# Optimization of the Fused Deposition Modelling Process Parameters for the Production of Biopolymeric Scaffolds

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***Abstract.*** *The advent of additive manufacturing has opened a bunch of possibilities in terms of research and advantages in various fields, starting from automotive, aerospace, to biomedical sector. Focusing on the last one, this kind of technology allows to study and design medical implants, in order to overcome limits that occur during traditional manufacturing methods, like long time and multiple steps production high cost, tissue inflammation and necrosis. The present work reports the optimisation of the printing parameters for selected biopolymers, i.e. poly(lactic acid) (PLA), polymethyl methacrylate (PMMA), poly(caprolactone) (PCL), poly(etheretherketone) (PEEK), to be used for the production of scaffolds and implants for craniomaxillofacial applications, by Fused Deposition Modelling Technology (FDM).*

**Keywords.** Biopolymers, biocomposites, additive manufacturing, 3D printing, craniomaxillofacial applications

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# 1 Introduction

Additive manufacturing technologies are achieving a lot of interest [1-3] and are employed in several industries. The main fields that have adopted the additive manufacturing approach are the aerospace, automotive and medical ones. In the medical sector it is mainly to produce custom made prostheses in order to replace damaged parts of the bone tissue, properly setting the level of hierarchical porosity within the piece [4]. Thus, the additive manufacturing technology has been proposed as a promising alternative to the traditional manufacturing methods of biopolymeric implants, that consist in the production of hand mallable pastes, allowing to overcome the associated criticisms, such as the obtainment of dense structures, the low mechanical properties, the induction of inflammation [5,6].

In this framework, in the present work, the printing parameters by fused deposition modelling (FDM) for three selected biomaterials, i.e. poly(lactic acid) (PLA), poly(caprolactone) (PCL), polymethyl methacrylate (PMMA), poly(etheretherketone) (PEEK) [7,8], with the final aim to design medical devices such bone scaffold, fixation system for craniomaxillofacial application and cranial implants, were properly selected. Microstructural, thermal and mechanical characterisations were performed by observation at optical and scanning electron microscopies, differential scanning calorimetry (DSC) and tensile and compression tests, respectively.

# 2 Materials and methods

Two different FDM printers were used, namely Creality Ender 3 Pro and and Intamsys Funmat HT. PCL filament from Facilan, PLA filament from Filoalpha, PMMA filament from TreedFilament and PEEK filament from ThermaX were employed. Different FDM printing parameters were tested, in terms of extrusion and bed temperatures,  and printing speed. Six different textures were investigated setting the percentage of empty of the samples nearly to 70% (Line, Triangle, Grid, Gyroids, Octet, Zig-Zag, ), in order to emphasise the influence of the pattern on mechanical strength. Mechanical characterisation was made in order to study the effective influence of the deposition patterns in terms of mechanical resistance, . In details, tensile and compression tests were made with MTS Insight 5 testing machine, following the D1708-02a and ASTM D695-15 standards, respecively, with a load cell of 2.5 kN. The samples were preloaded with 20 N and pulled with a tensile speed of 1.2 mm/s. Thermal characterization by differential scanning calorimetry (DSC, Q2000, *TA instruments*) was made to demonstrate the possible process influence on the materials thermal properties. The DSC measurements were performed on both filaments and printed materials, in the following conditions: temperature range -50–300 °C, heating and cooling rates 10 °C /min, nitrogen flux 50 ml/min, for two cycles.

# 3 Results

The observation at optical microscope allowed to identify the optimal printing parameters.

DSC analysis demonstrated a significant influence of the printing process on the polymer thermal properties. For example, in the case of PMMA printed disks, a decrement of around 10

°C for the glass transition temperature ($T_g$) with respect to the PMMA filament was revealed in the first heating scan, whereas the values were comparable in the second cycle, due to the removal of the thermal history, as expected [9].

Concerning the mechanical characterization, as expected and evident from the comparison among the acquired stress-strain curves, (Figure 1), PEEK presented the highest mechanical properties with a maximum value recorded nearly to 70 MPA, followed by PMMA and PLA with comparable behavior, whereas PCL showed the lowest performance.

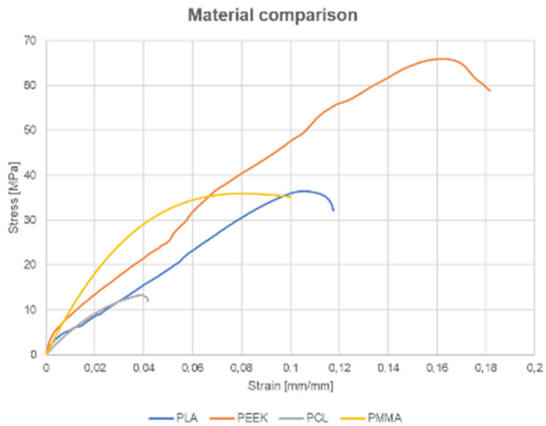


**Figure 1.** Stress-strain curves of PEEK, PMMA, PLA and PCL printed samples.

Moreover, a significant influence of the selected deposition pattern on the material tensile strength was evidenced (Figure 2), whereas comparable values were obtained in the compression tests. As an example, in Figure 2, the stress-strain curves of PMMA printed using different deposition patterns by maintaining constant the level of porosity (70%), were compared. More specifically, Line and Gyroids patterns offered the highest mechanical strength due to the same orientation of fibers and applied load.

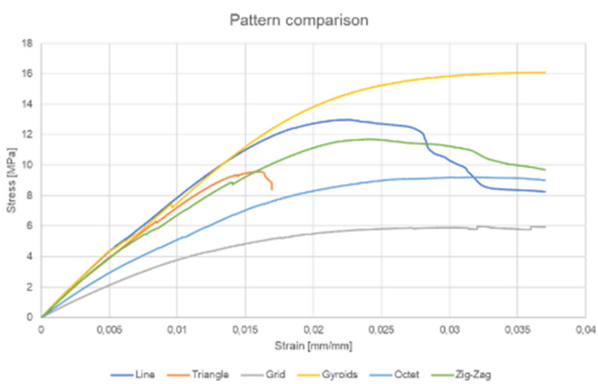


**Figure 2.** Stress-strain curves of PMMA samples printed using different deposition patterns (porosity level: 70%

Using the selected optimal printing parameters, both supports for the tissue regeneration (i.e. scaffolds) and cranial implant prototypes were produced (Figure 3) [10,11].

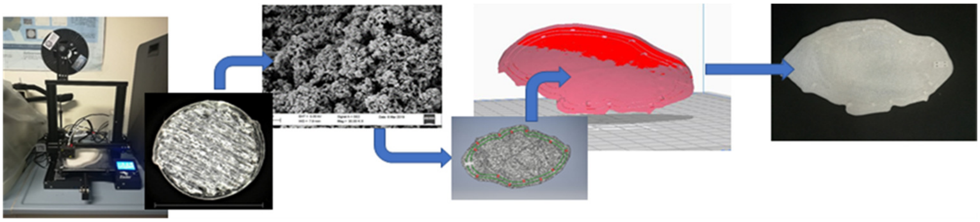

**Figure 3.** Towards the 3D printing of a cranial implant prototype

## 4 Conclusions

Optimal printing parameters of different materials for FDM technology were found, fill pattern Line and Gyroids offered the best mechanical tensile strength; but no infill has been found that provides significative mechanical reinforcement in terms of compression. Effective influence of the process on the thermal properties of the material was demonstrated. Future developments will involve the study of the printed supports mechanical properties after the sterilisation process, as well as biological characterisations.

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