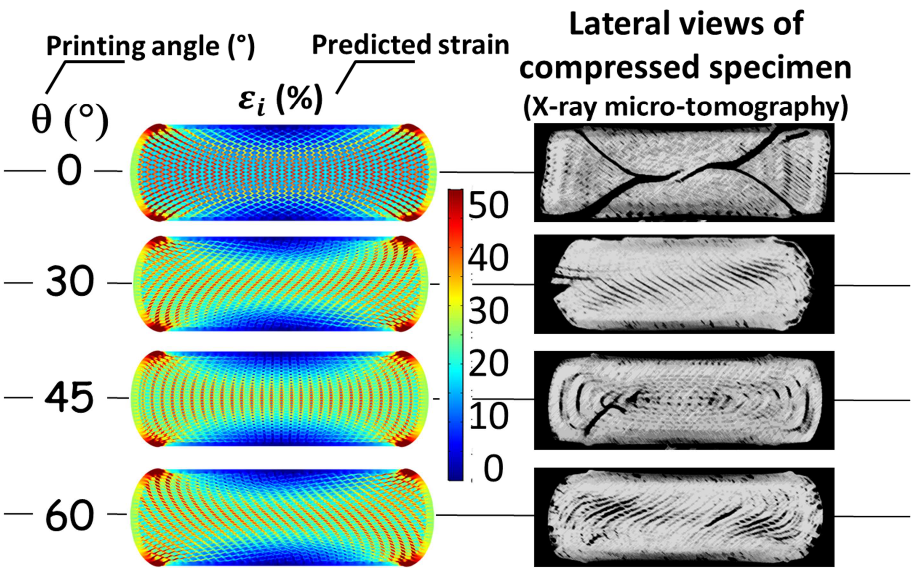

Figure 5. Comparison between finite element results and cross-section views showing damage extent as function of printing angle.

Keywords: Finite element computation, Fused deposition modelling, X-ray micro-tomography, elasticity, damage modelling

References

Guessasma, S., Zhang, W., Zhu, J., Belhabib, S. and Nouri, H., (2016). Challenges of additive manufacturing technologies from an optimisation perspective. *International Journal for Simulation and Multidisciplinary Design Optimization* **6**, A9.

Ben Hassana , O., Guessasma , S., Belhabib, S. and Nouri, H., (2016). Explaining the Difference Between Real Part and Virtual Design of 3D Printed Porous Polymer at the Microstructural Level. *Macromolecular Materials and Engineering*, in press.

Guessasma, S., Belhabib, S. and Nouri, H., (2015). Significance of pore percolation to drive anisotropic effects of 3D printed polymers revealed with X-ray mu-tomography and finite element computation. *Polymer* **81**, 29-36.