THIN-PLY COMPOSITE MULTIFUNCTIONAL STRUCTURE

ICCM23

23rd International Conference on Composite Materials (ICCM)

Bruno Giuntoli , Rajasundar Chandran, Gioele Balestra, Joël Cugnoni

August 1st 2023

HEIG-VD

Haute école d'ingénierie et d'architecture Fribourg
Hochschule für Technik und Architektur Freiburg

Hes·so Haute Ecole Spécialisée de Suisse occidentale

HEIG-VD

2

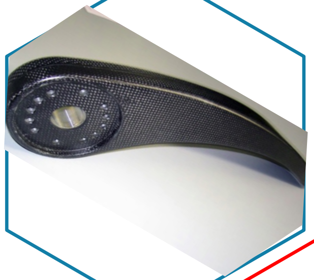
PROJECT SCOPE

&

PARTNERS

The Multi-Functional Structures (MFS) project objectives:

- Study the integration possibilities of thin-ply MFS layers into high performance principal structures.
- Determination of conductive traces deposition into composites (i.e. ink-jet)
- Evaluation of the structural capabilities and design limitations.
- MFS testing for FEM correlation and functional parts modelling.

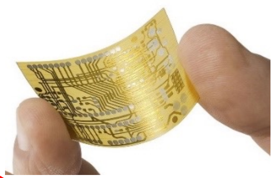


Thin-Ply composite structures

High performance
Lightweight
Energy-efficient

Multi-functionality
Flexible
Integration

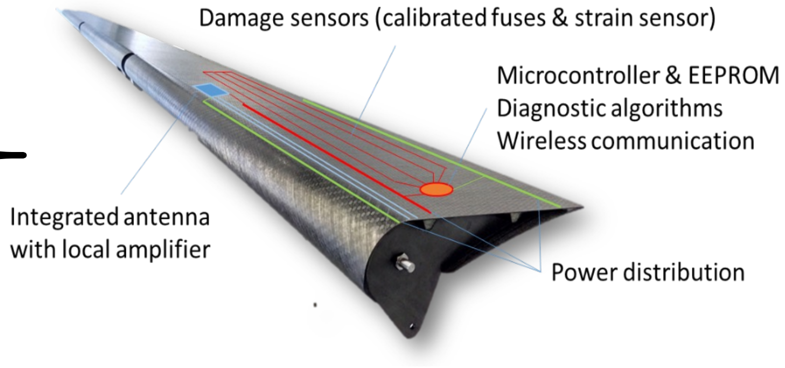
Multi-material digital printing



Multi-functional Digital Manufacturing

Repeatability
Low resources
High productivity

Potential uses of the technology



HEIG VD

3

PROJECT SCOPE

&

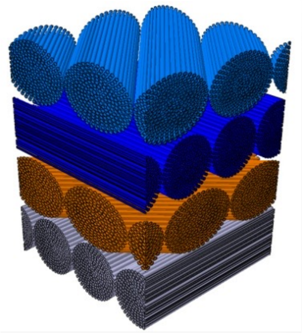
PARTNERS

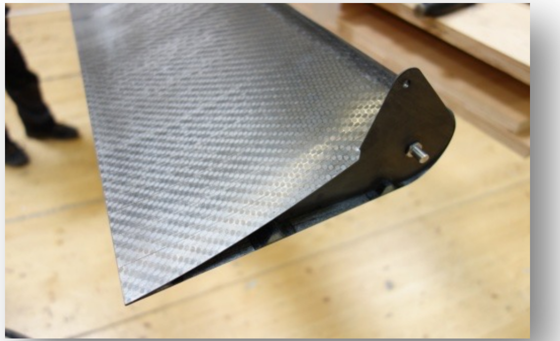
Hes·so
Haute Ecole Spécialisée
de Suisse occidentale

HEIG VD
HAUTE ÉCOLE D'INGÉNIERIE ET DE GESTION DU CANTON DE VAUD

Expertise:

- Thin-ply composite materials
- Composite Additive Manufacturing (AM)
- Fast Prototyping





Thin-ply composite airframe structure

iPrint Center
Haute école d'ingénierie et d'architecture Fribourg
Hochschule für Technik und Architektur Freiburg

Expertise:

- Additive manufacturing
- Multi-material AM (conductive inks)
- Ink-jet printing specialists

adphos.com

4

DESIGN

&

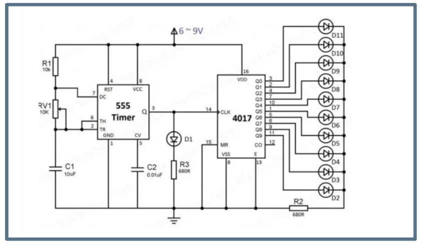
MANUFACTURING

PROCESS

Multi-Functional Structures (MFS) design and manufacturing process:

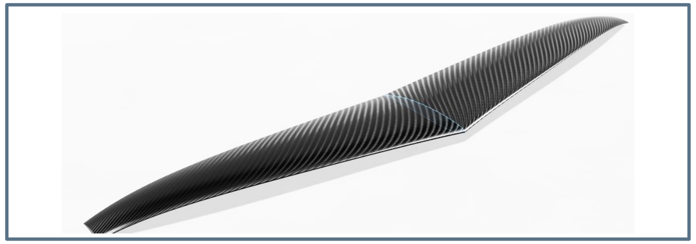
CONSTRAINTS

Electronic schematic diagram



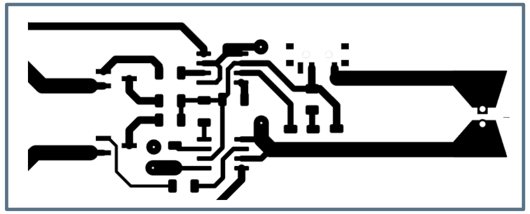
+

Geometrical design space

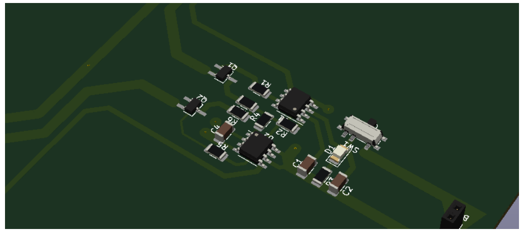


CIRCUIT DESIGN

PCB design traces

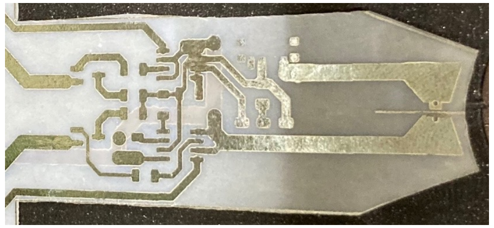


PCB Design CAD render

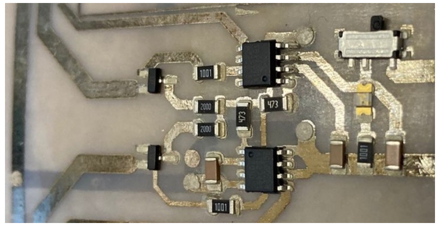


SUBSTRATE PREPARATION

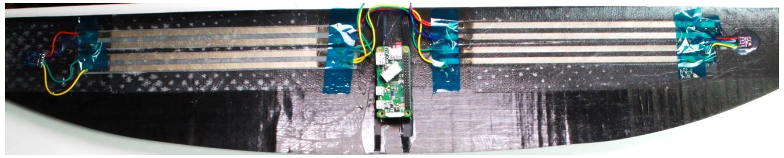
Ink-jet printed circuit (double sided)



Integrated component into PCB



MFS INTEGRATION

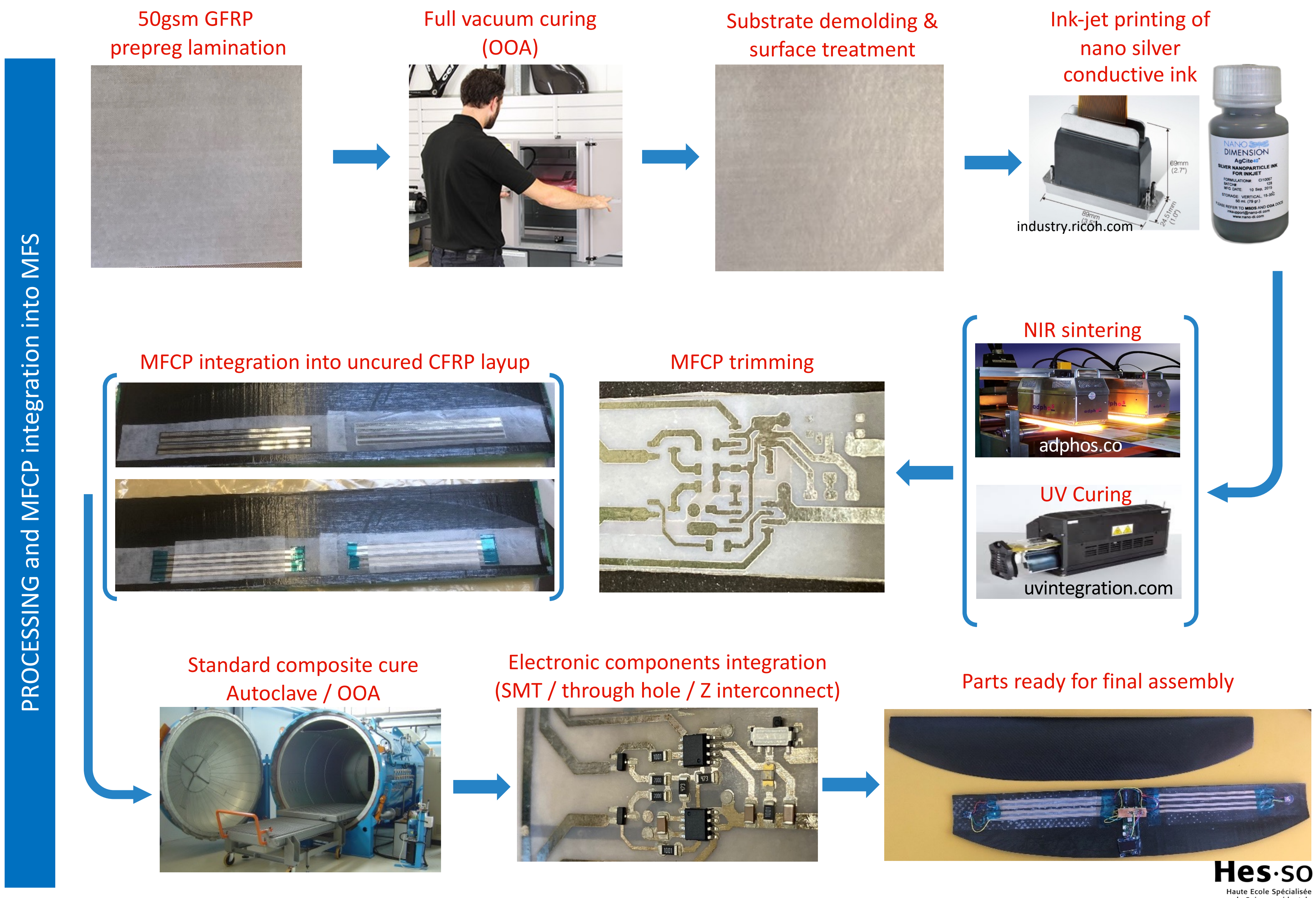


HEIG-VD

5

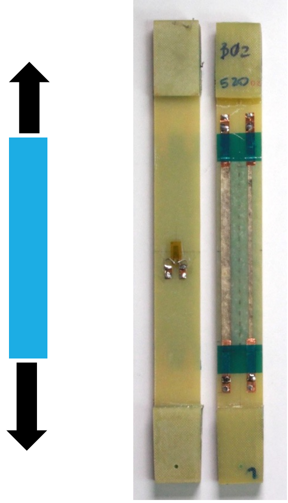
MFCP MATERIALS & PROCESSING

Multi-Functional Composite Ply (MFCP) Materials and processing:

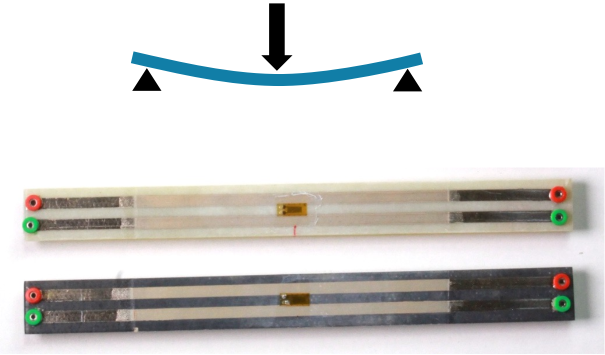


Three testing setups to evaluate the multifunctional structure

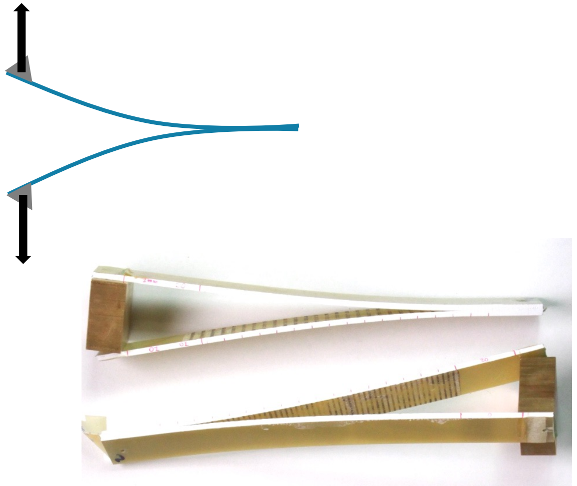
Tensile



Bending

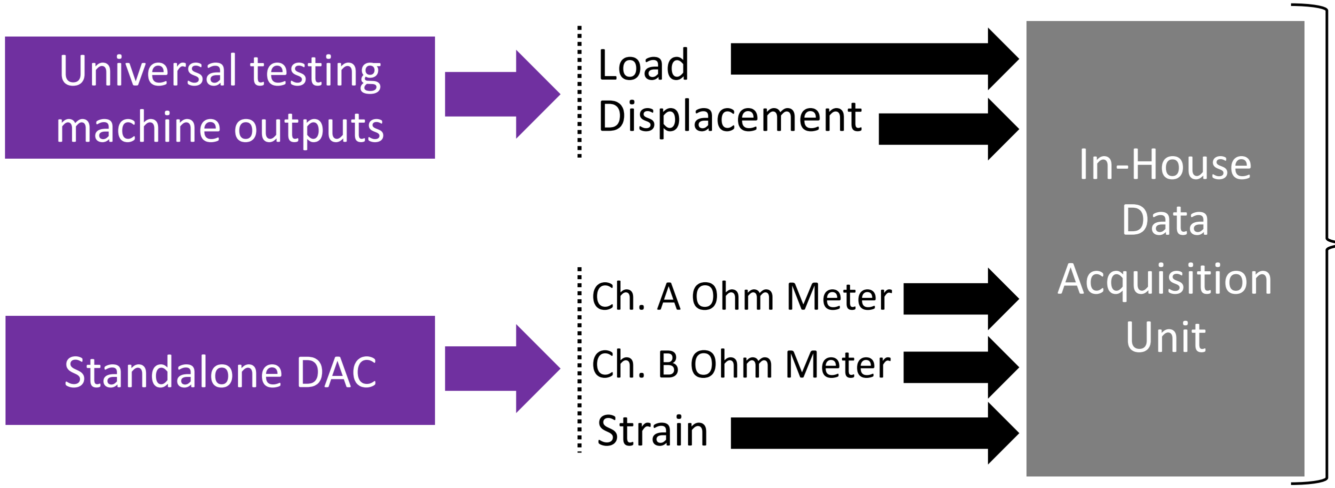


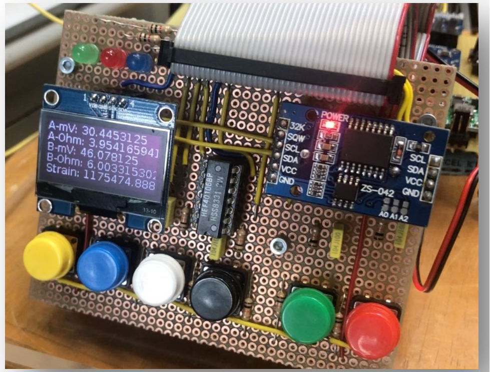
DCB/Mode I



Data acquisition

- The Load-Displacement-Time data was correlated to the traces resistance and strain gauges data.
- A twin-channel milli-ohm resistance and strain measuring apparatus was developed for this purpose.



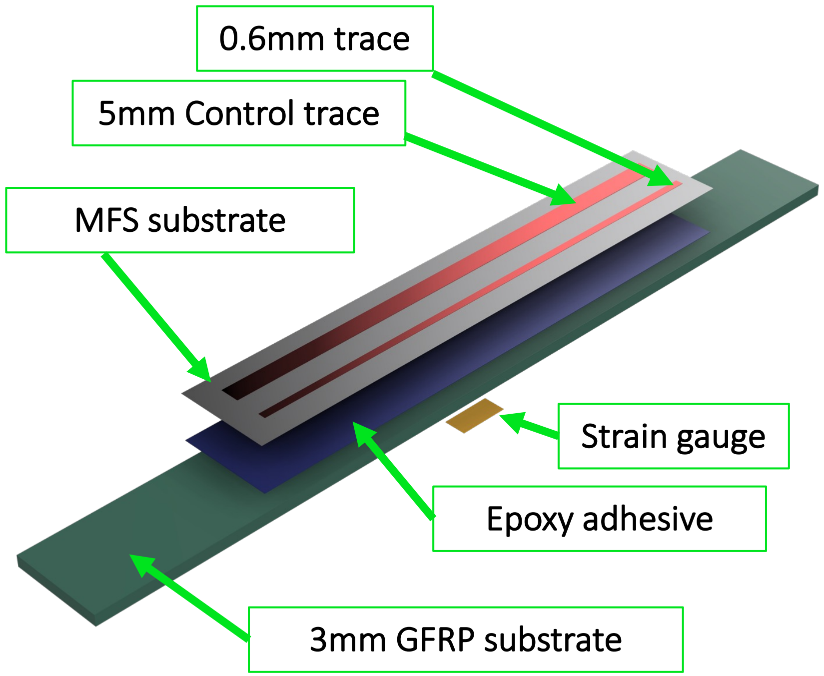


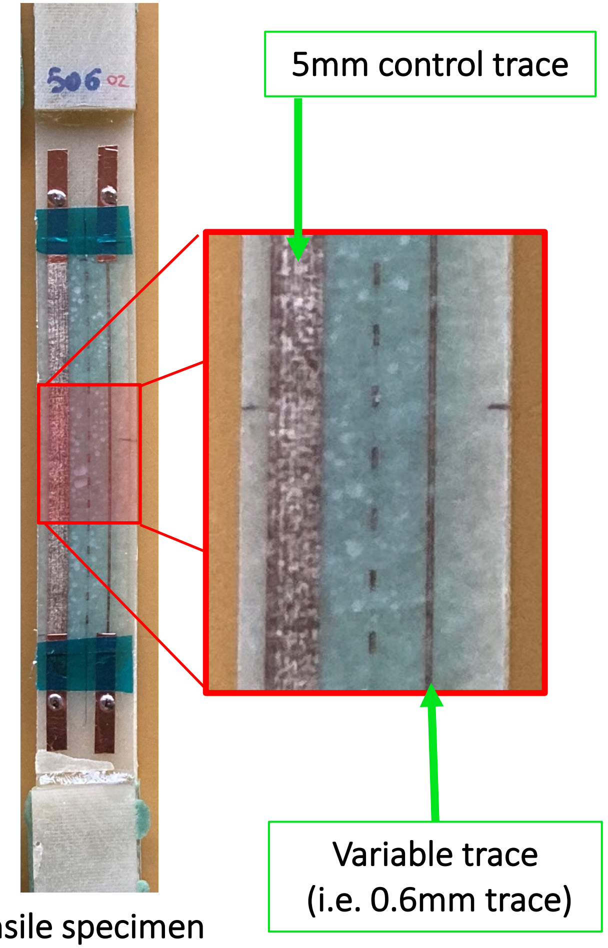
TESTING

TENSILE

Objectives:

- Evaluation of the resistance variation and maximum strain capabilities of the conductive traces
- Thin-ply printed specimen bonded to a QI 3mm pre-cured GFRP plate.
- Two traces per specimen with a **5mm control trace** on the left side.
- Five traces evaluation, 0.4mm, 0.6mm, 1.0mm, 2.0mm and 5.0mm





Tensile specimen
0.6mm trace width

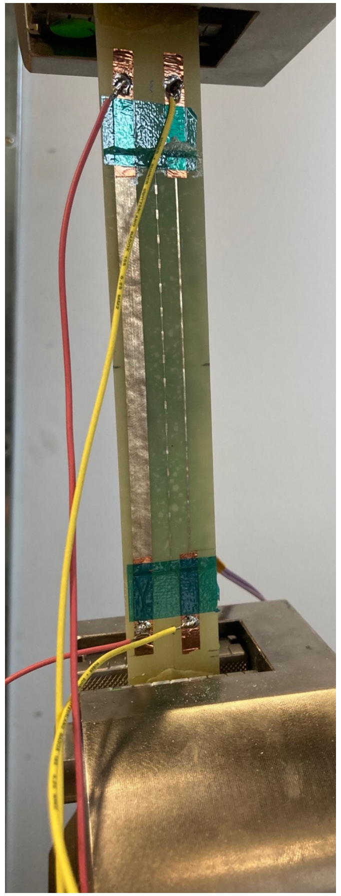
8

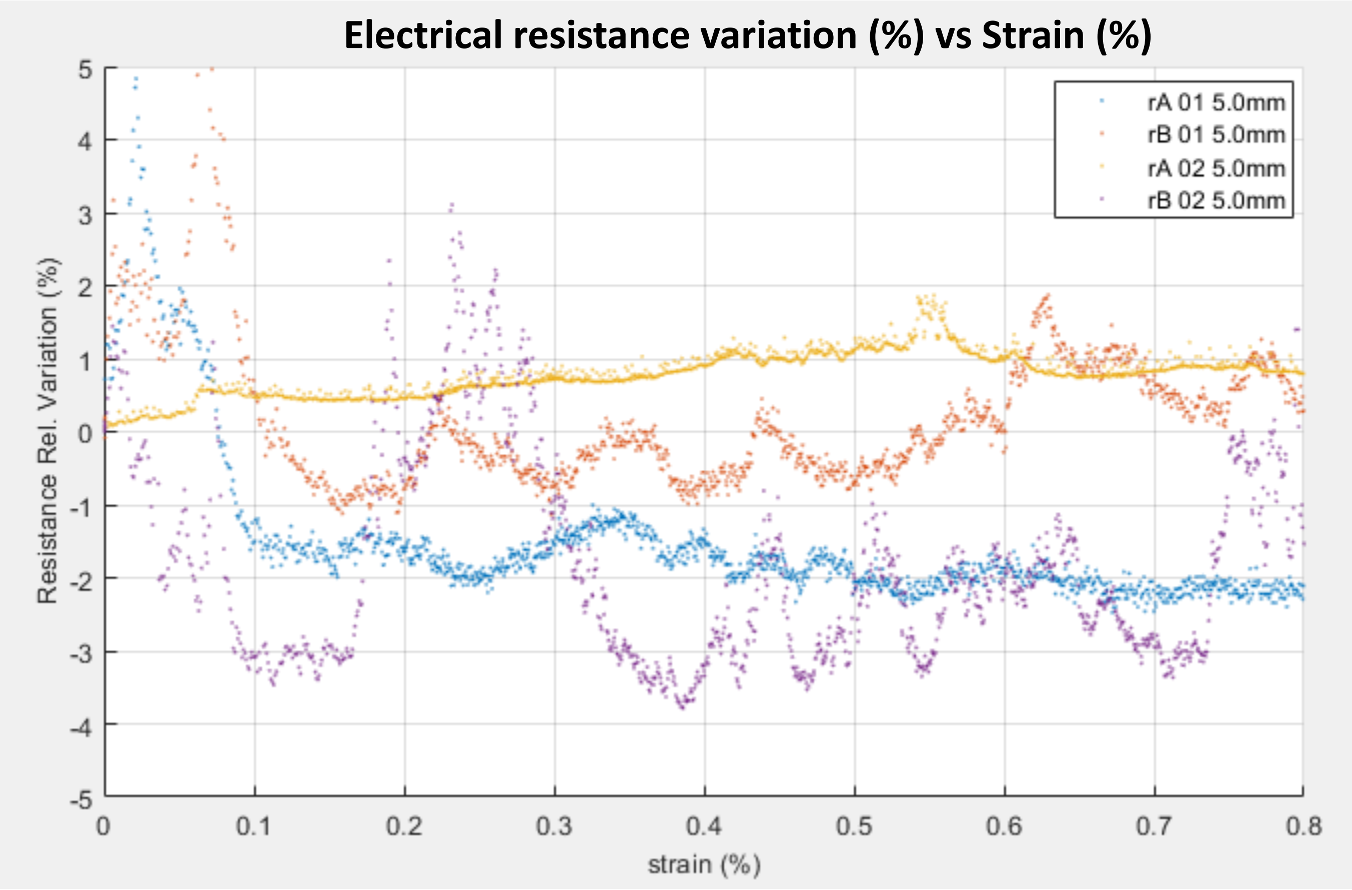
TESTING

TENSILE

Results:

- Failure of the GFRP composite support prior to the failure of the conductive trace
- On first loading electric resistance does not follow a traditionnal linear scaling with strain: potential preconditionning effect of the sintered nano silver particles on first load cycle.
- Variations of resistance inside the tolerance limits for electronics
- No significant resistance variation (increase) at high strains, no sign of damage before failure of the composite





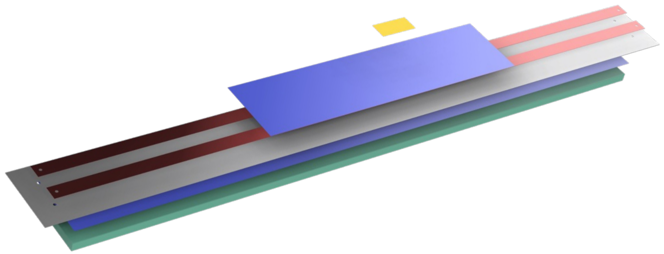
Trace resistance = 0.2 Ω⊡

TESTING

THREE-POINT BENDING

Test objective

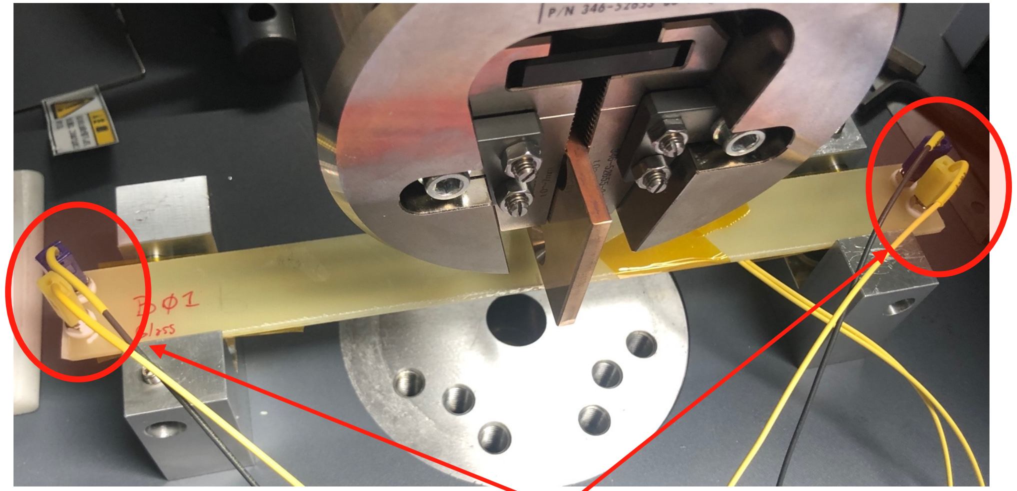
- The three point bending test goal was to evaluate the cyclic response of the conductive traces.
- Three sets of 1500 cycles at 0.5% strain were made and measured



Results

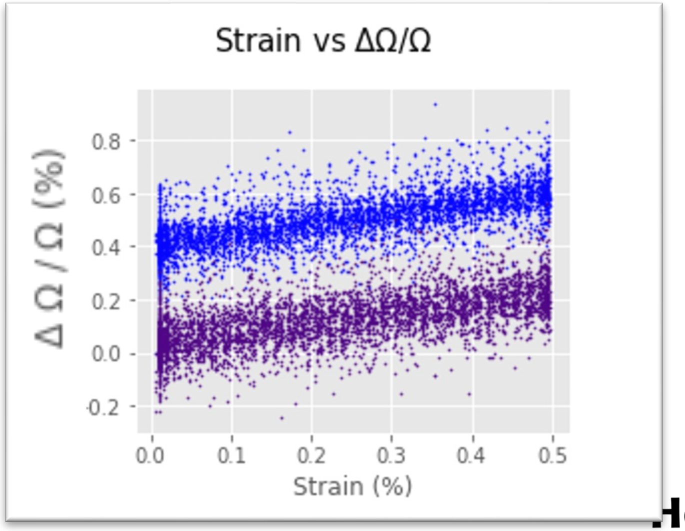
- No degradation observed for the cyclic bending at 0.5%.
- Linear response response between strain and resistance variation in cyclic loading. Potential for sensing applications.

Three point bending setup (conductive traces on tension side)



Rmeter connectors

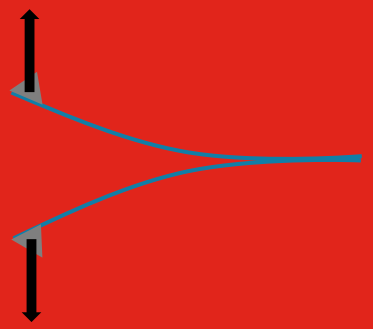
Cyclic results of traces on GFRP specimen



10

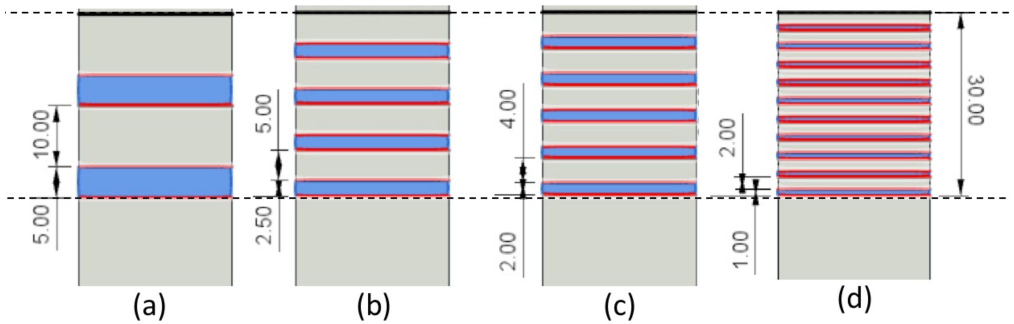
TESTING

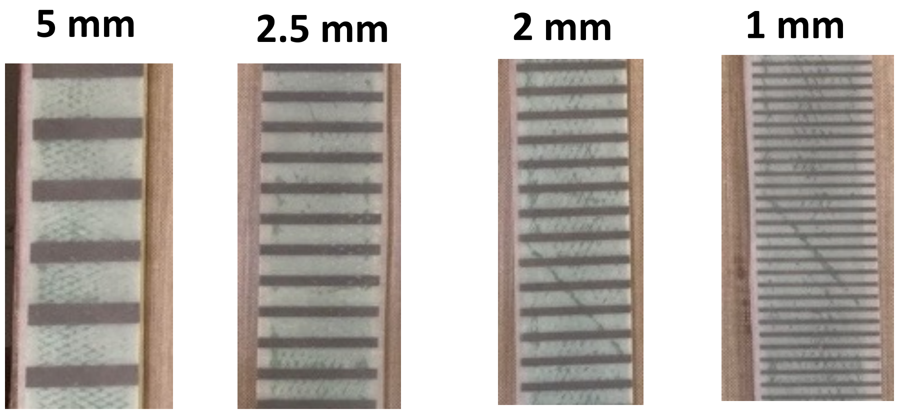
ZEBRA-DCB

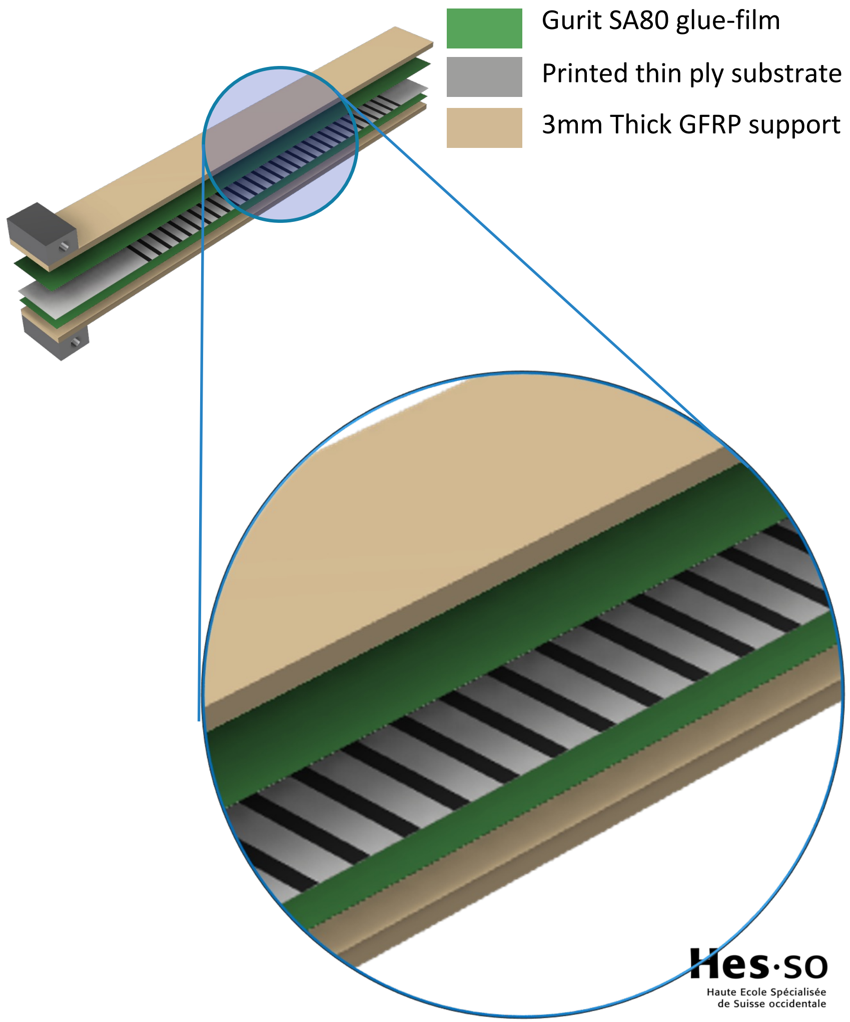


Test objective

- The **Zebra-DCB** testing objective was to evaluate the **interlaminar fracture toughness** between different traces width on a constant 1/3 area.
- **Four patterns** (a, b, c, d as shown on image) were evaluated wit a control length of 30mm
- A “**Raw**” specimen with no print or treatment was also evaluated as a baseline.



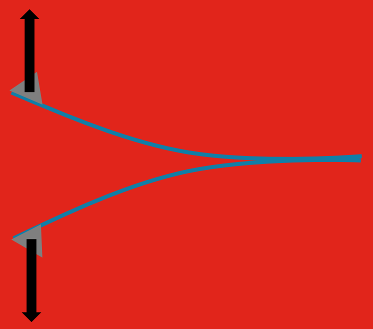




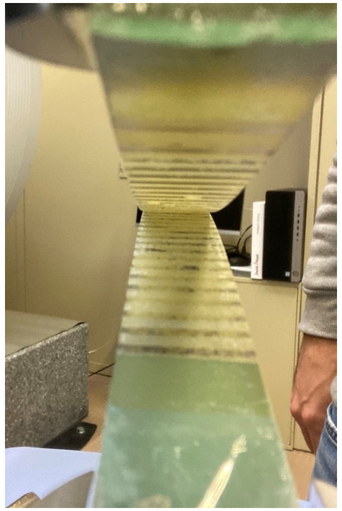
11

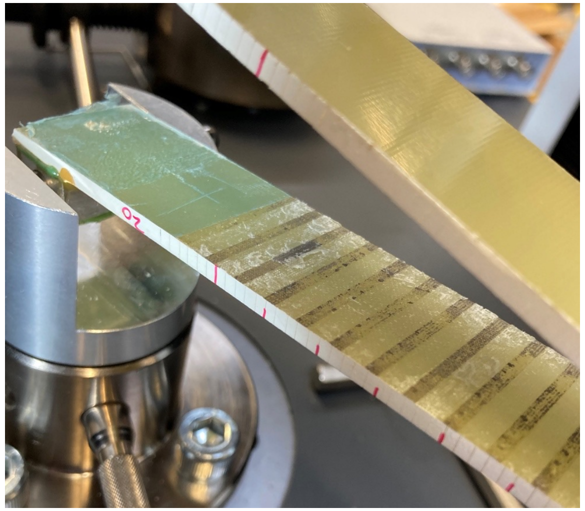
TESTING

ZEBRA-DCB

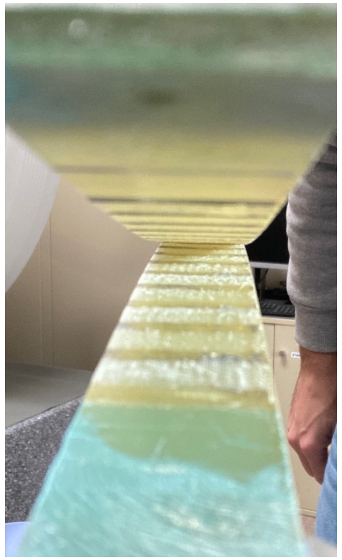


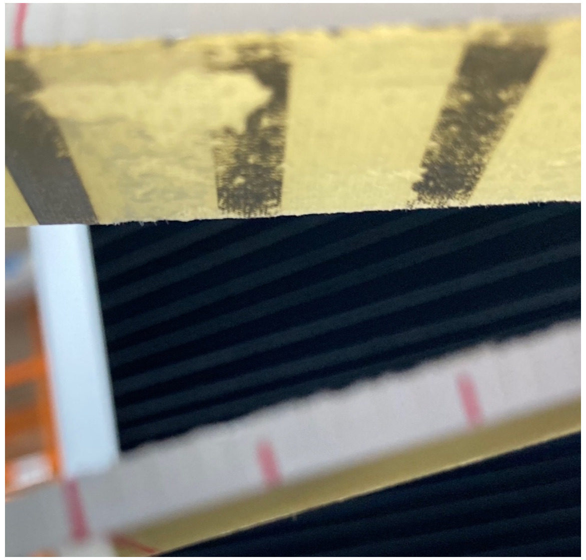
Fracture surface





2.5mm traces



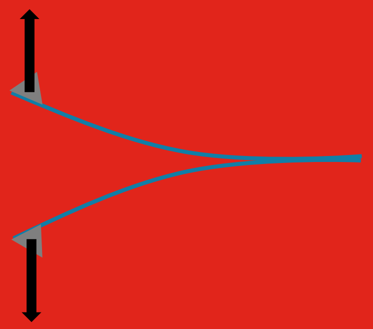


5.0mm traces

12

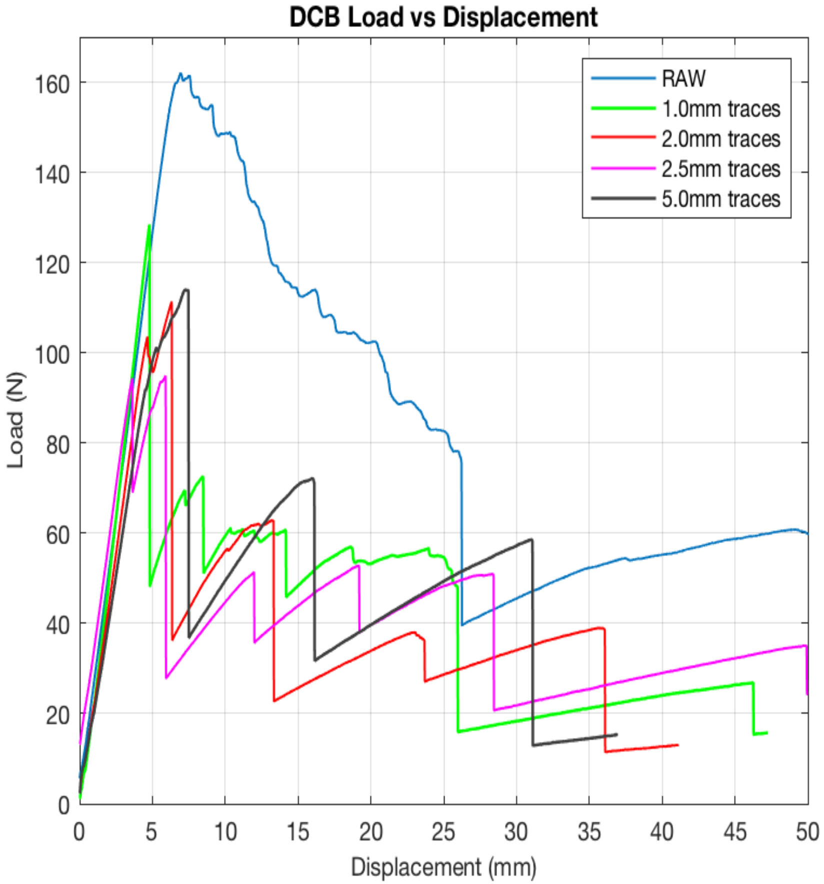
TESTING

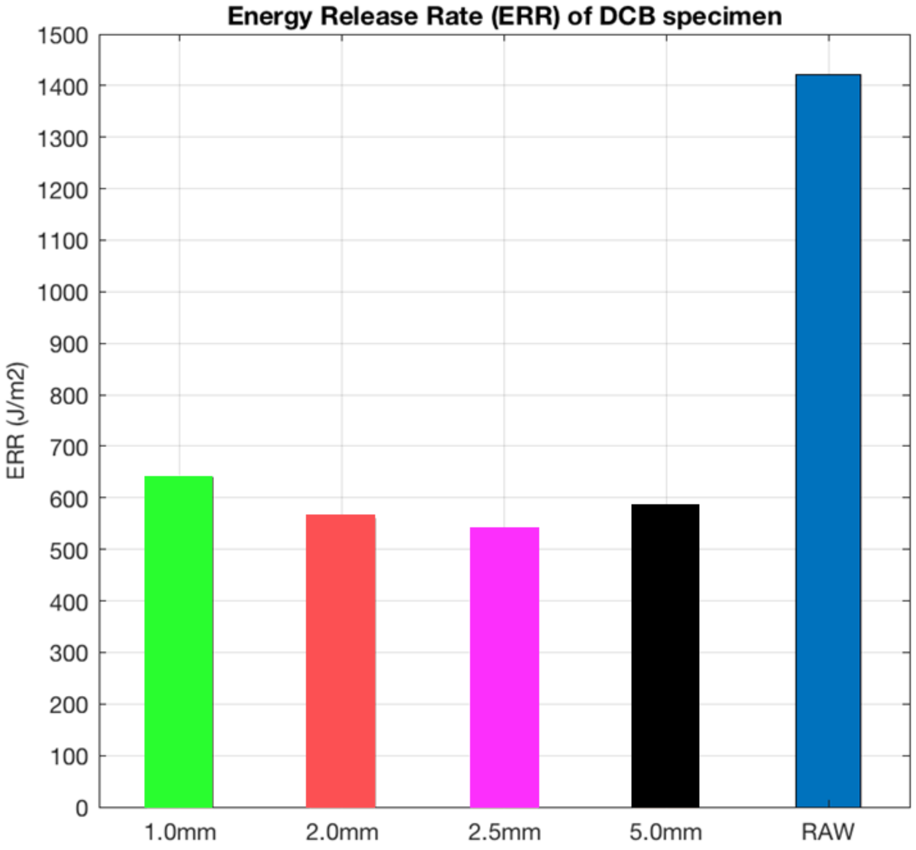
ZEBRA-DCB



Results:

- Reduction of peak load in DCB test, in line with reduction of toughness.
- Fracture alternates within the multifunctionnal ply and at the interface with ink traces
  Reduction of toughness larger than rule of mixture: 30% printed area => 50% of fracture energy
- Potential degradation of substrate during NIR particle sintering process:
  substrate exposed to elevated temperature > Tg for a few seconds

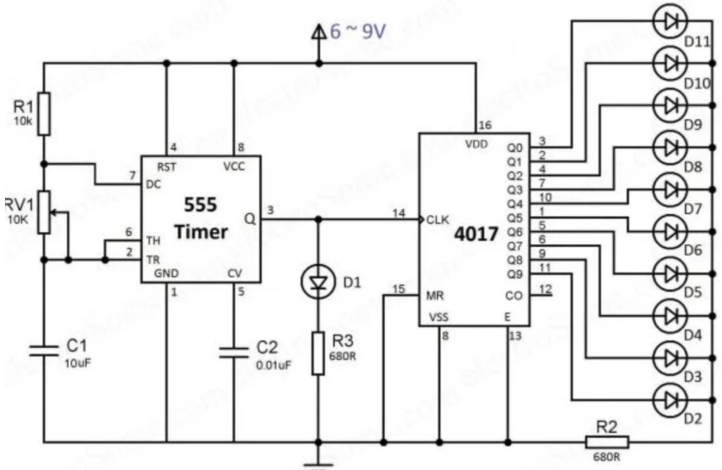




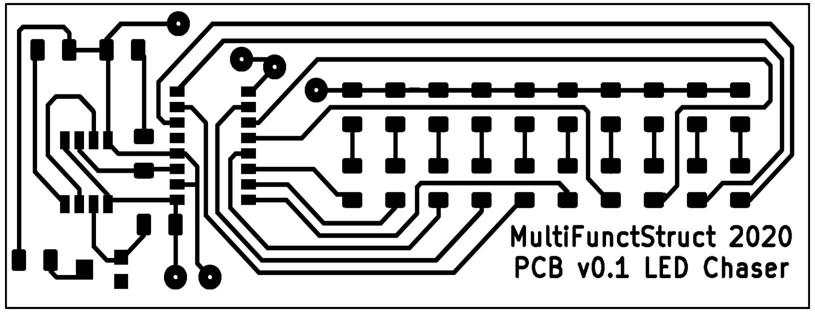
Sufficient toughness for most composite applications, comparable to CFRP composite laminates in mode I

MFS "LED Chaser"

- Analogic circuit with 555 + 4017 IC's
- Printed on MFS substrata
- Components bonded using conductive epoxy adhesives
- Challenging procedure on such small components
- New techniques being developed to automate the process

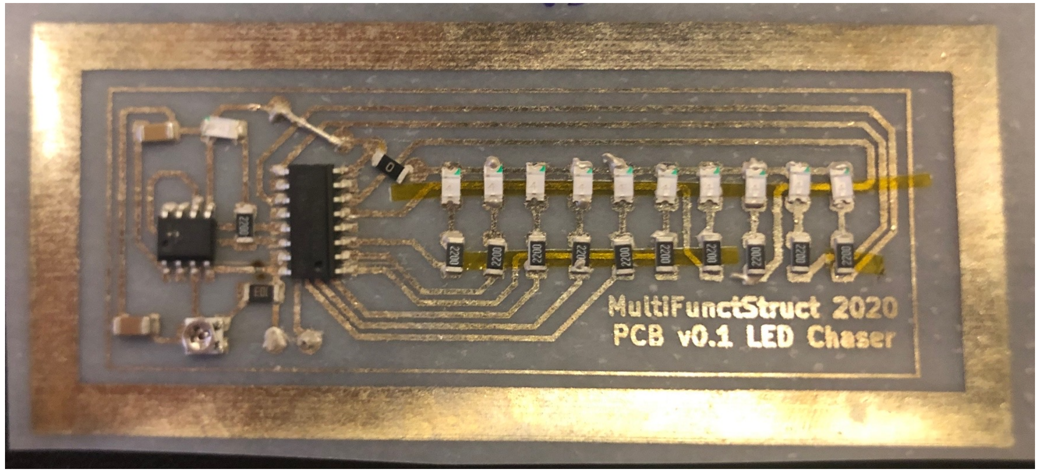


Schematic



PCB Layout design

ICs size comparison
(image: JeeLabs)



MFS working prototype

Technology integration: Wingfoil Smart Boom

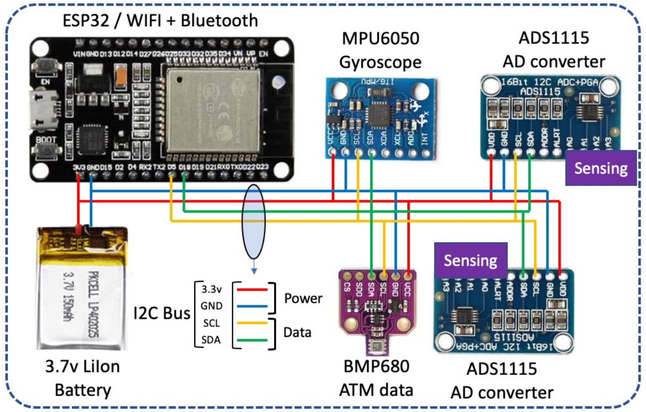
14

WINGFOIL

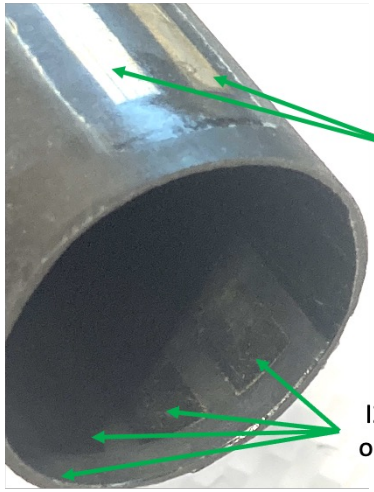
SMART BOOM

Embedded system into the Wingfoil smart handle

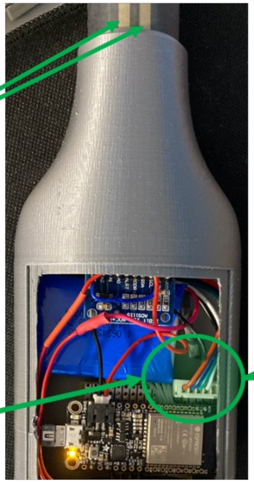
I2C bus, power and sensing interconnected via MFCPs



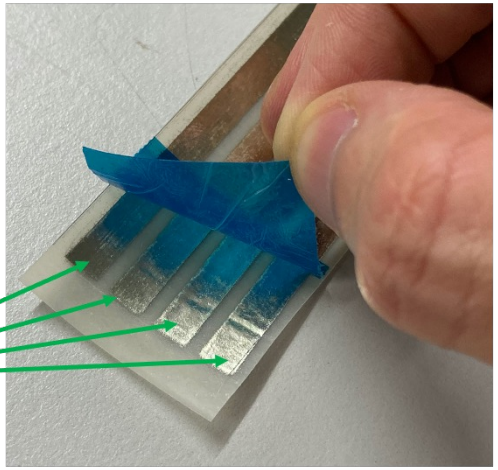
CFRP tube with MFCP end



Handle head internal cavity



I2C MFCP before integration



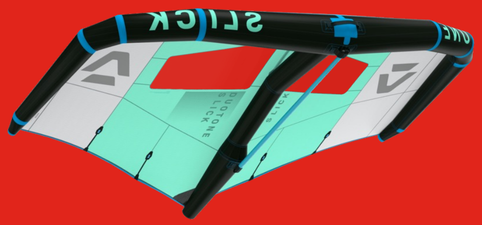
Sensing Traces

I2C Bus traces on Internal face

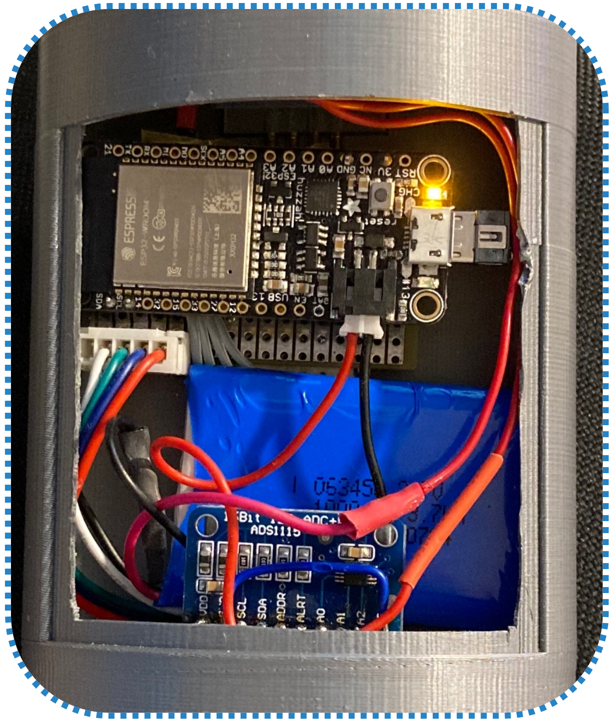
15

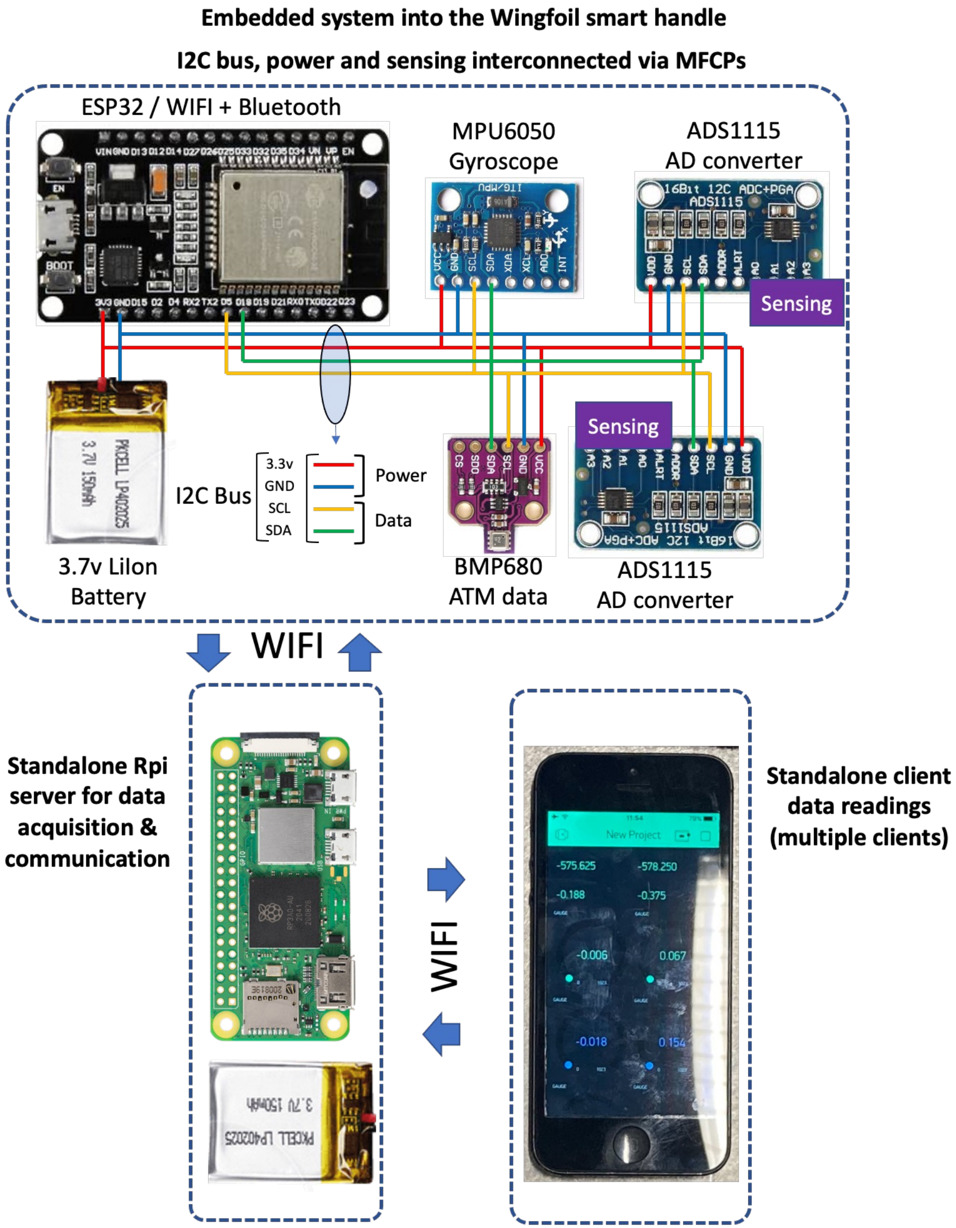
WINGFOIL

SMART BOOM



Technology integration: Wingfoil Smart Boom





16

TECHNOLOGY

CAPABILITIES

Key Technology Specifications:

1. Thin-Ply High definition in-jet printed conductive traces and circuits
2. Seamless integration into laminate, including CFRP:
   multifunctionnal ply thickness with adhesive ~100 microns, very flexible
3. High strength structure and fatigue: compatible with most CFRP applications
4. Multi-layer circuit capabilities, with Z interconnections
5. Type of traces: low power DC bus, digital comm (I2C/SPI), analog signals
6. Strain sensing / crack detection or capacitive / touch-sensitive applications

Mechanical Specifications

- **Max strain =** 1.2 % (laminate failure)
- **Mode I toughness =** 600 J/m²
- **Fatigue life @0.5% strain >** 1500

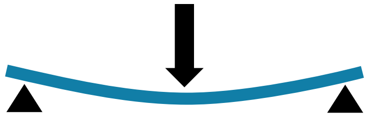
Electrical Specifications

- **Trace resistance =** 0.2 Ω⊡
- **Min trace width =** 0.1mm
- **Min Trace Space =** 0.05mm
- **Current <** 250mA
- **Voltage <** 120 Volts DC

Multifunctionnal inkjet printed composite

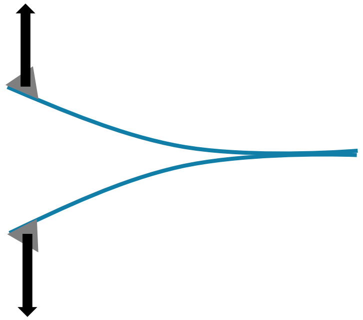
Tensile

Bending



- No strength reduction due to the printed traces
- Strains > 1.2% tested with no failure
- Traces can be used as strain gauges once preconditioned

DCB/Mode I



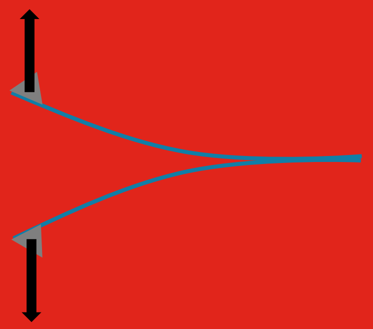
- ERR does not correlate with expected values on Zebra DCB specimens
- NIR treatment and sintering process partially damages the substrate
- Prediction is possible using simple cohesive modeling (no bridging)
- Sufficiently high toughness for most applications

Technology is ready to move to industrial applications !

Questions ?

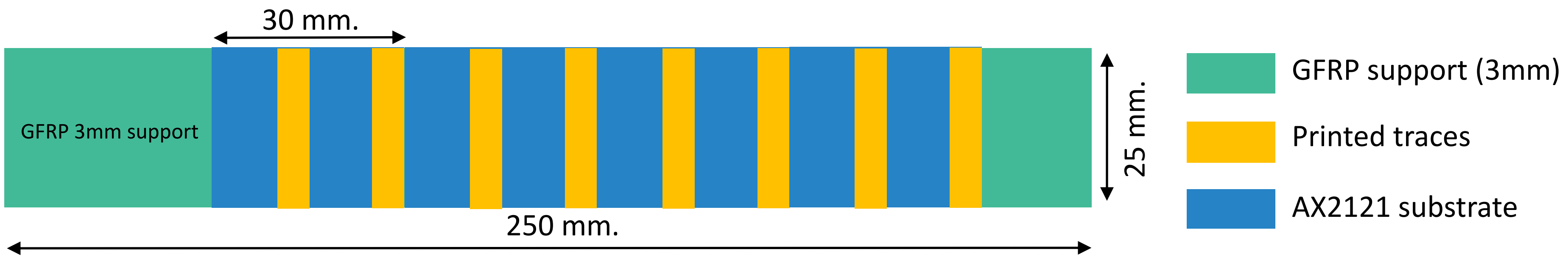
TESTING

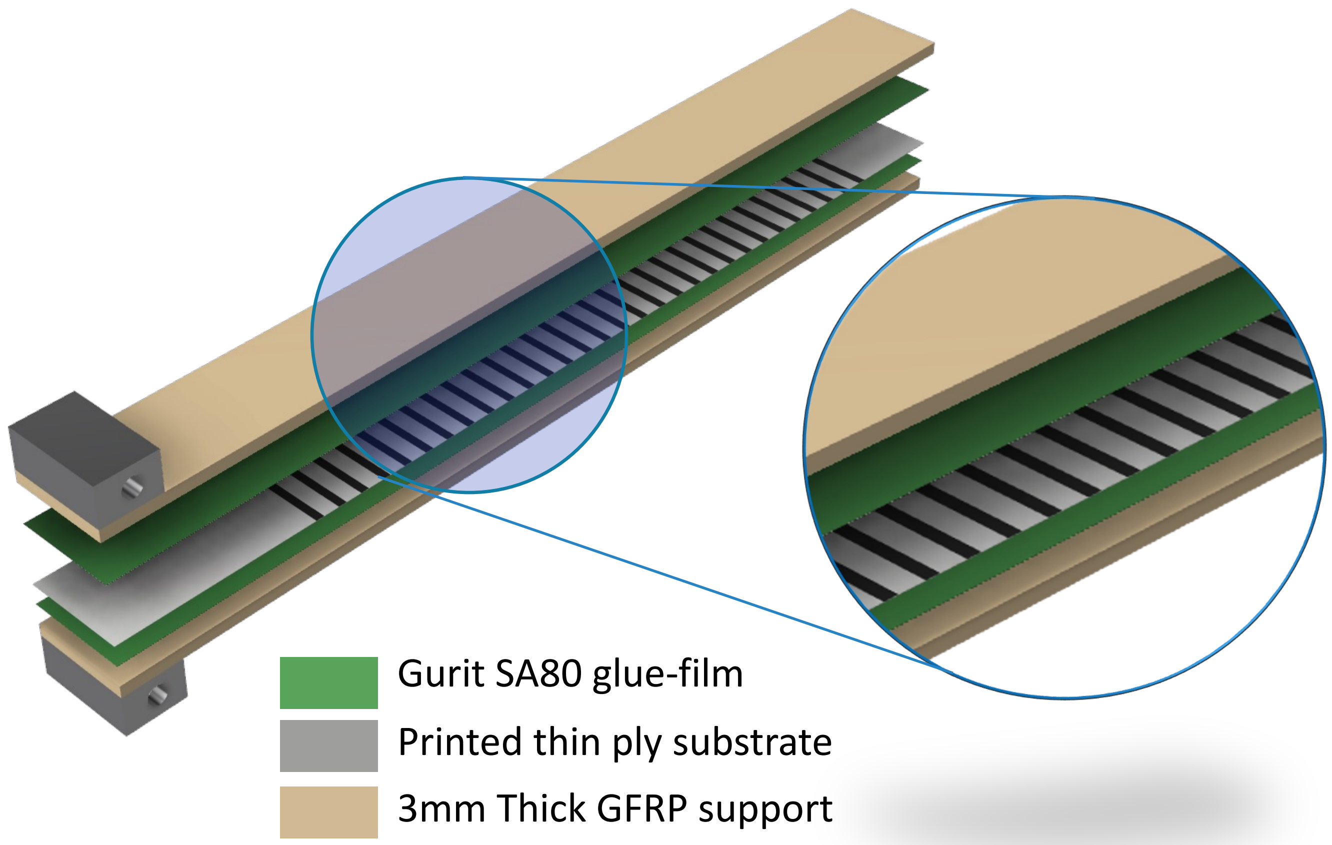
ZEBRA-DCB

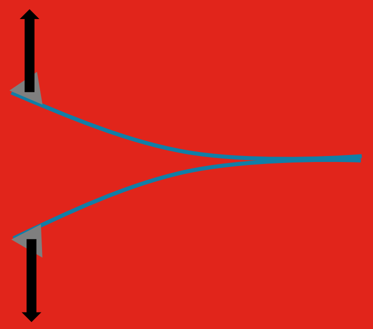


19

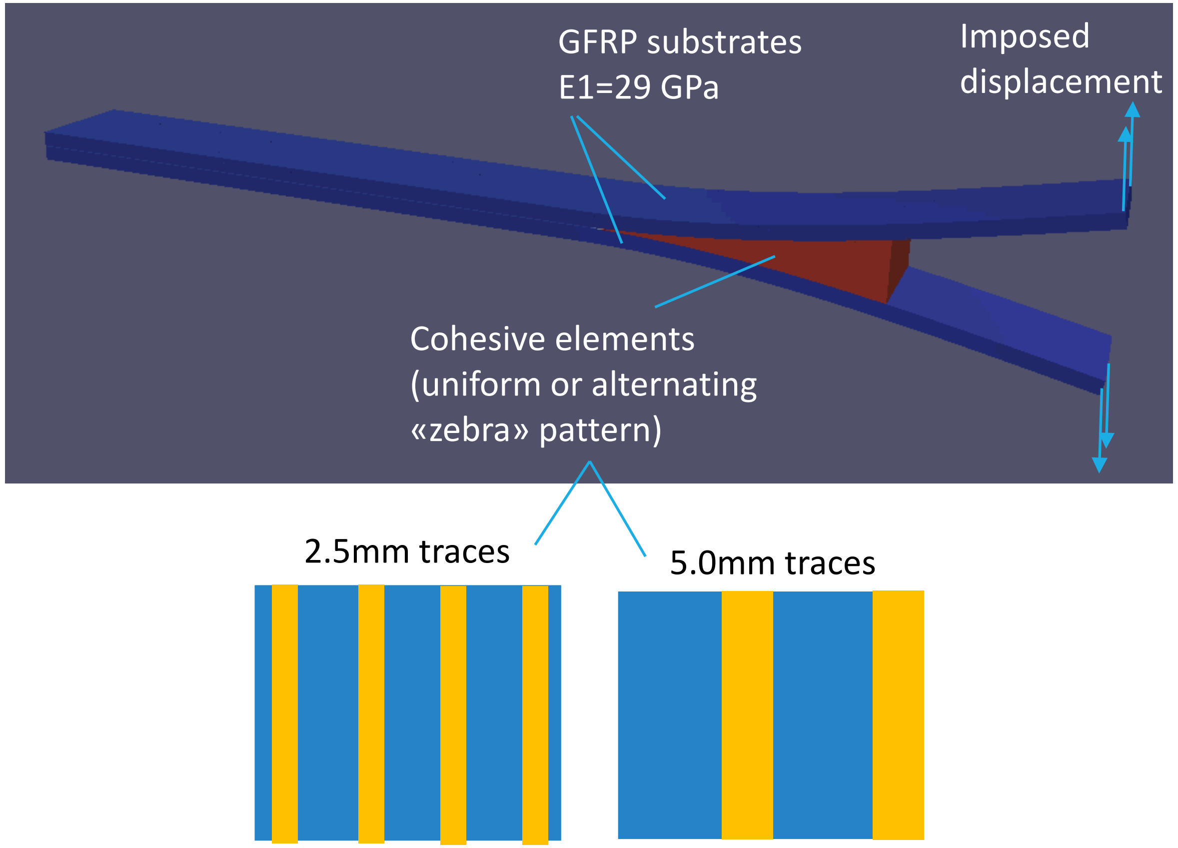
Zebra-DCB exploded layup







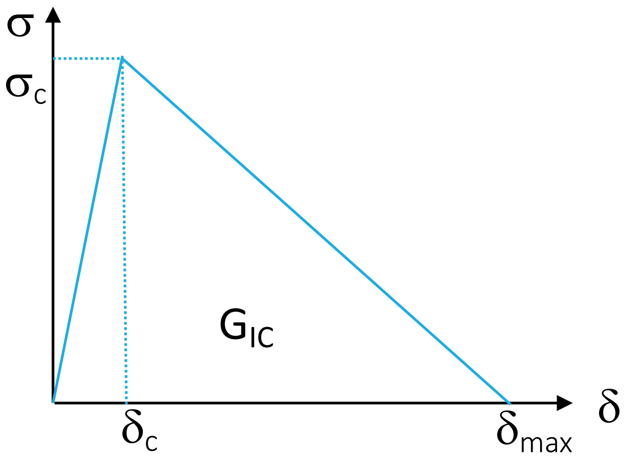
Cohesive zone modeling



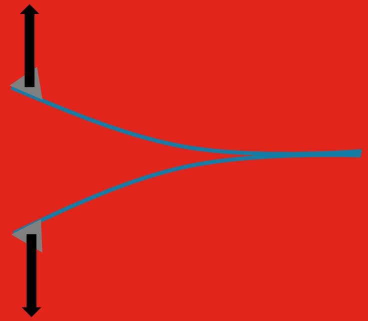
FE Modeling:

Code-Aster non-linear statics
3D FE model, 1st order hexa
Element size = 0.75 – 1.25mm

Cohesive law:
Bilinear traction separation

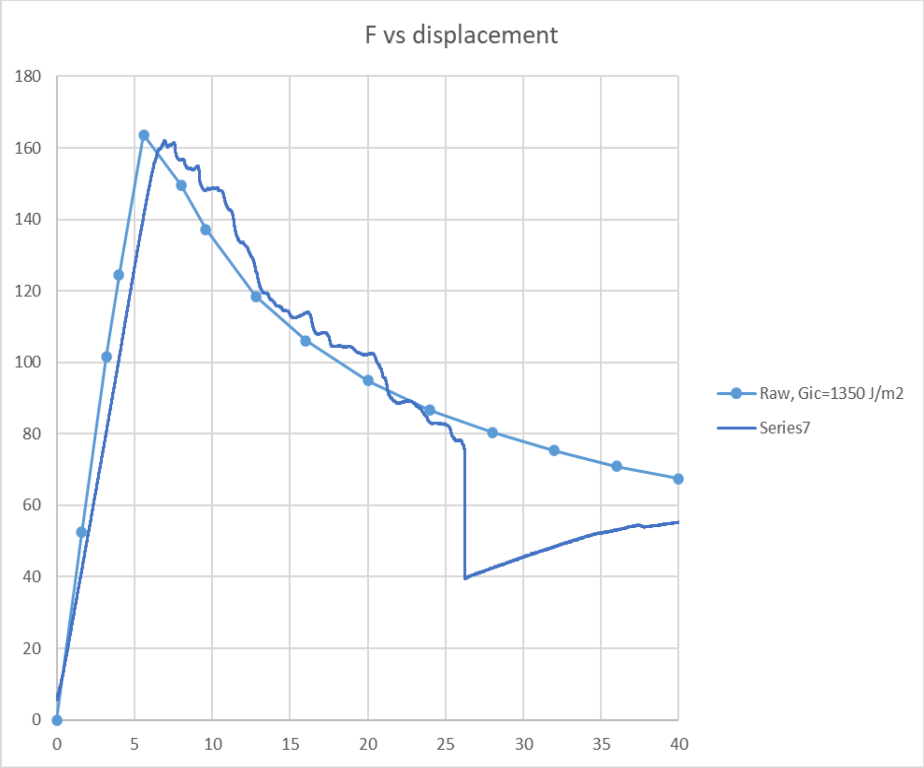


Interface	σ_c [MPa]	G_{IC} [J/m²]	δ_c [mm]
Printed traces	5	100	1/40 δ_{max}
Composite (raw)	35	1350	1/40 δ_{max}
Composite (printed)	15 - 35	600 - 1350	1/40 δ_{max}

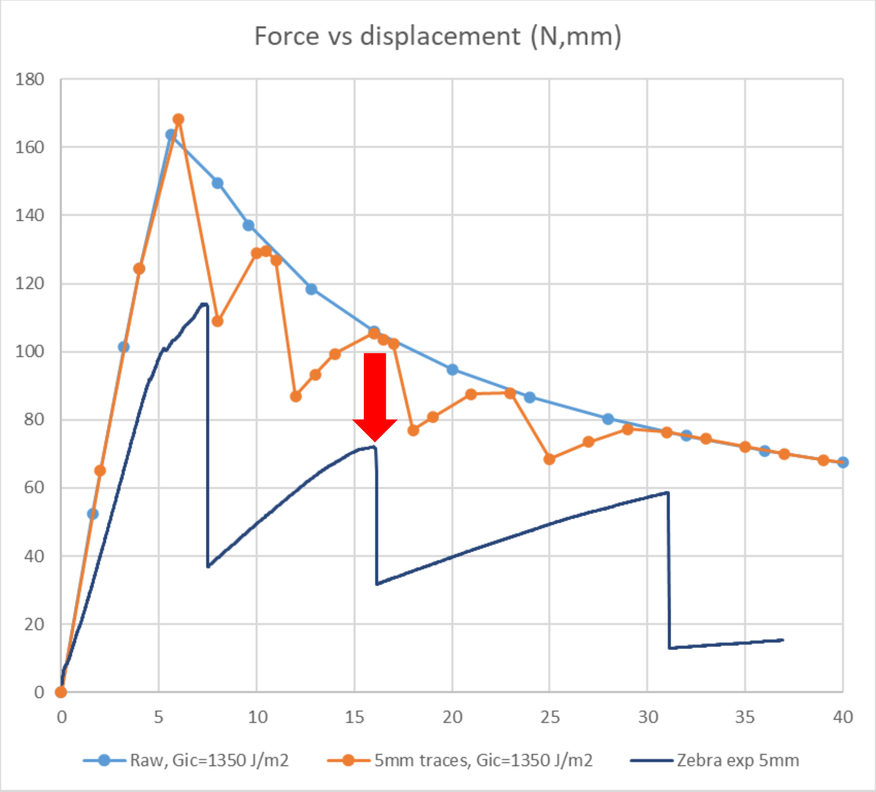


Results

Raw specimen



5.0mm printed traces



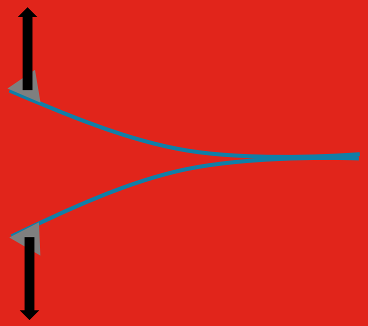
Raw specimen:
Cohesive model with experimental value of Gic matches well the measured load – displacement curve.

1st hypothesis:
Weak interface properties on printed traces
Same interface properties as raw on composite

HE IG VD

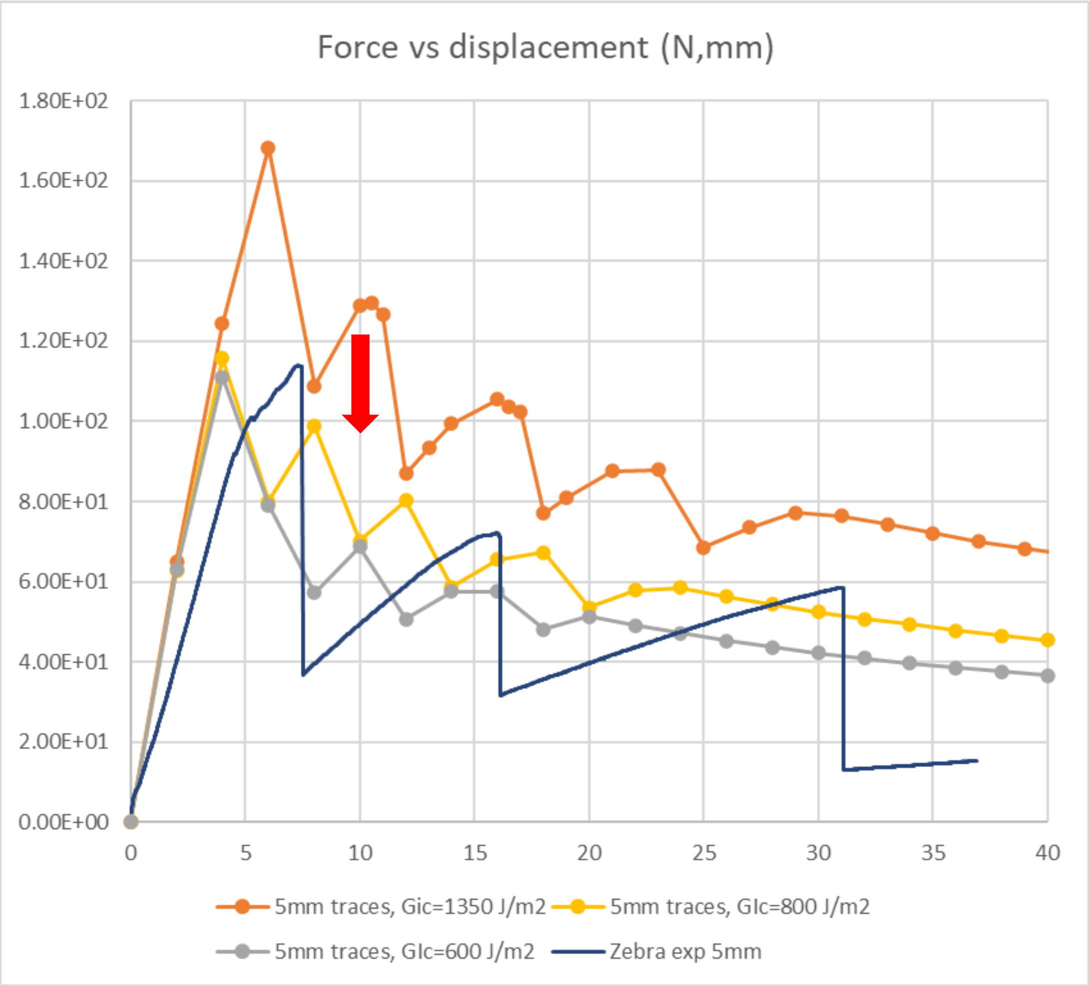
TESTING

ZEBRA-DCB



Results

5.0mm printed traces



2nd hypothesis:

Weak interface properties on printed traces

Altered interface properties of composite

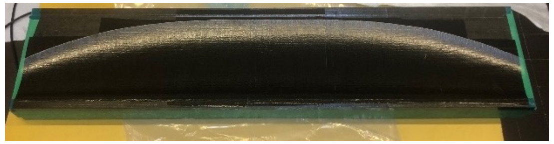
Identified Gic composite interface = ~ 800 J/m2

IR sintering of ink degrades the GFRP printing substrate!

MFS “HydroFoil Wing”

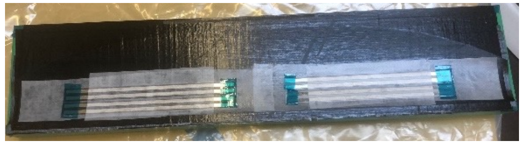
- I2C Digital circuit with Magnetometer and atmospheric sensors
- Digital bus (VCC,GND,Data,CLK)
- Typical Prepreg manufacturing process of layers (visible for demo purposes)

(1) Mould preparation

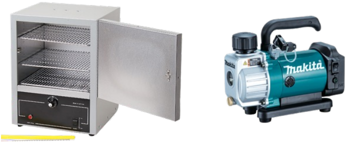


(2) Pre-preg stacking and debulking

(3-4) Printed substrates integration



(5-6) Layup continuation



(7) Standard composite part curing

(9) Demoulding and trimming to final shape

(10) Electronics integration