High-temperature thermoplastic composites reinforced with recycled carbon fibers and thermal black for Fused Filament Fabrication

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DEVELOPMENT OF HIGH PERFORMANCE COMPOSITES FOR FUSED FILAMENT FABRICATION FOR AEROSPACE APPLICATIONS

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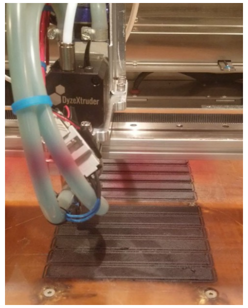
CREPEC | Centre de recherche sur les systèmes polymères et composites à haute performance

OUTLINE

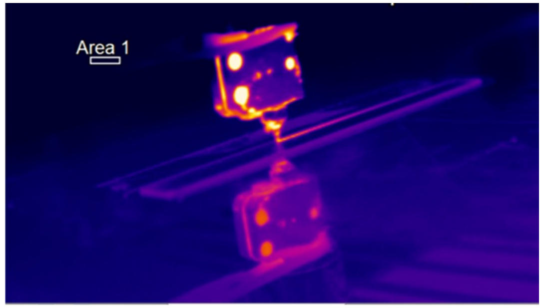
- Introduction
- Objectives
- FFF printing parameters
- Porosity analysis of 3D printed part (SEM and Micro CT)
- Mechanical performance of injected and FFF 3D printed composites
- SEM characterization of FFF printed composites
- Effect of TB incorporation in advanced composites microstructure
- Summary and future works

Advanced composites compounds

Filaments



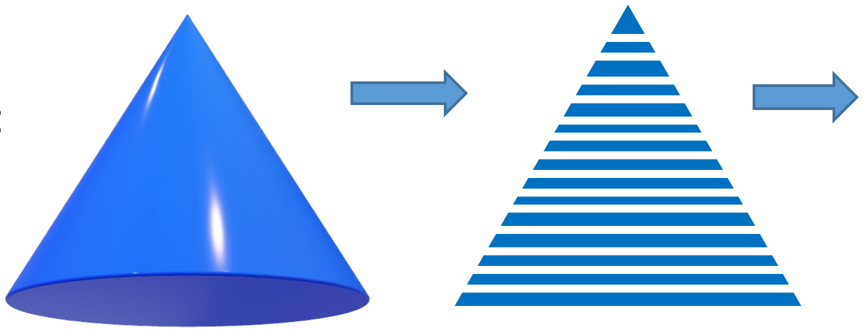
FFF printing



Advancement of FFF process

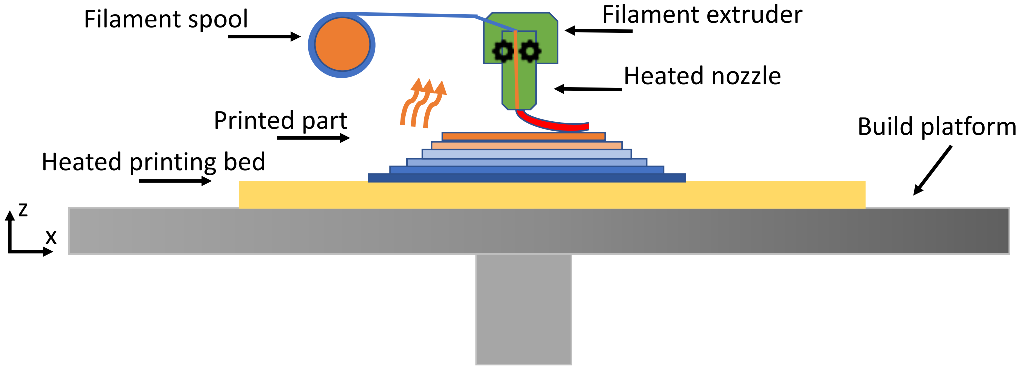
INTRODUCTION

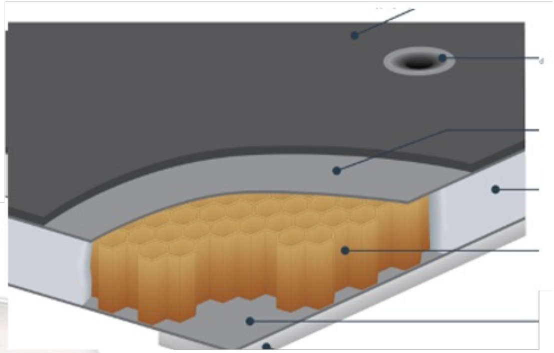
Fused Filament Fabrication (FFF)

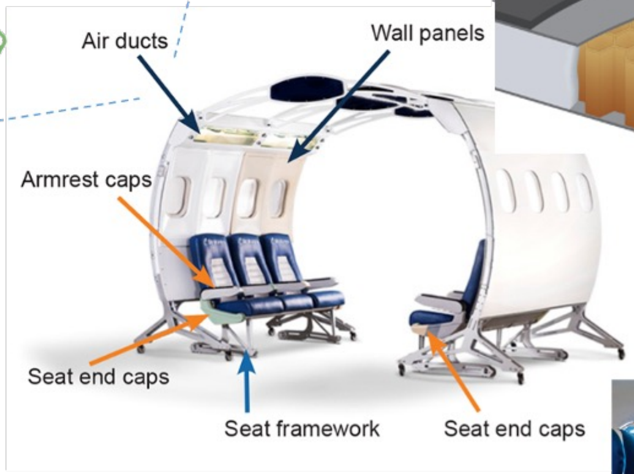


CAD design → Slicing & G code generation → Printing

Use of thermoplastic feedstocks







"Up to 60% of a next-generation aircraft cabin could be 3D printed" *.

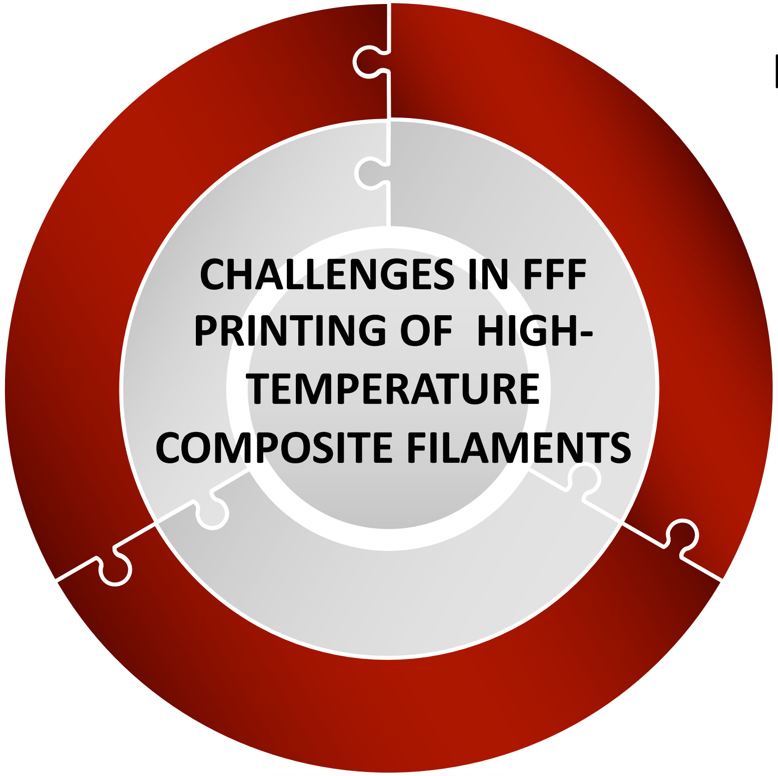
*https://www.etihad.com/en/news/etihad-engineering-unveils-3d-printing-lab-and-receives-the-regions-first-approval-to-3d-print-aircraft-parts-using-eos-powder-bed-fusion-technology

https://www.stratasysdirect.com/applications/environmental-control-systems-ducting

INTRODUCTION – WHAT ARE THE CHALLENGES?

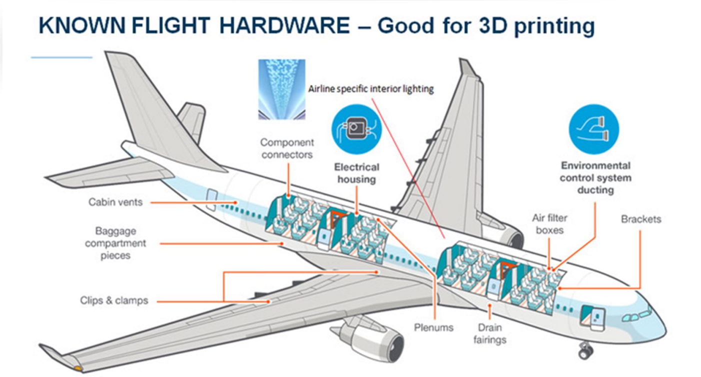
High Cost

- High Performance Polymer
  - ✓ PEEK, PEI, PEKK, PPS, PESU
- Additives
  - ✓ Fibers, filler particles, pigments, etc.
- Commercial filament prices
  - ✓ 400-1000 $/kg



High temperature processing

- Compounding (extrusion)
- Injection-molding
- Filament extrusion
- 3D printing



High mechanical performance

Parts for applications in:

- Aerospace (interior of planes)
- Ground transportation (trains)

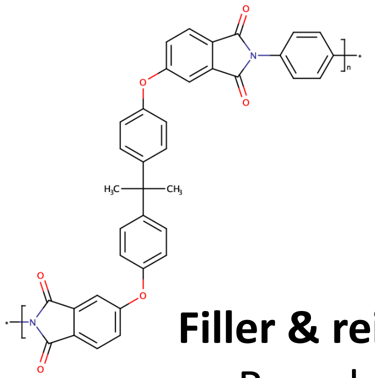
https://www.tctmagazine.com/additive-manufacturing-3d-printing-news/additive-manufacturing-in-the-aircraft-cabin

OBJECTIVE

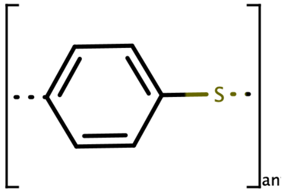
Main Objective: FFF 3D printing of advanced thermoplastic composites through the development of novel materials by improving open-source 3D printing process to fabricate at high performance of composite parts.

Formulation, Compounding and Filament Extrusion

Polyetherimide
PEI ULTEM 1040A
(amorphous)



Polyphenylene Sulfide
PPS Fortron 0214
(semicrystalline)

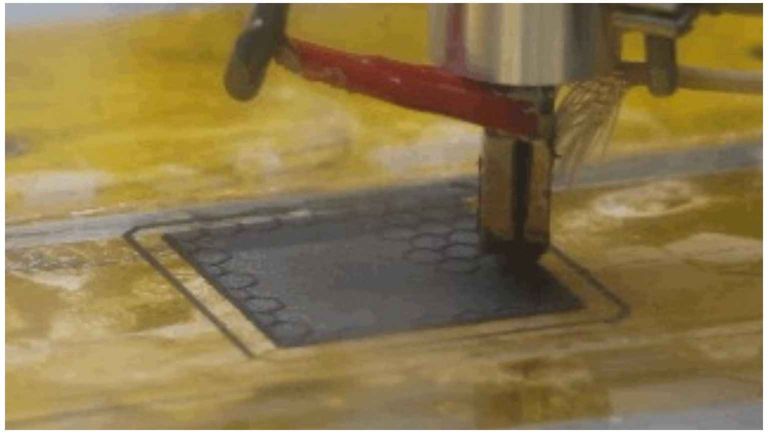


Filler & reinforcement:

- Recycled Carbon Fibre (rCF)
- Thermal Black (TB)

4 advanced composites of each PEI and PPS were formulated, compounded, injected and extruded into filaments at NRC lab.

Advancement of FFF printing



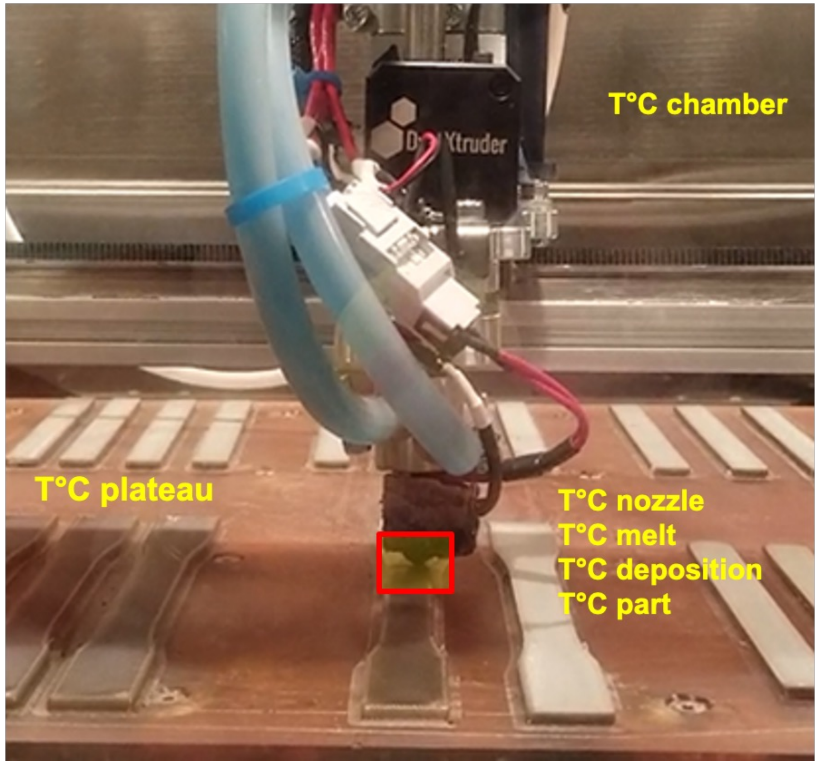
3D printing of advanced composites:

- Use of AON-M2 3D printer with heated chamber.
- Advancing the FFF printing process
- 3DP of high performance. composites parts.

FFF 3D PRINTING PARAMETERS

Before each processing stem, i.e. compounding, filaments extrusion, FFF 3D printing, all composite filaments were dried at 130-140 °C at least 12 hours and maximum 24 hours.

Heated Chamber - AON-M2 3D printer
FFF printing of tensile and flexural specimens



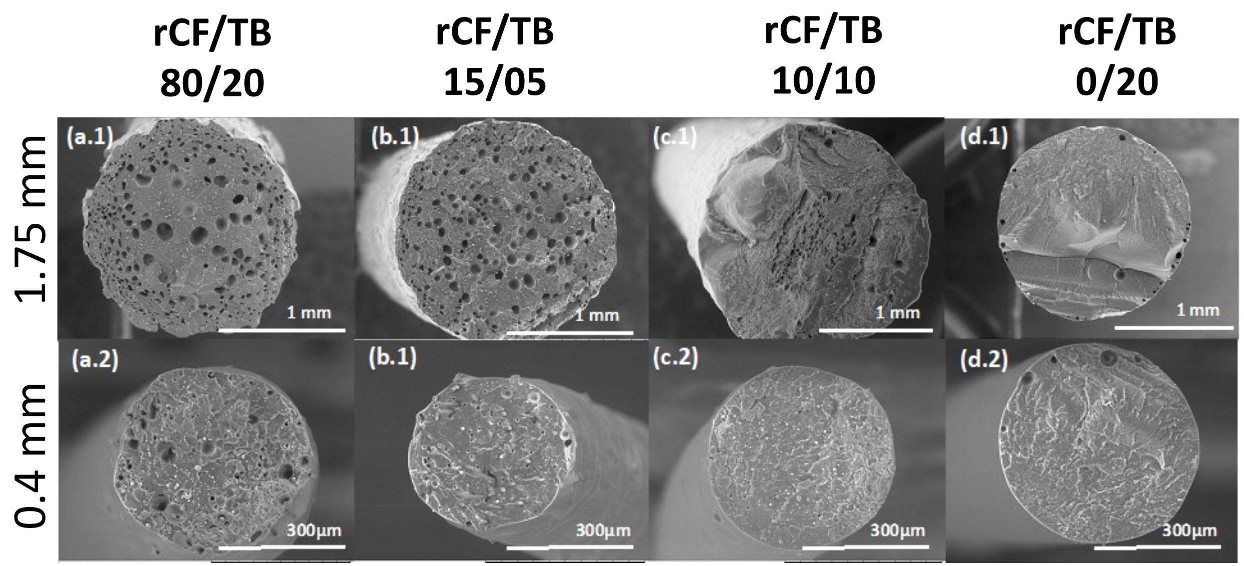
3D Printing parameters:

- Nozzle Temperature: 400°C
- Bed Temperature: 180°C
- Heat Chamber Temperature: 130°C
- Nozzle Diameter: 0.4 mm
- Layer height: 0.2 mm
- Printing Speed: 20 mm/s
- Raster angle: +/- 45°

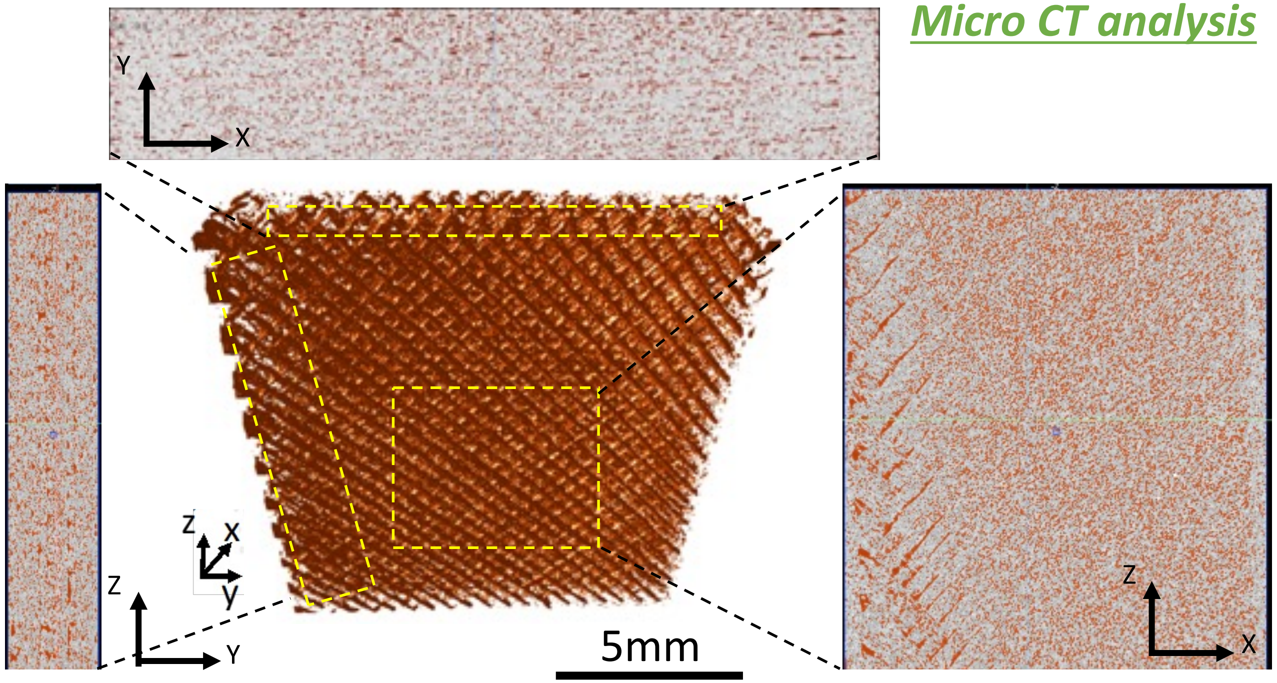
Type-1 dogbone specimens
ULTEM1040A/rCF/TB advanced composites

POROSITY PRESENCE IN FILAMENTS AND IN FFF 3D PRINTED SPECIMENS

SEM characterization



Micro CT analysis

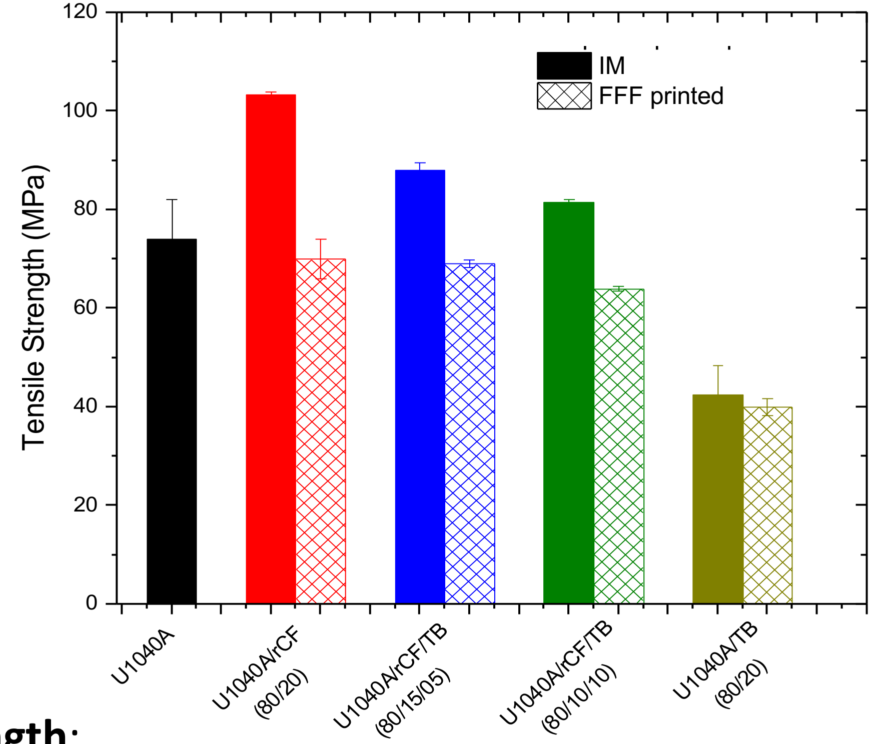


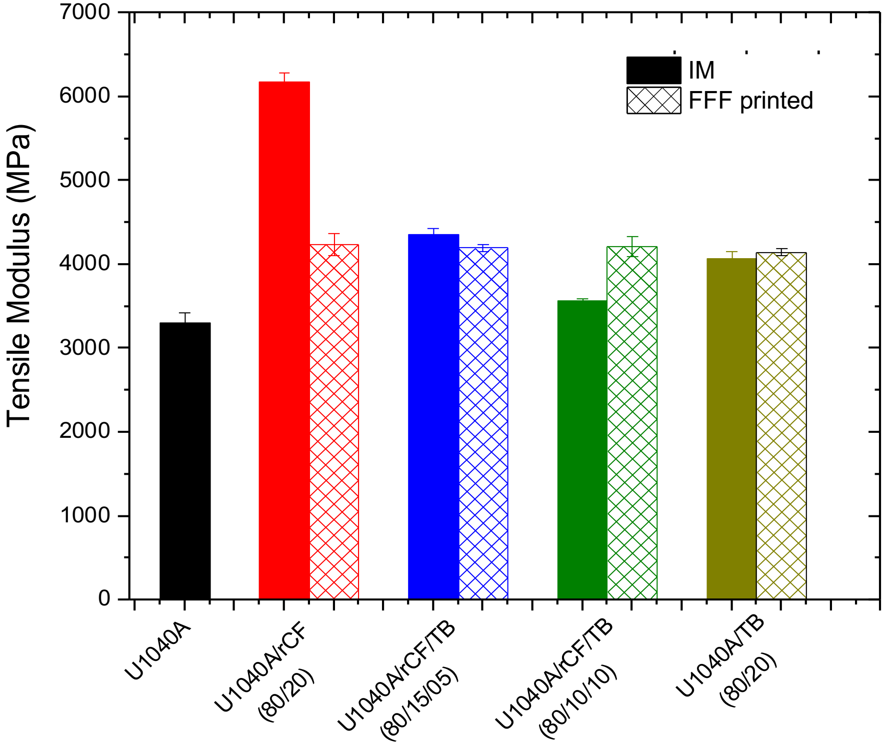
Porosity of 3DP specimens decreased by applying adequate drying and by increasing TB content:

Formulation	Intra-layer porosity (%)	Inter-layer porosity (%)	Total porosity (%)
ULTEM 1040A/rCF (80/20)	8.9	7.9	16.8
ULTEM 1040A/rCF/TB (80/15/05)	6.2	7.6	13.8
ULTEM 1040A/rCF/TB (80/10/10)	4.5	2.5	7.0
ULTEM 1040A/TB (80/20)	0.0	2.8	2.8

TENSILE PERFORMANCE: FFF 3D PRINTED VS. INJECTION MOLDED (IM) SPECIMENS

Tensile performance of FFF 3D printed ULTEM 1040A advanced composites similar to IM





Tensile strength:

- FFF printed composites shown slightly lower tensile strengths when compared to IM ones, possibly due to the presence of some porosities (low contents)

Tensile modulus:

- All printed composites presented higher modulus when compare to IM pure ULTEM 1040A
- **3DP composites containing 15 wt.% rCF / 5 wt.%, 10 wt.% rCF / 10 wt.%, and 20 wt.% TB shown the same Tensile Modulus as their IM counterparts**

SEM: GOOD LAYER-TO-LAYER ADHESION FOR 3D PRINTED ULTEM 1040A ADVANCED COMPOSITES

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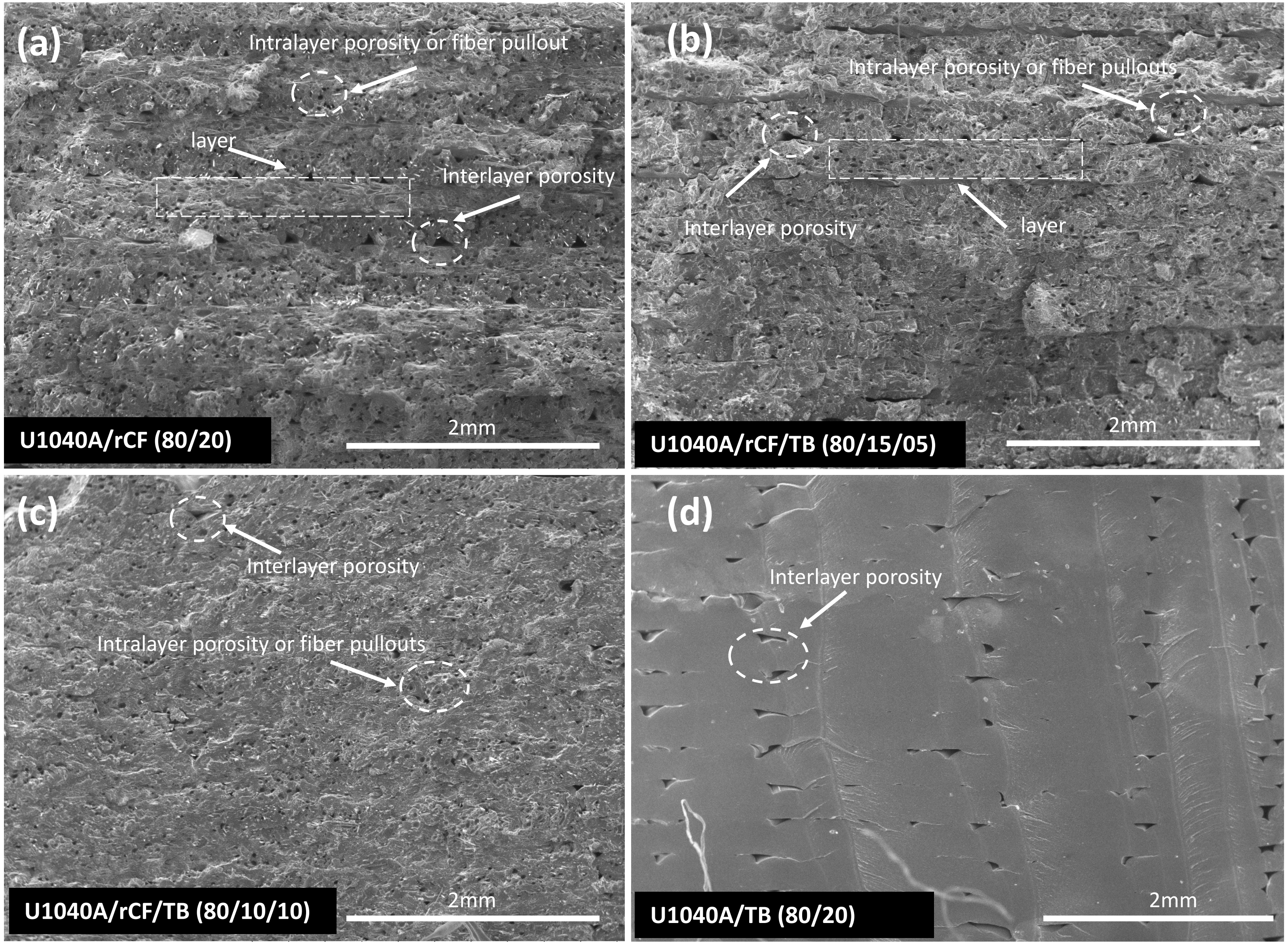
Fracture surface of FFF printed composites investigation was done in terms of layer adhesion and porosity presence



- Observed fractured surfaces presented, in general, low Inter-layer and Intra-layer porosity contents
- Intra-layer porosity formation decreased significantly when rCF was replaced by TB
- Almost no intra-layer porosity for composites with 20 wt.% TB, only inter-layers
- Inter-layer porosities could be reduced at minimum by further improving the FFF process

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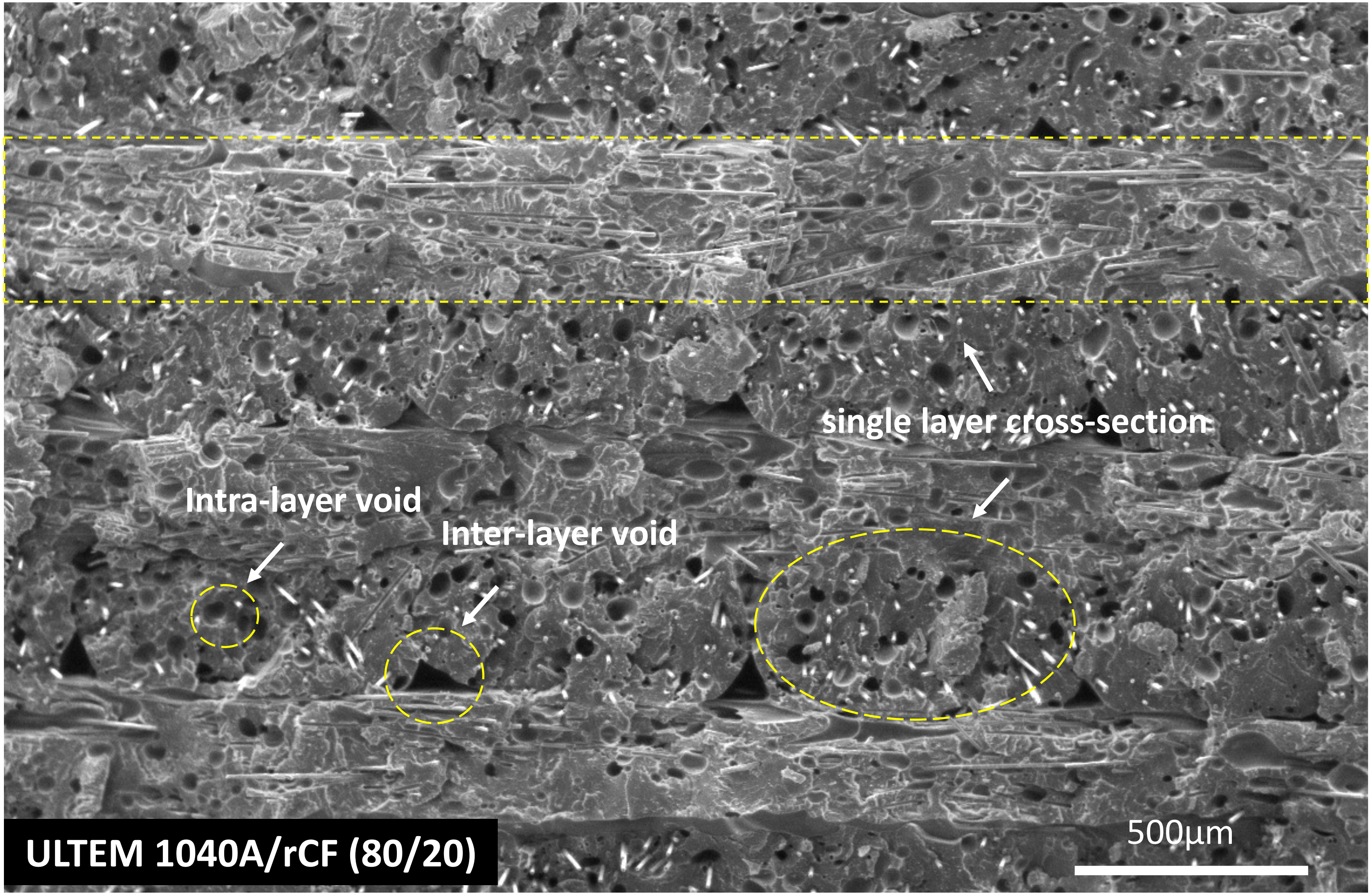
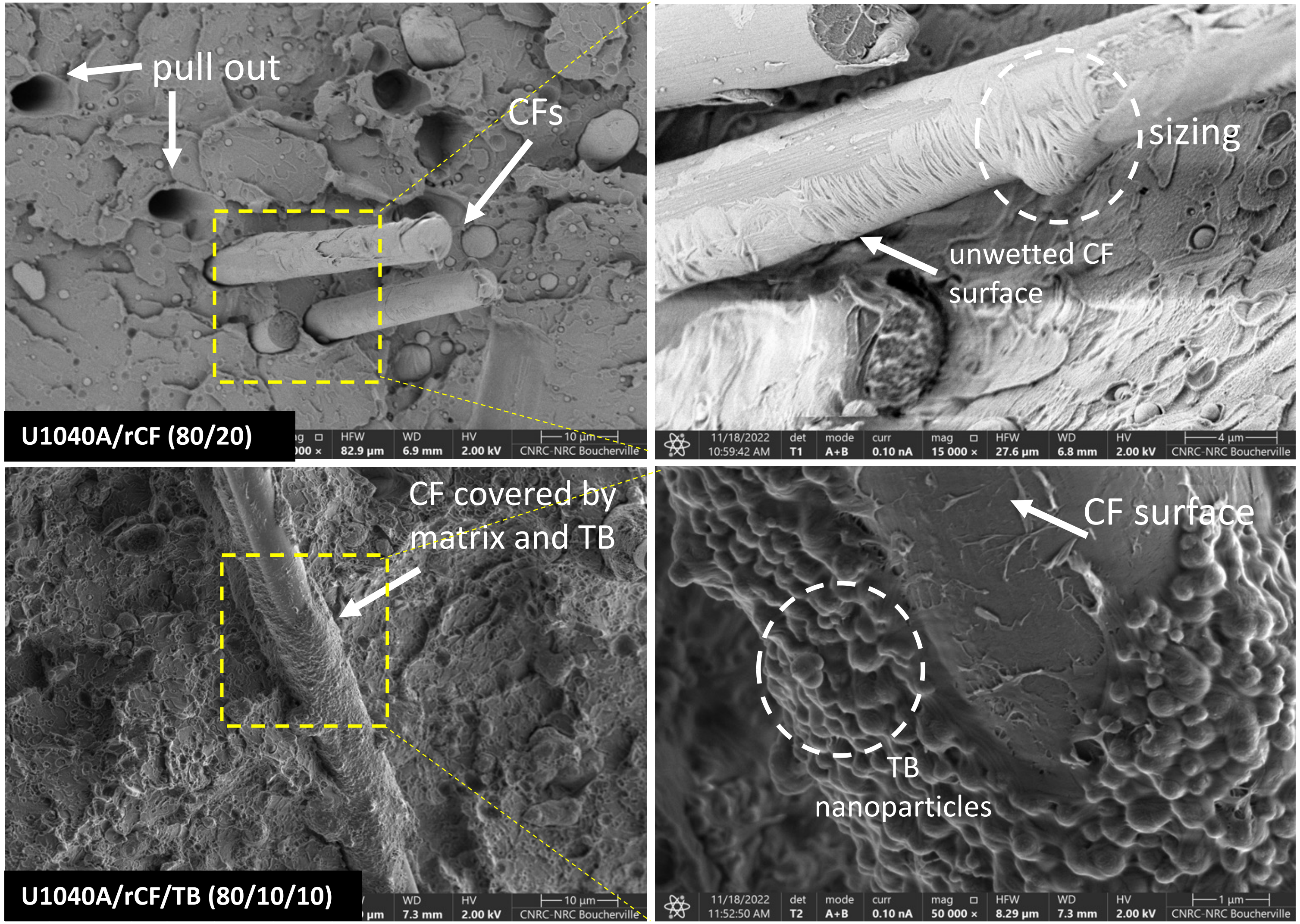
SEM: FRACTURE SURFACE OF FFF PRINTED COMPOSITES

Good layer-to-layer adhesion was observed for 3D printed ULTEM 1040A advanced composites



EFFECT OF TB INCORPORATION ON FIBER-MATRIX ADHESION

The fractured surfaces resulted from Impact testing were investigated by SEM to observe fibres/fillers dispersion and distribution and fiber/filler-ULTEM 1040A matrix adhesion

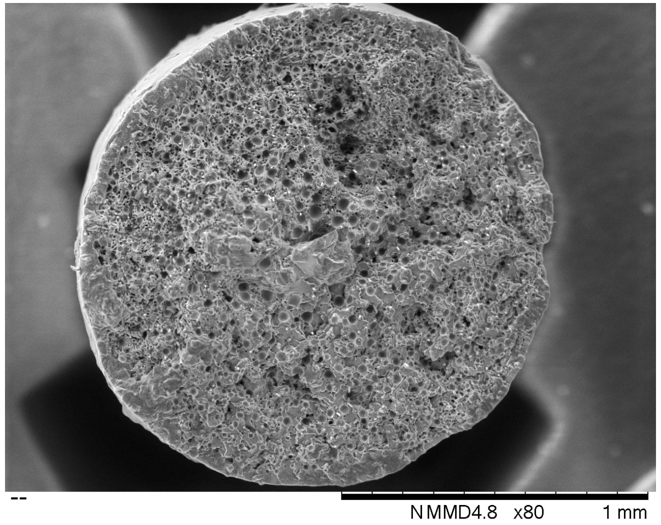


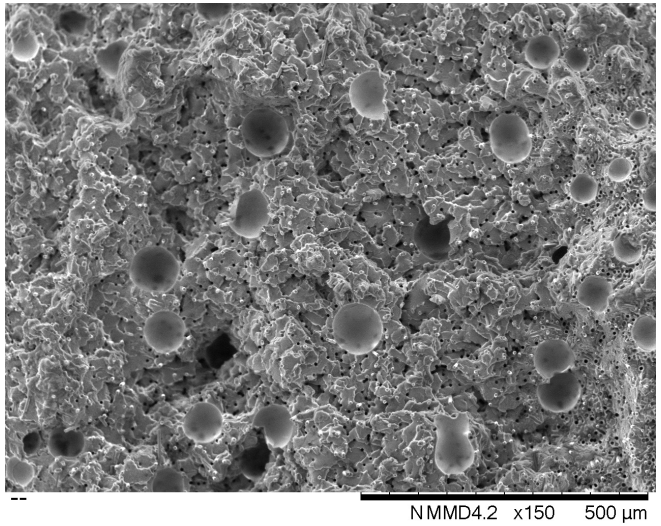
- Very good dispersion and distribution of TB and rCF were observed
- Low-medium fiber-matrix adhesion for composites with 20 wt.% of rCF
- The incorporation of TB seems to provide a synergistic effect by enhancing fiber-matrix adhesion
  - rCF surface was covered by matrix and TB particles

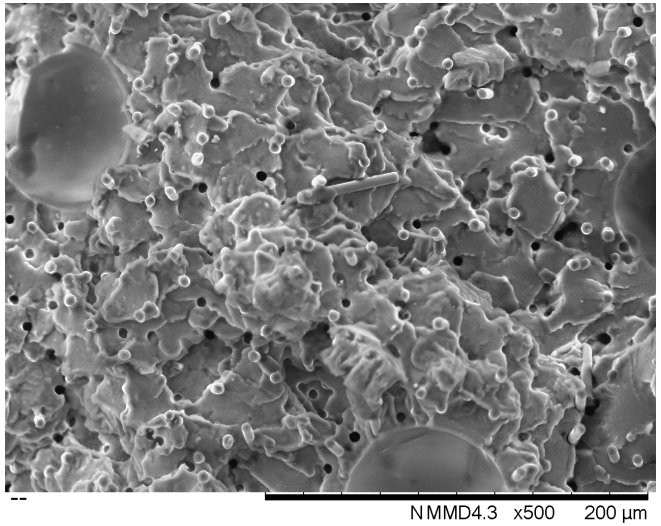
MORPHOLOGY OF PPS/rCF 80/20 FILAMENTS

Filaments obtained from PPS/rCF/TB composites

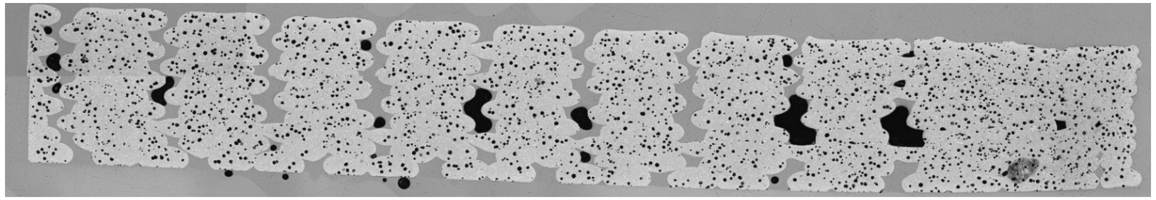
SEM on fracture surface of PPS/rCF 80/20 filament







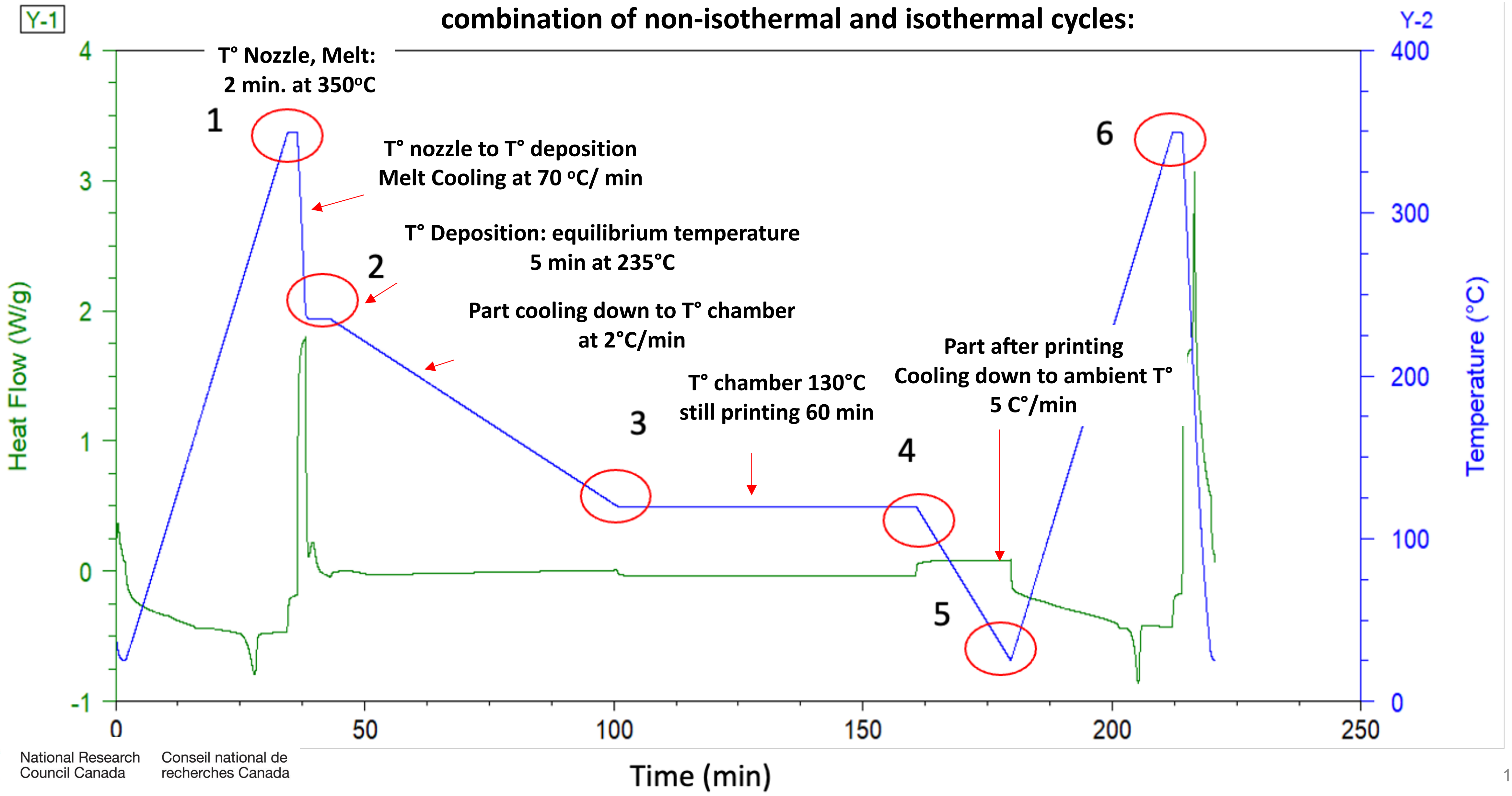
Voids % calculation in PPS/rCF 80/20 FFF 3D printed part: 18%



Work is on-going to fine-tune the FFF parameters to the crystallization behavior of PPS composites and hybrids

EFFECT OF TB INCORPORATION ON PPS CRYSTALLIZATION

FFF printing of the semicrystalline PPS composites in AON-M2 environment were experimentally simulated using a combination of non-isothermal and isothermal cycles:



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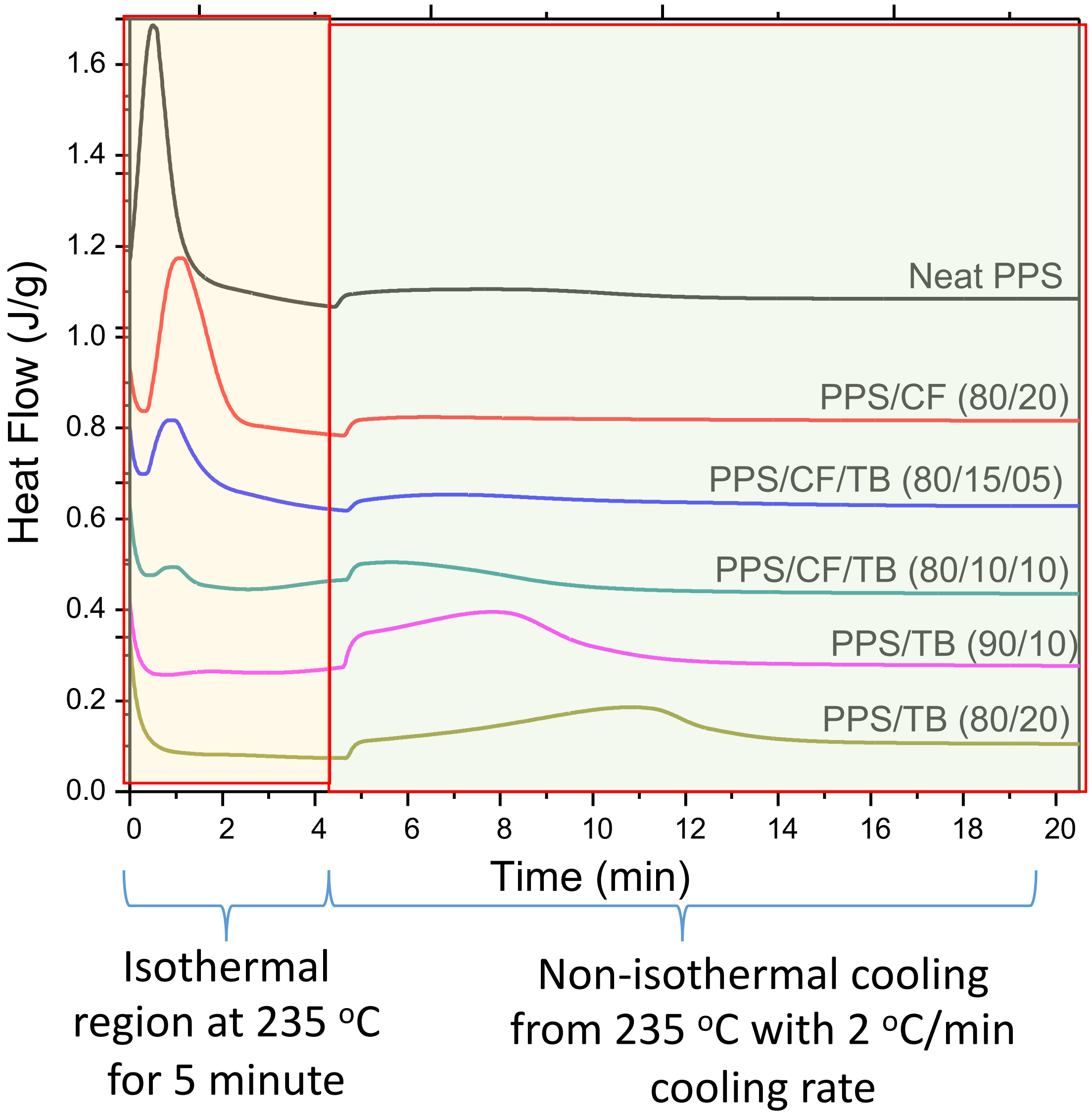
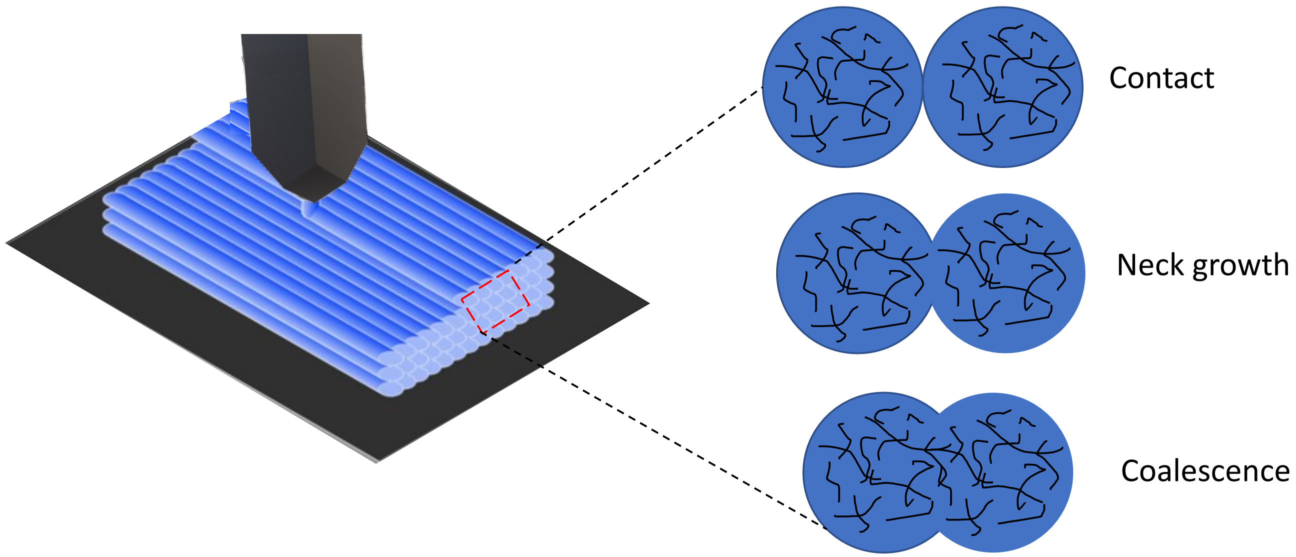
EFFECT OF TB INCORPORATION ON PPS CRYSTALLIZATION

rCF and TB incorporation significantly affects the crystallization behavior of PPS composites which is expected to directly affect adhesion mechanism between printed layers.



- Incorporation of TB significantly postponed the crystal formation
- No crystallization was observed during isothermal step at 10 wt.% of TB incorporation
- TB incorporation is expected to help at the enhancement of layers adhesion of printed part since the crystallization was significantly hindered



SUMMARY AND FUTURE WORK

Summary

- Formulations of advanced composites based on PEI ULTEM 1040A and PPS Fortron 0214 with rCF and TB were successfully obtained
- Our advanced composites proved to be easily processed in filaments for FFF printing
- PEI ULTEM 1040A composite filaments were successfully printed using the open-source high-temperature 3D printer, AON-M2 (heated chamber)
- 3DP specimens with relatively high-performance were printed (very low porosity contents)

Future work

- Further improvement of 3D printing parameters for PPS/rCF/TB composites while considering its crystallization behavior
- FFF 3D printing of airplane interior parts and their characterization
  - Air ducts
  - Seat framework
  - Sandwich panels