domminio

Digital method for improved manufacturing of next-generation multifunctional airframe parts

Improving thermal management of FFF nozzle for aerospace applications

2nd Workshop
18th of October 2022

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** CT-IPC ° ESI*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101007022.

“**IPC, Centre Technique d’Innovation** et d’expertise au service de l’industrie de la **Plasturgie et des Composites**”

“**IPC, Technical Center of Innovation** and expertise supporting **Plasturgy and Composite** industry.”

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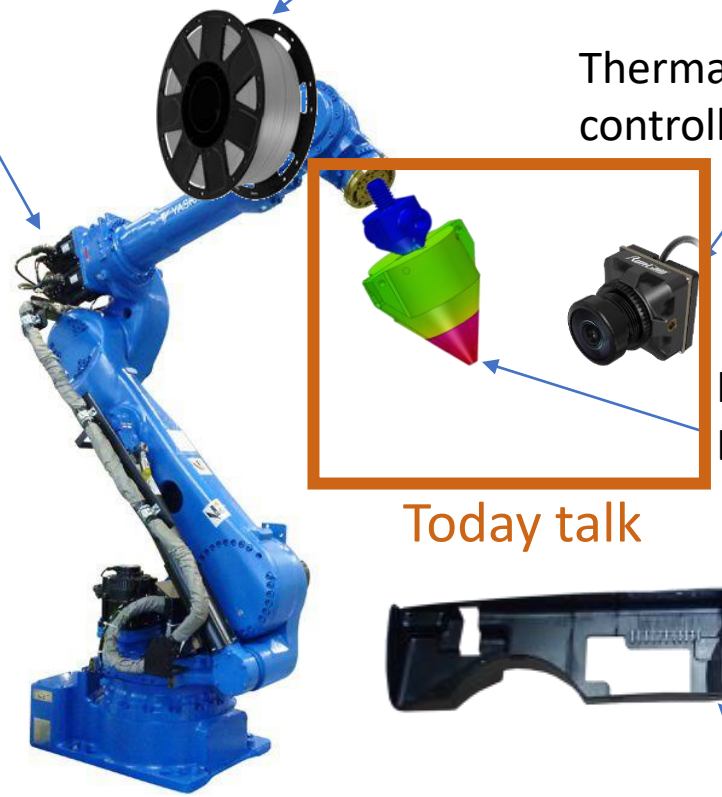
Introduction - FFF Process

State of the art :

- Heated chamber -> Slow
- Limited size
- No hybridation possible

Only for low volumes

Objectif



Technical filament (PEKK), with or without continuous fibre

5 axis

Thermal camera, PID temperature controller

Instrumented nozzle
Local thermal management

Today talk

Existing part

Serial production

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IPC

Nozzle specifications

Printed materials

Non Planar printing (NP)

Instrumented

PEKK 60:40 $T_{op} = 320$ à $360°C$

User case design
→ No congestion around the nozzle

T° → Thermocouples
Adapted on each nozzles

<u>3 Filaments = 3 nozzles:</u>

1. PEKK60:40 + **magnetics** NP
   → 1,75mm
1. PEKK60:40 + **cCF** → 0,8mm
3. PEKK60:40 + **CNT** → max 0,8mm

→ L-PBF

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Agenda

Introduction

1) Development of the nozzle for PEKK+MNP filament
2) Improving PEKK layers adhesion
3) Development of the nozzle for PEKK+cCF filament

Conclusion

Outlook

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101007022.

I – Development of the PEKK+mNP nozzle

Filament parameter :

- Standard diameter : 1,75mm
- PEKK with dispersed magnetic particles ∽ PEKK

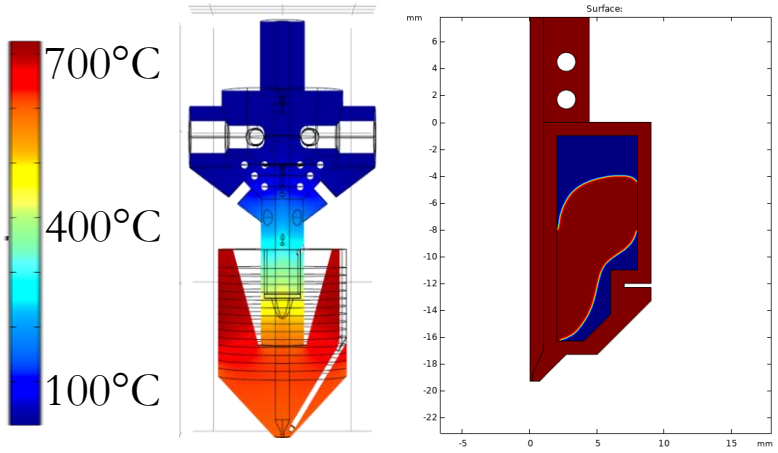
Objectives :

- Home made nozzle to have control on thermocouples placement and tip geometry

Constraints :

- Operating temperature : 320-360°C
- Machinability

Thermal simulation → sizing the nozzle



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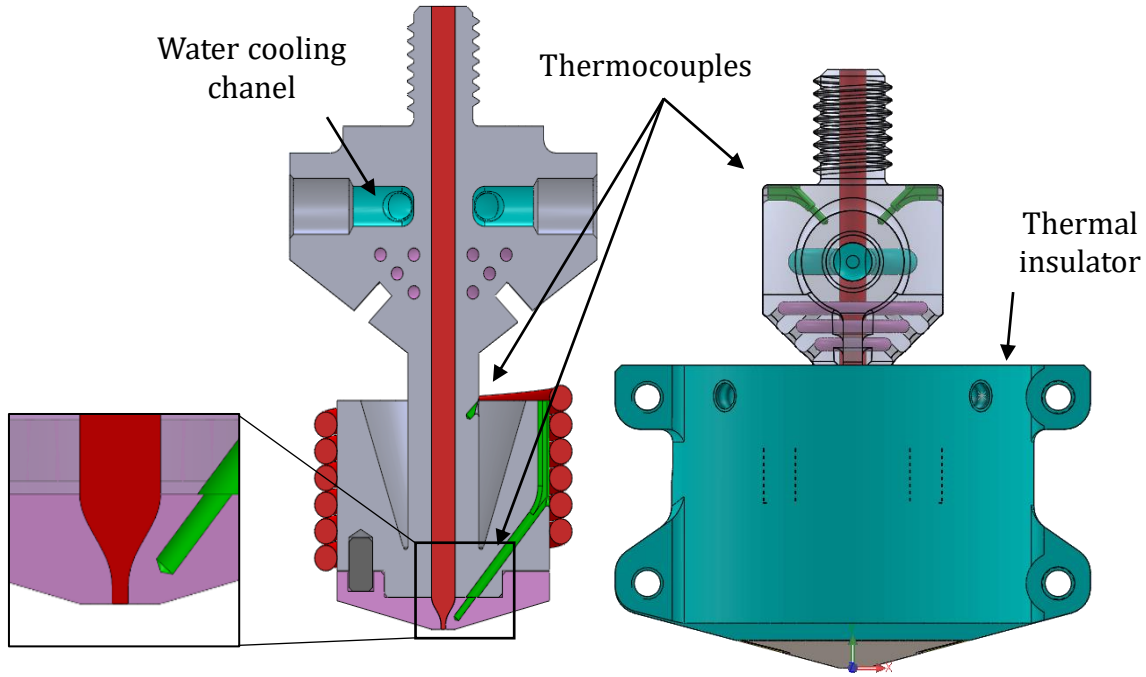
Thermocouples implantation



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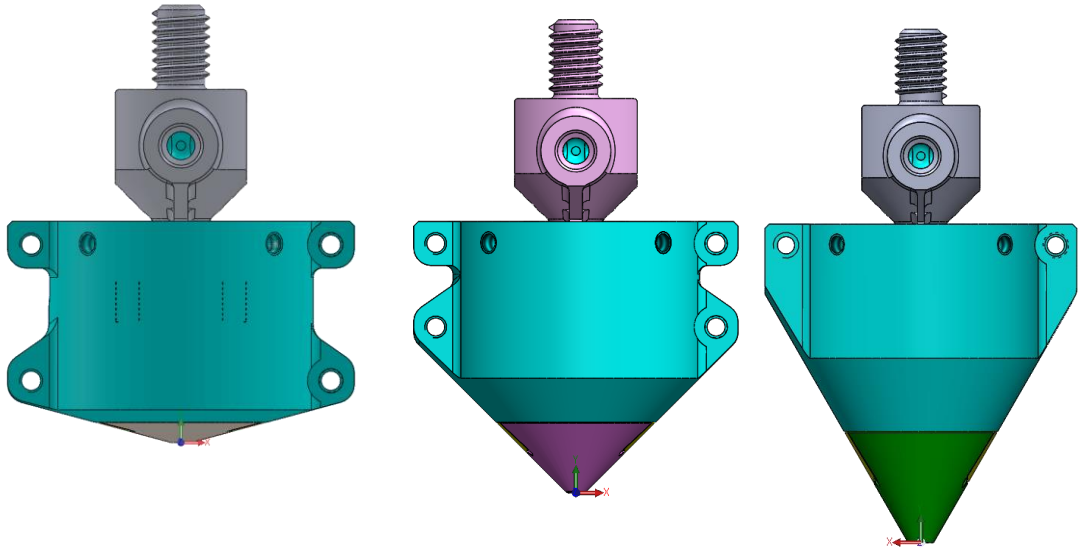
Most promising designs → L-PBF



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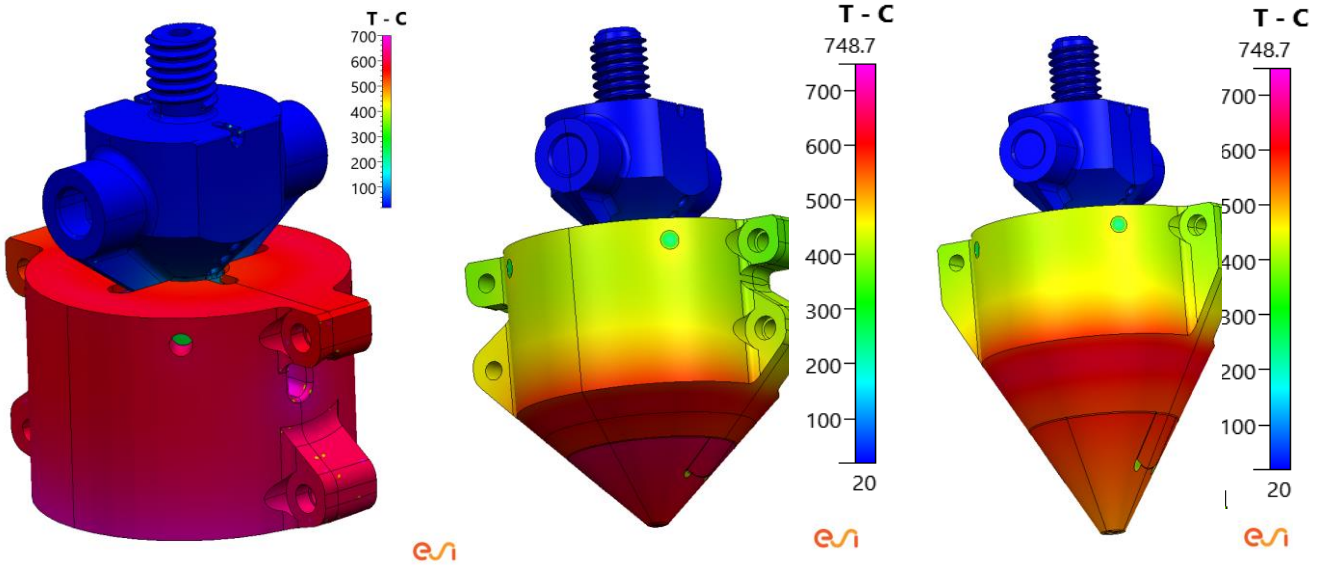
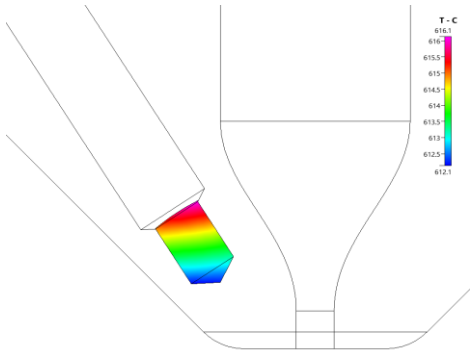
Simulation





Measurements

At the inside thermocouple
Maximum temperature, without extrusion

- **15° nozzle**

Simulation: T = 822°C
Experiment: T = 823 °C

- **45° nozzle**

Simulation: T = 612 – 616 °C
Experiment: T = 588 °C

- **60° nozzle**

Simulation: T = 534 – 538 °C
Experiment: T = 538 °C

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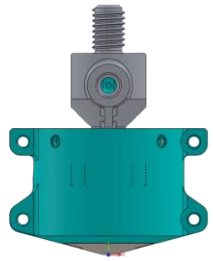
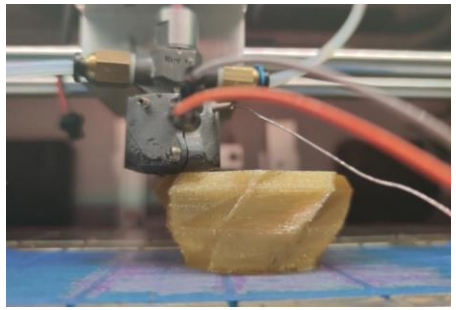
I – Development of the PEKK+mNP nozzle

PEKK

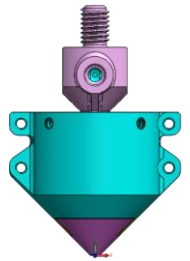




Too flat, heating issues

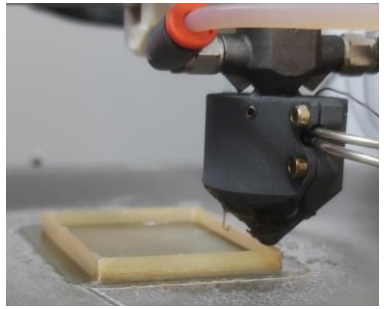
Experiments

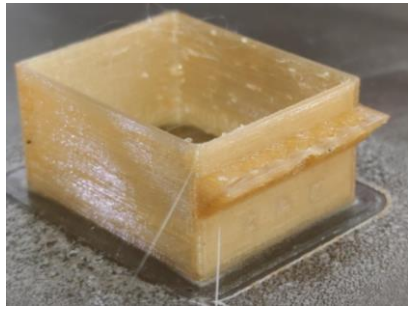
- Prusa (modified) and Roboze FFF machines
- Industrial PEKK and PEI filaments



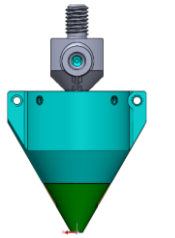
Best compromise

PEKK **PEI**





PEKK **PEI**



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II – Improving PEKK layers adhesion

Radiative heat transfer between nozzle tip and substrate should be different:

Heat absorbing area on substrate should be bigger for the 60° nozzle. At the same time the heat flux emitting nozzle tip is around 70K smaller:

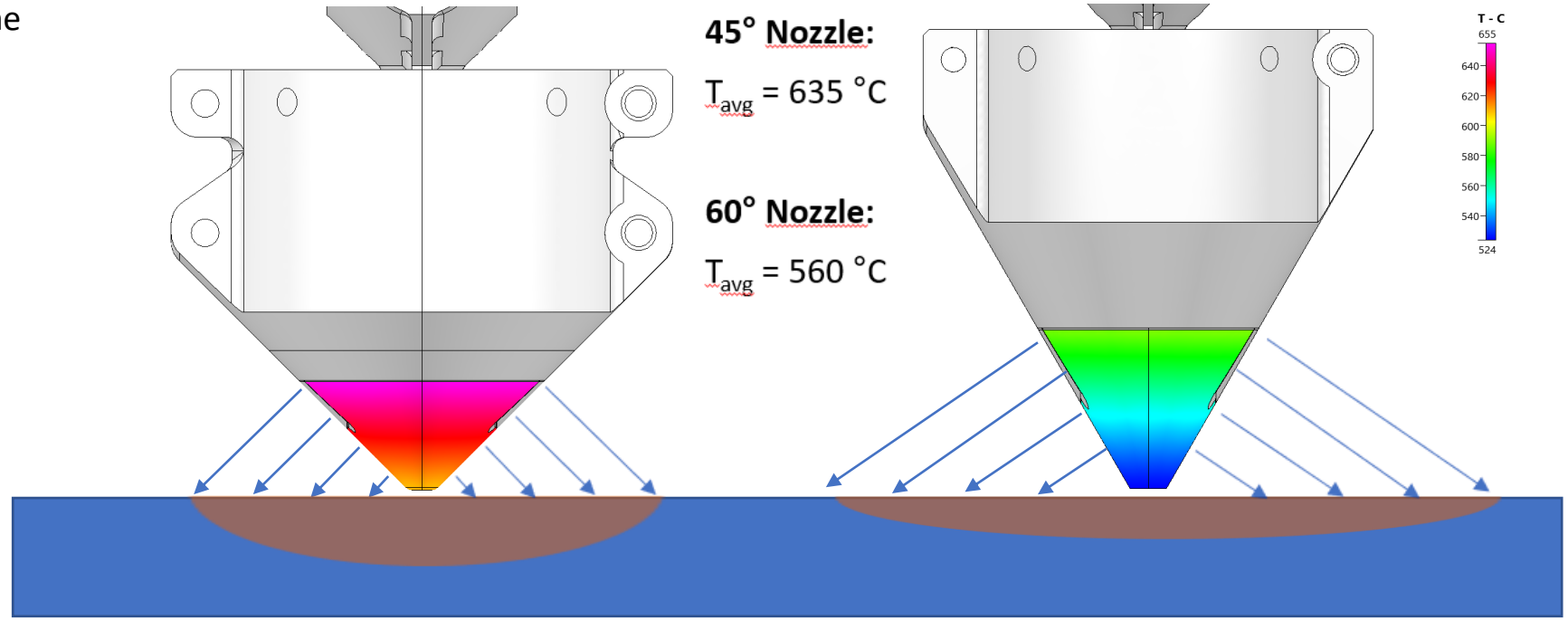
$$\dot{Q}_{60°} = \epsilon \cdot \sigma \cdot A_{nozzle} \cdot 833^4_{nozzle} = 4.81 \cdot 10^{11} \cdot \dots$$

$$\dot{Q}_{45°} = \epsilon \cdot \sigma \cdot A_{nozzle} \cdot 903^4_{nozzle} = 6.80 \cdot 10^{11} \cdot \dots$$

$$\frac{\dot{Q}_{45}}{\dot{Q}_{60}} = \frac{6.8}{4.81} = 1.41$$

$$\frac{A_{45}}{A_{60}} = \frac{\cos(45°)}{\cos(30°)} = 0.82$$

1.41/0.82 = 1.7195



45° Nozzle **60° Nozzle**

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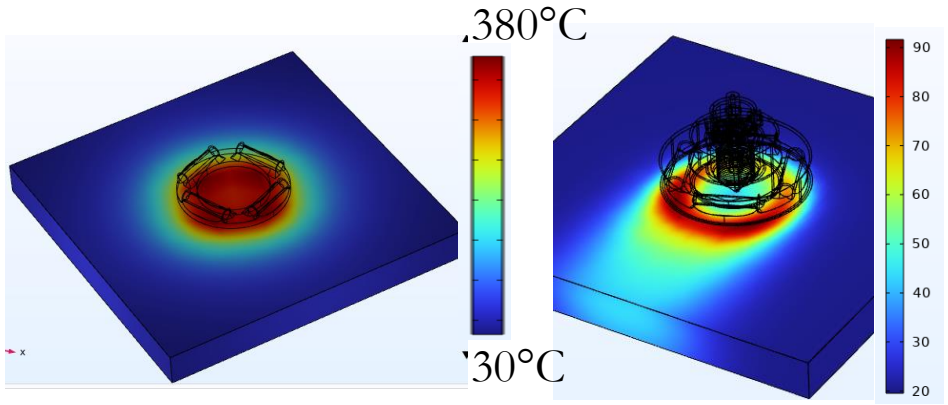
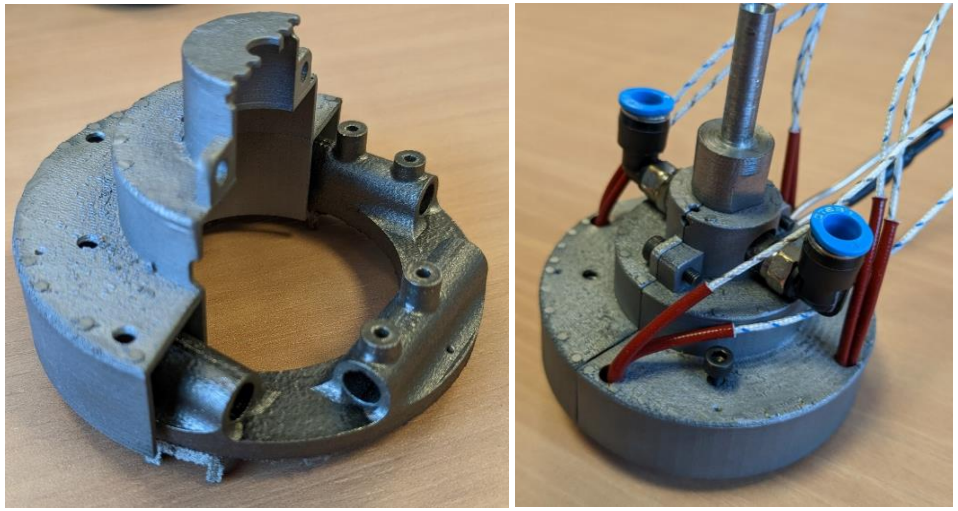
Thermal « dome »

- To improve the layers adhesion by creating a high temperature atmosphere around the printed zone.
- Heats independently of the nozzle



Thermal simulation
Help to size the thermal « dome »



Thermocouples integrated for a heating management

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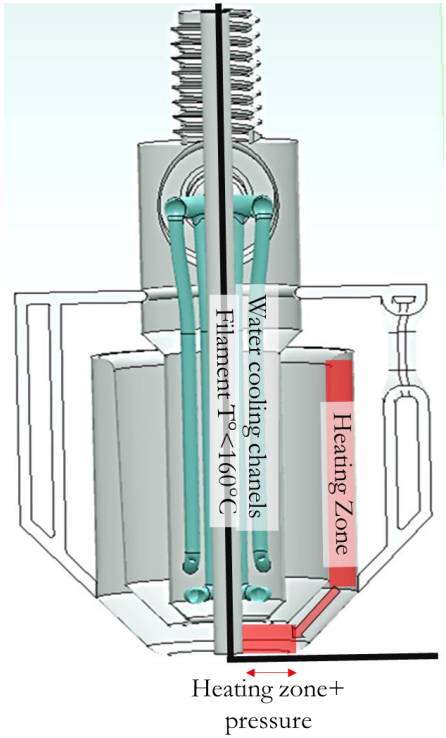
III – Development of PEKK+cCF nozzle

Filament parameter :

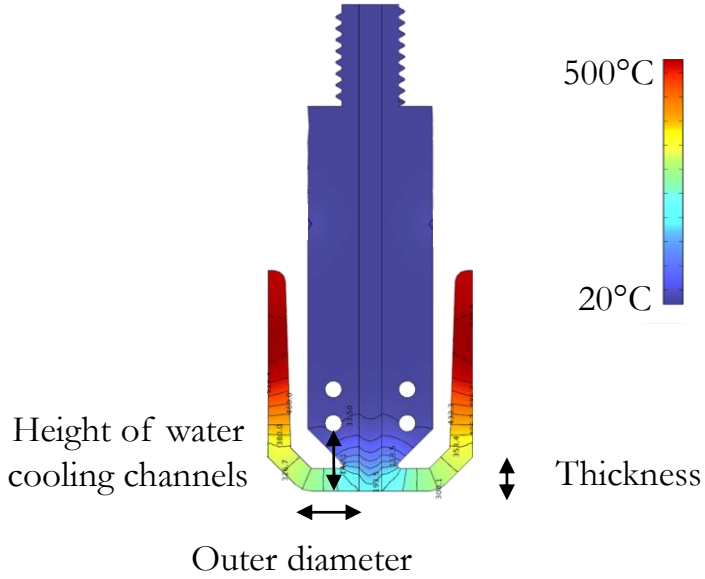
- Non standard diameter : 0,8mm
- Core/shell structure

Objectives :

- Design that avoid delamination issues
- Home made nozzle to have control on thermocouples placement and tip geometry
- Operating temperature : 320-360°C



Thermal simulation → sizing the nozzle



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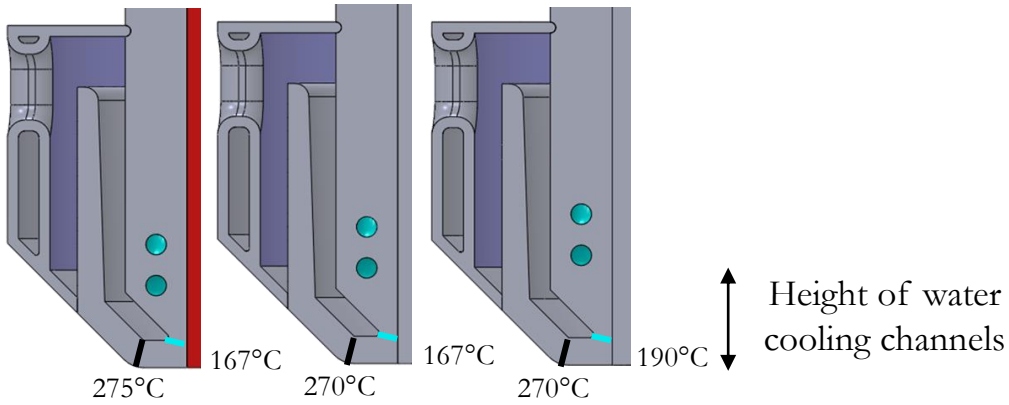
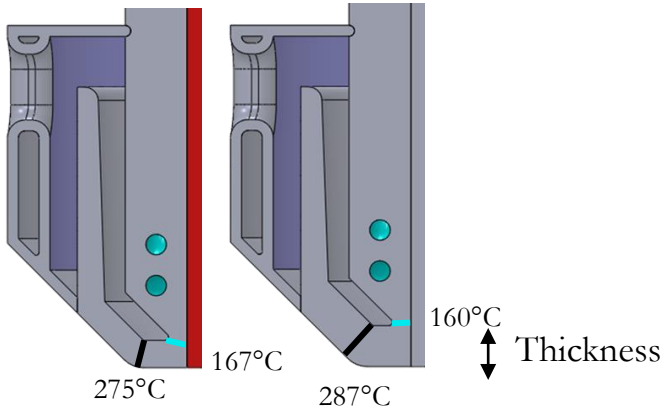
III – Development of PEKK+cCF nozzle

Height of water cooling channels



Thickness



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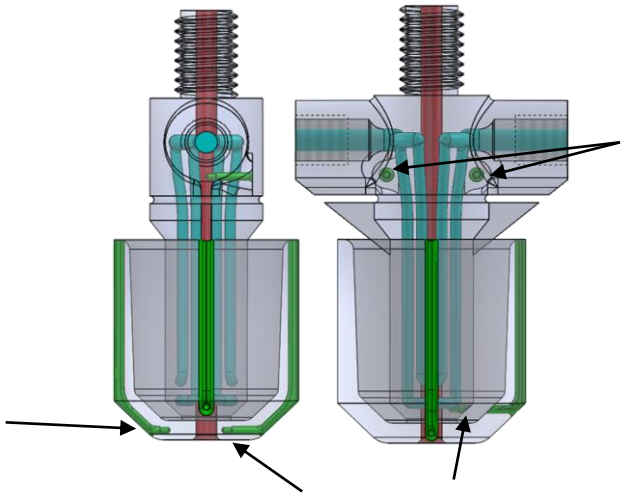
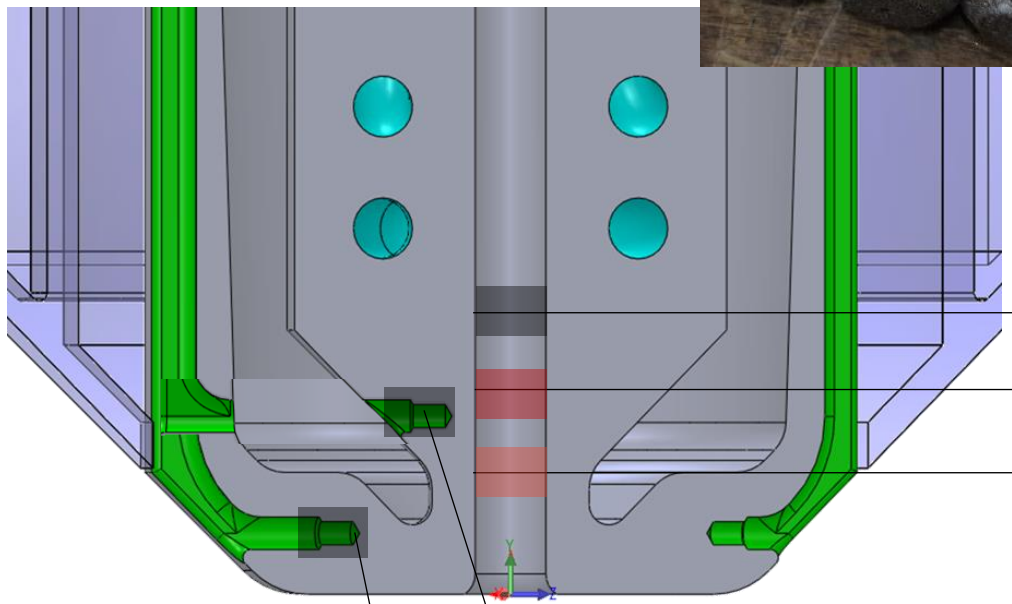
Thermocouples implantation



Water T° control
(a small delta sould be observed)

Control the T° where the filament should be melted
(should be > 300°C)

Control the T° at the tip of the nozzle
(should stay <160°C)



Experiments

T°>Tg inside on the last 5mm
Need to be tested with AIMEN filament

→ Tested on Commercial cCF/PA filament (line printing)

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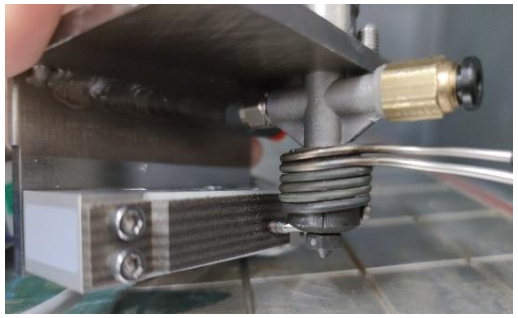
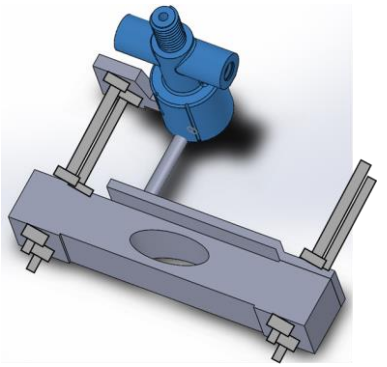
Conclusions

- We have developed a nozzle that allow to print PEAK commercial filament on a modified prusa FFF machine
- We are developing a heating system to help printing PEAK filament
- We have developed a specific nozzle for PEKK+cCF filament

Outlook

- Compare the impact of the heating “dome” onto the mechanical properties of the printed samples
- Testing PEKK+cCF nozzle on AIMEN FFF head
- Implement force sensor





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Thank you for your attention

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