# Optimization of 3D Printed Continuous Carbon Fiber Reinforced PETG Composites

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## Stakeholders

IMT Nord Europe
École Mines-Télécom
IMT-Université de Lille

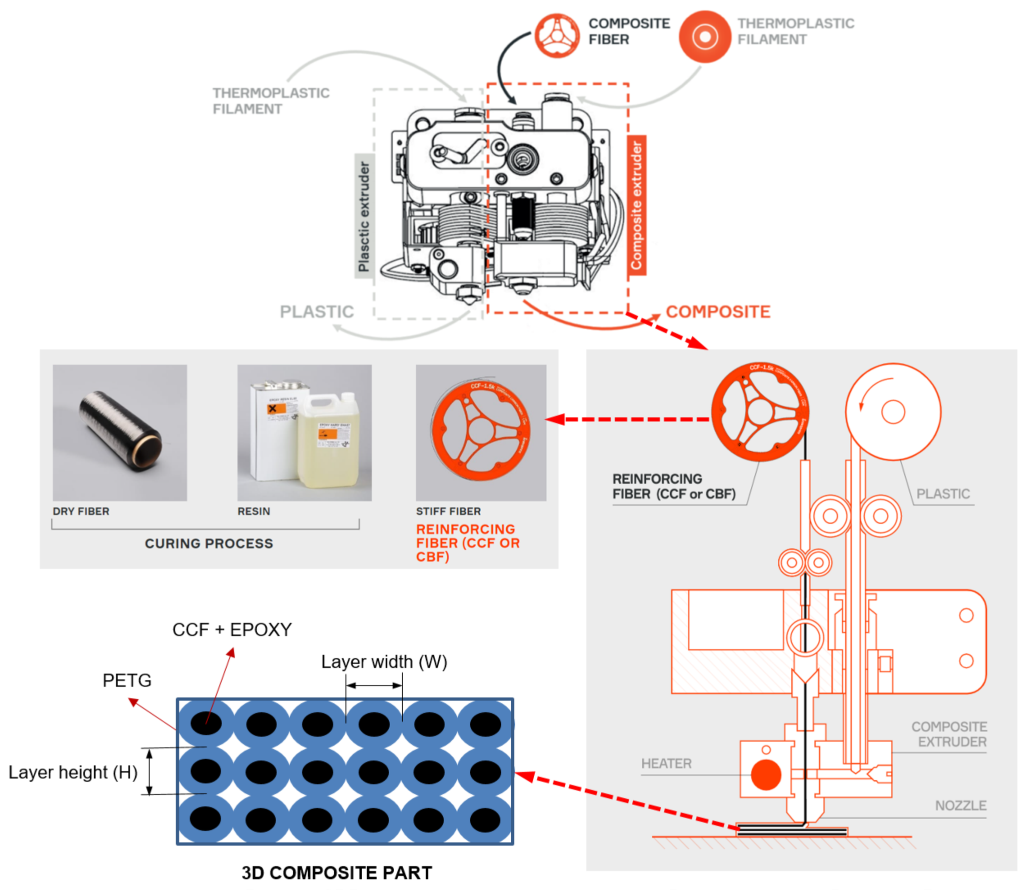
agence nationale de la recherche

## Context

- The 3D printing of continuous carbon fiber reinforced composites (CCFRCs) based on Fused Filament Fabrication (FFF) has achieved great potential for producing complex geometries, excellent mechanical performances, and light-weight structures.
- The mechanical performances of the 3D printed CCFRCs remain restricted by the fiber orientation within the printing layers, and the relatively low strength of inter-layer bonding.

## Objective

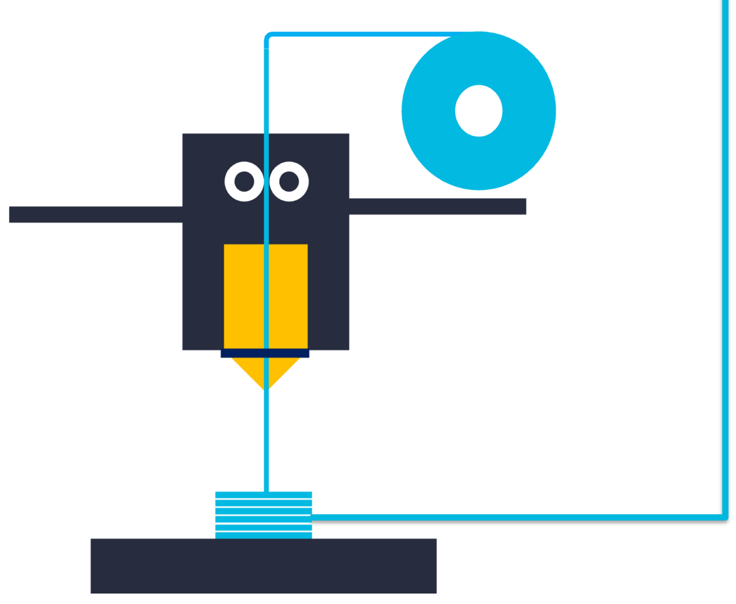
- The present study aims to optimize the printing parameters (i.e. nozzle temperature, and layer height) in order to maximize the mechanical properties (i.e. tensile strength, and the interlaminar shear strength) of the 3D printed continuous carbon fiber-reinforced PETG composites.

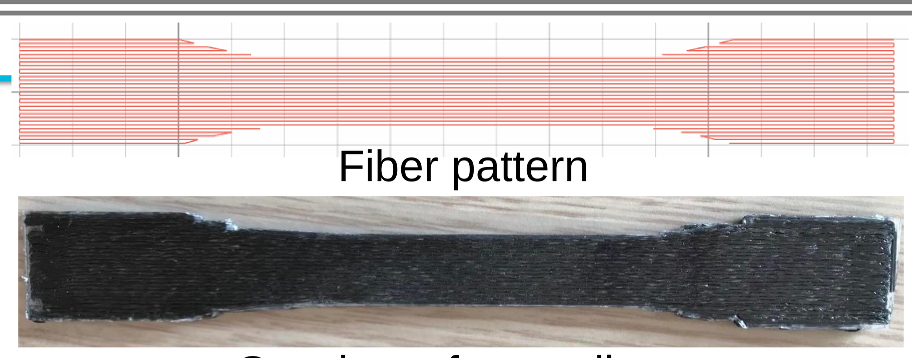



**Composite fiber co-extrusion technology**

## Methodology

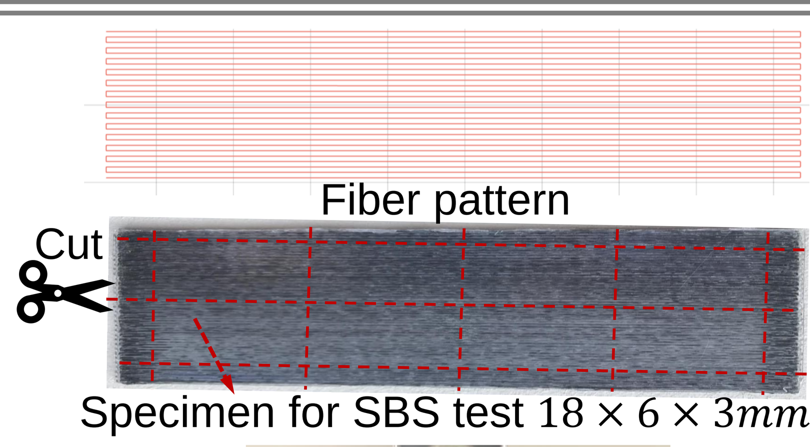
**3D printing of samples**



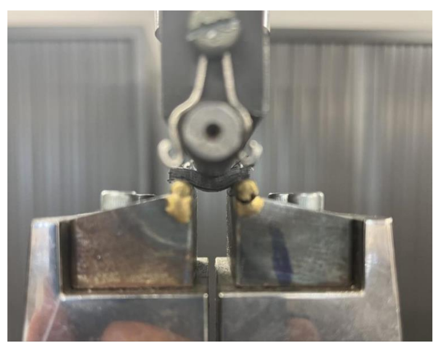



Specimen for tensile test

Tensile test (ISO527)



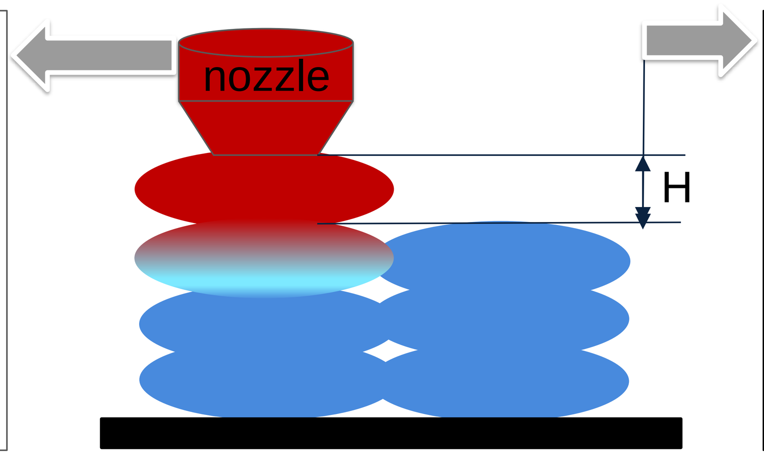

Specimen for SBS test $18 \times 6 \times 3mm^3$



Short beam shear (SBS) test (ASTM D2344)

**Effect of nozzle temperature**

- Variation in thermal history
- Improvement of flowability
- Enhanced impregnation of CCF in matrix PETG
- Improvement of molecular mobility facilitating interdiffusion across the interface




**Effect of layer height**

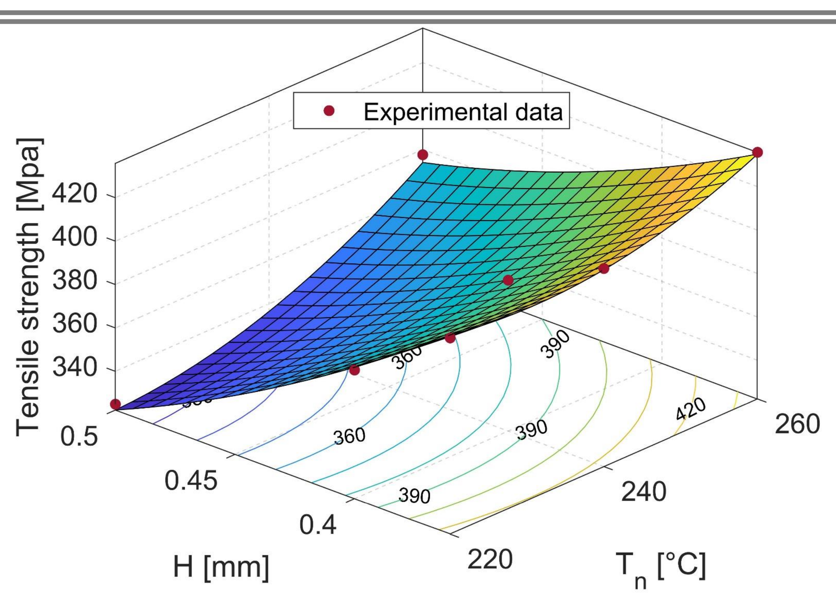
- Modified of carbon fiber content in 3D printed composite parts
- Variation in contact pressure between nozzle and deposited material
- Reduced interlayer voids
- Enhanced interlayer bonding

- Analysis of variance (ANOVA) was performed to determine the significance of the studied parameters in order of influence on the mechanical performance.
- The response surface method (RSM) was used for the prediction of the mechanical performance as a continuous function of the studied parameters:

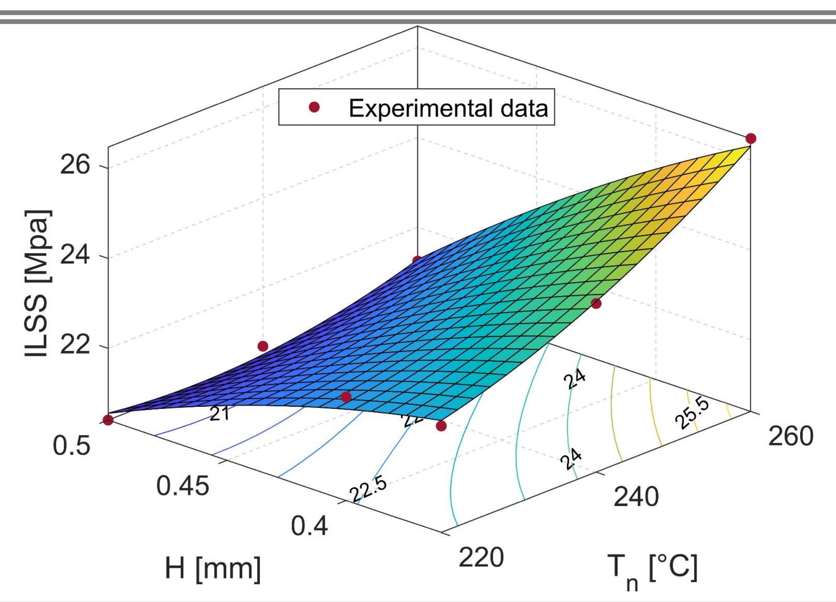
$$Y = \beta_0 + \sum_{i=1}^{N} \beta_i X_i + \sum_{i=1}^{N} \beta_{ii} X_i^2 + \sum_{i \neq j}^{N} \beta_{ij} X_i X_j + \varepsilon$$

## Results

Response surface of tensile strength




Response surface of ILSS

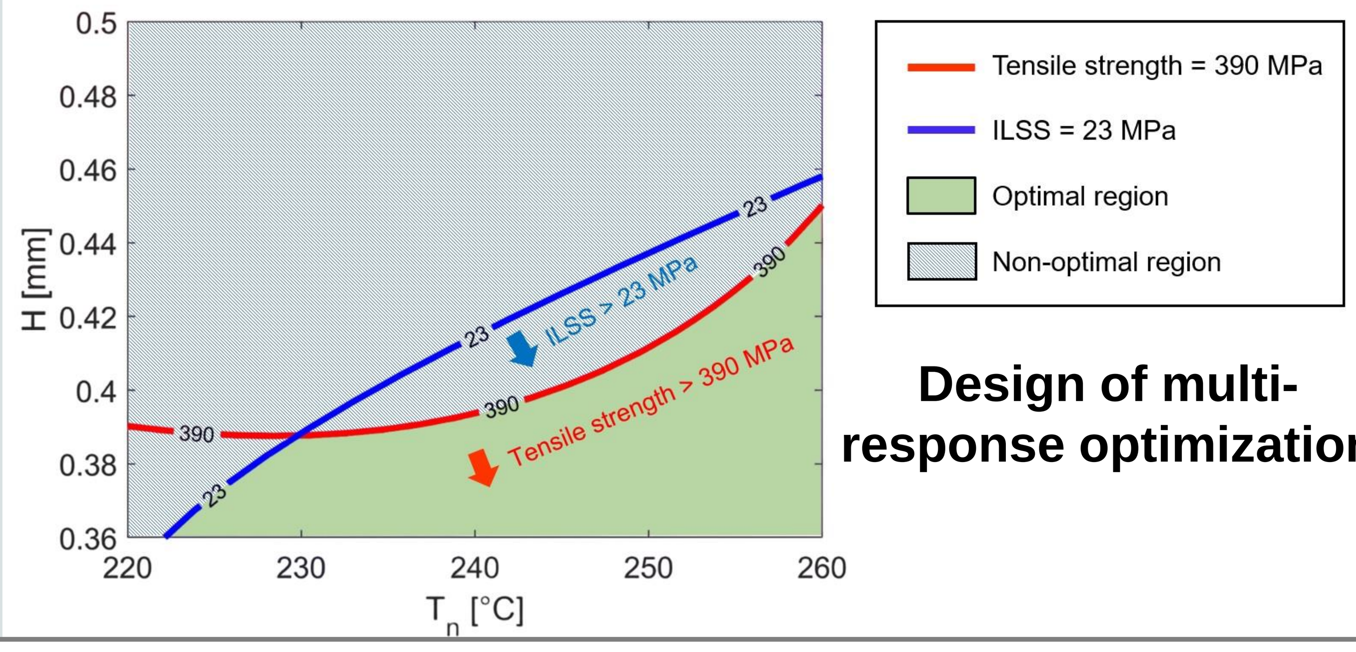



ANOVA for tensile strength

| Source | DF | Adj SS | Adj MS | F-Value | $p$-Value | Remark |
|---|---|---|---|---|---|---|
| $T_n$(°C) | 2 | 6059.4 | 3029.7 | 12.61 | 0.004 | Significant |
| $H$(mm) | 2 | 27063.2 | 13531.6 | 56.32 | <0.001 | Significant |
| $T_n \times H$ | 4 | 1101.1 | 275.3 | 1.15 | 0.367 | Insignificant |
| Error | 18 | 4324.7 | 240.3 | | | |
| Total | 26 | 38548.4 | | | | |

ANOVA for ILSS

| Source | DF | Adj SS | Adj MS | F-Value | $p$-Value | Remark |
|---|---|---|---|---|---|---|
| $T_n$(°C) | 2 | 39.953 | 19.9767 | 19.81 | <0.001 | Significant |
| $H$(mm) | 2 | 111.779 | 55.8895 | 55.41 | <0.001 | Significant |
| $T_n \times H$ | 4 | 10.643 | 2.6607 | 2.64 | 0.05 | Insignificant |
| Error | 36 | 36.311 | 1.0086 | | | |
| Total | 44 | 198.686 | | | | |




**Design of multi-response optimization**

## Conclusions

- The nozzle temperature and the layer height have a significant impact on the tensile strength and the interlaminar shear strength of the 3D printed continuous carbon fiber-reinforced PETG composites.
- Optimal range of values for the nozzle temperature, and the layer height were determined satisfying the requirements for the mechanical performances of the 3D printed composites using RSM.

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23rd International Conference on Composite Materials - Belfast, 30th July - 4th August 2023