ICCM 23
BELFAST 2023

domminio

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

Belfast, 30th July – 4th August 2023

A STUDY ON CONSOLIDATION OF THERMOPLASTIC COMPOSITES WITH IN-SITU AUTOMATED FIBER PLACEMENT PROCESS

Dr. E. Rodríguez- Senín, N. González- Castro, B. Simoes and I. Coto

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

AIMEN TECHNOLOGY CENTER

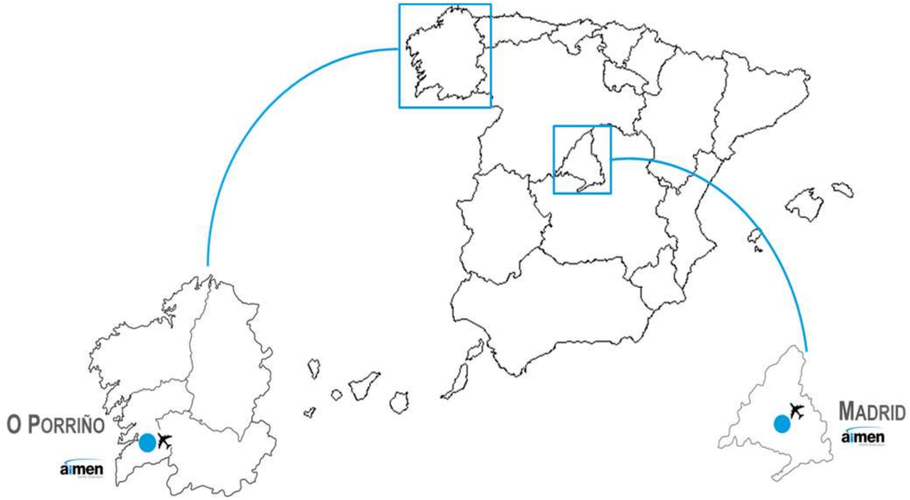
1967 • **AIMEN** was established with the aims of promoting **R&D** and high-added value **technology services**. **Industry supported, private centre.**

2023
- Main technological capabilities in:
  - **Advanced Manufacturing**
  - **LASER Processing**
- Multisectoral Centre
- International activities in 20 countries
- Over 750 active customers
- More than **50 R&D projects per year**
- Headcount: **280** ***(50% in R&D&i)***
- **18 M€** average annual income
- Over **30 M€** in assets

Testing & Analysis

Industrial Services

R&D&i



Location:
- HQ and Laser Processing Centre (O Porriño, Galicia)
- Offices in Madrid

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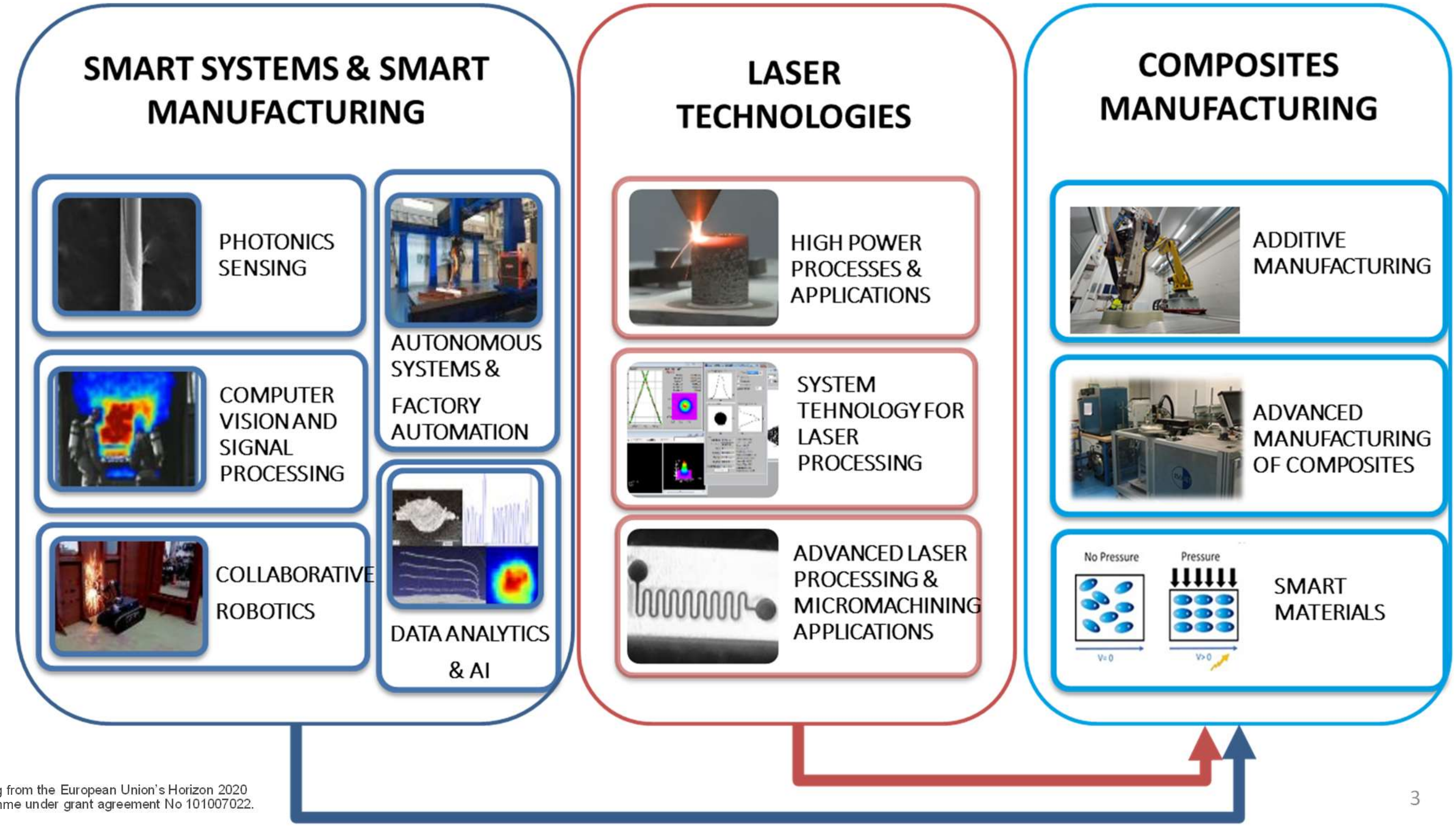
R&D Areas



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CONTENT:

- ✓ DOMMINIO PROJECT INTRODUCTION
- ✓ AUTOMATED FIBER PLACEMENT PROCESS: IN-SITU CONSOLIDATION OPTIMIZATION

  RESULTS:

  - Effect of layup tool temperature
  - Effect of compaction roller
  - On-going work: laser heating control
- ✓ CONCLUSIONS AND NEXT STEPS

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Introduction

DOMMINIO is the acronym of:
'Digital method for improved manufacturing of next-generation multifunctional airframe parts''

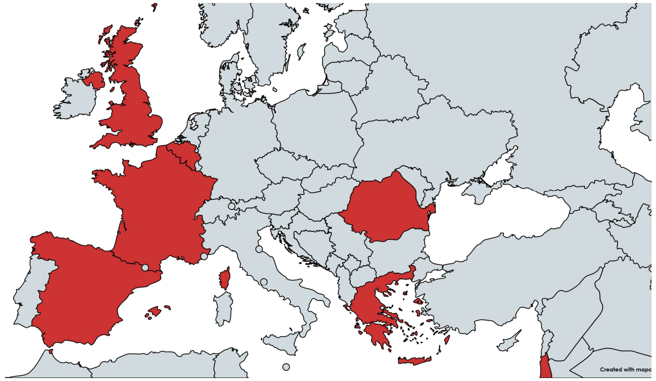
*Horizon Europe Topic MG-3-5-2020: 'Next generation **multifunctional and intelligent airframe** and engine parts, with emphasis on **manufacturing, maintenance and recycling**' (RIA, TRL 2-4)*
Call within - Work Programme 2018-2020 Smart, green and integrated transport

Starting Date: First of January 2021	Duration: 42 months (July 2024)

- To enable flexible multistage robotic-based manufacturing production processes
- To develop a Quality-by-Design (QbD) manufacturing strategy.
- To set a data-driven pipeline supporting the design, simulation and production planning.
- To build a combined digital-physical driven methodology for Monitoring and Management of the Health of multifunctional airframe parts.

Introduction

Consortium: 13 partners from 7 countries



- aimen TECHNOLOGY CENTRE
- BAE SYSTEMS INSPIRED WORK
- ACITURRI
- easn Technology Innovation Services
- IRES Innovation in Research & Engineering Solutions
- Dasel sistemas
- INNOVATION PLASTURGIE COMPOSITES
- institute imdea materials
- TORTECH nano Fibers
- R-NANO
- esi
- INCAS National Institute for Aerospace Research "Elie Carafoli"
- Arts Sciences et Technologies et Métiers
- EASA European Aviation Safety Agency

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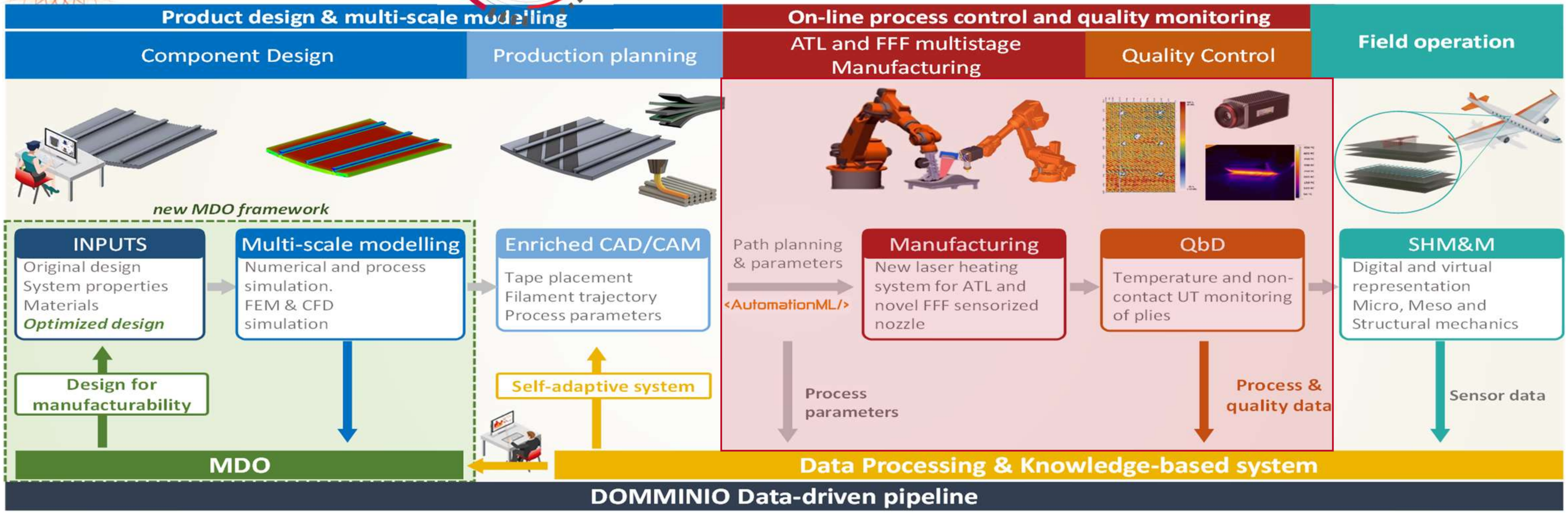
Introduction



MATERIALS & MANUFACTURING

- Flexible multistage robotic-based production processes
  - Combining AFP and FFF
  - cCNT filaments (SHM), CCF and NPs reinforced filaments
- Quality-by-Design (QbD) manufacturing strategy
  - Laser scanning-assisted heating
  - FFF nozzle with improved thermal control
  - Non-contact ultrasound method for in-line

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Demostrators

Taken from: https://www.aeroclass.org/spoilers-airplane/

Taken from: https://raisbeck.com/raisbeck_product/high-flotation-gear-doors/

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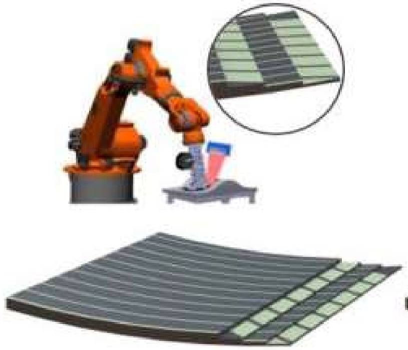
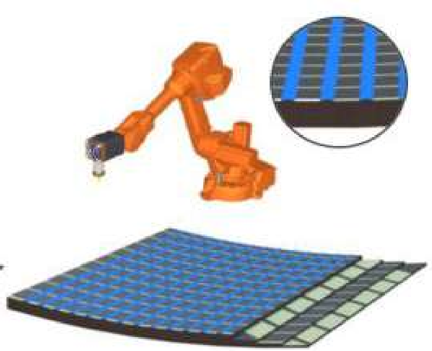
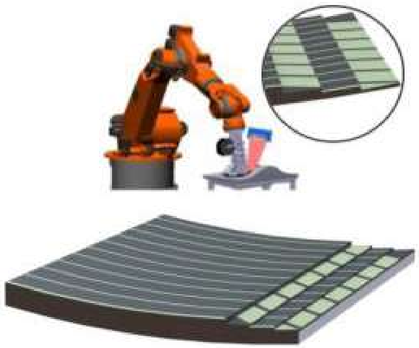
Multistage robot-based manufacturing process (AFP + FFF)



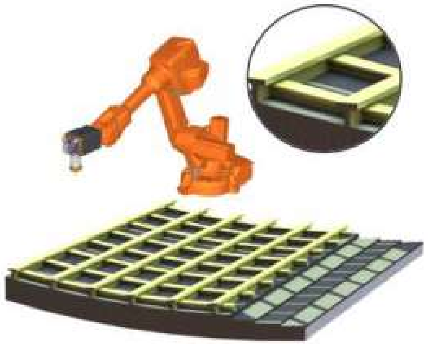
1- AFP
Laying up UD tapes



2- FFF
cCNT reinforced filaments for SHM



3- AFP
Laying up UD tapes



4- FFF
a) Filaments reinforced with MNp´s (disassembly)
b) Filaments reinforced with cCF (structural reinforcement)

Multifunctional component

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Introduction

Multistage robot-based manufacturing process (FFF)

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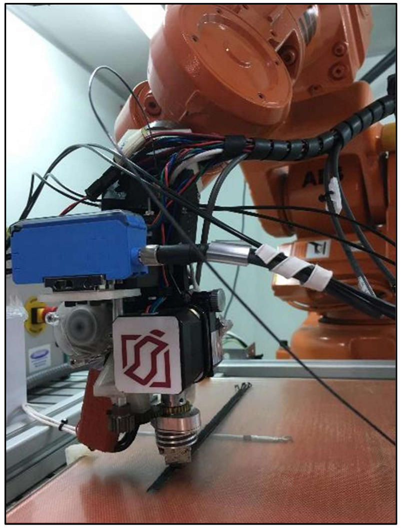
- **FFF robotized pilot cell**
  - 3D printing head (*high temperature and continuous CF*)
  - LASER heating integrated in FFF process.

- **LFAM cell**
  - Robotized, CEAD pellets extruder and Typhoon filament extruder.
  - Laser heating system.



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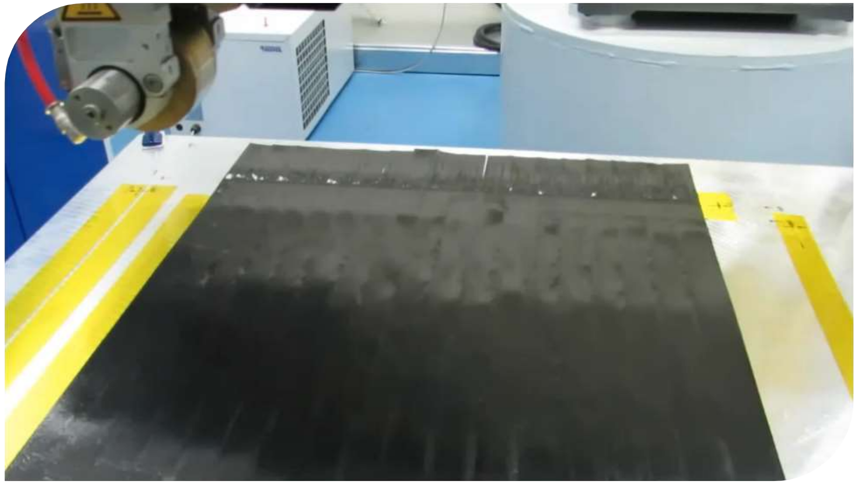
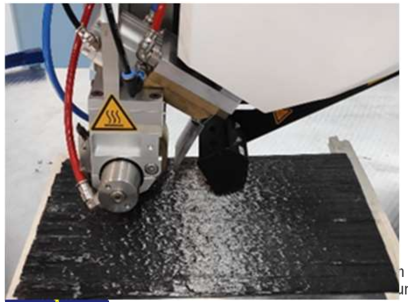
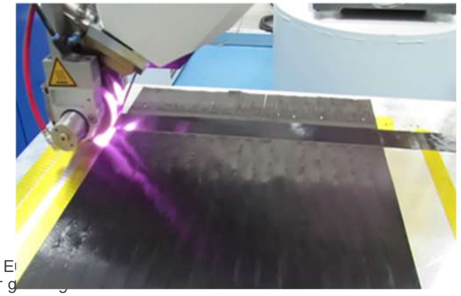
Multistage robot-based manufacturing process (AFP)

AFP robotized cell:

- Laser diode (6 kW and 4 kW) and VCSEL
- IR heating
- TS, TP and DF materials
- Heated lay-up tool




IR HEATING


LASER HEATING

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- ✓ **AFP (Automated Fibre Placement)** is a very implemented process that have been used for decades in aerospace industry for manufacturing large structures with thermoset composites.
- ✓ **Thermoplastic Composites (TPCs)** offer advantages such as unlimited shelf life at room temperature, reciclability or reprocessability.
- ✓ **LASER assisted In-Situ Consolidation AFP** can contribute to introduce TPCs in aircraft components since is one-step and out-of-autoclave process.
- ✓ **NEED:**
  - To ensure that ISC-AFP obtains the required TPC properties:

    ⇒ Thermal input during manufacturing *vs* final material properties

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AFP tape

Material: semi-crystalline low melt PAEK thermoplastic matrix and a T800G carbon fibre reinforcement:

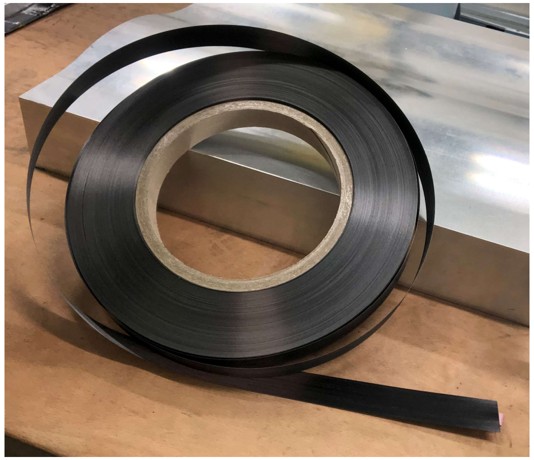
Toray Cetex® TC1225 LMPAEK / T800G UD tape

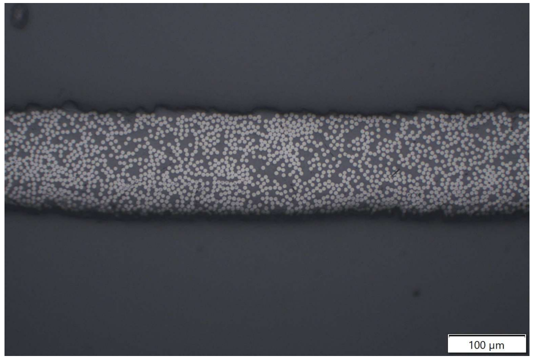
Material properties of matrix.

Material	Tm (°C)	Tg (°C)	Recommended processing temperature by supplier (°C)
LM-PAEK TC1225	305	147	340-385

Composite tape format

Material designation	Fiber Areal Weight, FAW (g/m^2)	Resin content (%)	Ply Thickness (mm)	Width (mm)
TC1225 T800G UD	145	36	0.145	25.4





Raw tape micrograph.

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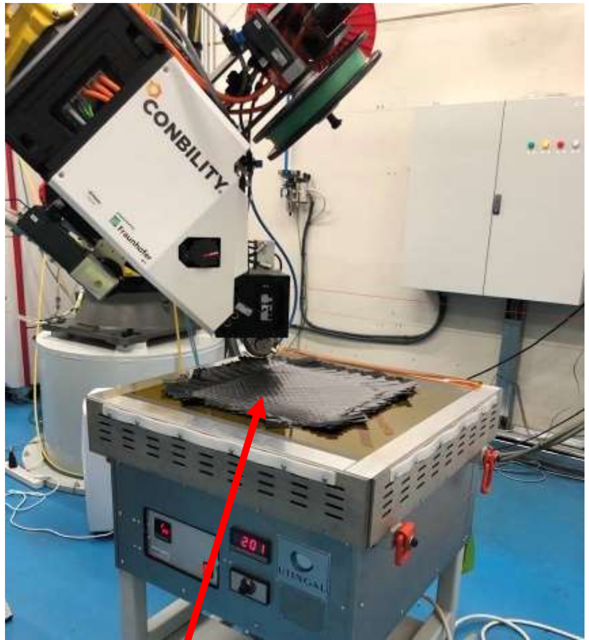
Equipment

- AFP (Automated Fibre Placement) head system: PrePro3D model from Conbility manufacturer.
- The AFP system is mounted in a FANUC R-2000iC/165F Robotic Arm.
- Heated layup tool. Aluminium alloy plate heated with resistances.
- Laserline diode laser source (model LDF6000-40) of 6300W and operating wavelengths ranging from 940 to 1060 nm.



Heated lay-up tool

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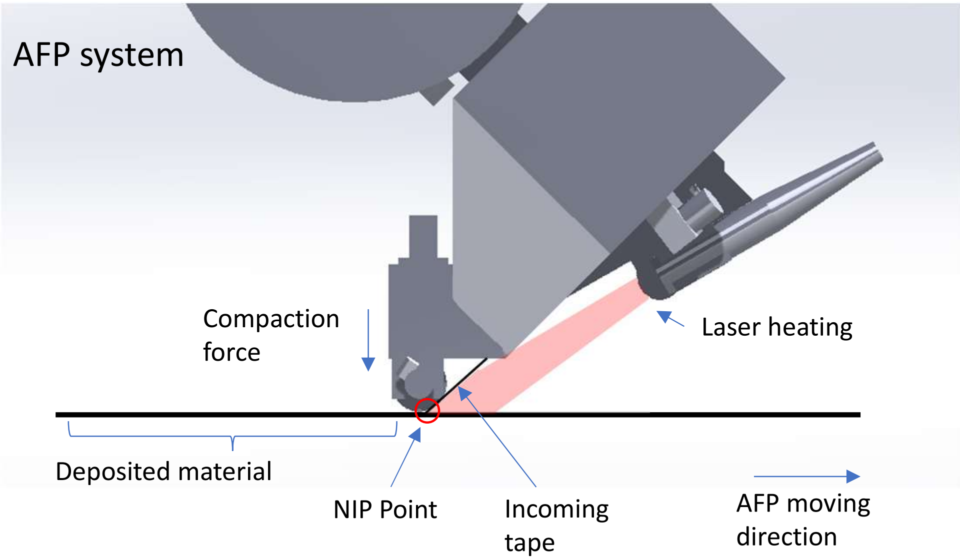
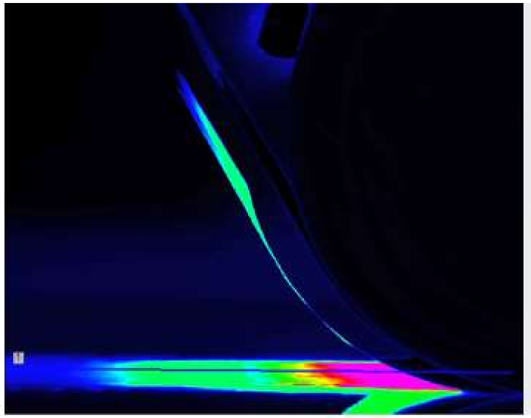
Equipment



AFP parameters

AFP Parameters	Value
Layup speed [mm/s]	100-250
Compaction Max. Foce [bar]	6
Temperature [°C]	✓



Thermocamera analysis

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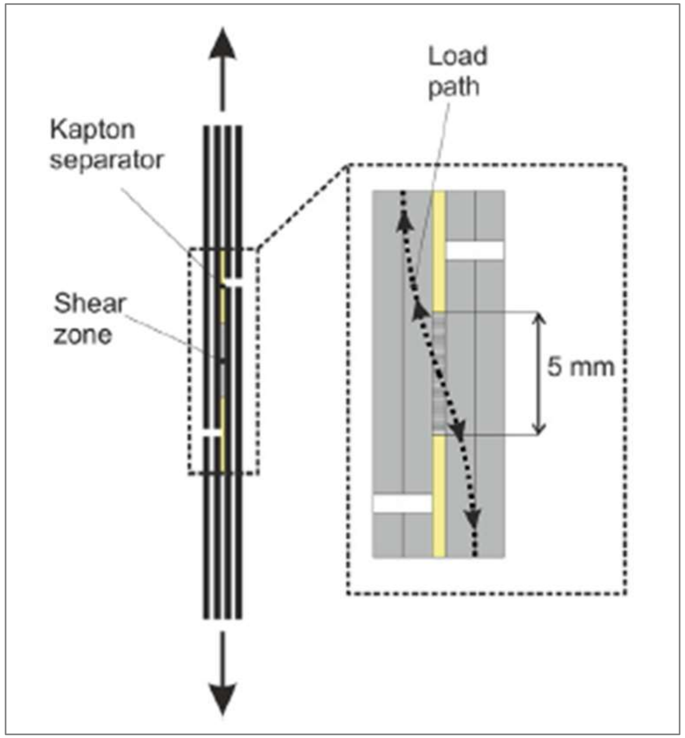
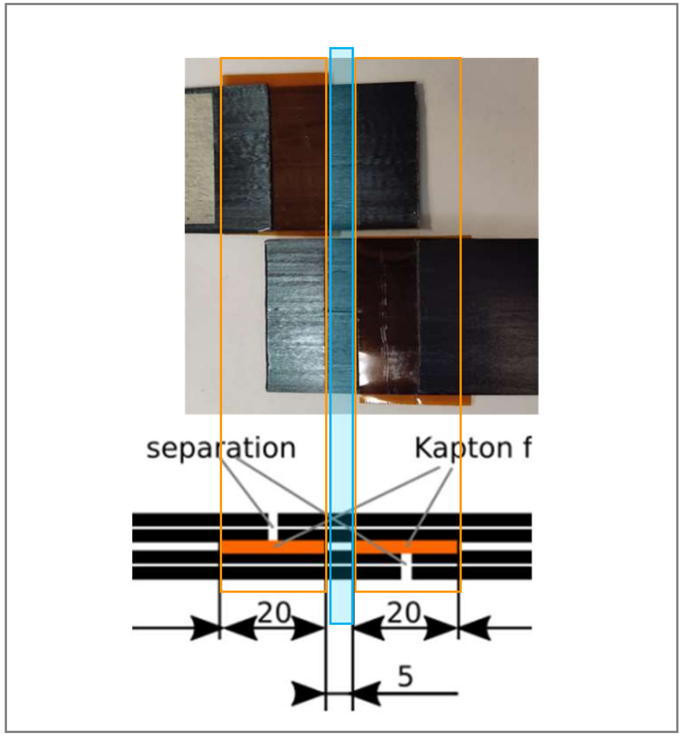
Characterization – Mechanical Test: SLSS coupons

Simplified <u>Single Lap Shear Strength</u> test, coupons manufactured with 4 plies stacked, isolating the load carrying area with Kapton film strips.





Test defined in: *Dreher P, Chadwick AR, Nowotny S. Optimization of in-situ thermoplastic automated fiber placement process parameters through DoE. In: Proceedings of the 40th SAMPE Europe conference; 2019, p. 1–13.*

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Layup tool temperature effect:

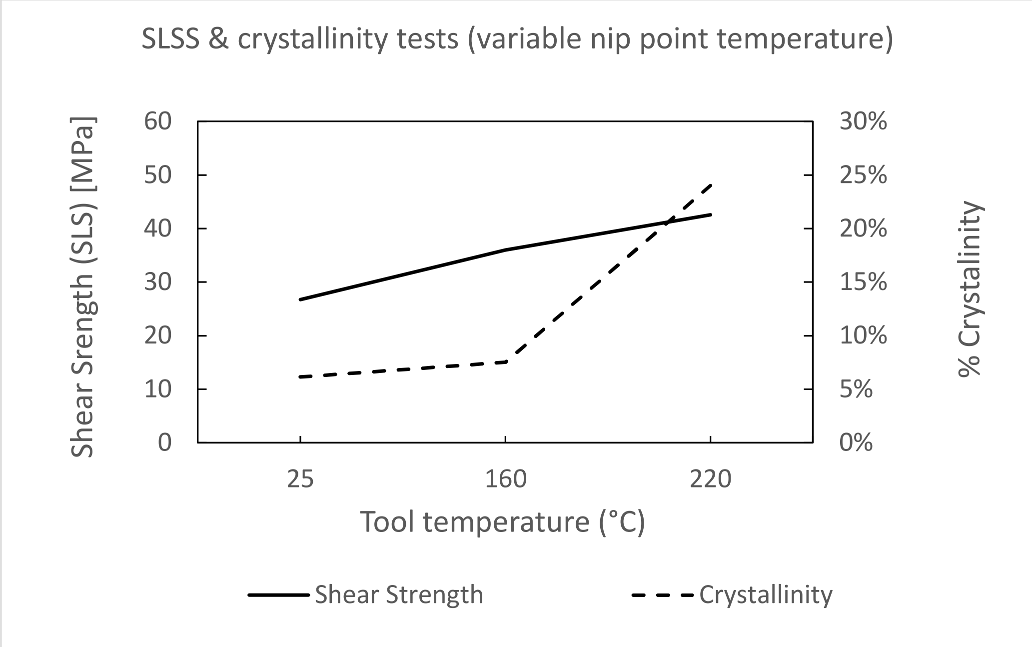
Coupons manufactured varying the tool temperature.

NIP point affected by tool temperature.

Layup tool temperature [°C]	Nip point temperature (substrate) * [°C]	Crystallinity [%]	Shear Strength [MPa]
25	265	5.8	26.70±5.09
160	335	7.1	36.00±5.10
220	385	22.7	42.58±5.45

* Temperature measured at the substrate in the nip point area. The incoming tape was kept at a stable temperature of 350±15°C.

SLSS and DSC *(crystallinity)* results



Higher substrate temperature higher crystallinity and higher SLSS

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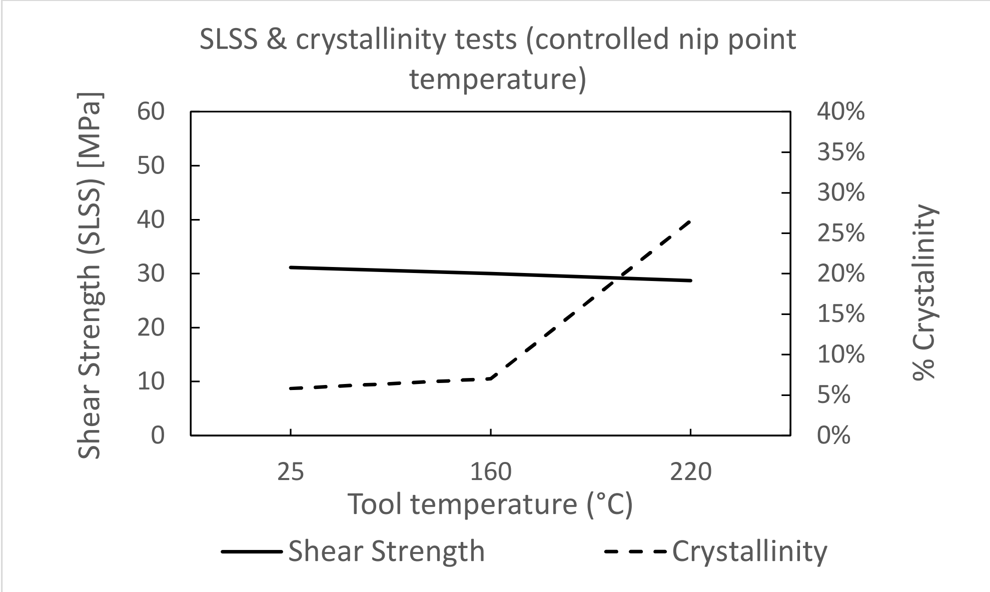
Layup tool temperature effect:

Laser power is controlled to achieve a homogeneous nip point temperature.

Layup tool temperature [°C]	Nip point temperature* [°C]	Crystallinity [%]	Shear Strength [MPa]
25	330	5.8	31.11±4.85
160	350	7.0	30.00±3.37
220	360	26.5	28.67±1.77

* Temperature averaged from the substrate and the incoming tape in the nip point area.

SLSS and DSC *(crystallinity)* results



- ✓ Higher crystallinity doesn't mean higher SLSS.
- ✓ NIP Temperature influences in SLSS more.

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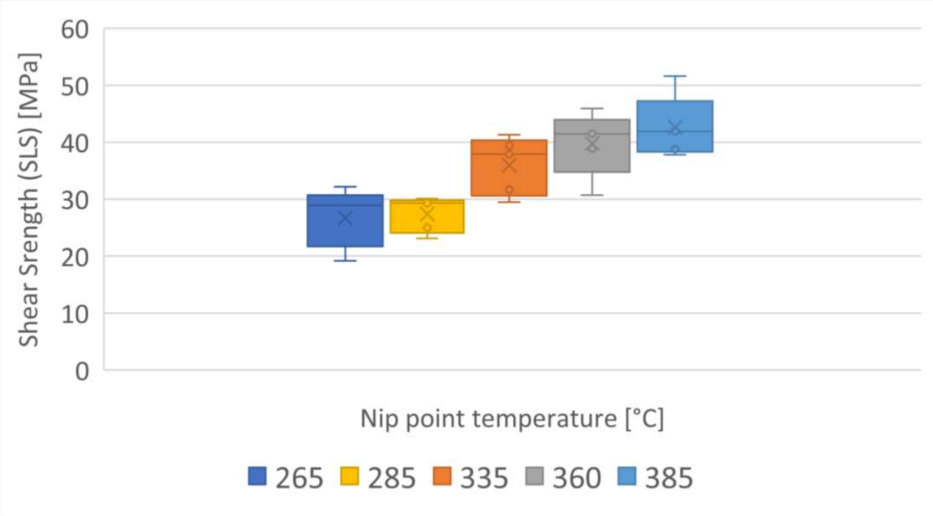
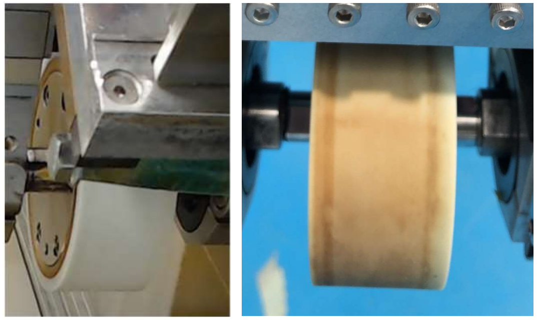
LASER – NIP Temperature Control:

Relation between SLS strength and nip point temperature

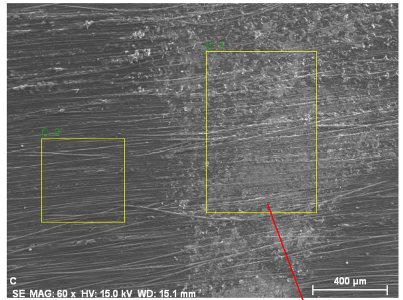


Higher NIP temperature means higher SLSS

Above 400 °C, silicone rollers show thermal degradation



AFP roller. Left: roller without degradation. Right: roller with degradation.



Spectrum	C	O	Si
A- 1	84.21	15.79	-
B- 1	73.21	26.79	-
B- 2	79.32	20.68	-
B- 3	87.84	12.16	-
C- 1	41.81	36.47	21.73
C- 2	87.82	12.18	-

SEM EDS (Energy Dispersive Spectroscopy) for surface silicon evaluation.

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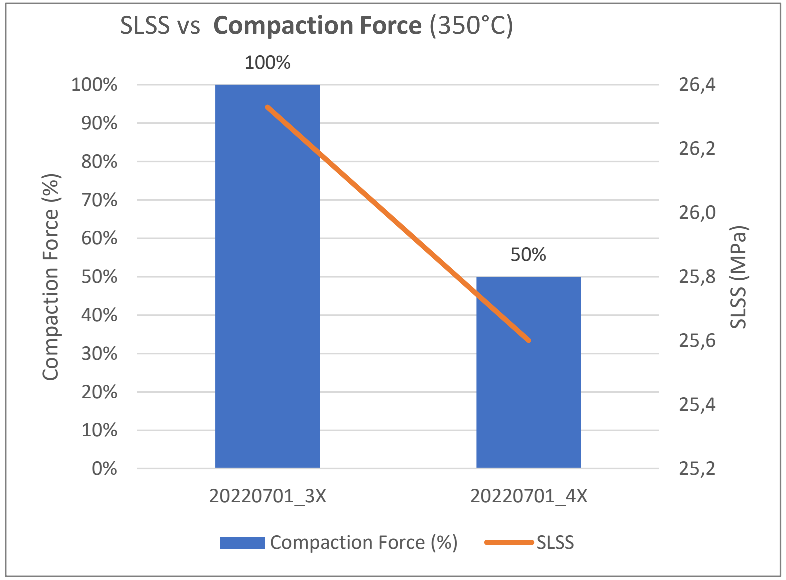
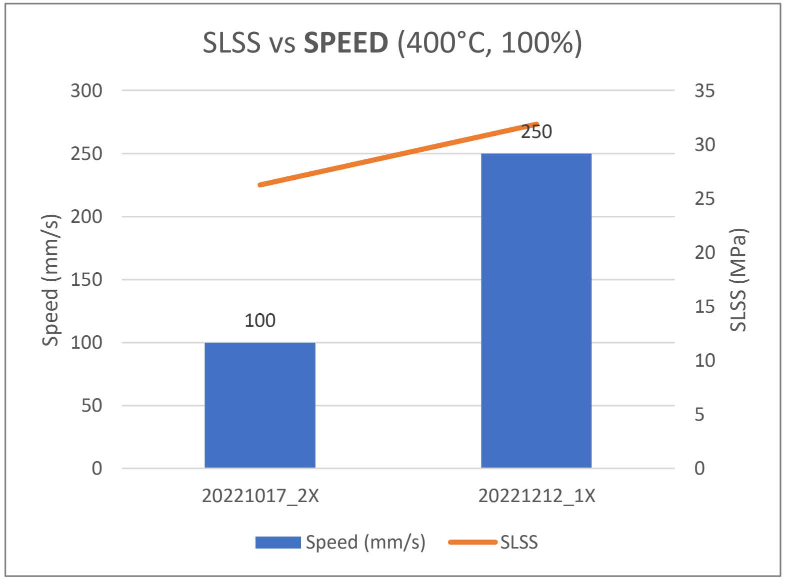
NIP Temperature and Compaction Force

100% = 6 bar.



Processing speed effect:



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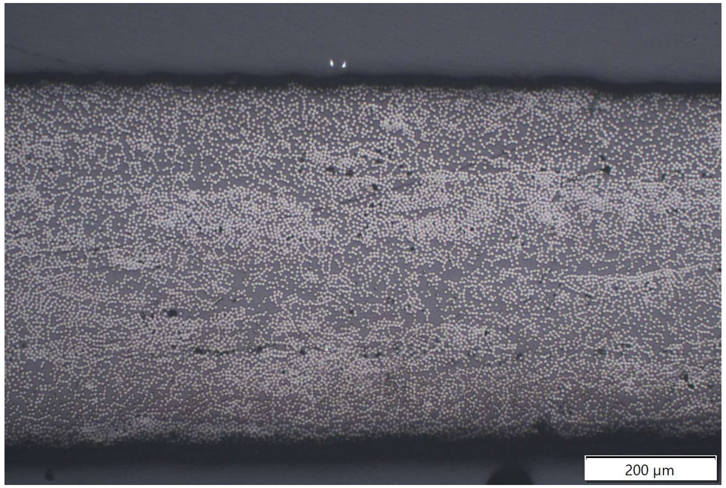
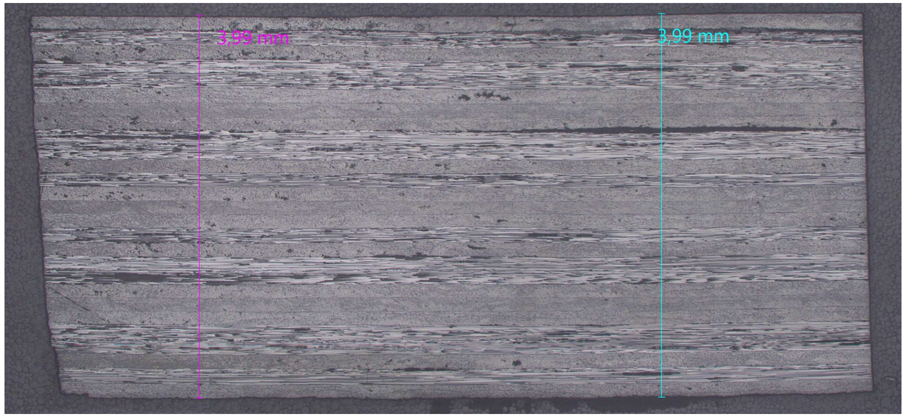
Void content at:

- ✓ NIP Temperature: 400 °C → Degradation of compaction roller
- ✓ Speed: 250 mm/s
- ✓ Compaction Force: 6 bar



Void content < 1% (4 layers)



Void content < 2% (with 27 layers)

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CONTENT:

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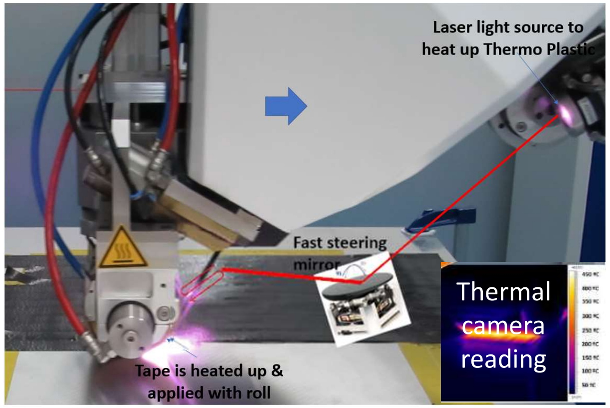
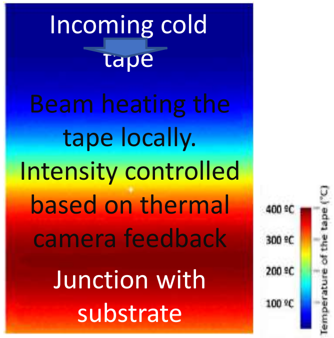
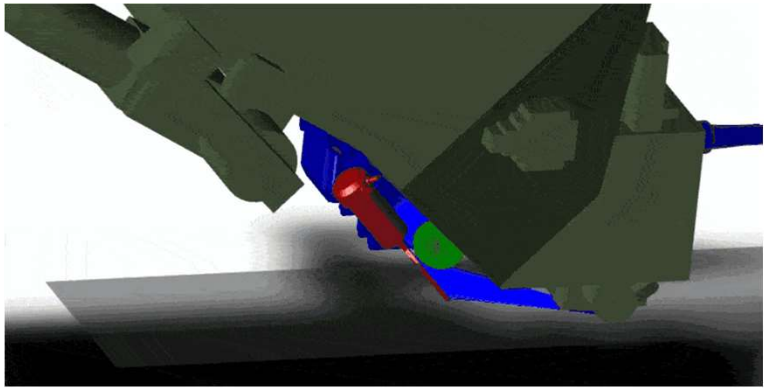
On-going work:

Laser-based heating system for through-width-modulated temperature profile in AFP process

- During AFP process, instead of heating constant area, a **<u>scanning laser</u>** heat locally the tape.
- A thermal camera will control the heat delivered with a feedback loop: beam speed and/or intensity can locally accommodate bad heating performance.
- This will ensure that the tape always reach the desired temperature, allowing for improved performance.







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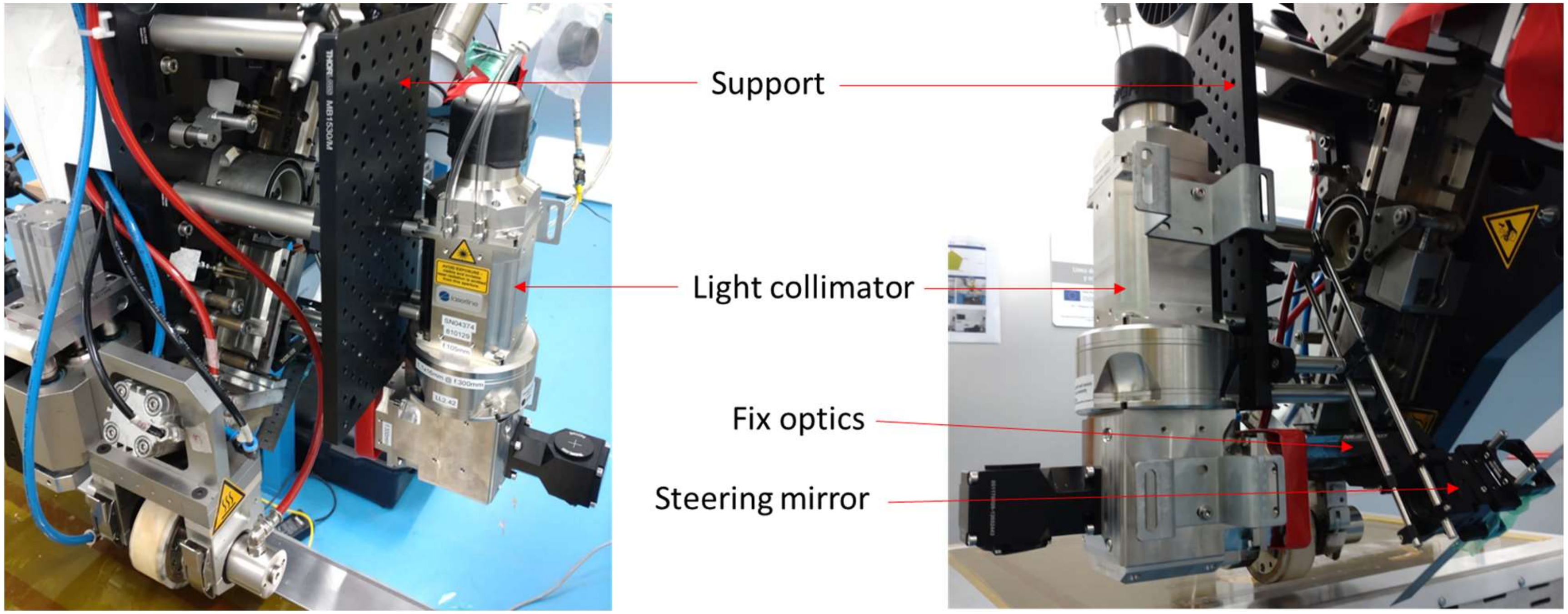
Laser-based heating system for through-width-modulated temperature profile in AFP process



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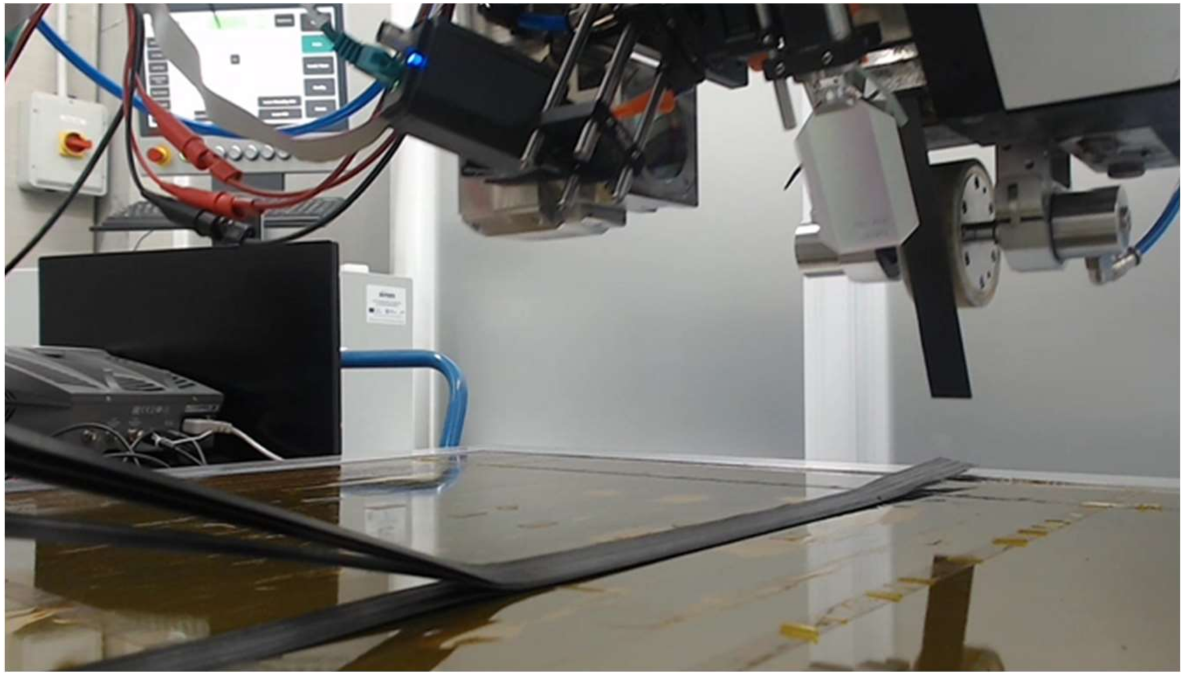

Energy profiles are sent to the tape and result successfully heating onto the tape.

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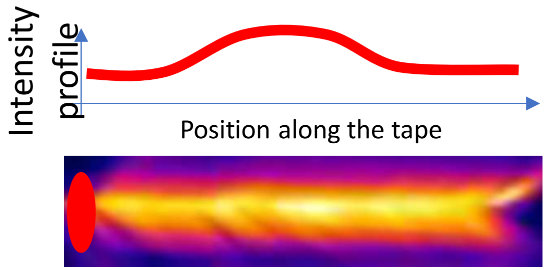
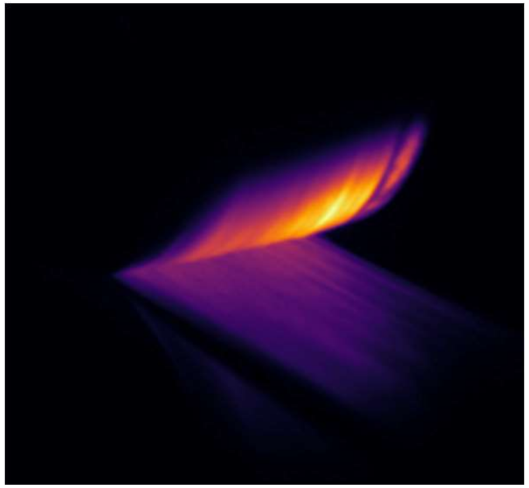
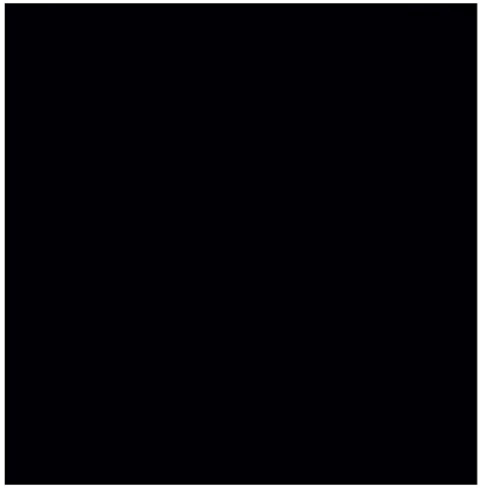
On-going work:

Laser-based heating system for through-width-modulated temperature profile in AFP process

- The steering mirror and the laser intensity can be controlled directly with low electrical current (0-10V).
- According to the thermal camera, the tape is successfully heated up locally.
- Heating profiles can be tunned (more intensity in the center or in the edges)







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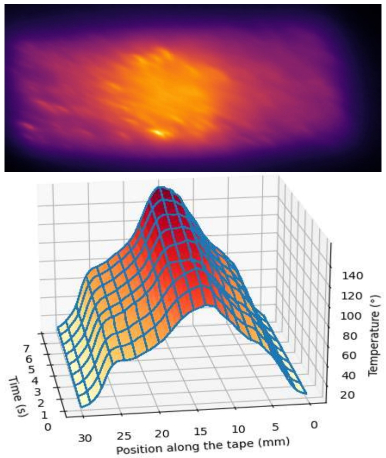
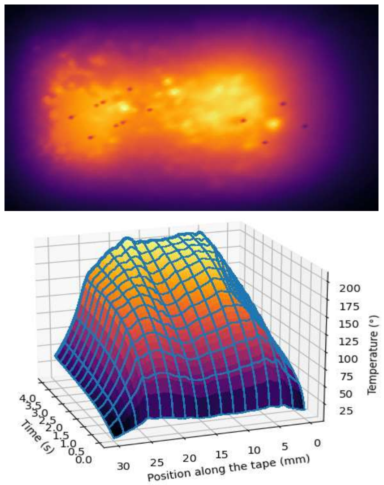
On-going work:

Open-loop: sending predefined energy perfil and monitor heat evolution in time.

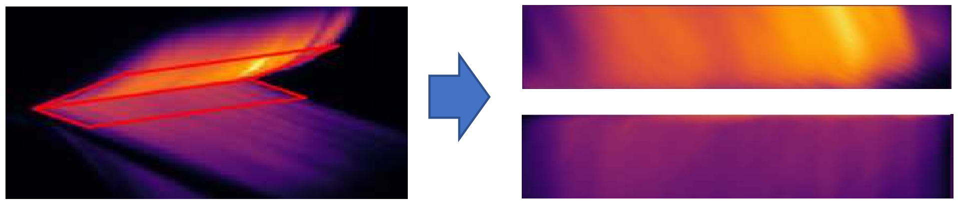


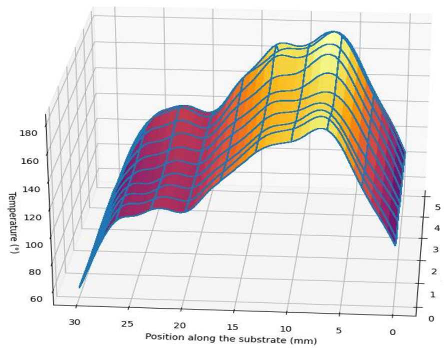
Temperature measurement on a metallic target, with a gaussian profile for intensity (request for more energy on the center and less on the edges).



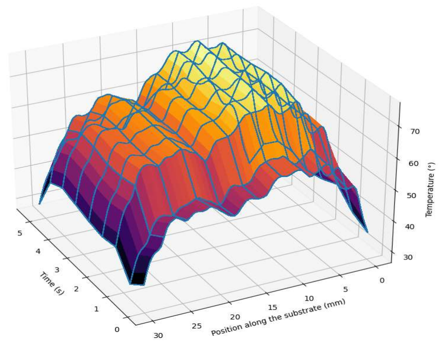
Similar experiment with an inverted gaussian profile (more energy on the edges)

Close-loop control with fix energy profile: the profile is predefined and only its "base intensity" changes base on the thermal camera (one point measurement)

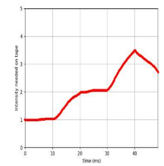




Evolution temperature top part (tape)



Evolution temperature substrate



Requested intensity profile

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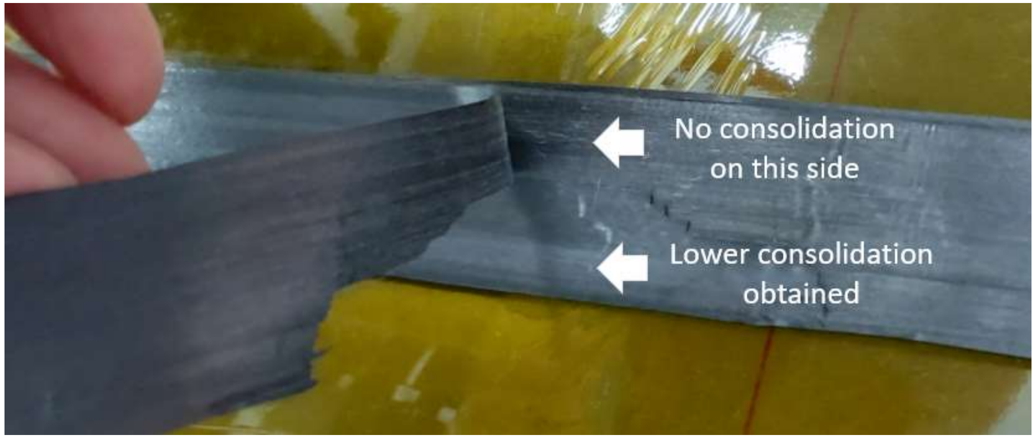
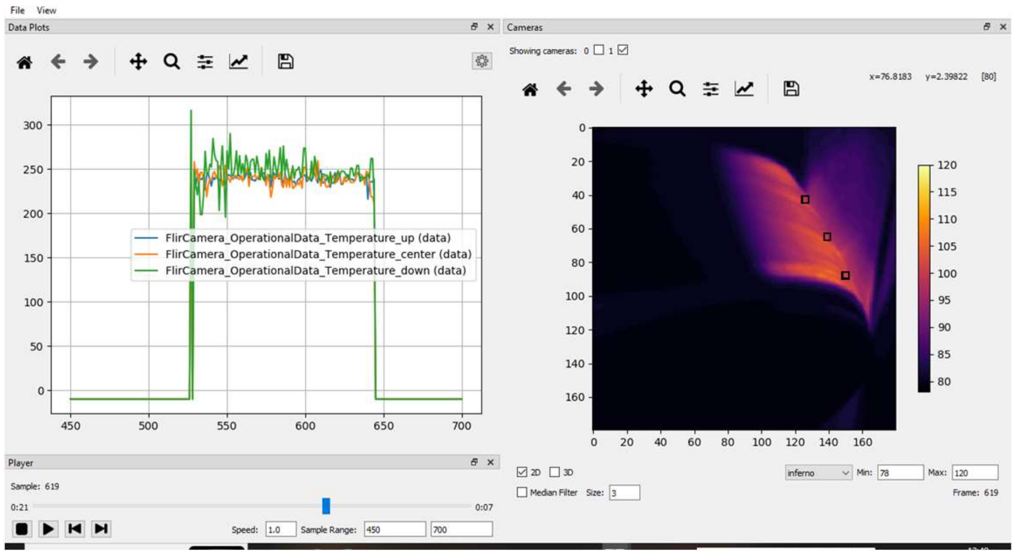
On-going work:

Laser-based heating system for through-width-modulated temperature profile in AFP process

- Intensity profile is dynamically calculated based on various measurement along the tape
- **Preliminary results**: Tape successfully heated = Good tape consolidation





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

CONTENT:

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Conclusions and next steps

- There is a high influence of the layup tool temperature on crystallinity:
    - High tool temperatures (above the Tg of the polymer): high crystallinity percentages (around 25%) are obtained.
    - Tool temperatures below the Tg (147ºC): high amorphous phase (below 10% crystallinity)

- NIP point control has high influence on SLSS values – higher NIP temperature higher SLSS.

- But…. above 400 °C, silicone rollers show thermal degradation.

- A scanning laser that heat locally the tape, instead of heating bigger and constant area, show promising results:
    - Tunned heating profile
    - Avoid roller degradation (more accurate heating)

- Future work: to develop an optimum scanning laser heating with feedback loop control.

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Acknowledgements

Thank you for your attention

- This work is developed in DOMMINIO project, which has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 101007022.

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