Optimized Digital Design and Production: Continuous-fiber-reinforced 3D printing of polyamides

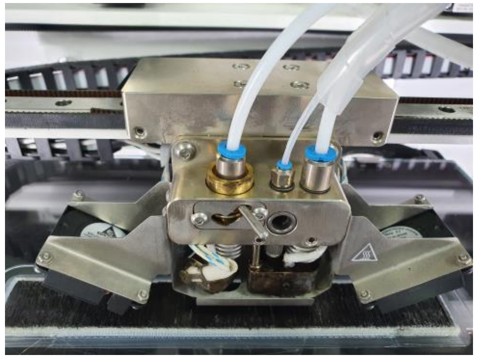
Aalto University & VTT

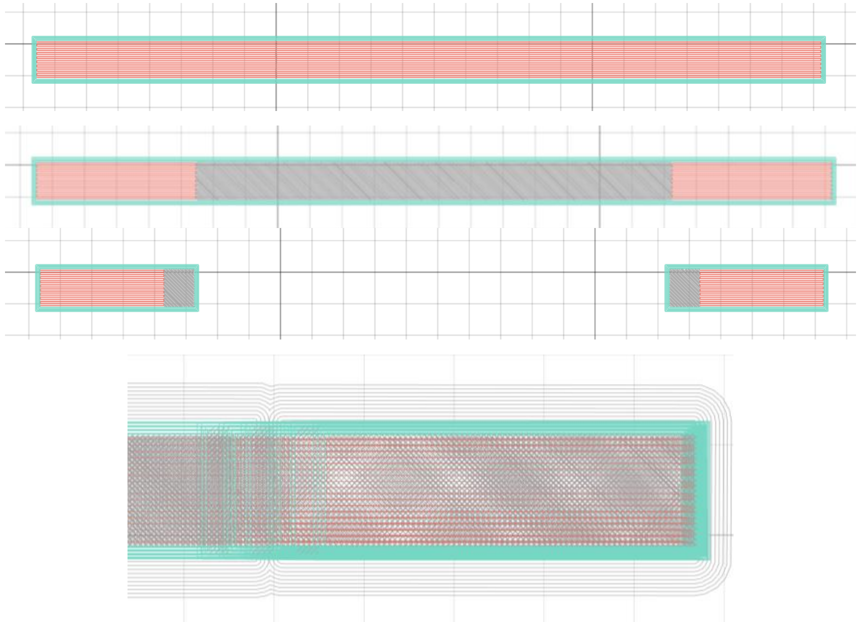
ValueBioMat WP1-WP2

Aalto University
School of Engineering

Optimized Digital Design and Production

- Fiber-reinforced extrusion of polyamides
  - Commercial copolyamide filament: BASF Ultrafuse
  - Continuous carbon fiber infill
  - 3DP at 240°C utilizing Anisoprint Composer A4

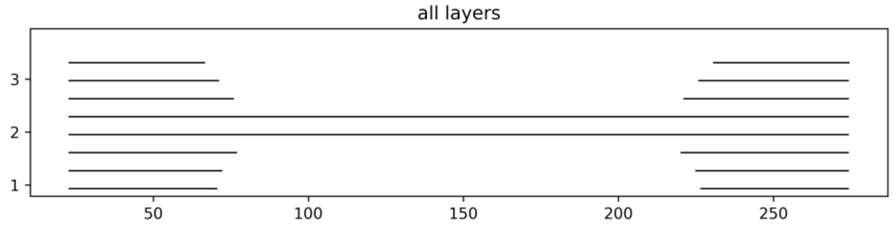


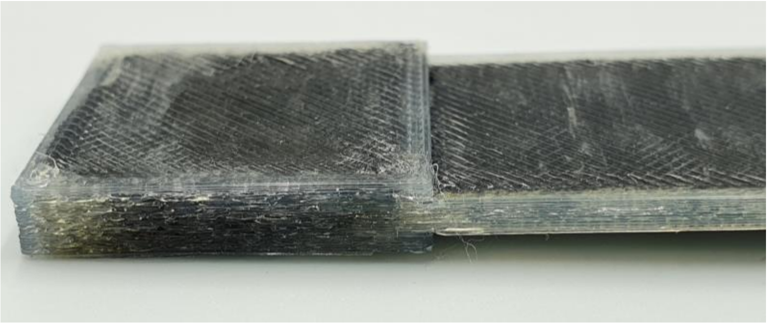


CCF reinforced Copolyamide: test specimen
Longitudinal tension (tensile_0)
Transverse tension (tensile_90)
In-plane shear (+-45)

Simulation

- *ORIENT subroutine to convert gcode into .inp file
- Model strictly following 3D printing
- Displacement-based
- Simulation based on the continuum damage mechanics (CDM) model
- The effect of different fiber orientations on the tensile strength were studied both experimentally and numerically.
- Hashin failure criteria





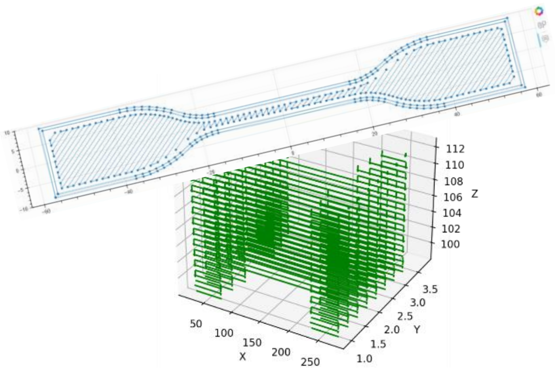
Done: FE-Model generation
Gcode → FE-model → Simulation

Read **Gcode**
- Geometry
- Fiber orientation

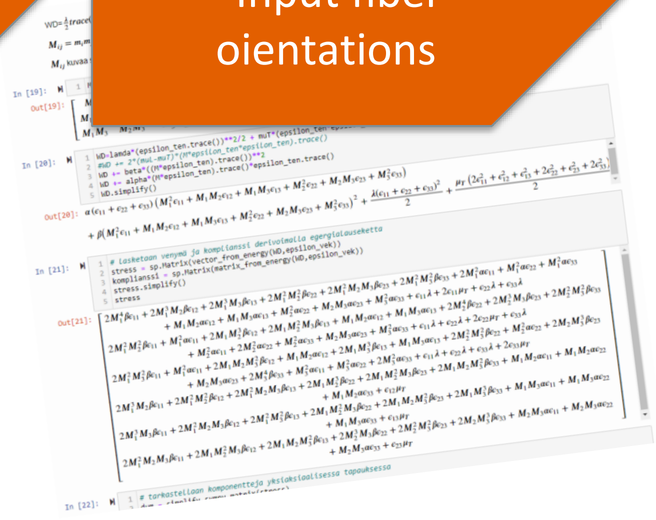
Generate **FE-Mesh**
- Input fiber oientations

Create user subroutines: **ORIENT & UMAT** for ABAQUS FE-solver

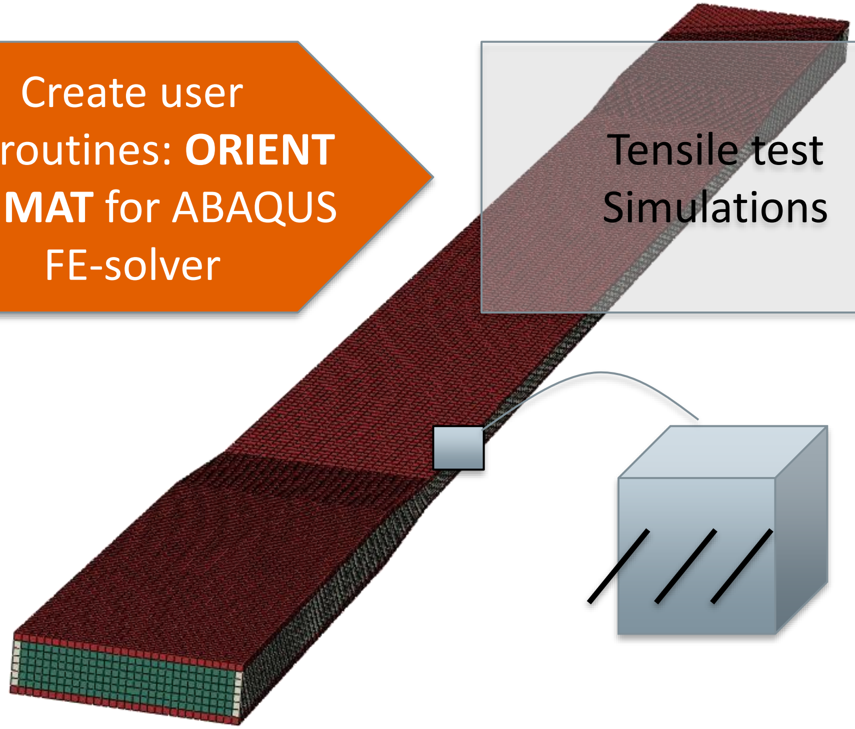
Tensile test Simulations



Fibers in printed specimen

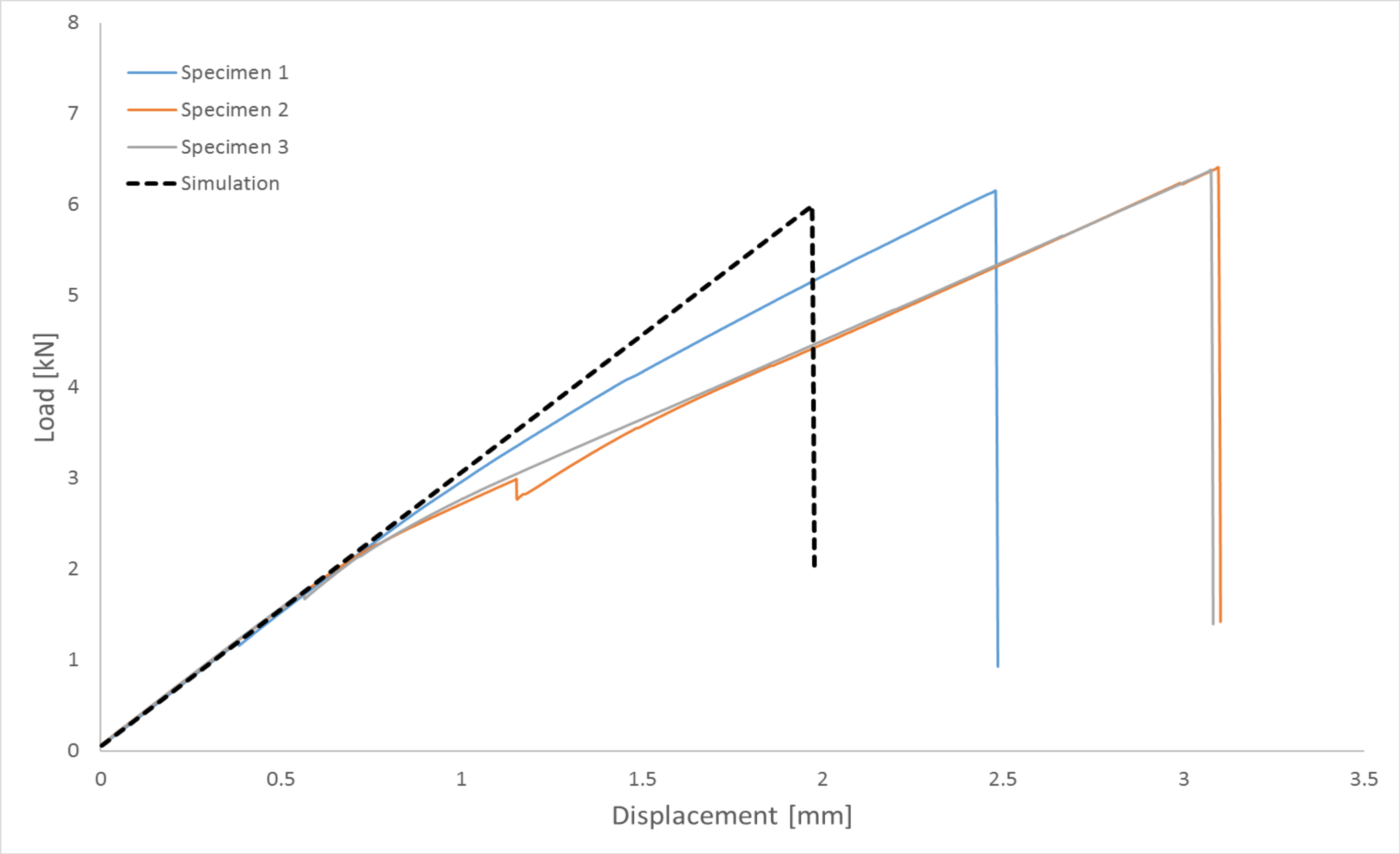


Python Coding



FE- Model & Fiber orientation

Material properties: tensile 0°



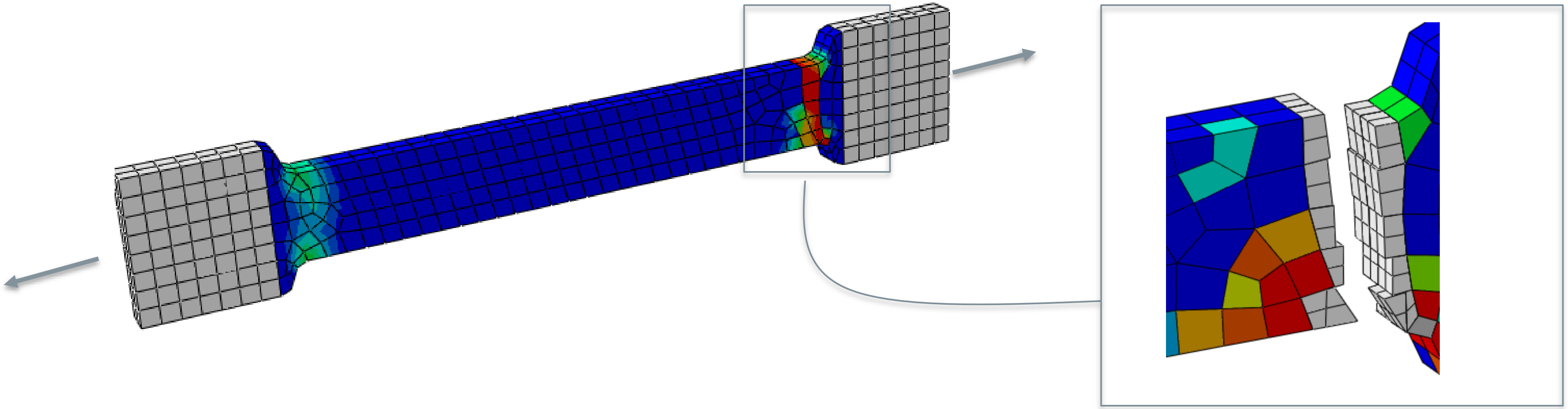
- The figure here illustrates tensile tests results for specimens where the fibre orientation is perpendicular to the direction of tension.
- Dashed line shows the simulated result. Despite the non linear deformation before failure, simulation is well in line with the experimental results.

Mechanical properties: Summary

Property	Description	Value
E_1 [GPa]	Longitudinal elastic modulus	19.5 ± 0.4
E_2 [GPa]	Transverse elastic modulus	2.2 ± 0.1
G_{12} [GPa]	In-plane shear modulus	2.0 ± 0.1
ν_{12}	Major Poisson's ratio	0.21 ± 0.03
X_T [MPa]	Longitudinal tensile strength	240.2 ± 47.4
Y_T [MPa]	Transverse tensile strength	20.8 ± 0.5
S [MPa]	In-plane shear strength	48.3 ± 1.3

To be done: Fracture & Damage Modell

Further develop and verify models for 3D printed CF reinforced composites



To be done: Optimised printing

FE - simulation

Optimised fiber orientation & Specimen shape

?
Printed specimen

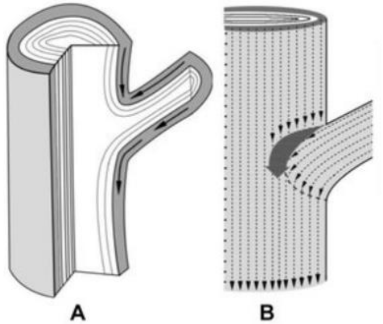
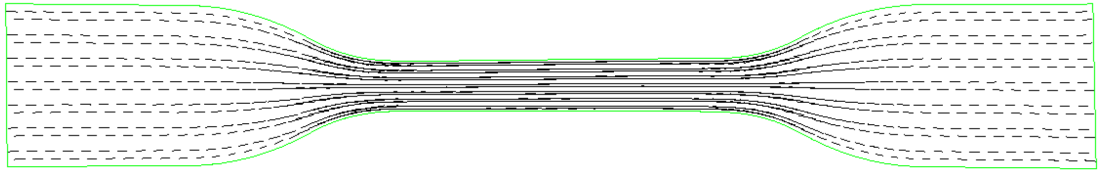


Fig by DOI:10.14214/sf.1461



Fiber orientations based FEM analysis & Principal stresses

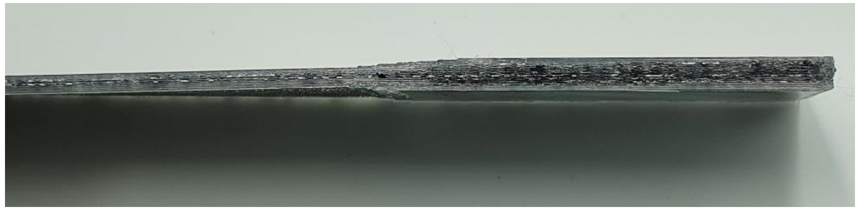
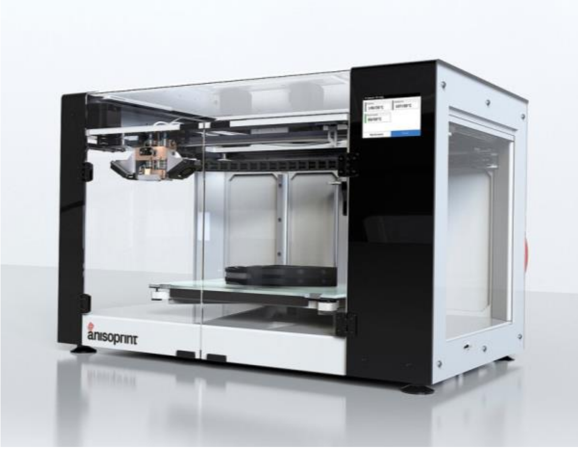


Fig. by Aalto (Sid)

Optimized Digital Design and Production

- Fiber-reinforced extrusion of polyamides
  - Bio-based PA11, Rilsan Besno
  - Filament made at VTT
  - Continuous carbon fiber perimeters
  - 3DP at 210˚C utilizing Anisoprint Composer A4

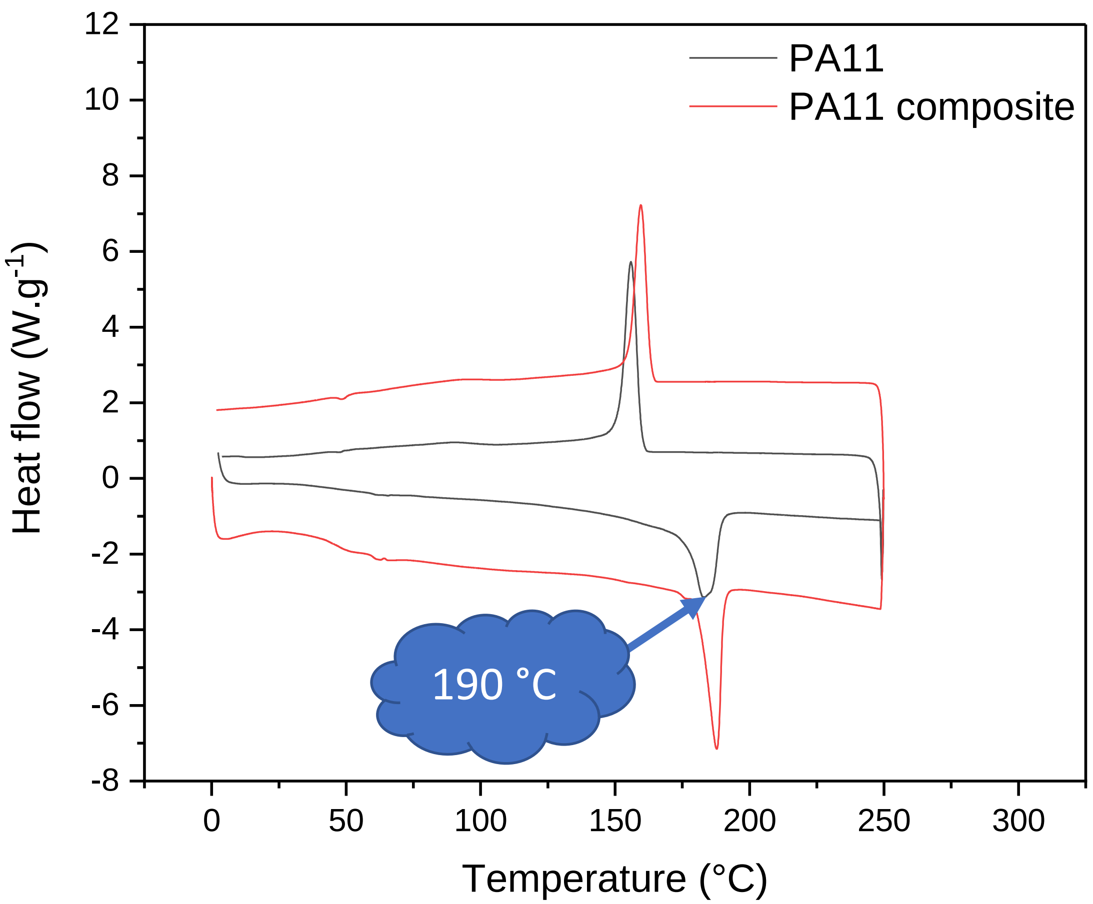


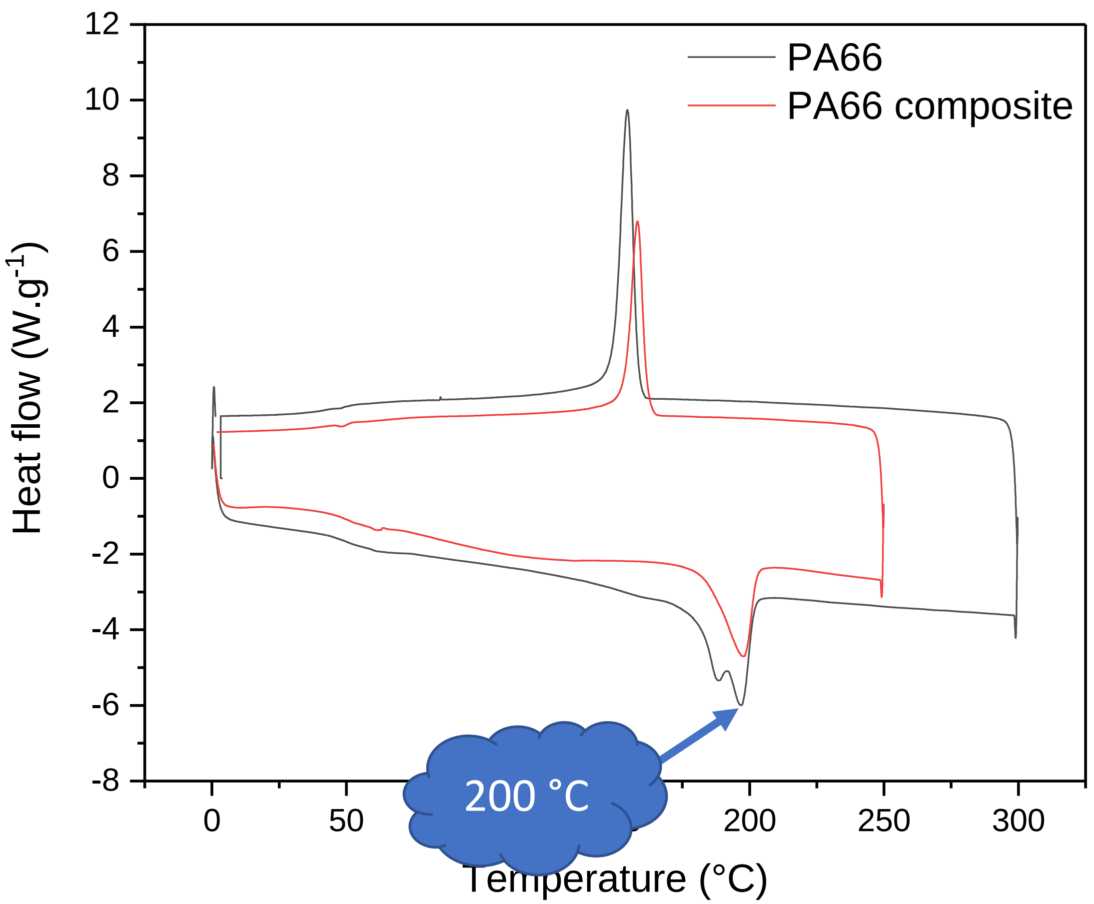
PA 11 & CCF

PA 11 & CCF

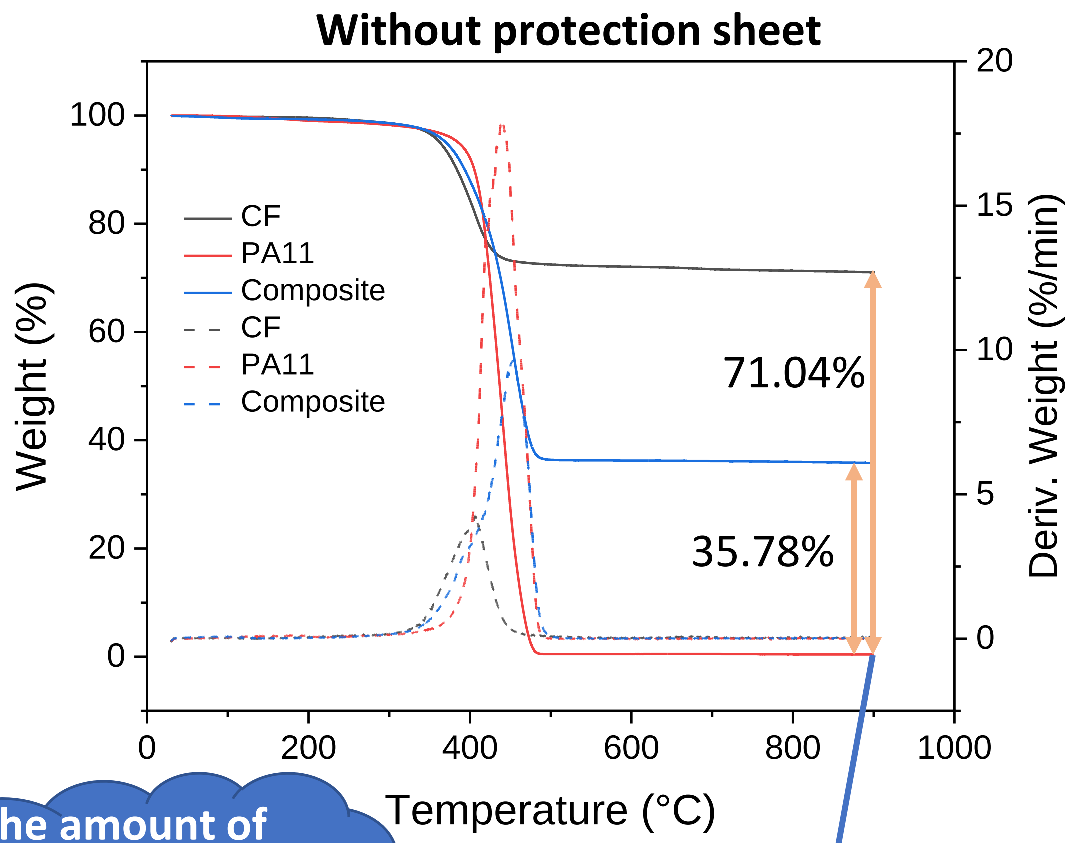
PA 11 & CCF

Material Characterization: DSC



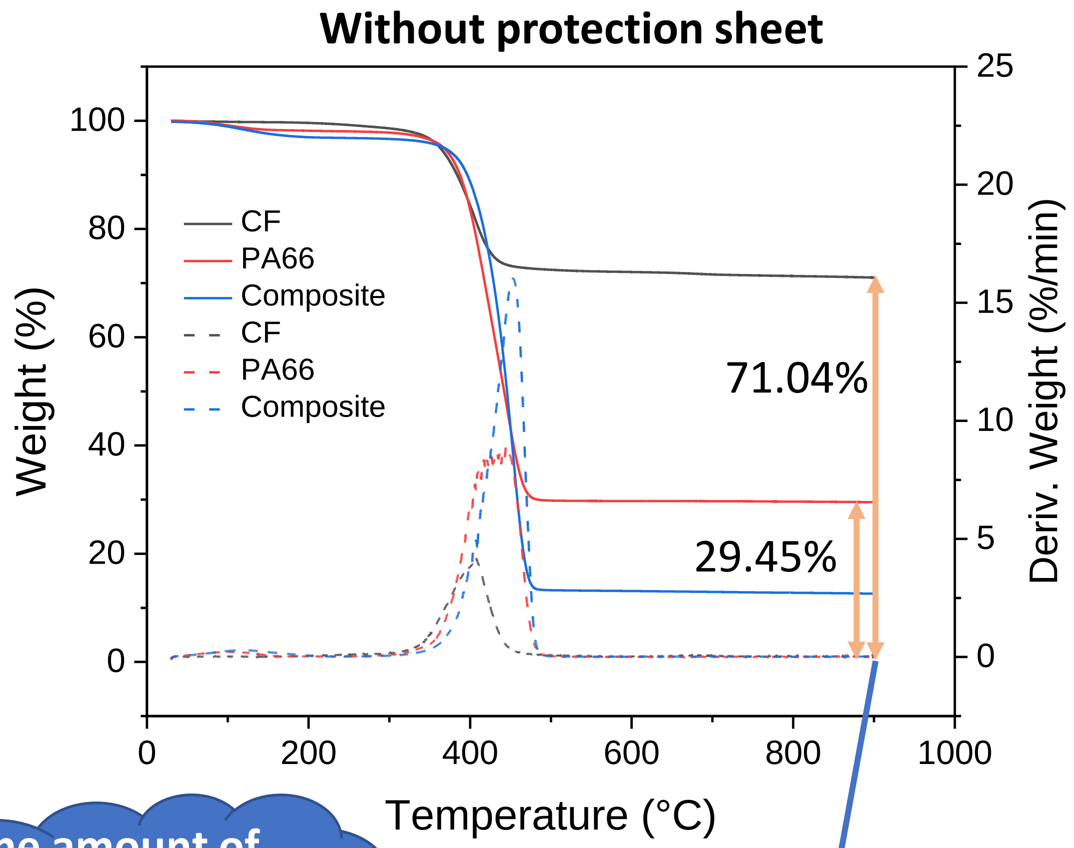


Material Characterization: TGA



The amount of CF in the composite is around 50%

0.4%

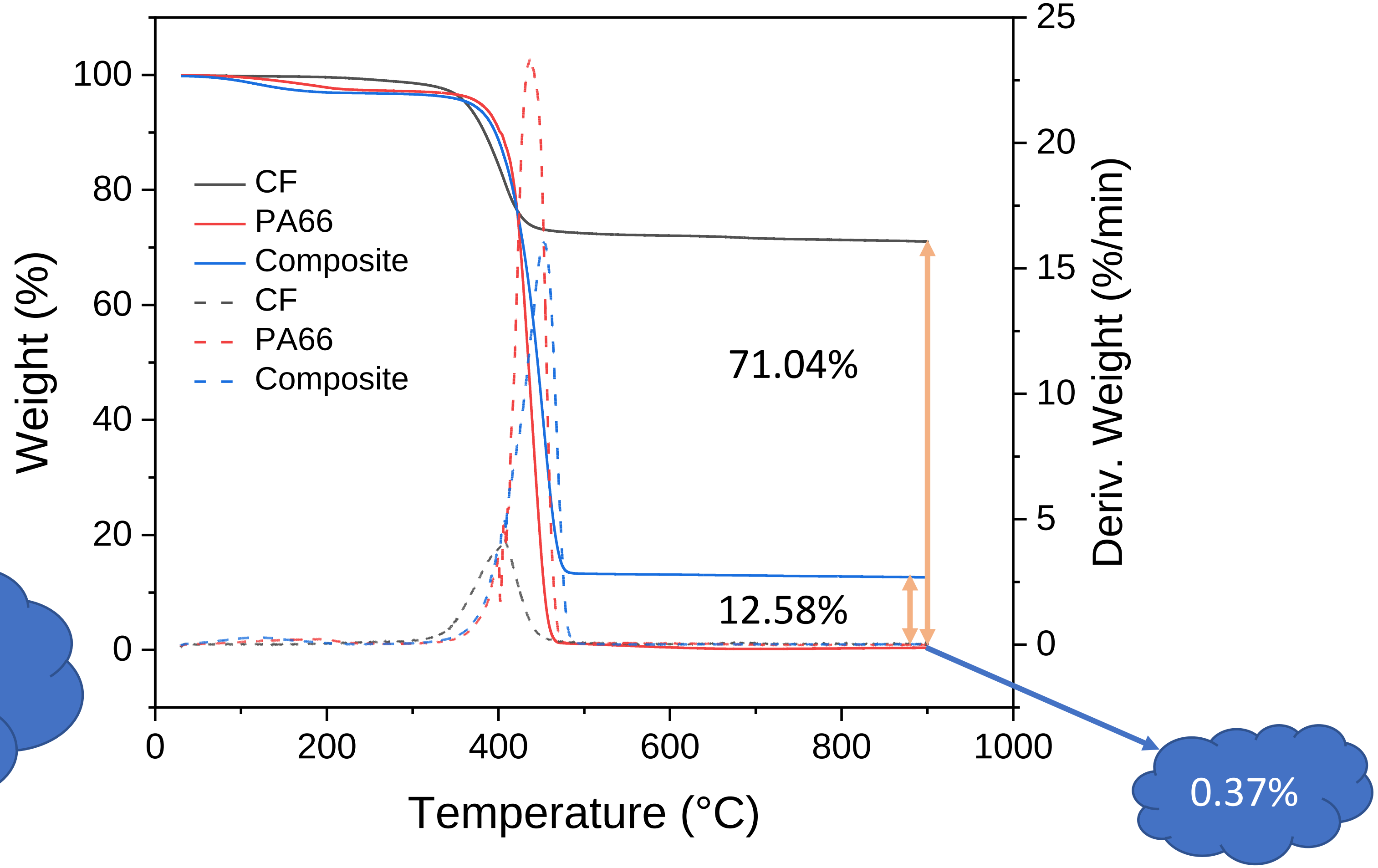


The amount of CF in the composite is around 41%

0.37%

Material Characterization: TGA

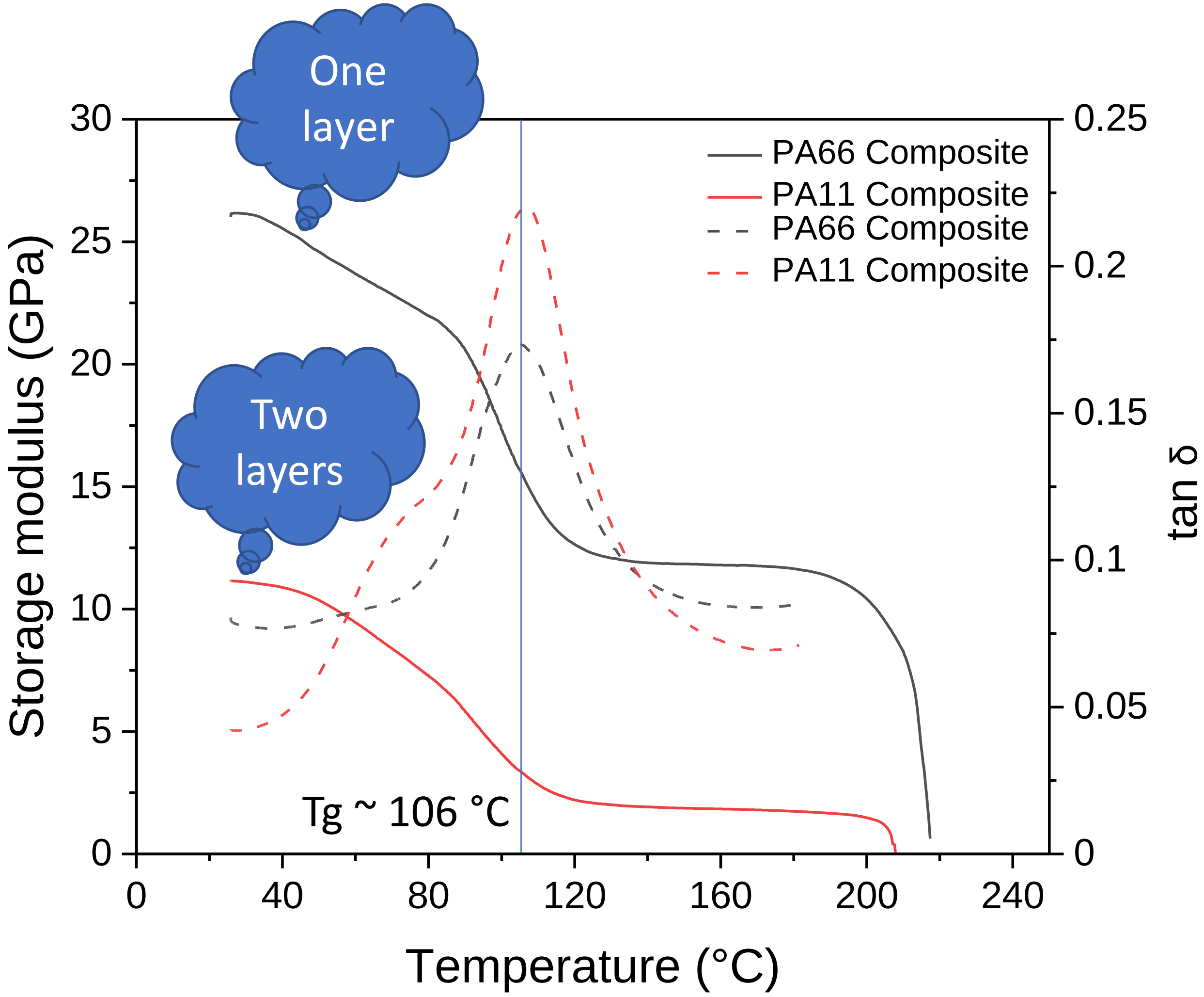
With protection sheet

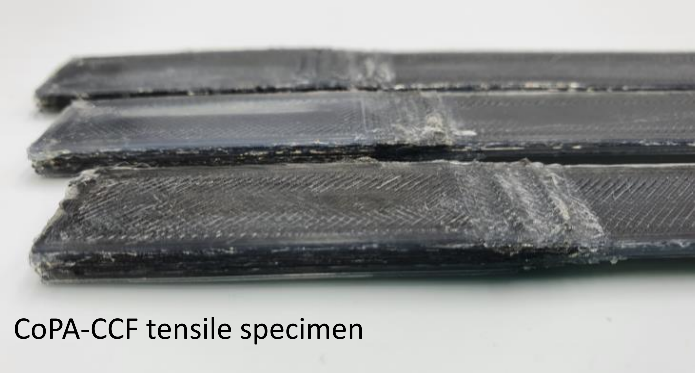


The amount of CF in the composite is around 17%

Material Characterization: DMA

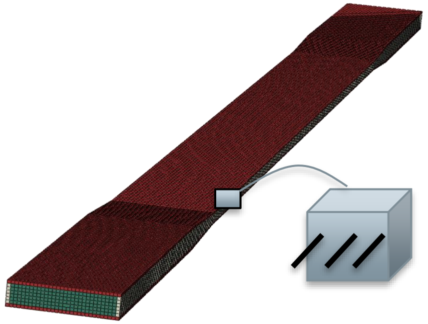
Both sample without protection sheet

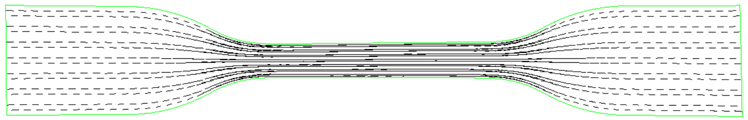




CoPA-CCF tensile specimen

FE- Model & Fiber orientation





Fiber orientations based FEM analysis & Principal stresses

PA 11 & CCF