Additive Manufacturing of quasi-isotropic fiber-reinforced composite laminates for biomedical applications

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1. Introduction and motivation

Fused Filament Fabrication (FFF) is a promising technology for treating bone defects, enabling the creation of complex customised structures and the use of materials like continuous fiber-reinforced composites that can mimic cortical bone properties. However, current studies focused on unidirectional reinforcement, limiting mechanical performance in different directions. This makes them less suitable for orthopedic devices, which require balanced mechanical properties. Developing a multidirectional fiber reinforcement, such us quasi-isotropic configuration, could improve the mechanical properties and suitability of FFF composites for bone implants.

2. Objectives

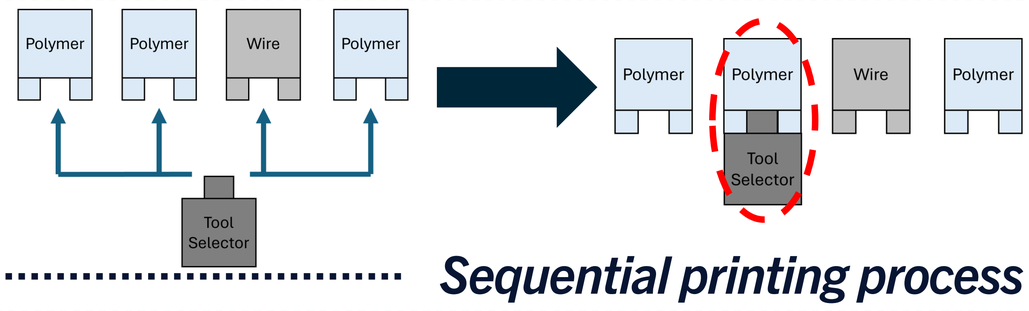
- Design, fabrication and characterisation of novel FFF 3D printed quasi-isotropic fiber-reinforced composites.
- Validate this manufacturing technique for its use in biomedical applications for the treatment of bone defects.

3. Multimaterial FFF printing process

Material

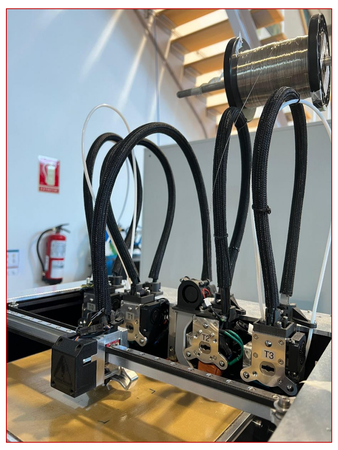
PLA filament (Ø = 1.75 mm) + Aluminium wire (150 alloy, Ø = 0.3 mm)

Sequential printing process



It is only possible to print with the print head that is engaged with the tool selector.

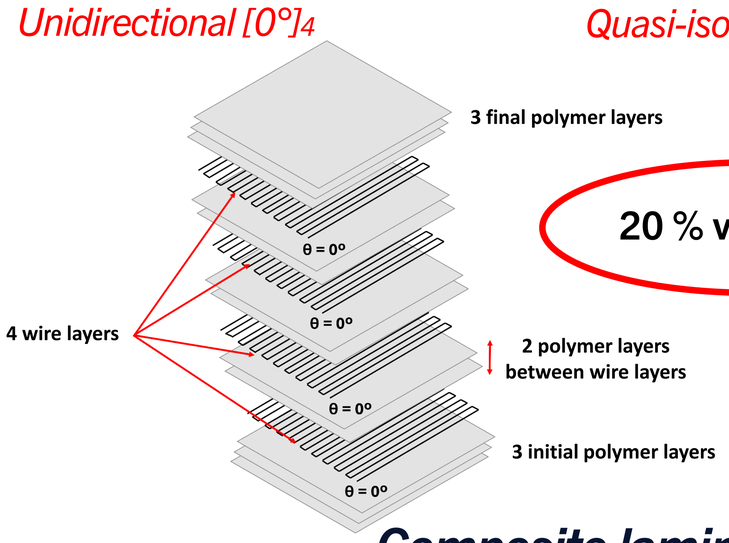
Customised multimaterial 3D printer



- 3 polymer print heads
- 1 continuous wire deposition print head
- 1 tool selector (engaged with one print head at a time)

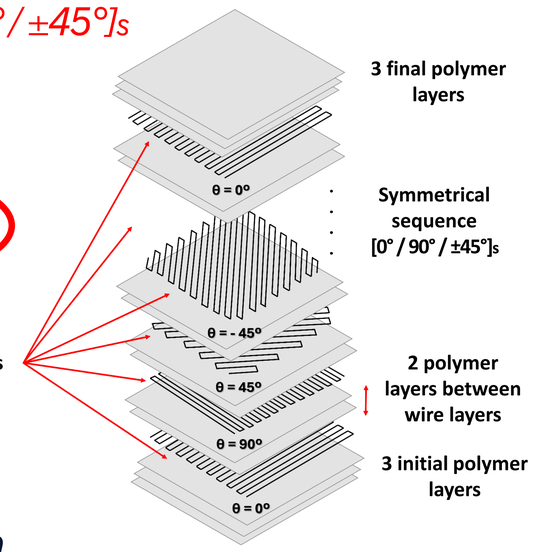
Composite laminate design

Unidirectional $[0°]_4$



Quasi-isotropic $[0°/90°/\pm45°]_s$

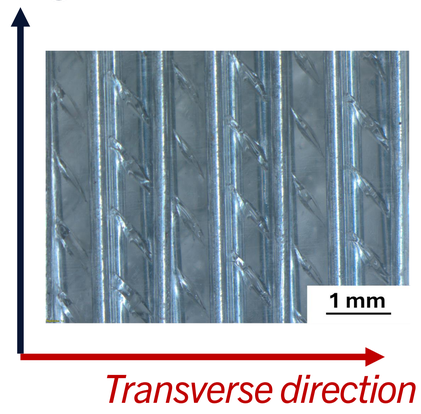
20 % vol. Al wire



4. Results and discussion

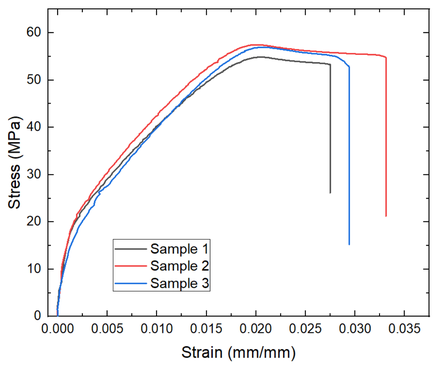
Unidirectional composites

Longitudinal direction



Porosity < 1%

Longitudinal tension (tensile properties)

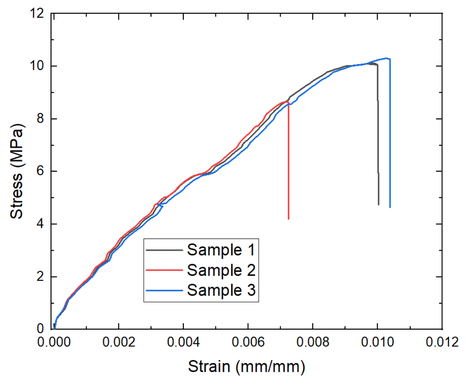


$E_{theorical} = 16.4\ GPa$

$E = 15.3\ GPa$

$UTS = 57\ MPa$

Transverse tension (tensile properties)

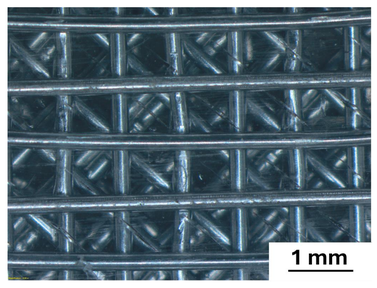


$E_{theorical} = 3.7\ GPa$

$E = 1.6\ GPa$

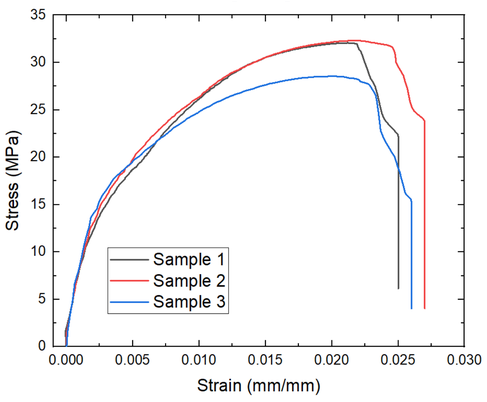
$UTS = 9.7\ MPa$

Quasi-isotropic composites



Porosity < 1%

Tensile properties



$E_{theorical} = 7.8\ GPa$

$E = 7.5\ GPa$

$UTS = 31\ MPa$

Discussion

- Fibers correctly deposited and oriented.
- Mechanical behaviour of unidirectional composites showed that elastic modulus and strength depend on the orientation of the deposited fiber.
- The highest mechanical properties were achieved in the longitudinal direction of unidirectional composites, while the worst corresponded to the transverse direction.
- Quasi-isotropic laminates exhibit balanced mechanical properties that allow them to meet load demands in all directions.

5. Conclusions

- **Quasi-isotropic composites** have been manufactured for the **first time** by means of **FFF**.
- Mechanical behaviour of unidirectional composite laminates is different in each direction. This allows to **optimise the ply orientation to achieve optimal and balanced mechanical properties in multidirectional composites**.
- This multimaterial printing process has been **validated for biomedical application and the treatment of bone defects.**

EXCELLENCE MARÍA DE MAEZTU

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