

STRUCTURAL HEALTH MONITORING METHODS THAT COULD BE BUILT INTO COMPOSITE STRUCTURES FOR MULTI SENSING PURPOSES

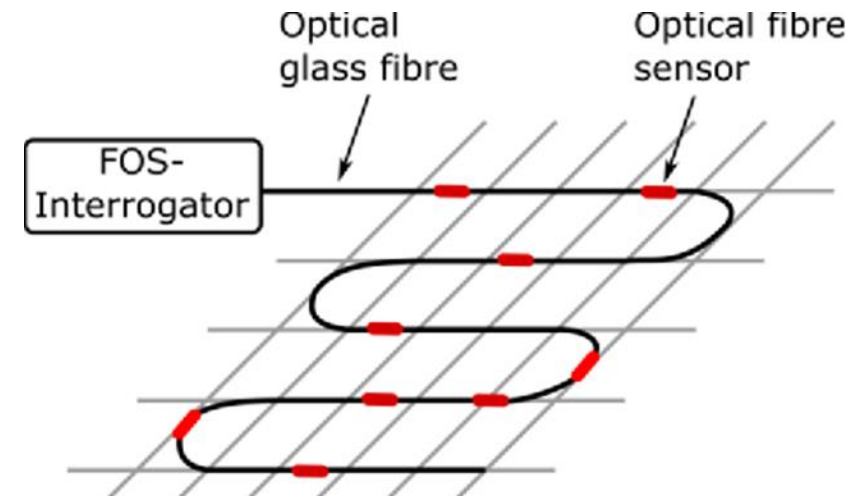
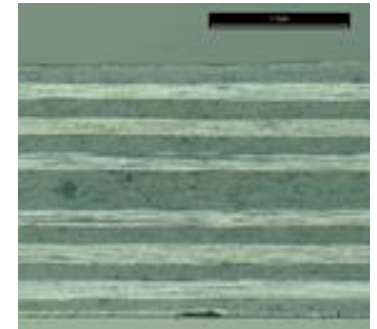
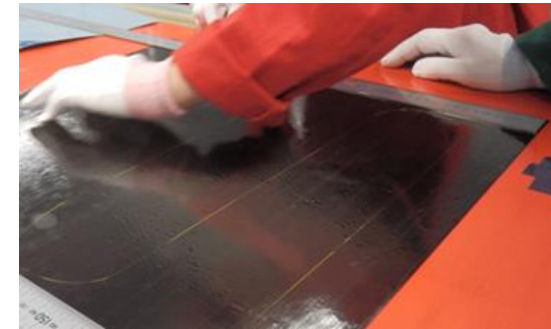
From traditional light weight structures to
multifunctional light weight systems

Per Hallander, Technical Fellow within Composites
Technology and manufacturing processes at Saab
Aeronautics



Outline

- Background
 - Highly integrated composites design
 - Multifunctional composite structures
 - Why Structural Health Monitoring
- Experiences of Fibre Optical Fibre Sensors
 - Tensile measurements
 - Pressure measurements
- Experiences of guided waves / lamb waves
- Experiences of resistive sensors
 - Carbon Nano Tubes
 - Graphene
- Conclusions

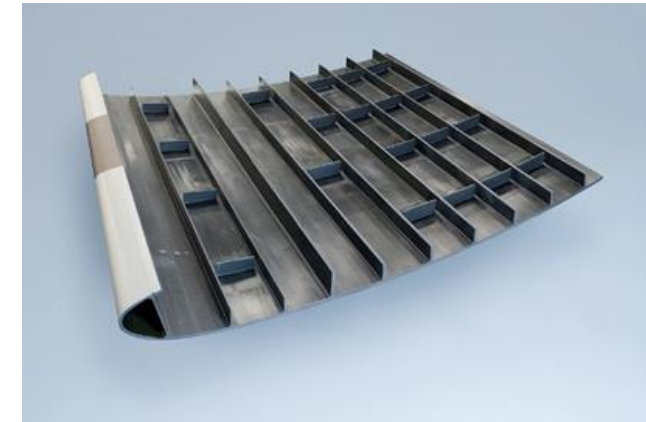
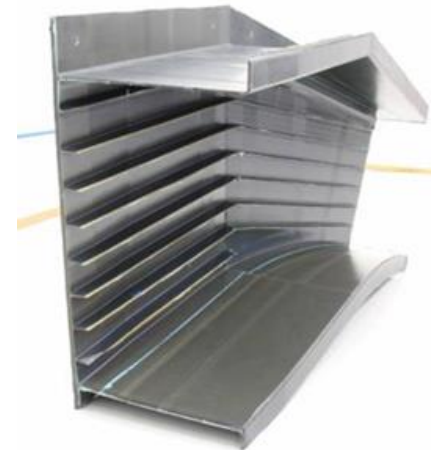
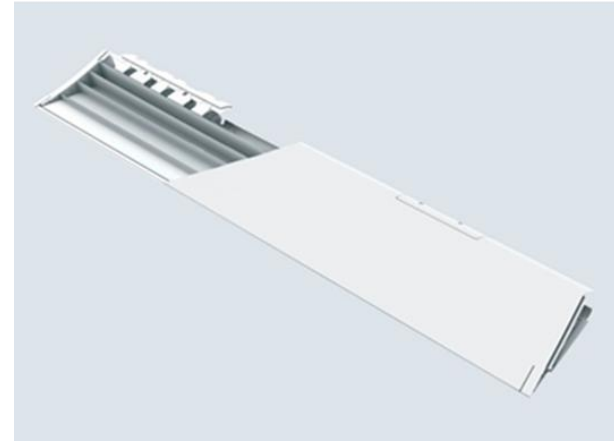


BACKGROUND: FROM THE FIRST CFRP PREPREG COMPONENTS TO HIGHLY INTEGRATED AND OPTIMIZED COMPOSITE DESIGNS

CFRP component 1971



Today: highly integrated and optimized composite designs



Saving weight on an aircraft is a hard work that requires cooperation across all technical disciplines

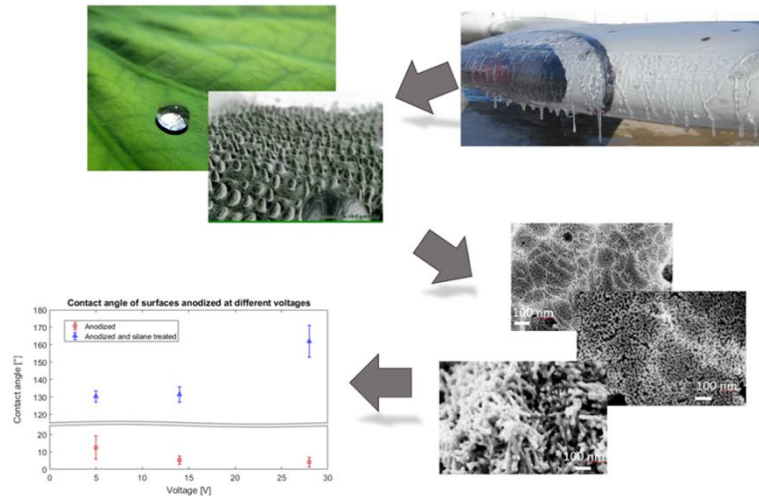
Airframe ~37% of total weight



System ~63% of total weight



Further weight savings to be reached through multifunctional structures & light weight systems



Passive multifunctional structures

- Lightning strike protections
- Anti-icing surfaces
- Passive cooling
- Radar transparency

Active multifunctional structures

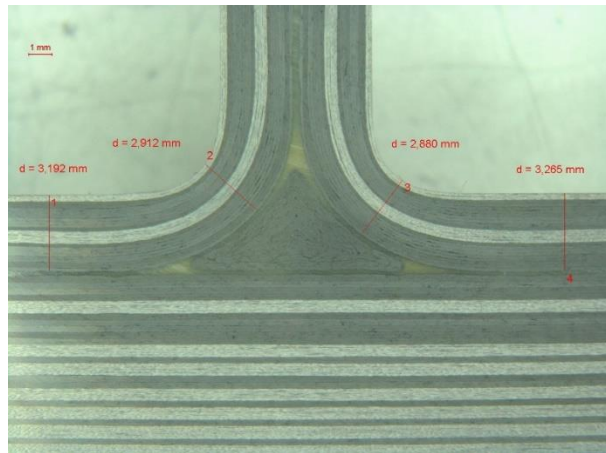
- **Structural Health monitoring**
- Morphing structures
- De-icing
- Energy management
 - Structural Batteries
 - Energy harvesting
 - Active cooling
- Built-in air-data sensors

Electric conductivity

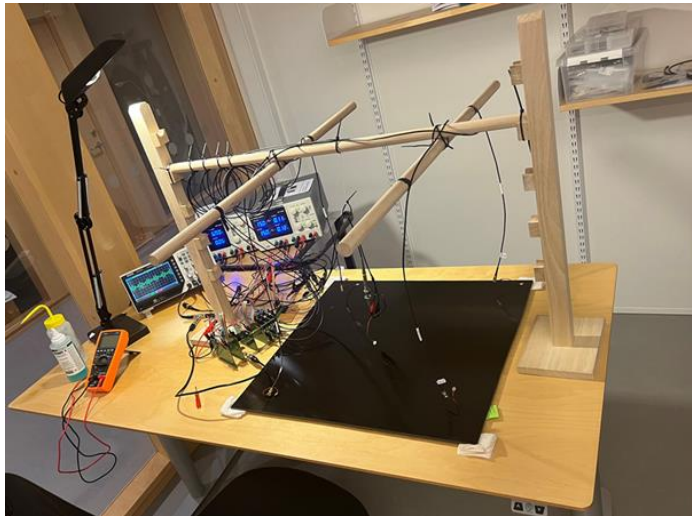
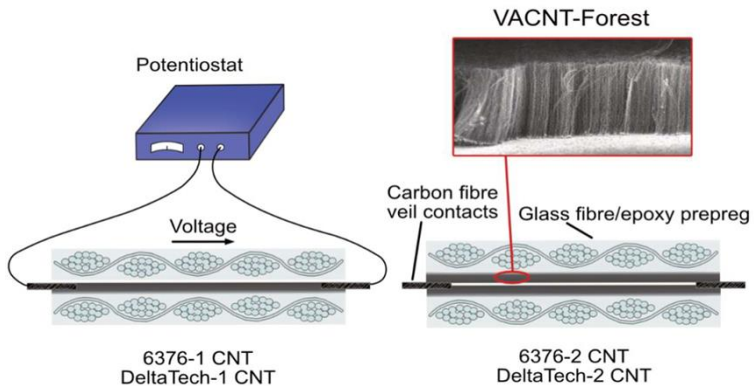
Thermal conductivity

Why Structural Health Monitoring

Highly integrated optimized composite designs demands for more advanced inspection



Structural Health Monitoring - SHM

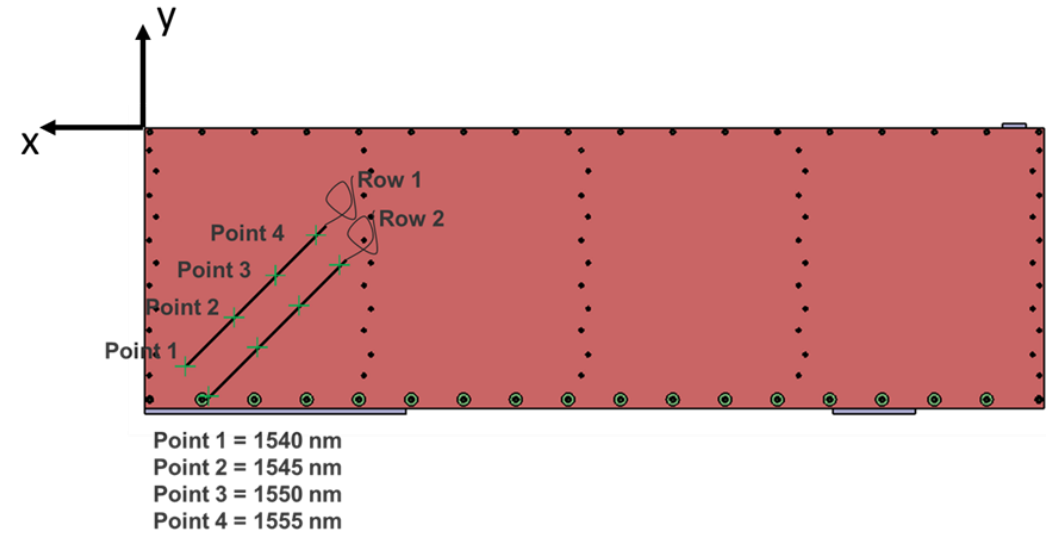
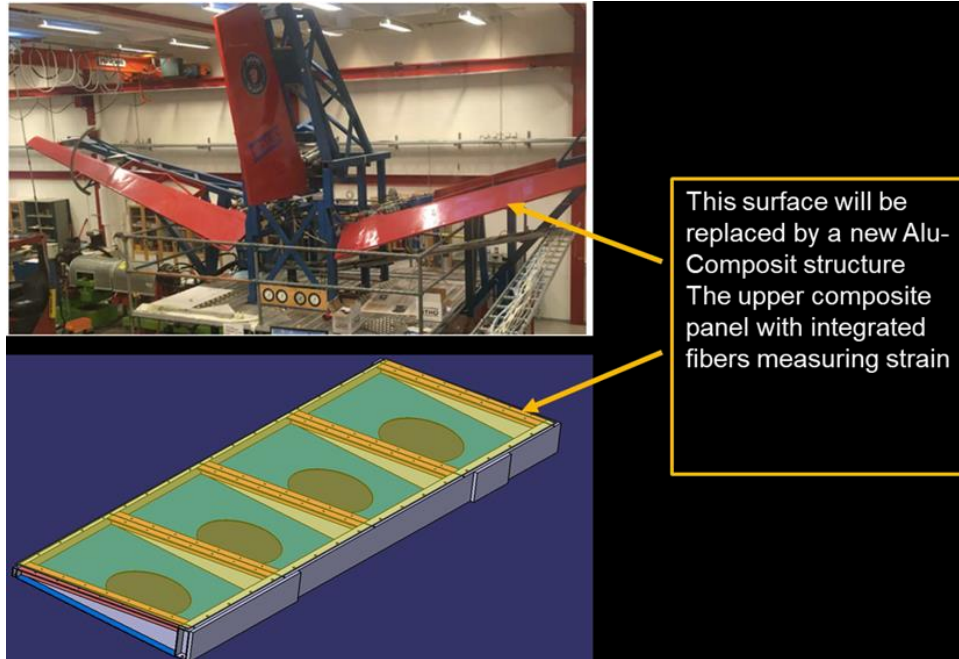


- Fiber optics
- Guided waves / lamb waves
- Resistive CNT sensors
- Resistive Graphene sensors



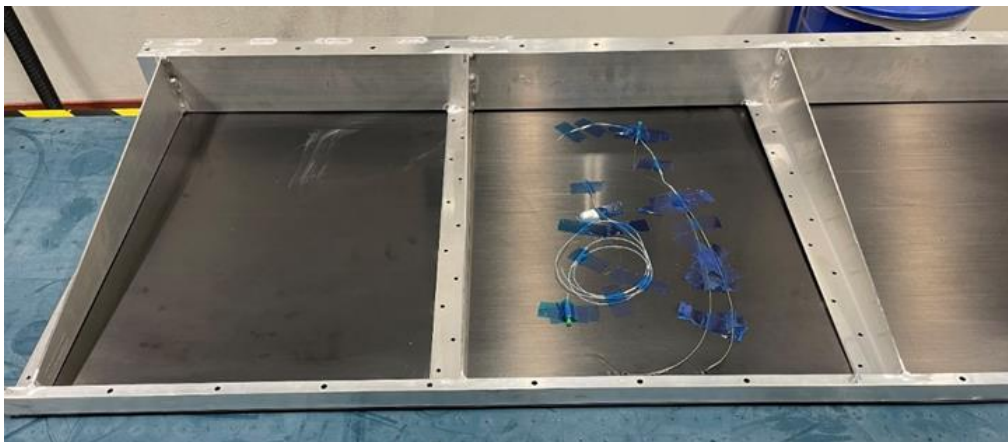
Example of SHM with FBG - Int-Demo

Control surface demonstrator in Iron bird rigg



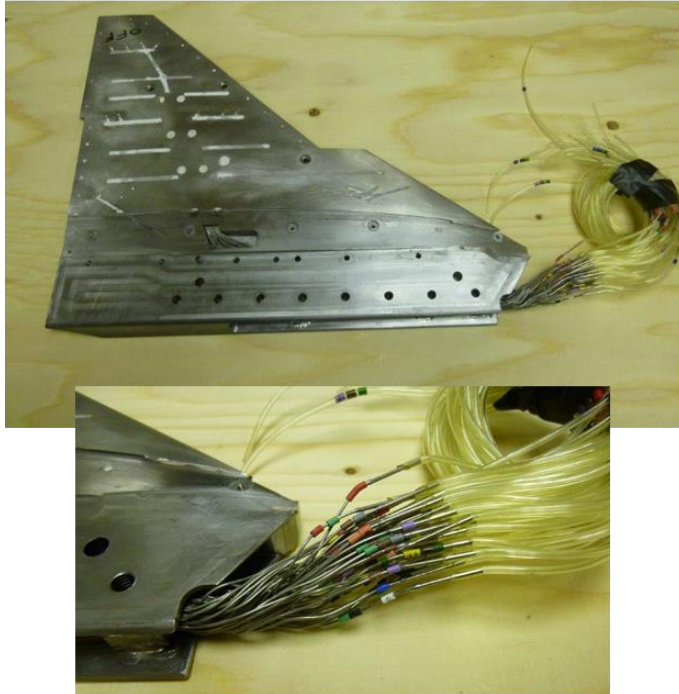
Comparison of strains for the 100 kg load case

	<i>με at point:</i>			
	1	2	3	4
FBG	-42	-57	-20	-62
FEM	-39	-50	-64	-73



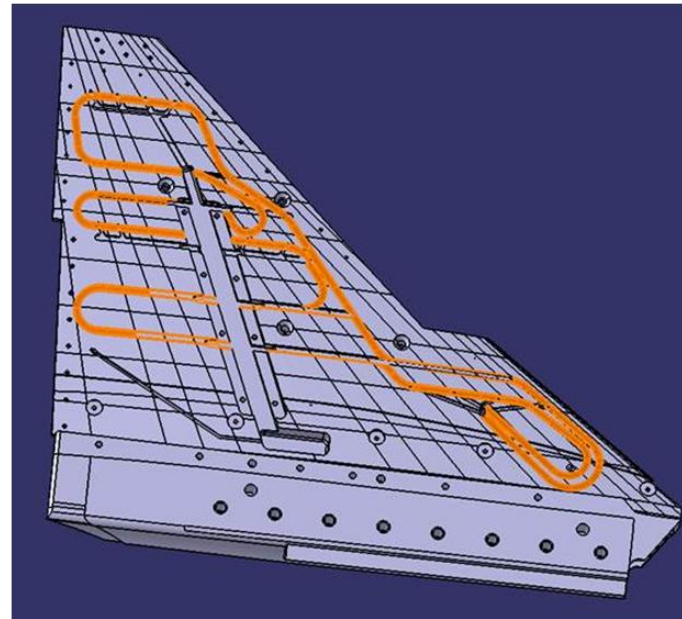
Composite embedded FBG:s are very accurate for measure strain. However not developed for pressure measurements

State of the art technology



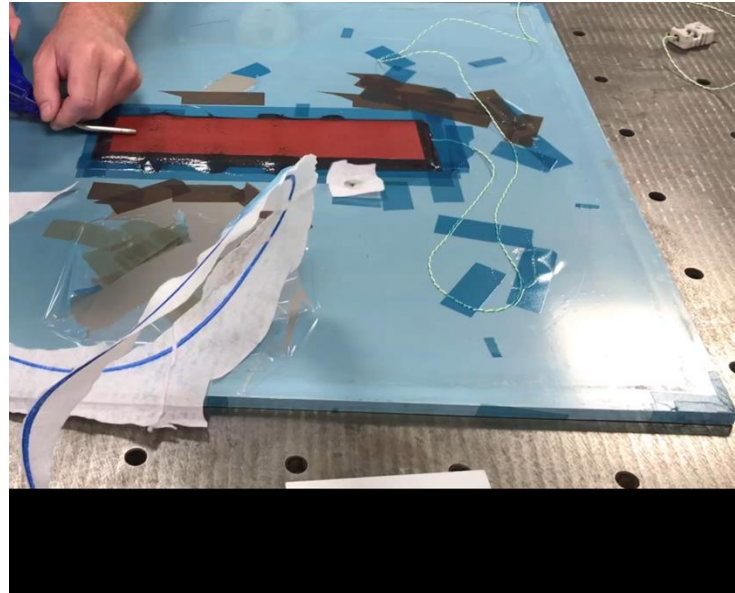
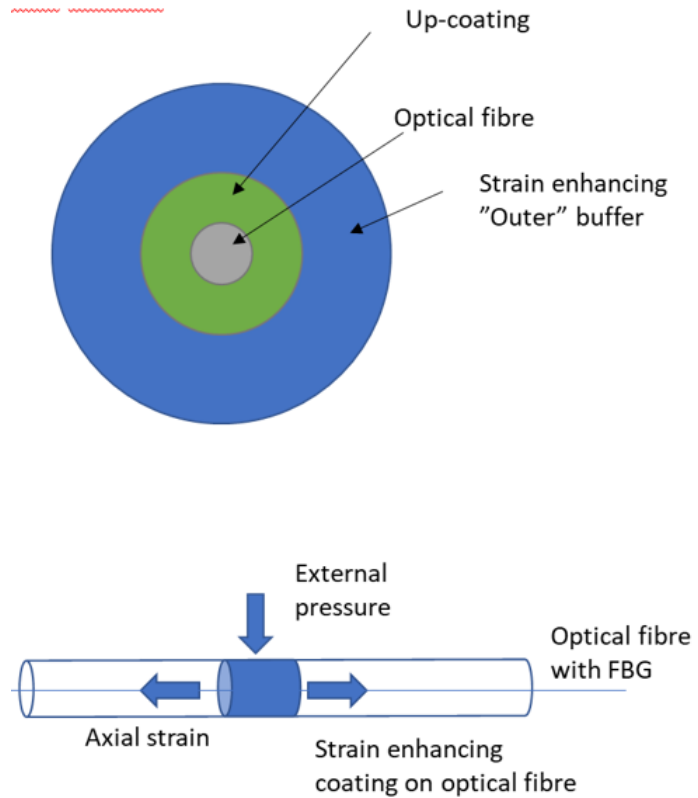
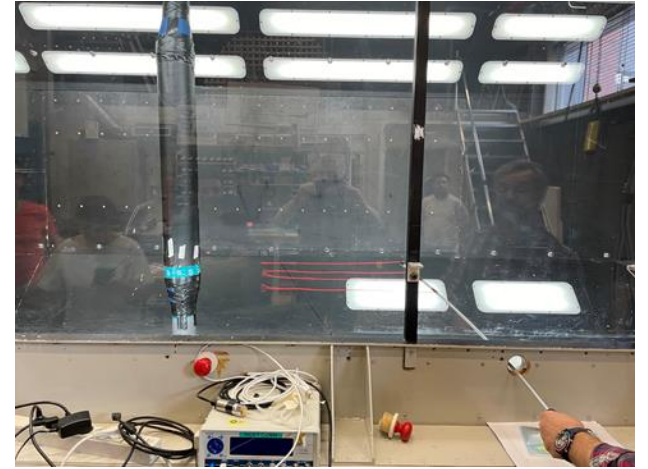
One tube and hose for each measuring point,

Network of fiber optical pressure sensors applied on a wind tunnel model

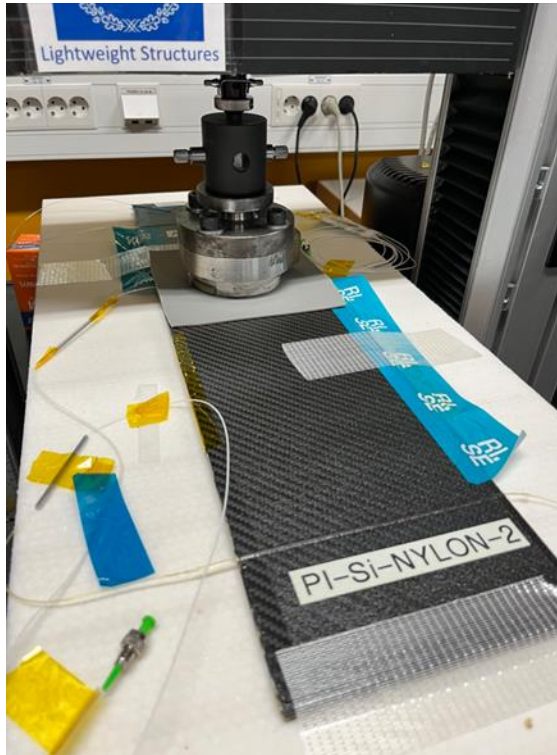


A simple installation including one fiber with the pressure sensors integrated in the fiber

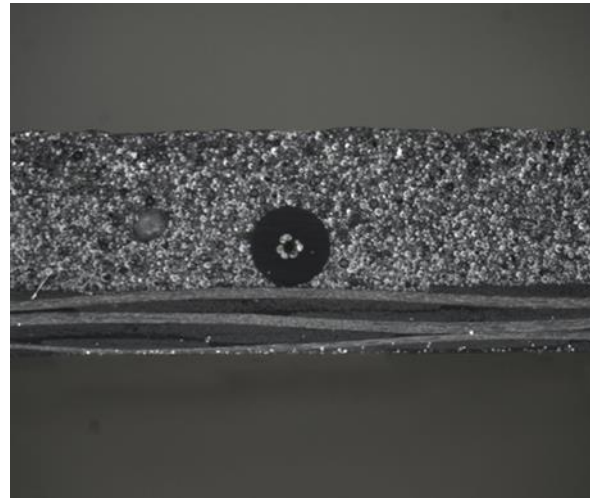
Modification of fibre optics at micro level for pressure sensitivity (Lighter QuPS)



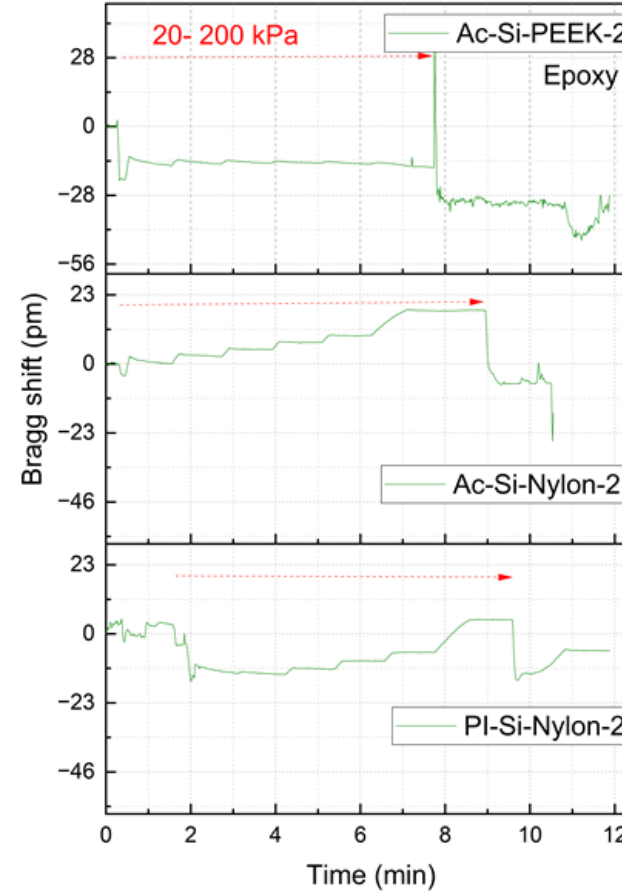
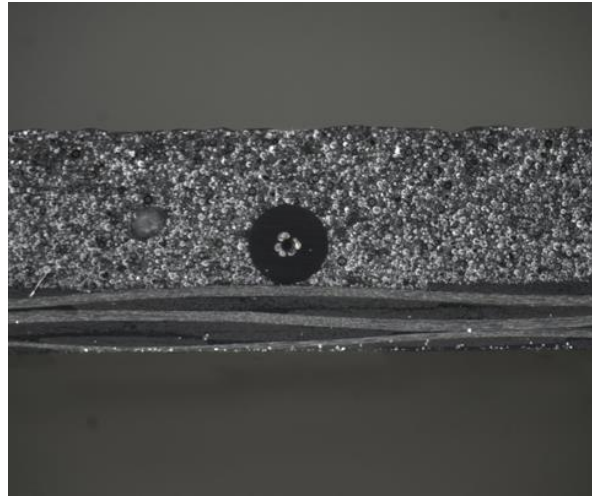
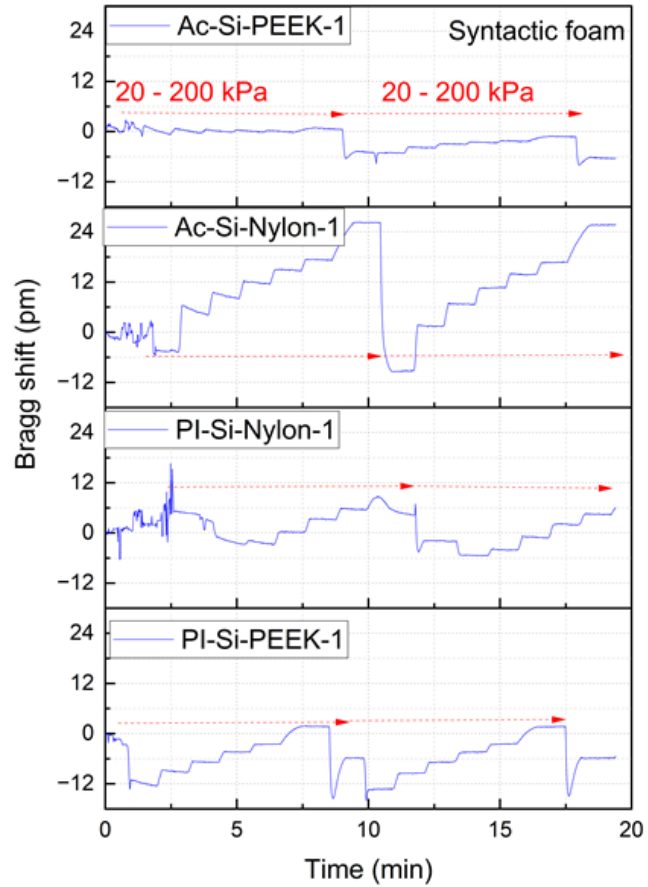
Pressure Measurements in Instron Machine



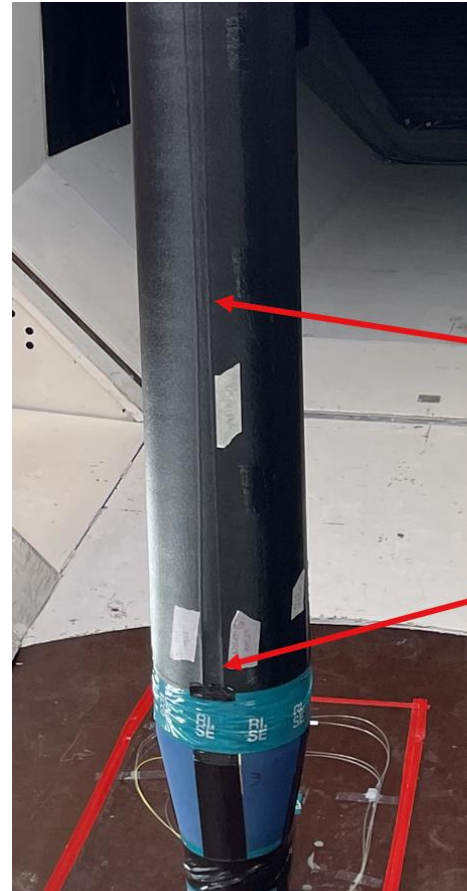
- Load steps: 20, 40, 60, 100, 200 kPa
- 1 minute hold each load step



Results pressure measurements in Instron Machine



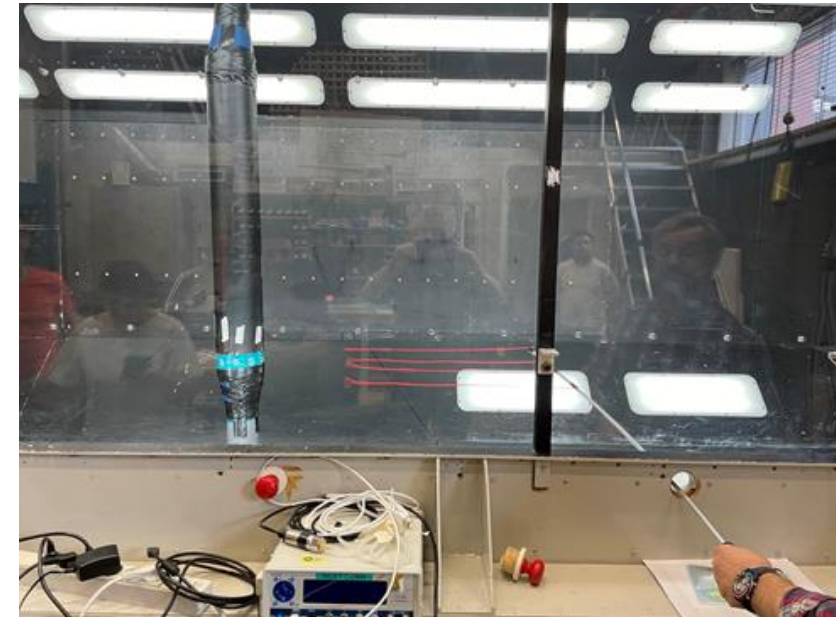
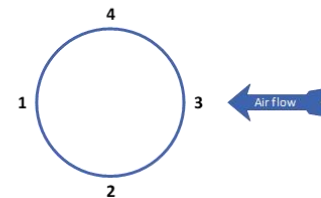
Demonstrator Wind tunnel test



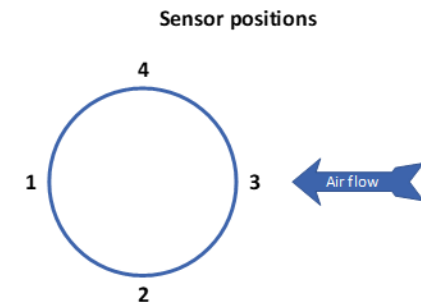
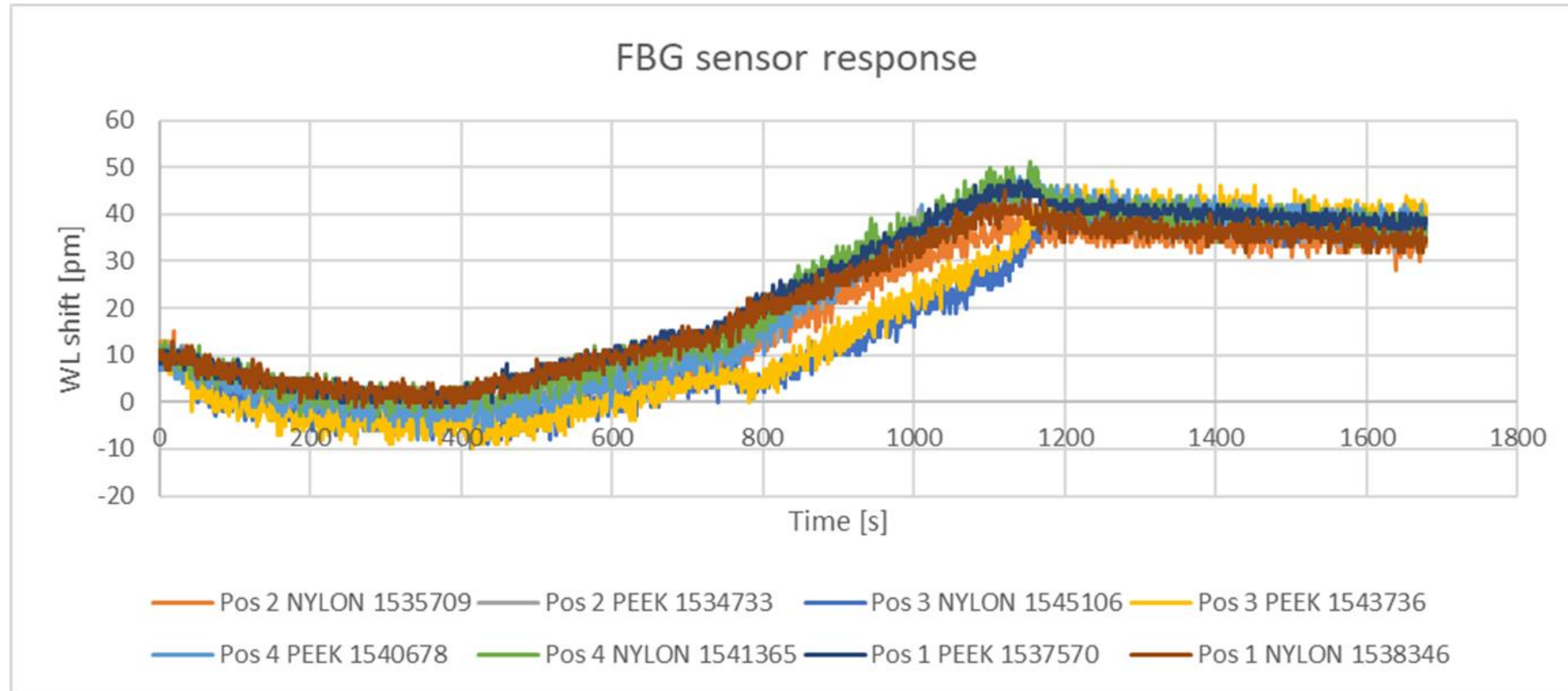
FBG sensors

Reference sensor – Pitot tube

Sensor positions



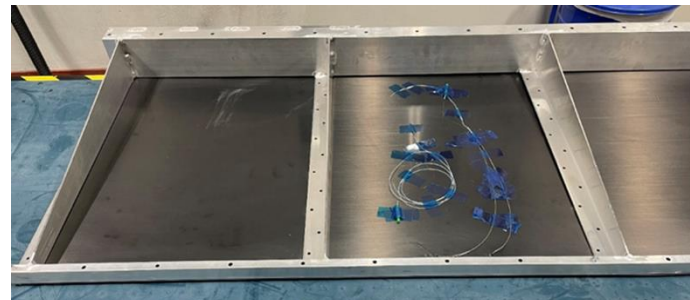
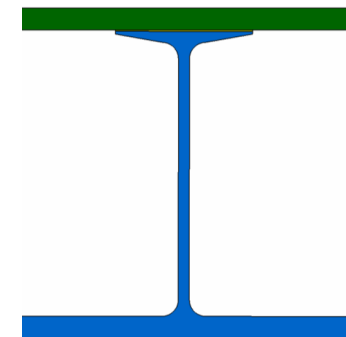
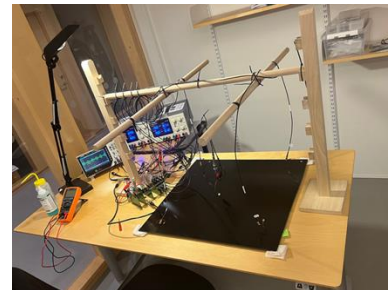
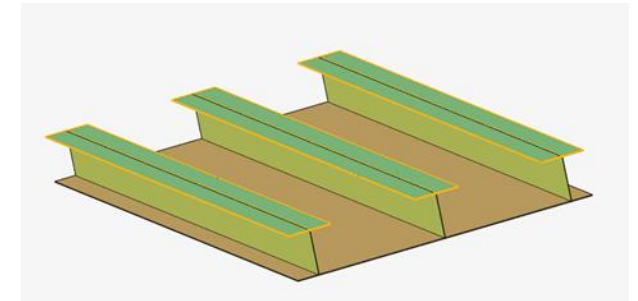
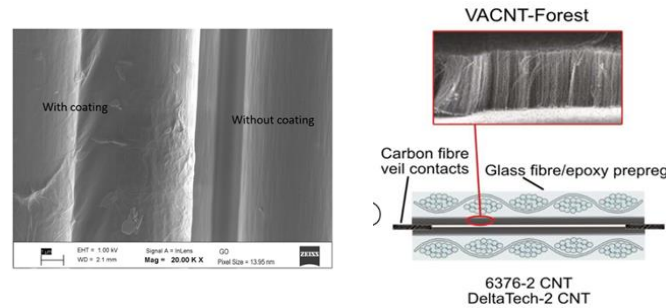
Preliminary data wind tunnel demonstrator test



From national research within multifunctional structures and SHM to collaboration with BAE Systems to Wing Demo concepts

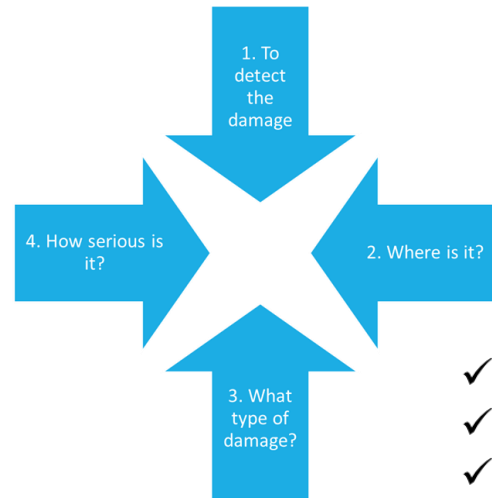
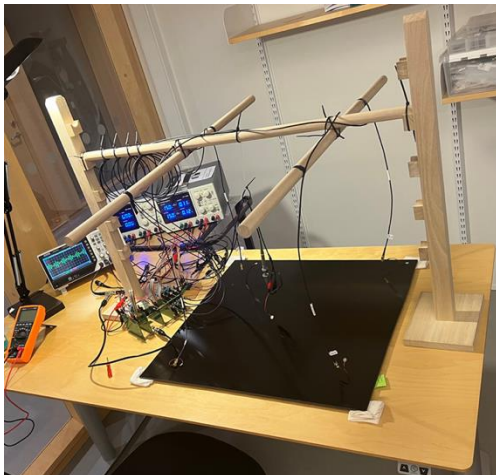
“Structural Health Monitoring for damage growth detection in composite structures” in collaboration with BAE Systems

- Vinnova/ SIO Lighterproject ” Quasi-distributed pressure sensors with composite structural integration”
- Eureka / Vinnova project ” Fatigue - and intelligent composites for sustainable structural health monitoring”
- Vinnova /NFFP8 “Mechanical and thermal properties of hybrid composite structures”

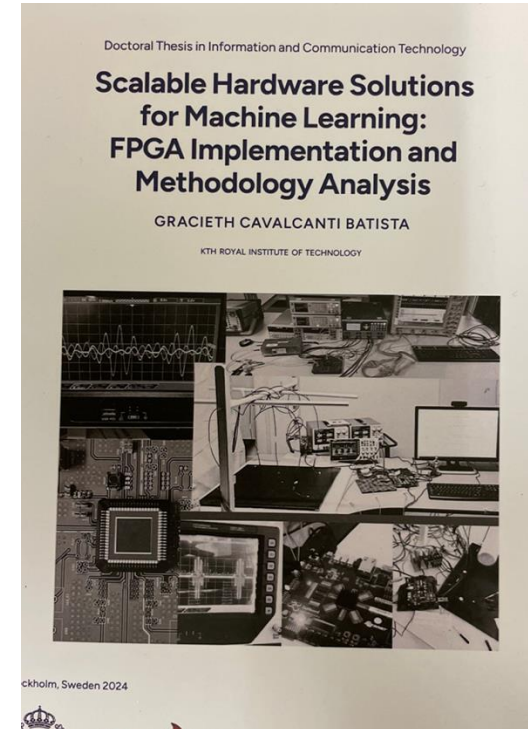


Guided waves / Lamb waves

- Vinnova call : ” *Stärkt svensk flygteknisk forskning och innovation genom internationell samverkan*”
 - Structural Health Monitoring for damage growth detection in composite structures
- PostDoc: Gracieth Cavalcanti Batista from ITA via CISB PhD project at KTH division of Electronics and Embedded Systems



- ✓ Reliability
- ✓ Cost
- ✓ On-flight or plug-and-play?
- ✓ Real-time
- ✓ Hardware-software co-design



Saab co-operation with MIT within "Nano-engineered composite aerospace structures consortium – NECST"

- NECST formally launched in early 2006 on the MIT campus, partnered with Airbus, ANSYS, Embraer, Lockheed Martin, Saab AB, Saertex, and Teijin Carbon America.
- A couple of joint publications has been performed between MIT and Saab Affiliated Faculty at Engineering Mechanics, KTH within Vertical Aligned Carbon Nanotubes (VACNT)



1. Introduction

Progressive damage in carbon (micro) fibers reinforced plastic (CFRP) composite laminates generally comprise a broad range of modes that span multiple material and structural scales, interact in complex sequences, and whose initiation and progression are strongly dependent on micro and mesoscale laminate morphology, damage precursors such as manufacturing defects, structural load-path discontinuities (e.g., holes, free edges, and ply drops), and loading configuration, identifiability, rate, and environment [1–13]. Among the various environmental conditions to which CFRP materials are often subjected, temperature and moisture levels especially influence the overall laminate mechanical response and associated progressive matrix damage mechanisms—such as intralaminar matrix cracking and interlaminar matrix voiding (delamination), e.g., Ref. [1], which typically arise early during pre-ultimate failure evolution. Environmental effects on



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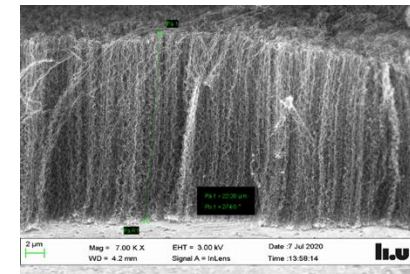
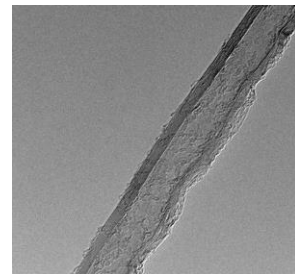
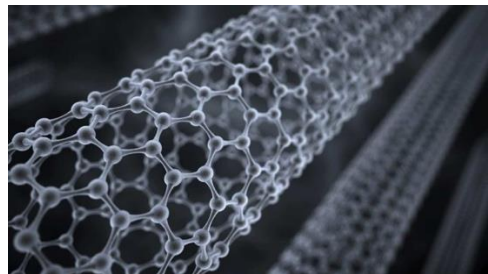
ABSTRACT

Aerospace-grade unidirectional carbon fiber laminate interfaces are reinforced with high densities (2–10 billion fibers per cm²) of aligned carbon nanotubes (A-CNTs) that act as nano-scale stitches. Such nano-scale fiber reinforcement of the ply interfaces has been shown to increase interlaminar fracture toughness and here we show that laminate in-plane strengths are also increased. Delamination damage modes associated with pre-ultimate failure are suppressed in the in-plane loaded laminates, significantly increasing load-carrying capability, tension-bearing (both pull out) critical strength by 30%, open-hole compression ultimate strength by 44%, and 1-octant bending energy and deflection by more than 25%. No increase in interlaminar or laminate thickness is observed due to the A-CNTs, but rather the 30 nm diameter carbon nanotubes interdigitate between carbon fibers in the adjacent laminae, i.e. the observed reinforcement is not due to formation of a thicker interlayer. These increases in structural in-plane strengths are in stark contrast to degradation that typically occurs with existing 3D reinforcement approaches such as stitching, weaving and z-pinning.

1. Introduction

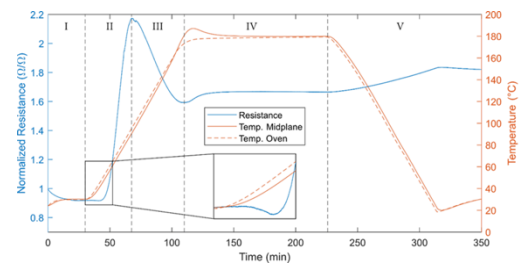
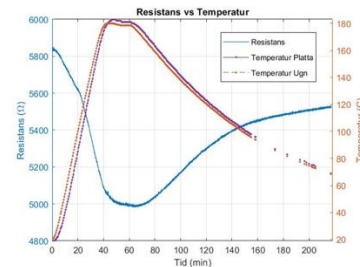
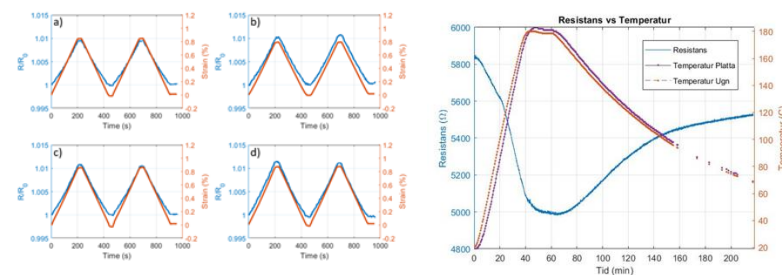
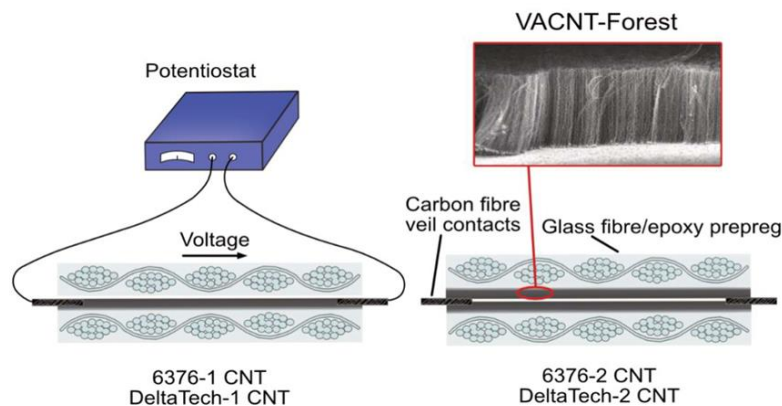
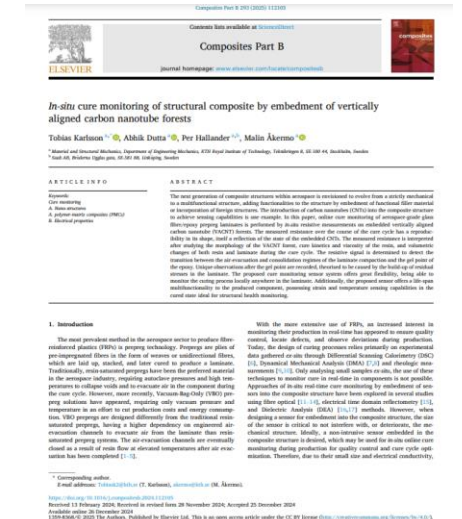
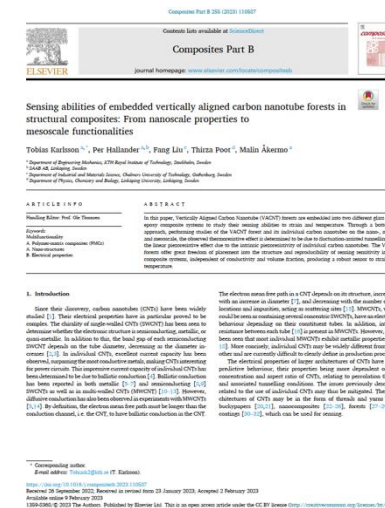
One of the main limitations of advanced composite materials is their poor z-direction mechanical properties due to the uniaxially oriented pure polymer region at ply interfaces, a known Achilles heel of advanced composites. There are several approaches to reinforce such composites in the through-thickness direction including 3D weaving, stitching, and z-pinning [1–4]. As these approaches are based on micro-diameter fibers and their assemblies (tows), in-plane fiber movement and/or damage, fiber volume loss, and stress concentrations are produced as unavoidable artifacts during manufacturing. These act to significantly reduce the in-plane mechanical properties of the laminate, such that these technologies are not in significant use [1]. Thus, the problem of weak interfaces in composites, and concomitant issues such as damage resistance and tolerance, and their implications for over-design, are outstanding limitations in composite structural performance.

In order to avoid this reduction of the in-plane properties, carbon nanotubes (CNTs) can be used as a secondary or hybrid reinforcement that can be integrated within advanced composites [5–13]. Nanomaterials, particularly carbon nanotubes (and now graphene) in their different forms, have been extensively investigated for enhancement of modulus and toughness [14–18] due to their high surface-to-volume relative to larger reinforcements, with excellent reviews available, including a specific focus on epoxies as utilized here [19–29]. Less work has taken on the challenge of introducing carbon nanofibers into the interlaminar region to improve mechanical properties (usually toughness). In the limited extent work, at most modest improvements are generally noted for interlaminar toughness and shear strength (e.g., [30], and see review article [31]), with in-plane properties not yet being addressed [32]. Reduction in properties are primarily attributable to the low loadings (order of 1% by volume fraction) of generally low aspect ratio randomly dispersed fibers, and most improvements are likely due to an increase in interlaminar thickness through process-zone toughening. Various nanofibers and nanofillers have been investigated with the pre-dominance of work focused on CNTs. The morphology of CNTs is typically randomly dispersed, although some attempts at structured morphology interfaces have been presented, notably aligned carbon nanofibers and nanotubes grown

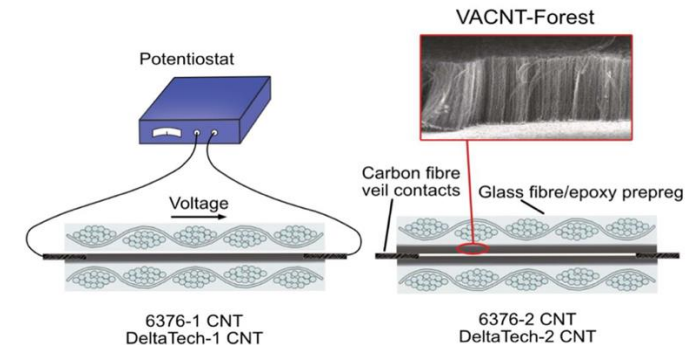
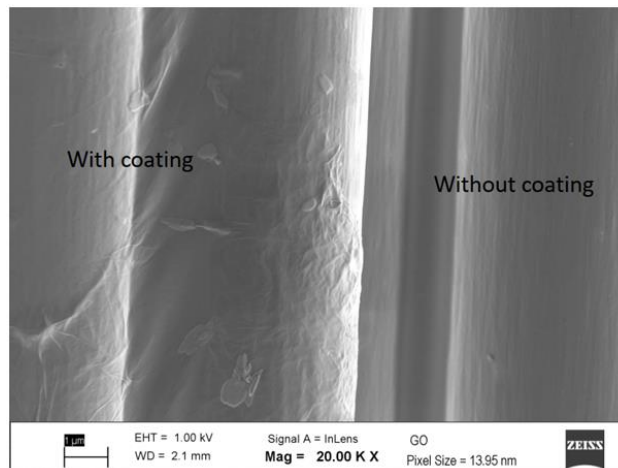
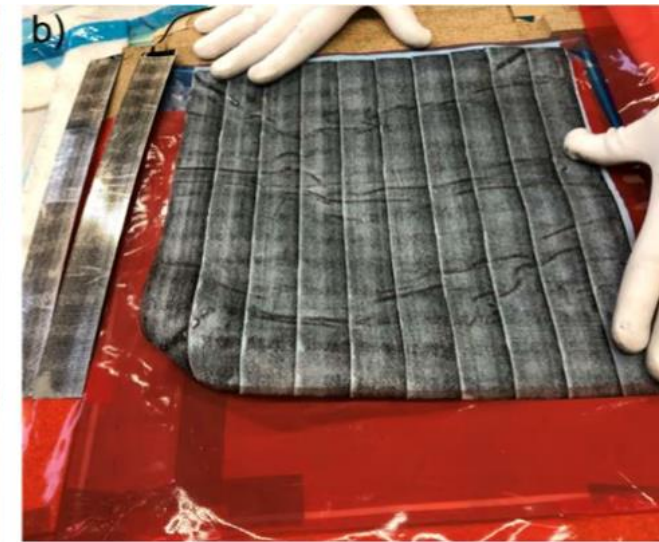
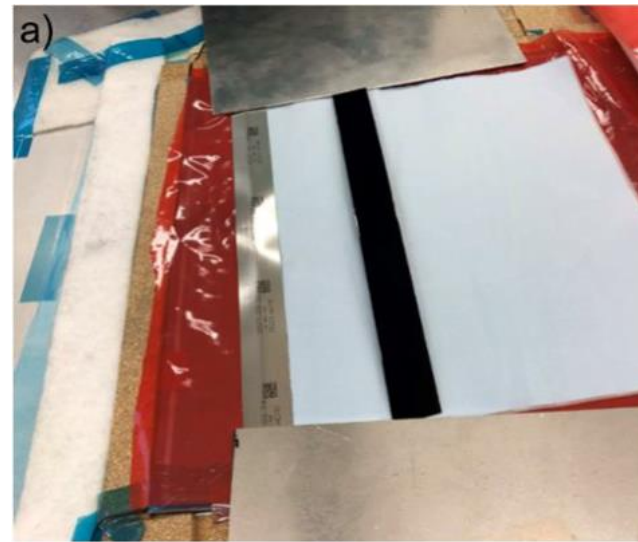


KTH-Saab PhD project of using VACNT for composite embedded sensors

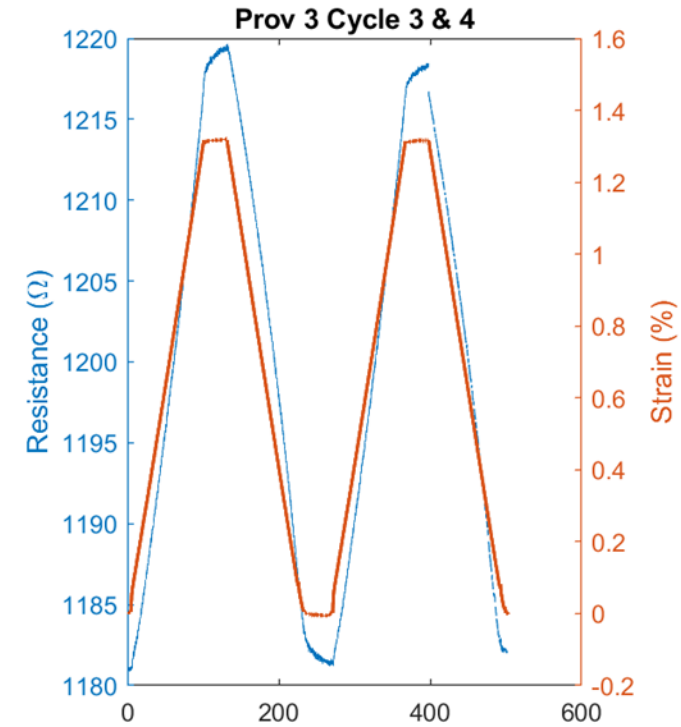
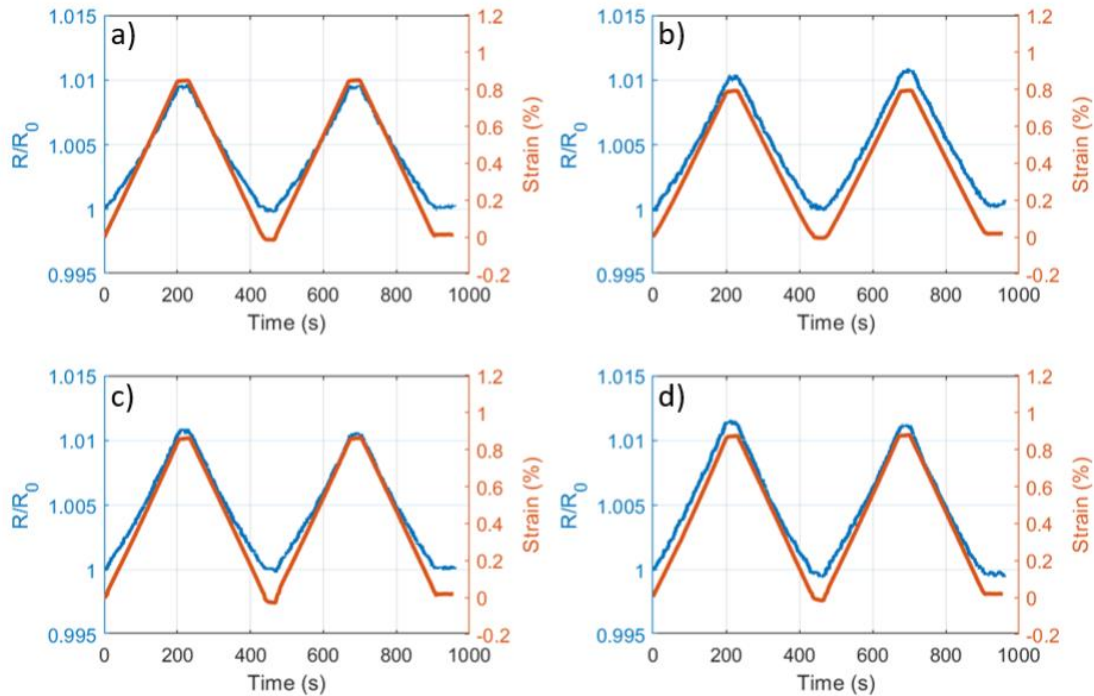
- Embedded sensors for measurements of temperature, strain, pressure and in-situ cure monitoring
- Platform for larger framework within Structure Health Monitoring - SHM



Graphene coated glass fibre and vertically aligned carbon nanotubes as sensor material



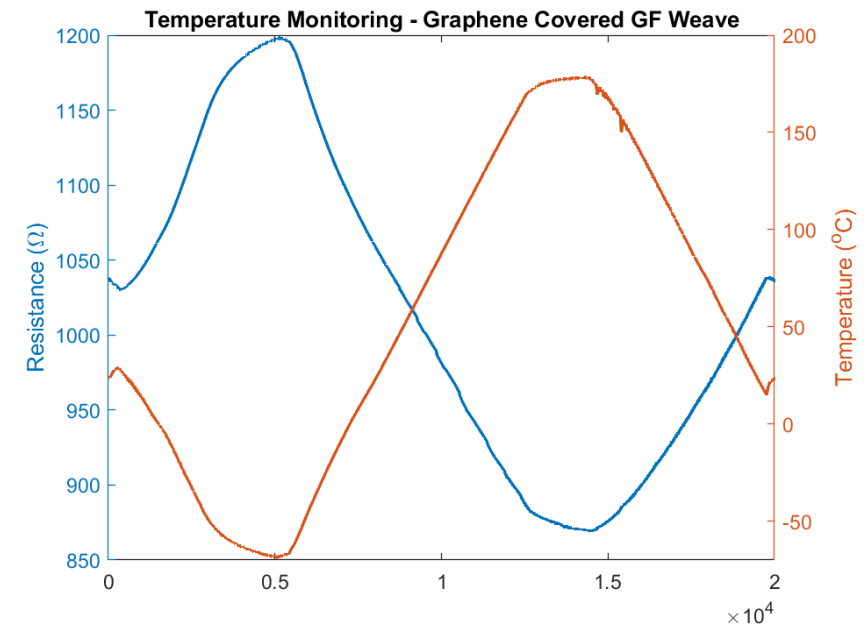
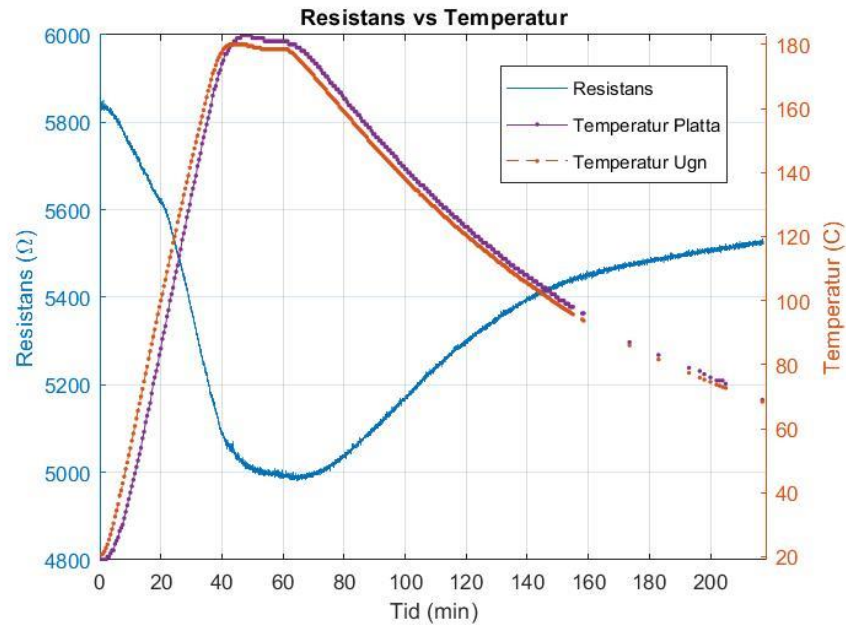
Strain sensing with carbon nanotubes and graphene



Courtesy of Tobias Karlsson, KTH



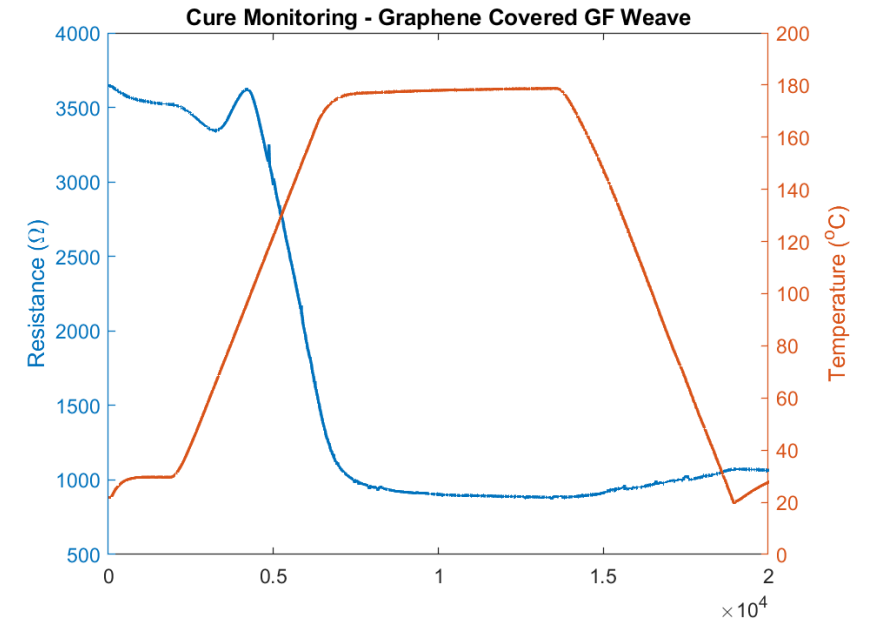
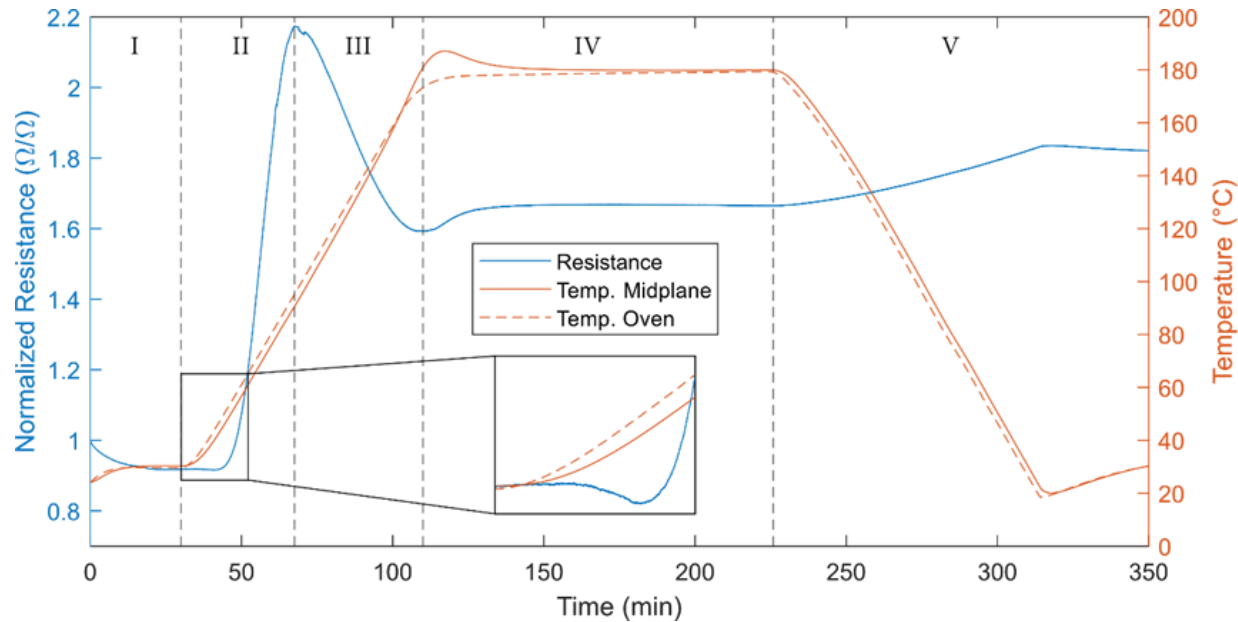
Temperature sensing with carbon nanotubes and graphene



Courtesy of Tobias Karlsson, KTH



Cure monitoring with carbon nanotubes and graphene

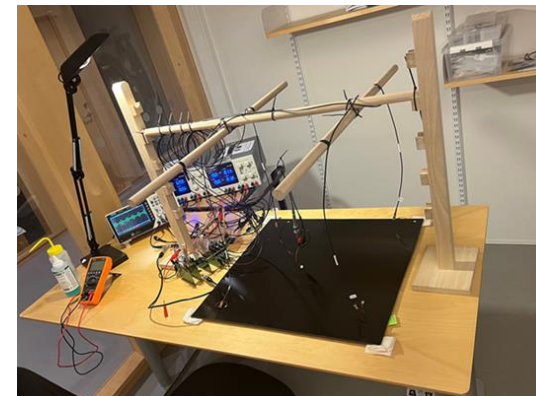
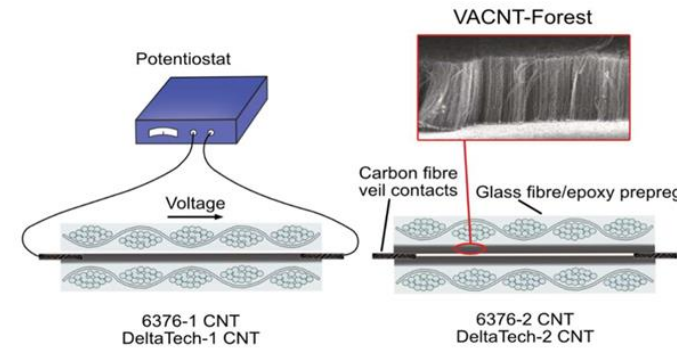
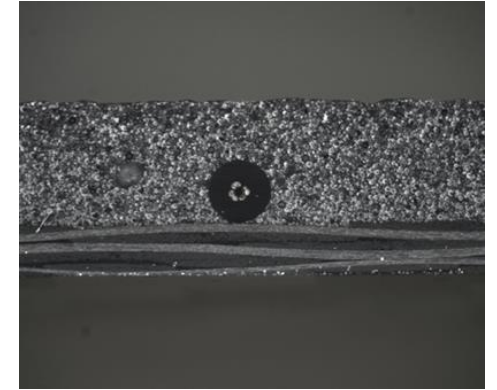
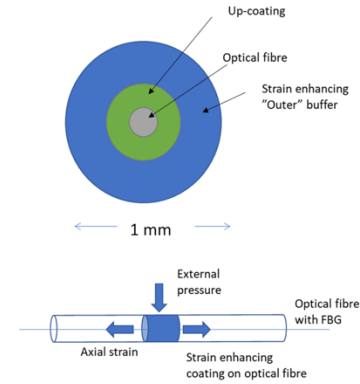


Courtesy of Tobias Karlsson, KTH



Conclusions

- Embedded Fibre optic sensors with Fibre Bragg Grating show great sensibility for multi-sensing. However the problem with sensitive connectors has to be solved.
- Guided waves show great potential for scanning of large objects. 3D geometries has to be expolred.
- Resistive sensors show a great potential for being embedded into composite structures for multisensing purposes. However, the short-circuit situation in a carbon fibre environment has to be solved.



Thank you for listening!

