Metal-coated optical fiber embedment in Wire Arc Additive Manufacturing aluminum parts for distributed sensing

J.Popławski[1], K.Wysokiński[1], D.Budnicki[1] , J.Domagalski[1], M.Karczewski[1], K.Markiewicz[1], P.Piątek[1], K.Wilczyński[1], T.Tenderenda[1], A.Iturrioz[2], I.Rodriguez[2], X.Angulo[2], M.Napierała[1], T.Nasilowski[1]

[1] InPhoTech Sp. z o.o., ul. Poznanska 400, 05-850 Oltarzew, Poland

[2] LORTEK Technological Centre, Basque Research and Technology Alliance (BRTA), Arranomendia kalea 4A, 20240 Ordizia, Spain

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 862617 – MULTI-FUN

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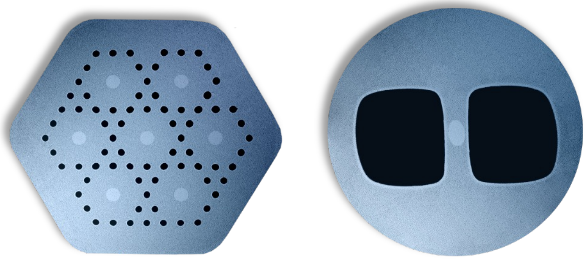
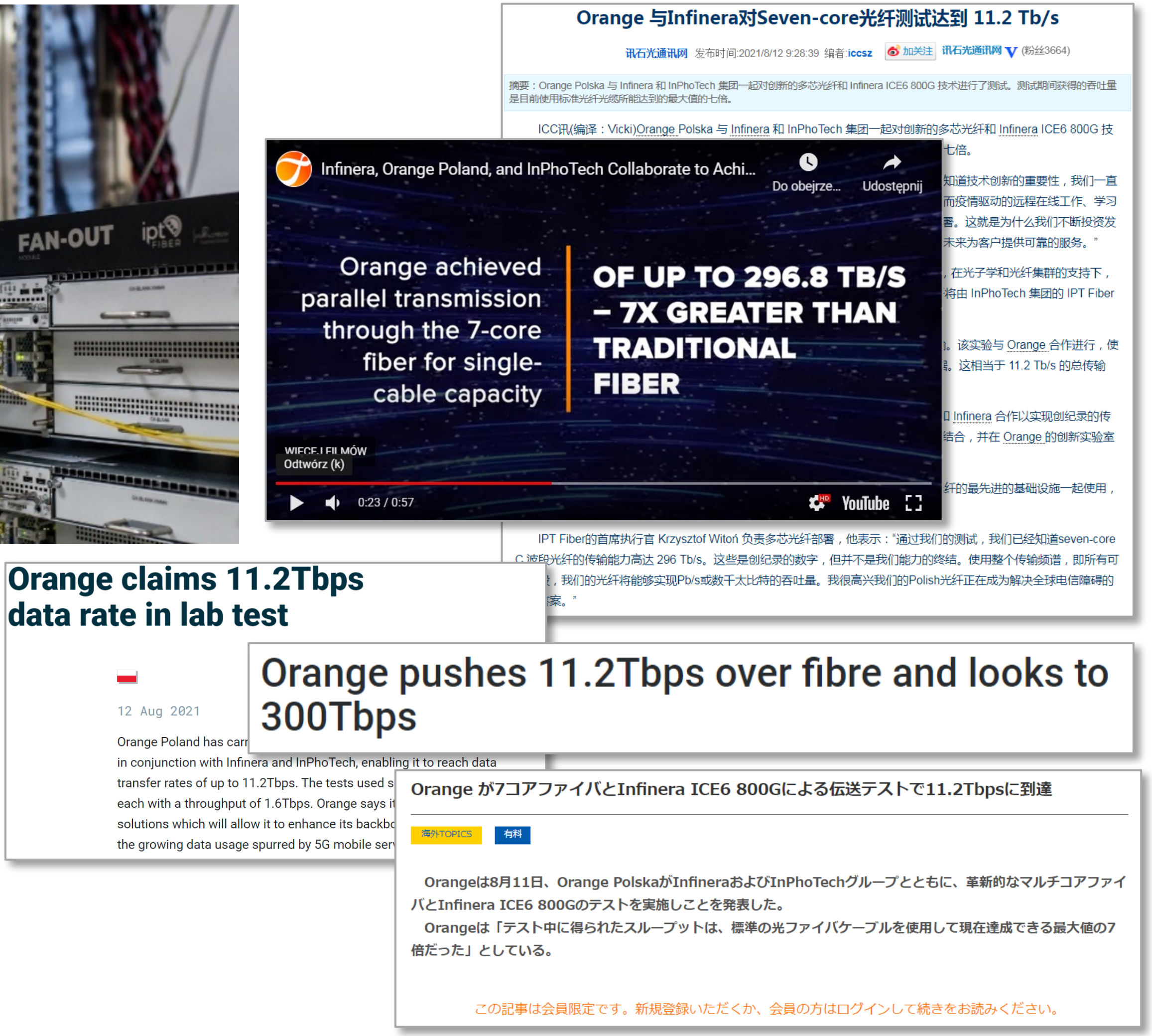
INNOVATION PHOTONICS TECHNOLOGY

InPhoTech – main areas of expertise

Specialty Optical Fiber design & manufacturing



- Multicore Fiber - **WR 11,2 Tb/s** live, **telecom standard** transmission tested by Infinera and Orange
- Side-Hole for temp. compensated **pressure sensing**
- Available **mass scale fabrication**
- Designated **specialty fiber components** (Fanouts, Mode filters, Power combiners)



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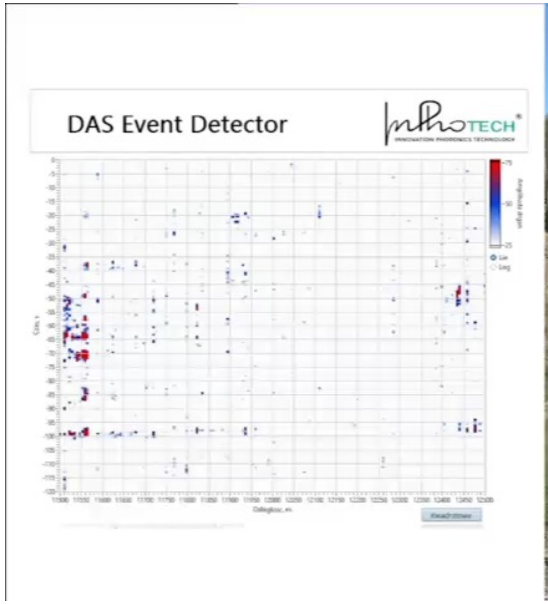
InPhoTech – main areas of expertise

Distributed Fiber Optic Sensors (FOS)

- Installed autonomus distributed sensor for permafrost depth monitoring in Spitzbergen, Svalbard (beyond north polar circle), - climate changes research
- Border/perimetric monitoring with dedicated Distributed Acoustic Sensor using existing telecom fiber network



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Distributed Fiber Optic Sensors (FOS)

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- Border/perimetric monitoring with dedicated Distributed Acoustic Sensor using existing telecom fiber network
- Distributed strain map monitoring of composite panels (delivered for European Space Agency)

European Space Agency

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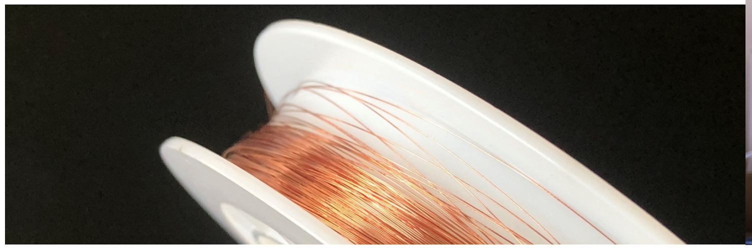
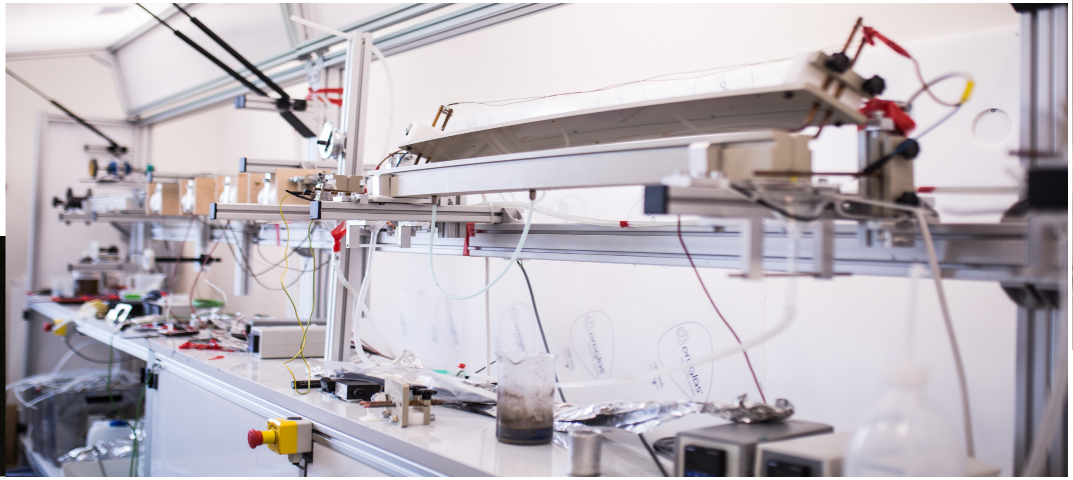
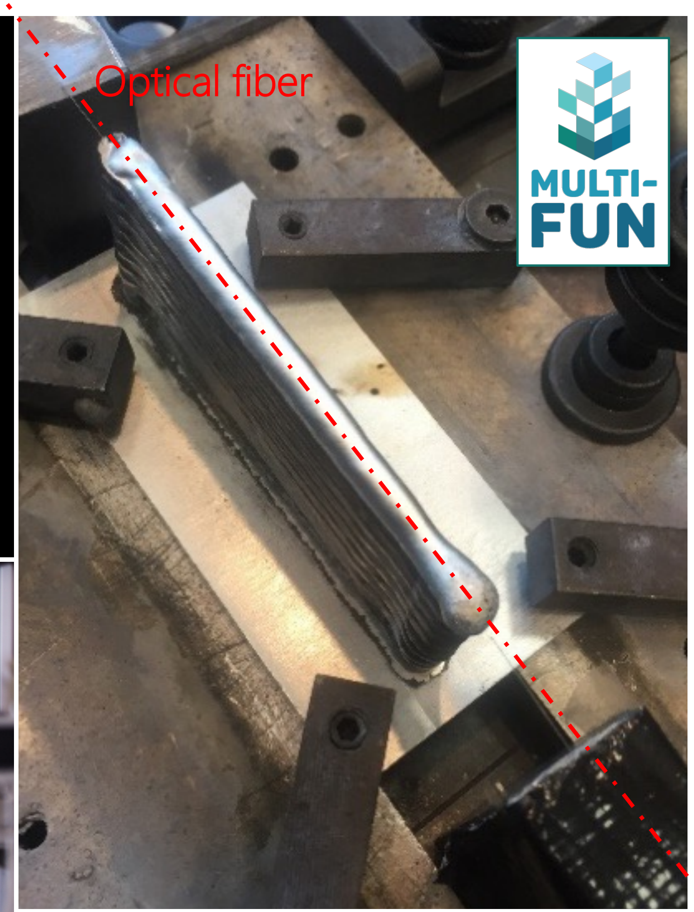
InPhoTech – main areas of expertise

Metallic coatings for any fabricated fiber

- Integrating fibers with metal components for sensing or heatsinking
- Harsh environment applications (e.g. high temp. **up to 1000°C**)
- More than **200 m continuous** length
- **Different materials and Multilayers** coating (Cu, Au, Ni, ……..)
- Removing acrylate and **recoating** with metal
- **Low induced attenuation**







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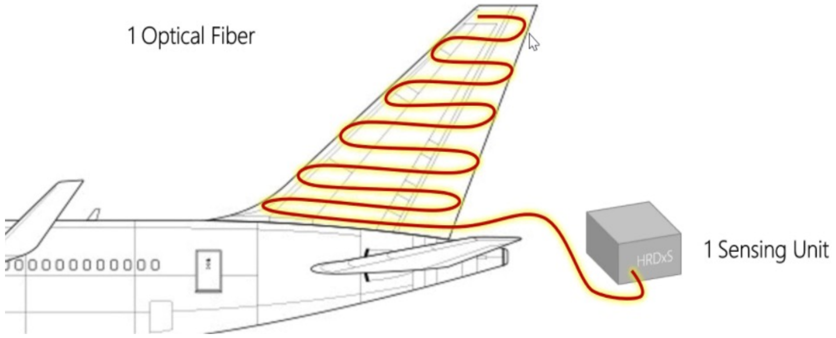
Motivation – Distributed fiber sensing for Structural Health Monitoring (3D print, composites, etc)

Great freedom in designing shape of element using WAAM (Wire Arc Additive Manufacturing) technology



Traditional forms of defect detection through service	Sensing by optical fiber integrated within the structure
Limited number of sensing points	Real-time full mapping of strain / shape / temperature distribution
Hard-to-reach sensing areas	Negligible effect on structural integrity of the structure during measurement
Expensive maintenance: acoustic sensing, visual and manual inspection	Comprehensive monitoring via optical fiber

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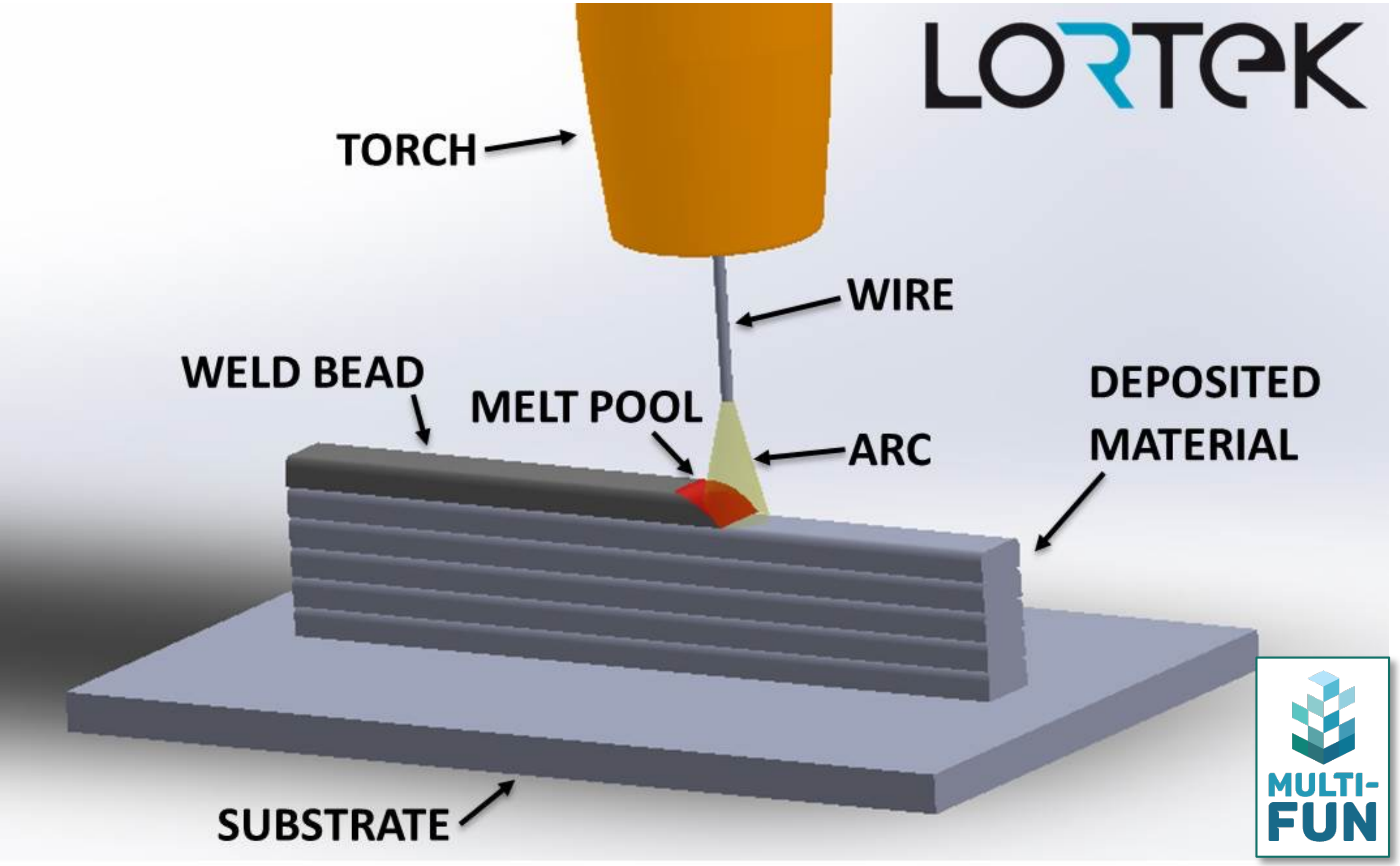
What is 3D metal printing – WAAM?



Wire Arc Additive Manufacturing is a variation of a Direct Energy Deposition technology that uses an arc welding process to 3D print metal parts.

Main issues:

- Frozen stress in 3D metal printed elements
- Probability of material discontinuities and defects

Solution – Integrated Fiber Optic Sensors

LORTEK is a member of Basque research & technology alliance

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Optical fiber embedment in WAAM process

Challenges:

- High temperature creates a need for specialty harsh environment coatings
- Inadequate coating materials might burn or melt and weaken the material

Sample before integration process

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Comparison of different coating materials

Same process conditions, imply different coating behavior, due to:

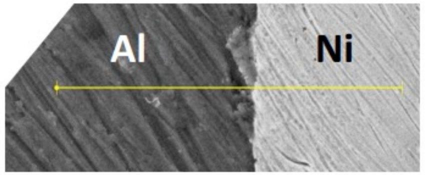
- Melting temperature of each material:

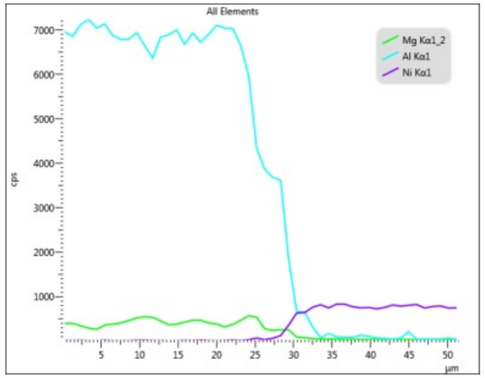
$$\begin{cases} Ni \approx 1455\,°C \\ Cu \approx 1085\,°C \\ Au \approx 1064\,°C \end{cases}$$

Where WAAM Al melting point is ~1200 ˚C

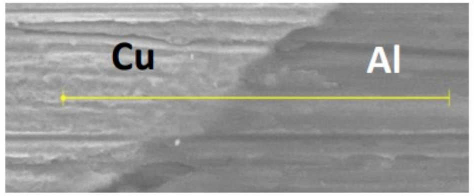
- Alloying behavior among materials; Ni-Al | Cu-Al | Au-Al

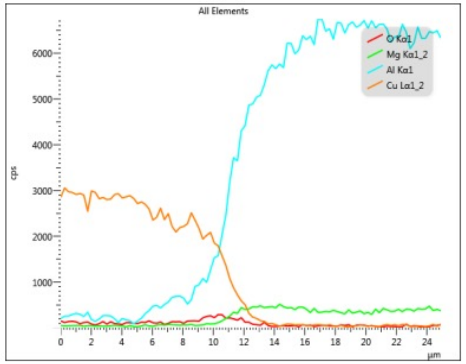
Ni-Al interface:



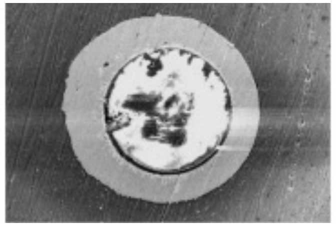


Cu-Al interface:

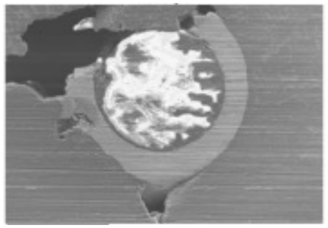




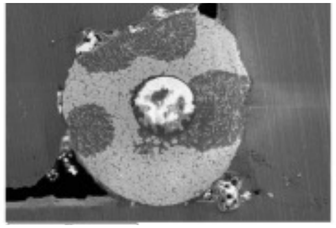
Comparison of cross-sections of samples:



Nickel



Copper



Gold

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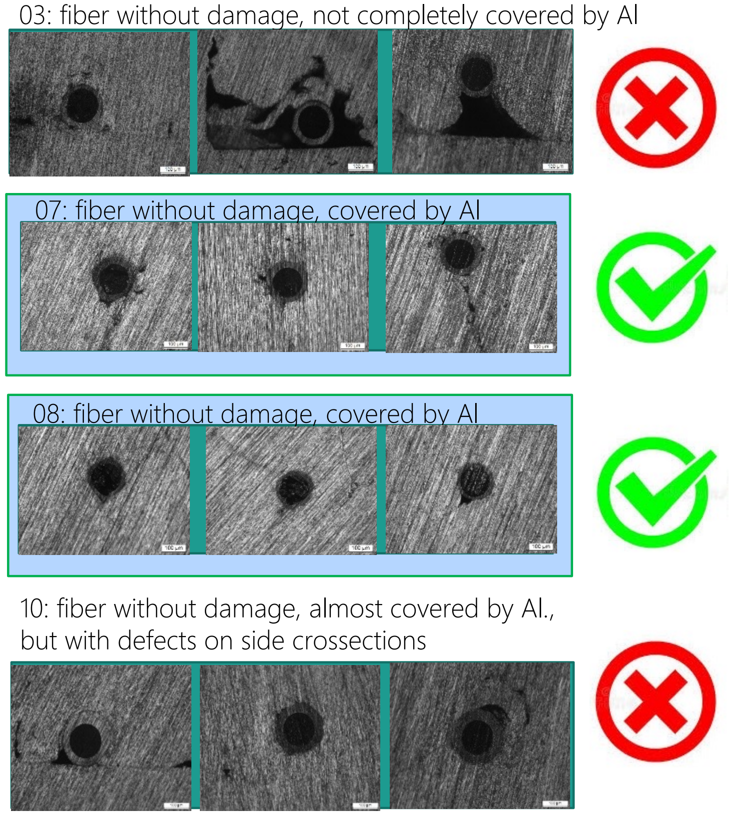
Optimization of welding process parameters

An influence of parameters of subsequent „filling" WAAM layer were analysed:

- Position of fiber throughout the process
- Cold Metal Transfer (CMT) mode
- Wire feed speed (WFS)
- Welding Current and Voltage

A suitable range of parameters were found



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Demonstration of embedding process

Sample after integration process

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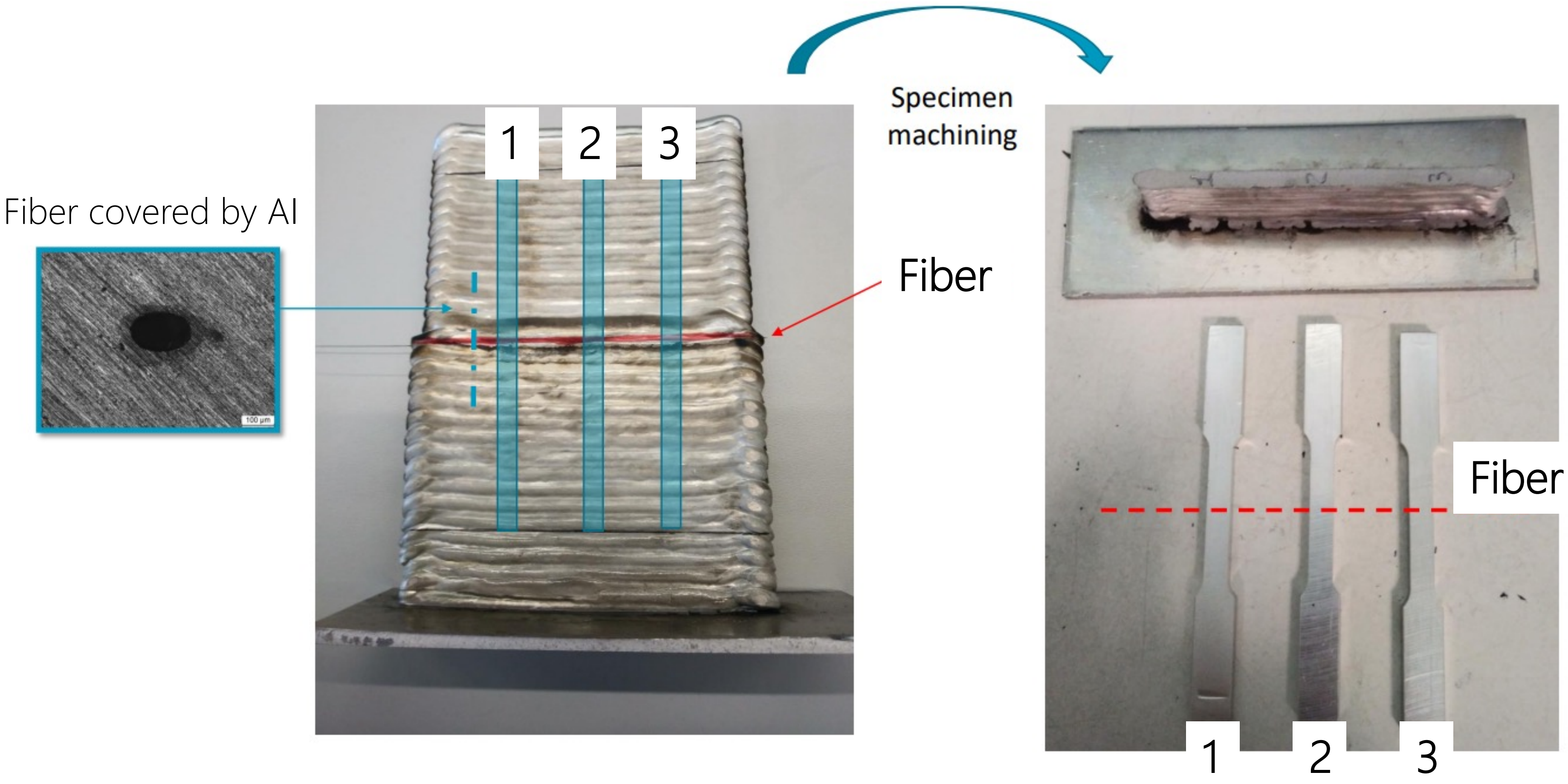
Mechanical strength analysis
- tensile test specimen machining



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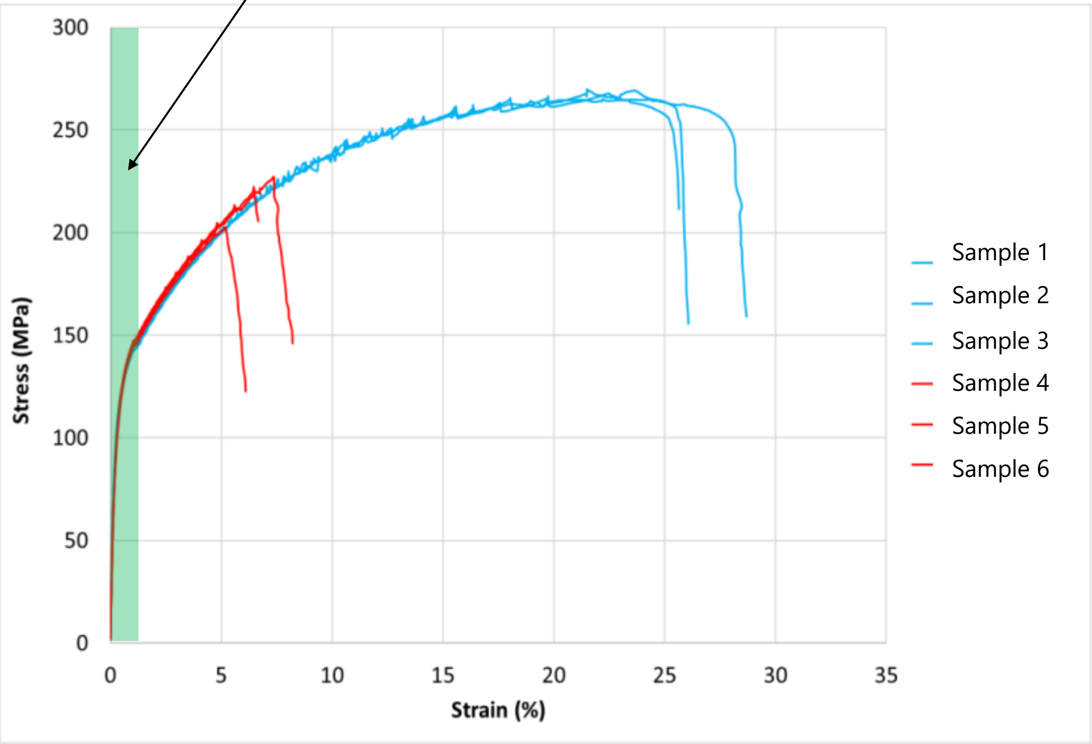
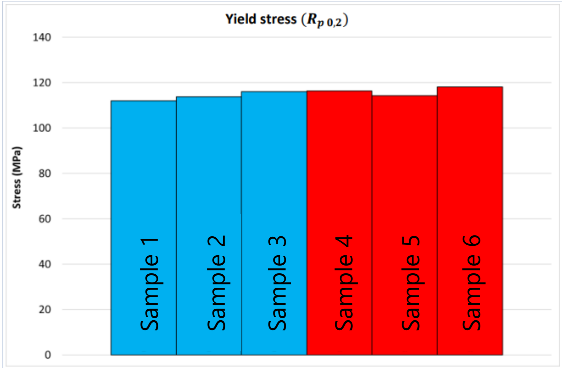
Mechanical strength analysis - tensile test results

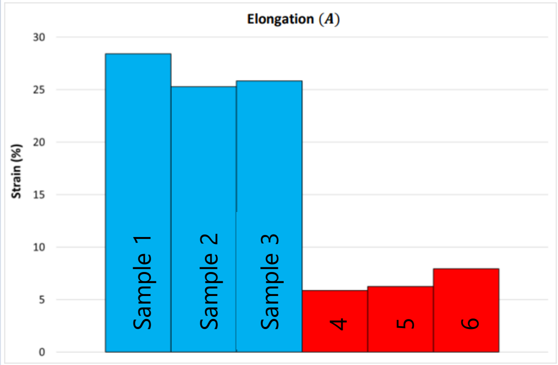
Useful range for components design (commercial applications)



No fiber embedded

Fiber embedded





Presence of an optical fiber does not affect yield stress. Samples maintain their properties within an elongation range useful for components design.

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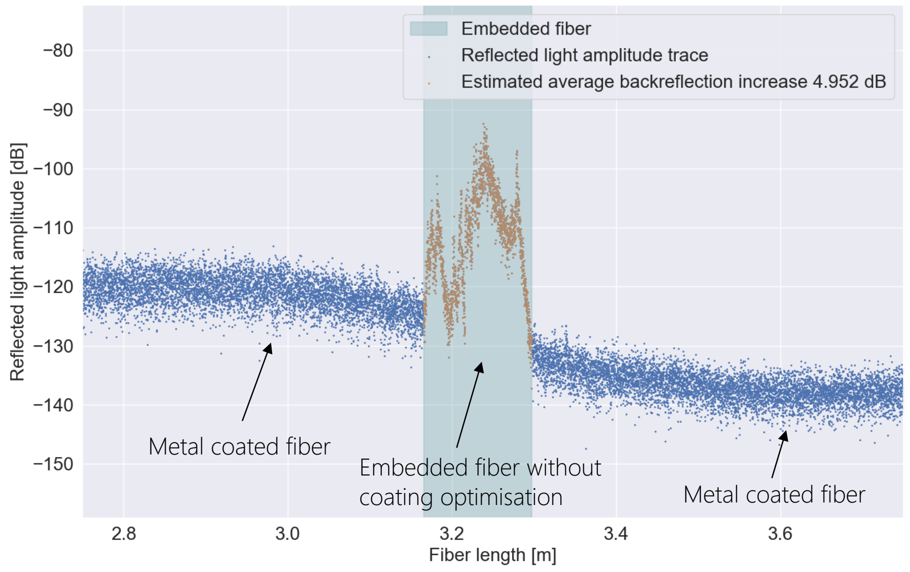
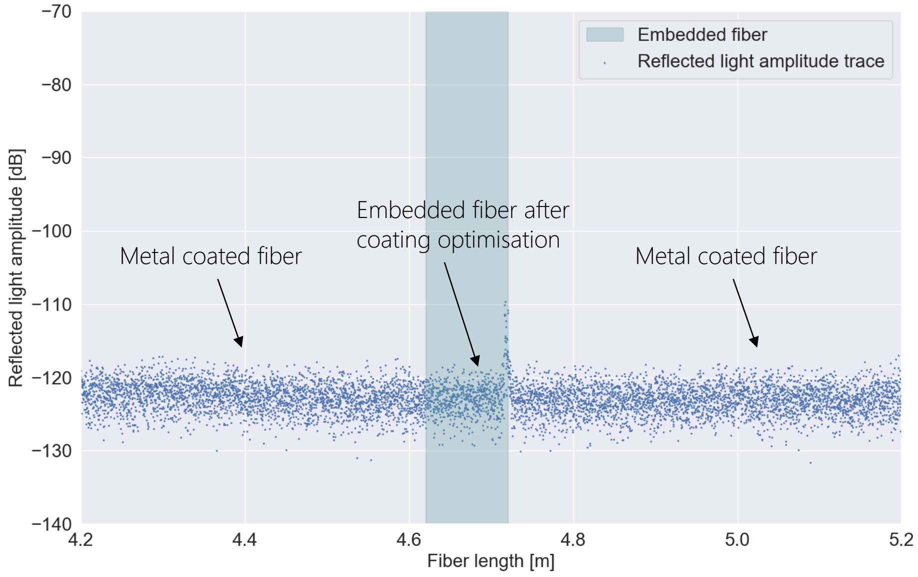
Optical analysis
– backscatter discontinuity phenomenon



Optimization of coating layers



The induced changes in backscatter were minimised by proper composition of coating and thickness selection

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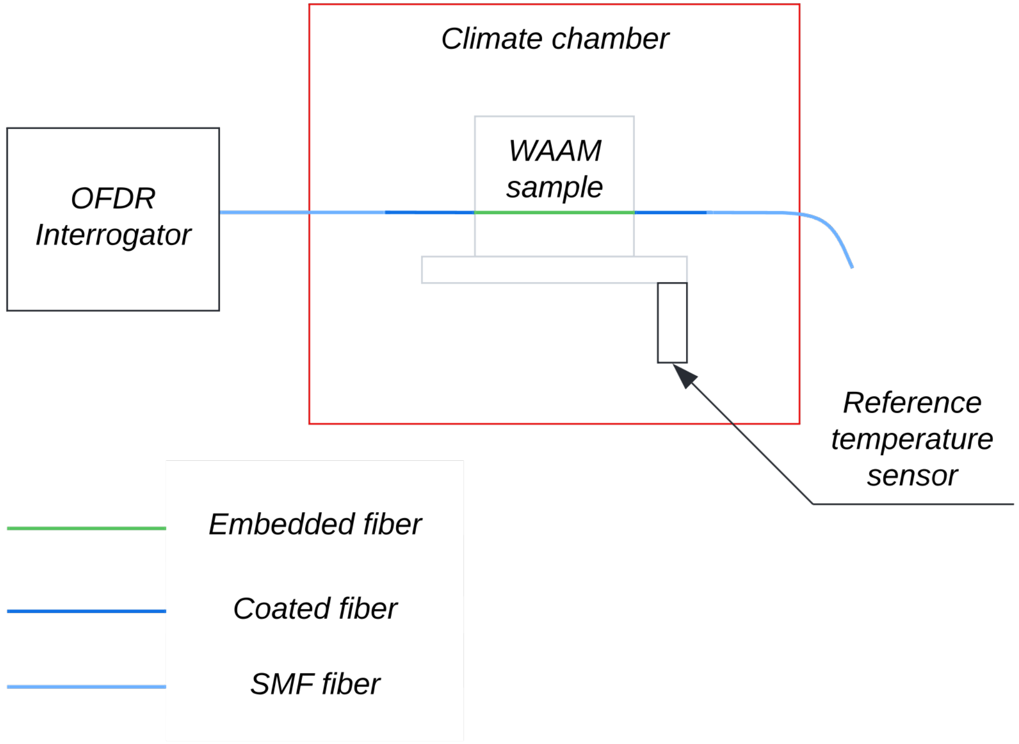
Optical distributed sensing
- temperature measurement testing setup



During the optical tests the temperature was set from -20 to 60˚C with steps of 10˚C

Temperature near a sample was measured with a reference sensor with 0.01˚C resolution

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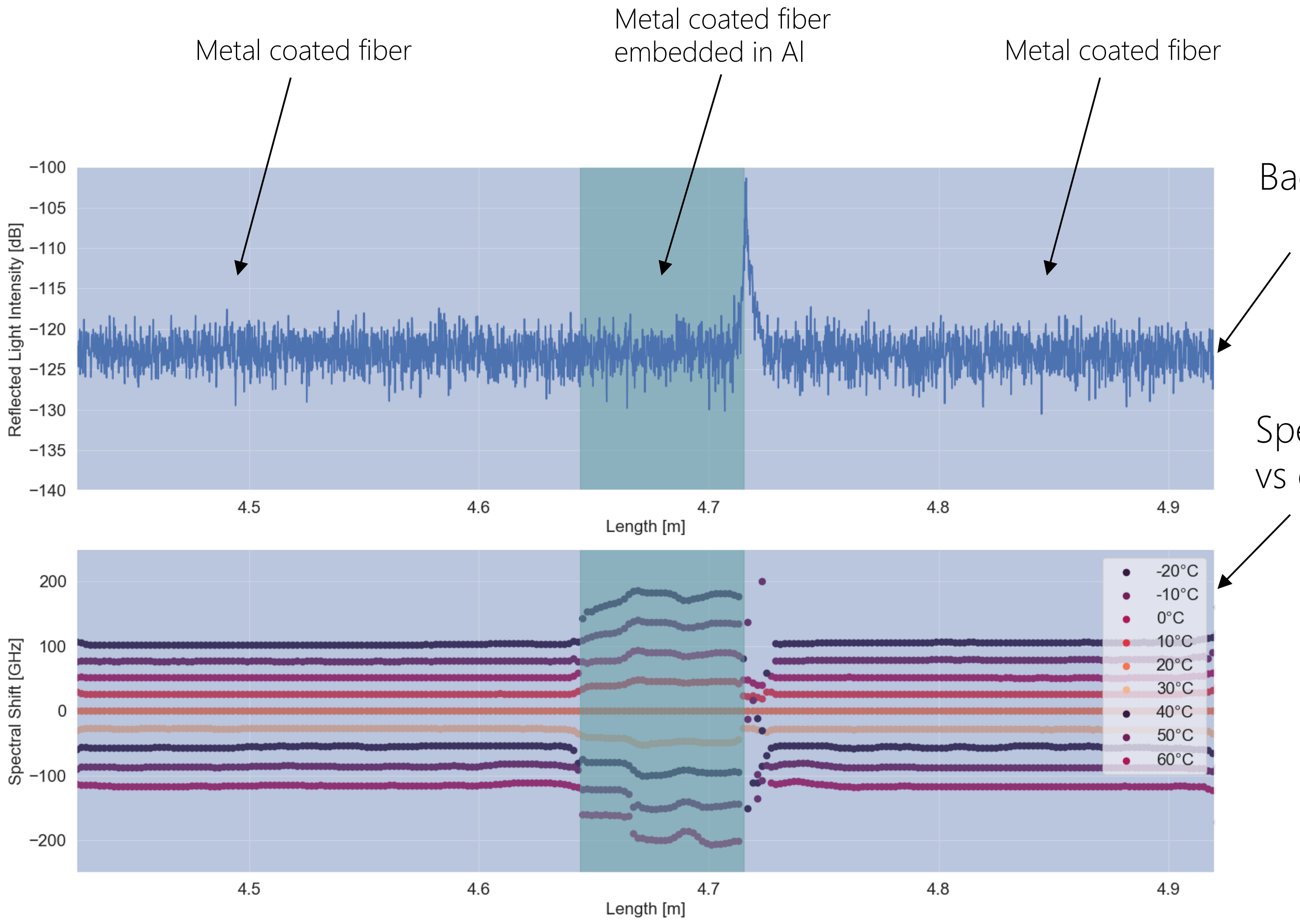
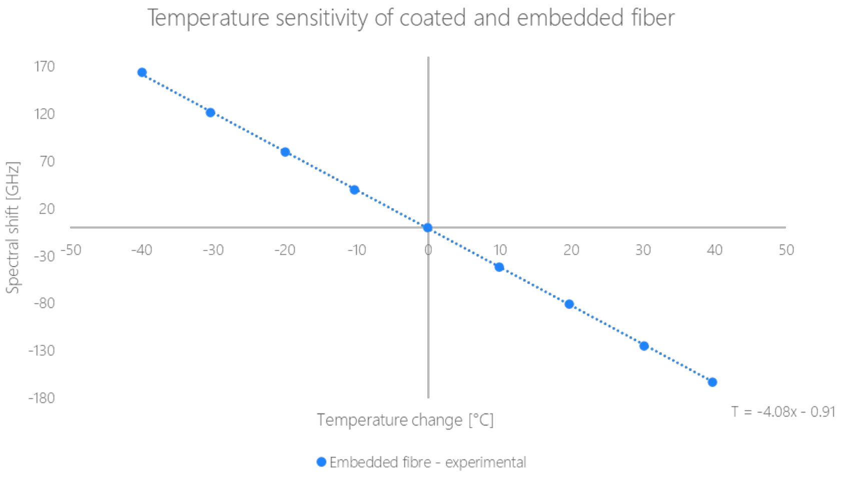
Optical distributed sensing
- temperature measurement results

Backscattered light amplitude vs distance

Spectral shift (optical response) for each temperature vs distance





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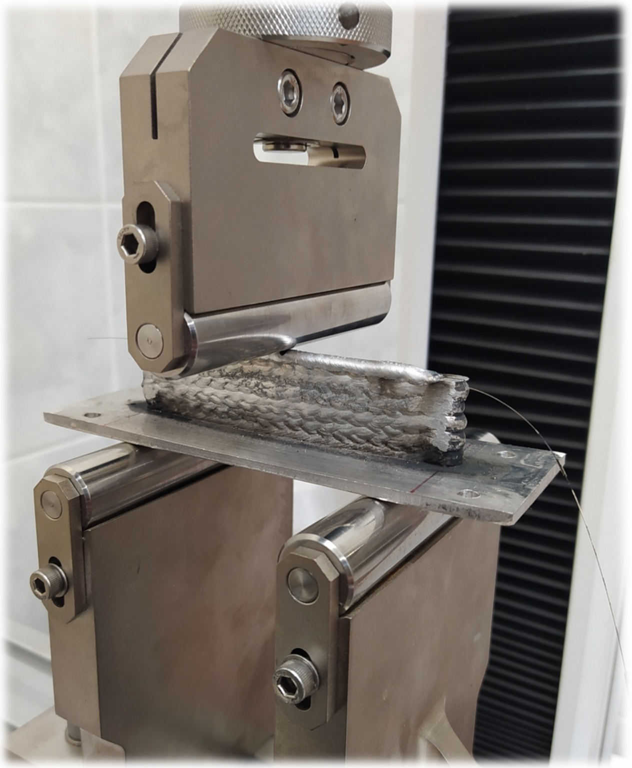
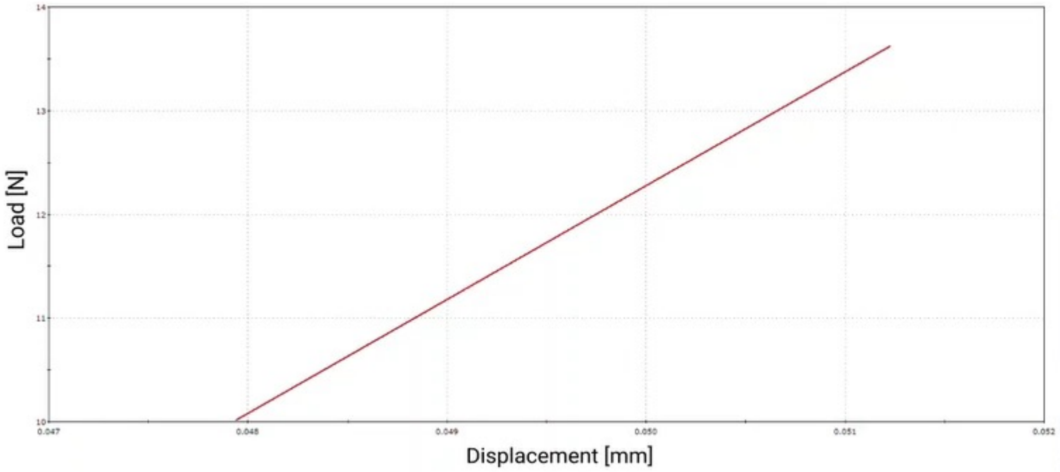
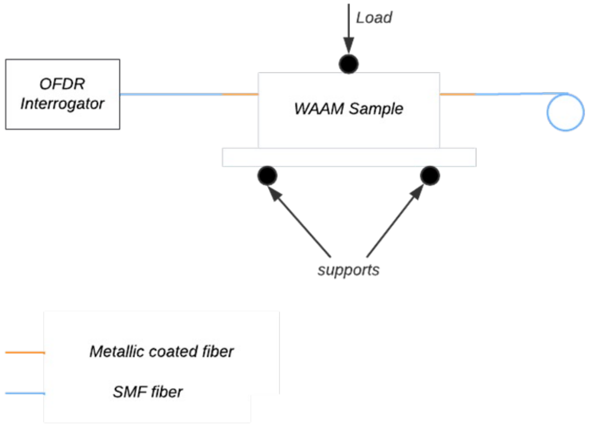
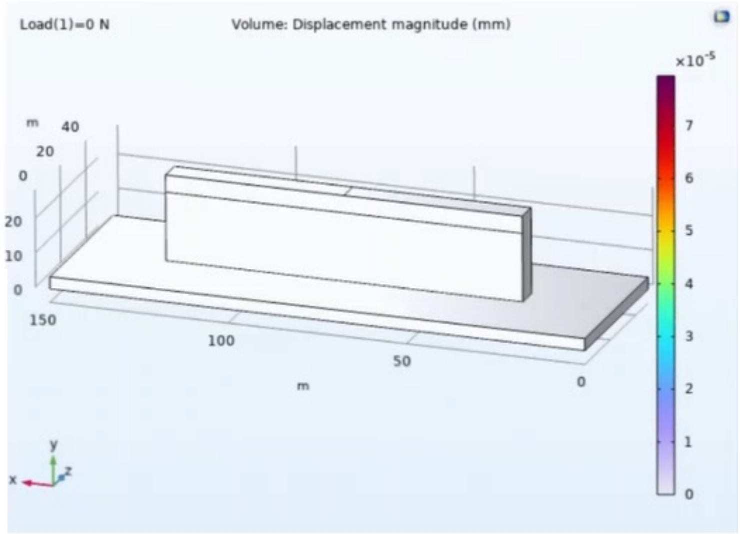
Optical distributed sensing - strain measurements





3-point bending





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Conclusions

An effective method of embedding optical fiber into WAAM printed parts was succesfsully developed:

- Optical Fibers were not destroyed during the integration proces and retained their optical properties
- Embedment does not cause local defects in 3D printed structure
- Mechanical properties (yield stress) of the constructed part are suitable

It was proven that we can monitor the stress and temperature of WAAM elements

Further development of technology is planned as follows:

- Manufacturing of a full-scale demonstrator of an aeroplane bulkhead panel

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THANK YOU FOR YOUR ATTENTION

Krzysztof Wilczyński
kwilczynski@inphotech.pl

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