Application of fibre Bragg optical sensors for the monitoring of filament wound composite canisters

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➢ Introduction and problem description

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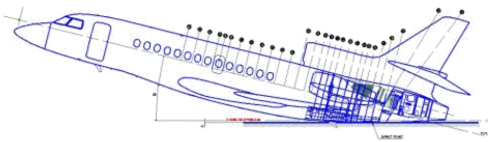
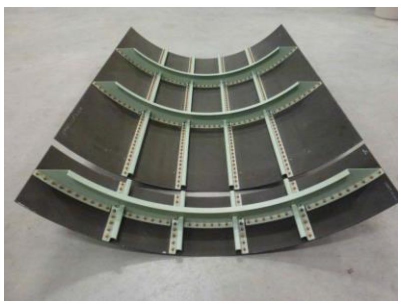
• The use of fiber-reinforced composite materials (FRPs) in advanced engineering applications, such as **transportation products** and **civil infrastructures**, has been widely expanded the last decades.





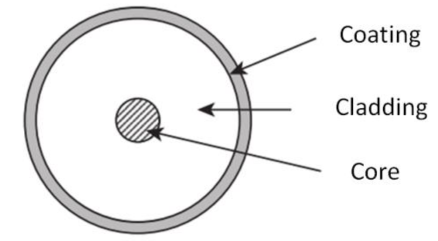
• The complex nature and the corresponding failure mechanisms of FRPs tend to limit their use within major structural components, indicating the need of more sophisticated **condition monitoring techniques**.

• One of the most promising sensing technologies for real-time condition monitoring is the **fibre optic sensors (FOS)**.

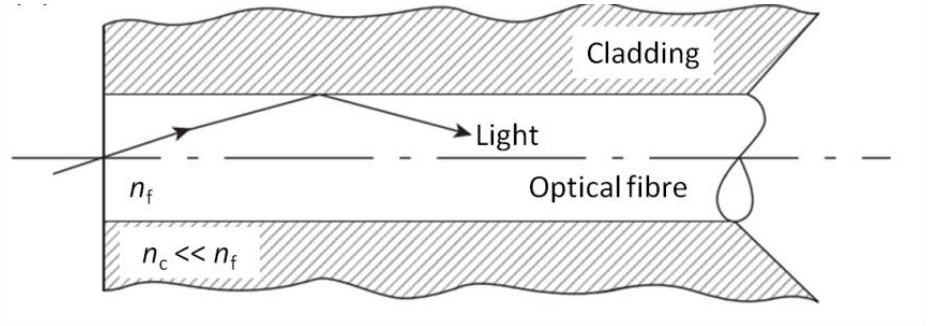
➢ Fibre optic sensors (FOS)

• This type of sensor technology has its origin at the telecommunication industry and presents some unique characteristics, such as **immunity to electromagnetic fields**, **multiplexing capability** and **embedding applicability into structures**.

• A typical optical fibre consist of a central core (~Ø 9μm) usually made of silica glass which is surrounded by an annular cladding and protective coating.



• Due to the phenomenon of total internal reflection that is attributed to the lower **refractive index of cladding** compare to **the core one**, the light wave is confined in the core and travels over large distances with the minimum loss.



Optical fibre reflection principle

➢ Fibre Bragg grating (FBG) sensing principle

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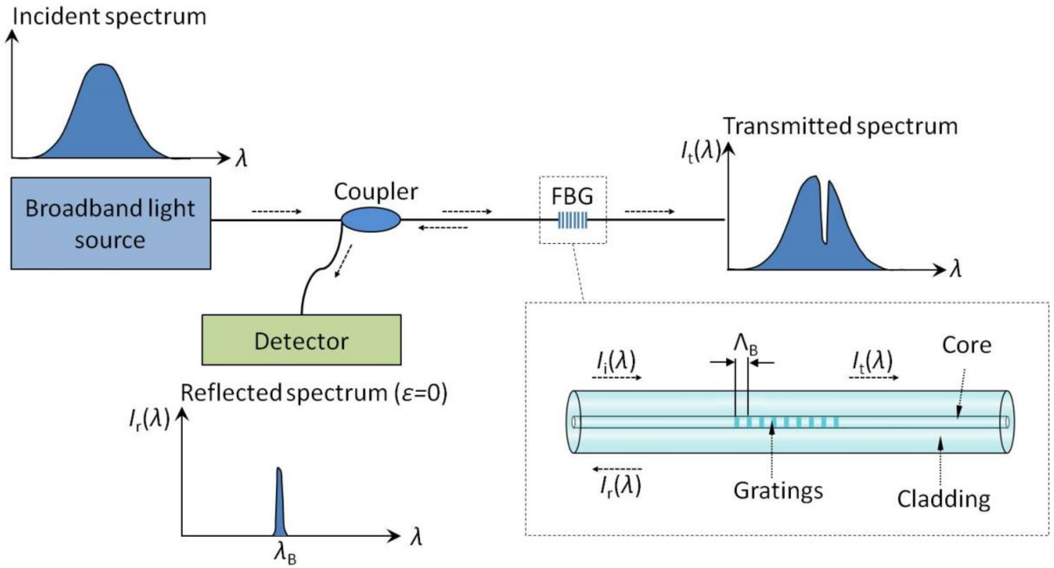
• One of the most widespread fibre optic sensor types, especially for structural health monitoring purposes, is the fibre Bragg grating sensors.

• A **fibre Bragg grating** is a **periodic modulation** of the **effective refractive index (n_{eff})** that can be inscribed in the optical fibre core using mainly excimer lasers or UV sources.

• When a broadband light source is coupled to an optical fibre with an inscribed Bragg grating, incident light travelling at the **Bragg wavelength (λ_B)** is reflected back by the grating and, as a result, is missing in the transmitted spectrum.



• The reflected spectrum is centred on the Bragg wavelength and depends on the effective refractive index and on the **Bragg period/pitch (Λ_B)** of the grating, according to:

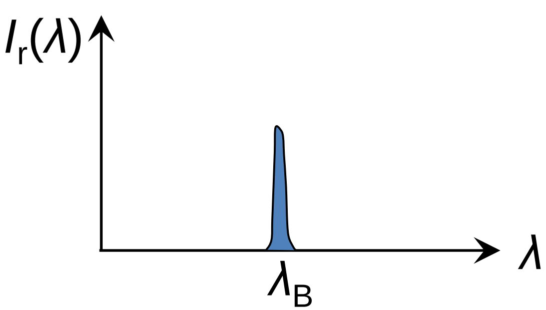
$$\lambda_B = 2 n_{eff} \Lambda_B$$

➢ Fibre Bragg grating (FBG) sensing principle

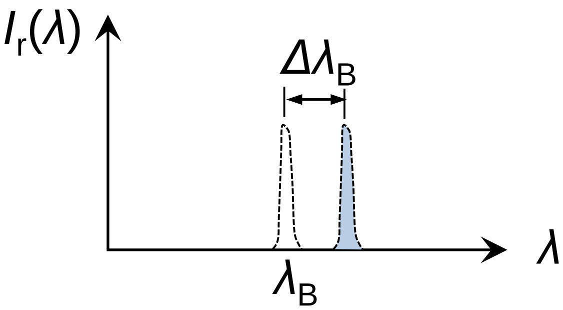
• The measuring principle is as follows; when a **mechanical strain (ε)** is present, the grating's period varies and the reflected wavelength (or Bragg wavelength) shifts ($\Delta\lambda_B$) according to the following equation:

$$\Delta\lambda_{\mathrm{B}} = \lambda_{\mathrm{B}}(1-\rho_e)\cdot\varepsilon$$

• ρ_e indicates the photo-elastic coefficient of the fibre core material, while the term $(1 - \rho_e)$ can also be found as the **'strain sensitivity coefficient' or 'F_g'**



Reflected spectrum (ε=0)



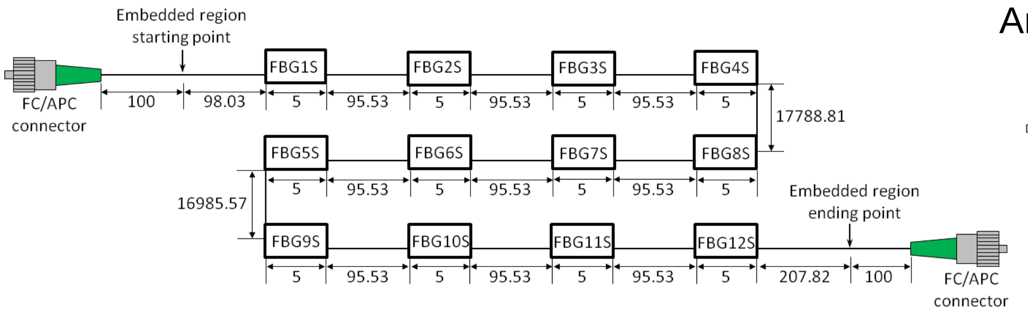
Reflected spectrum (ε=ε_0)

➢ Experimental arrangement

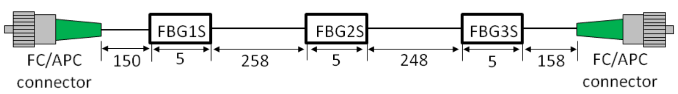
• In order to demonstrate the capability of fibre optic sensing technologies to precisely predict the strain fields developed within advanced composite structures, a cylindrical geometry was selected, which is representative of several primary structural components (e.g. pipelines).

•The composite (Kevlar/epoxy) cylinders (canisters) were manufactured using the filament winding technique, while two types of FBG arrays were installed for the strain monitoring.

Array 1 (embedded) – 12 FBGs



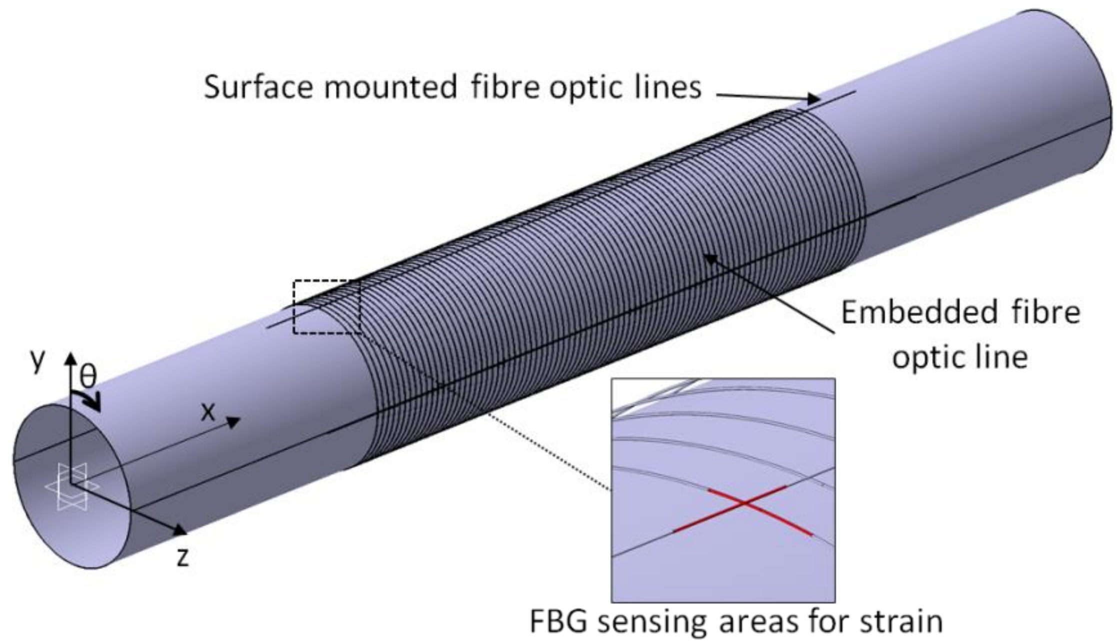
Array 2 (bonded on the surface) – 3 FBGs



Both arrays were made of the same optical fibre with diameters of 9 μm, 125 μm and 155 μm for the fibre core, the cladding and the polyimide coating, respectively

➢ Experimental arrangement

• Array 1 (12 FBGs) was embedded and wound between a pair of hoop Kevlar fibre layers following exactly the same orientation in order to minimize the disturbance (i.e. resin pockets and voids) of the host material.

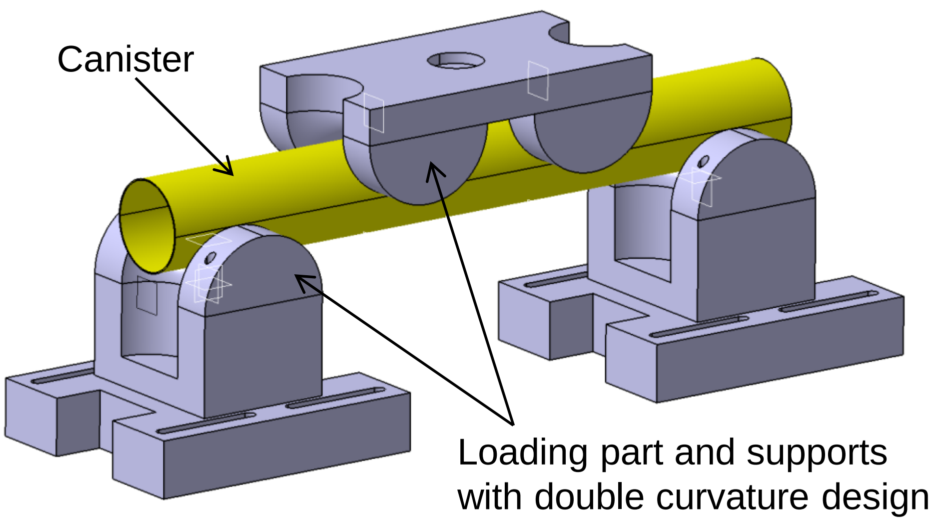


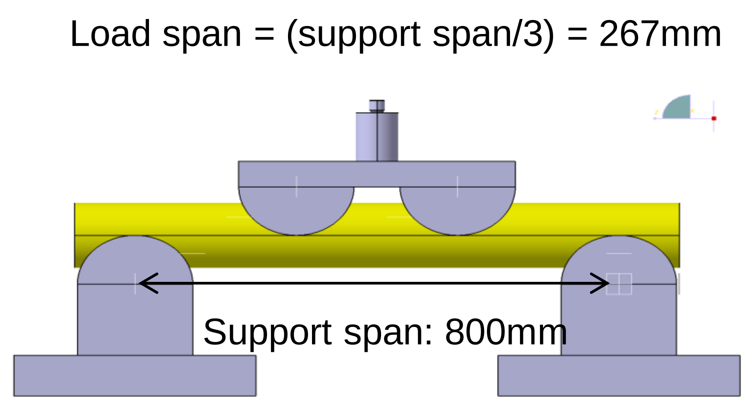
• Array 2 (3 FBGs) was bonded at several points on the surface of the composite cylinder (along its length) using a low viscosity adhesive (cyanoacrylate).

➢ Experimental arrangement

• A four-point bending loading arrangement was selected to assess the capability of fibre optic sensors as a reliable in-situ strain monitoring element.

• Since no standardized geometries exist for composite thin-walled cylinders under bending loads, and aiming to attenuate the high concentrated transverse loads at the loading/supporting points, a unique device was designed:

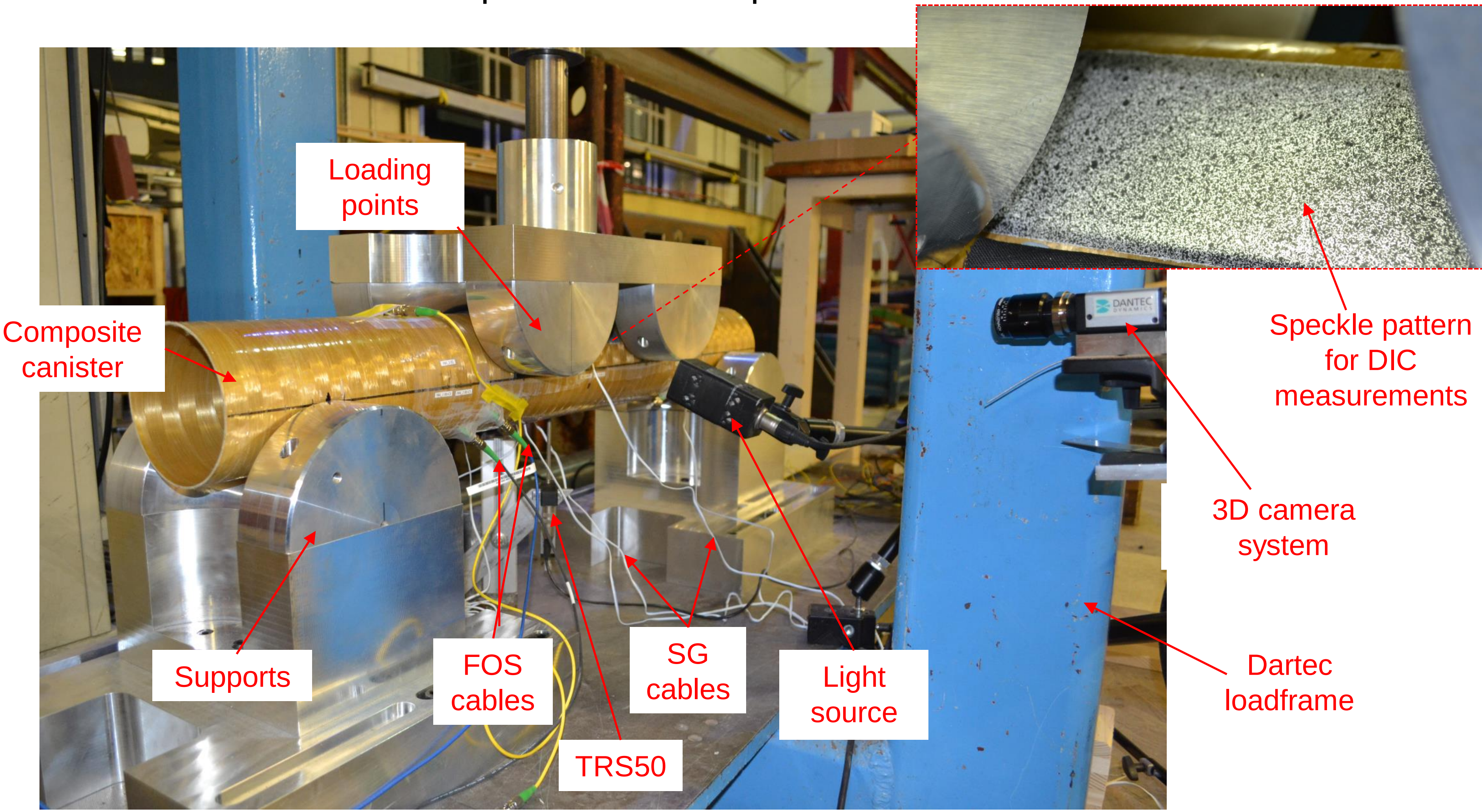




• Auxiliary measuring techniques were used for the evaluation of FBG readings, i.e. strain gauges (SG), 3D DIC camera system and displacement transducers.

➢ Experimental arrangement

- Instrumented canister experimental set up.

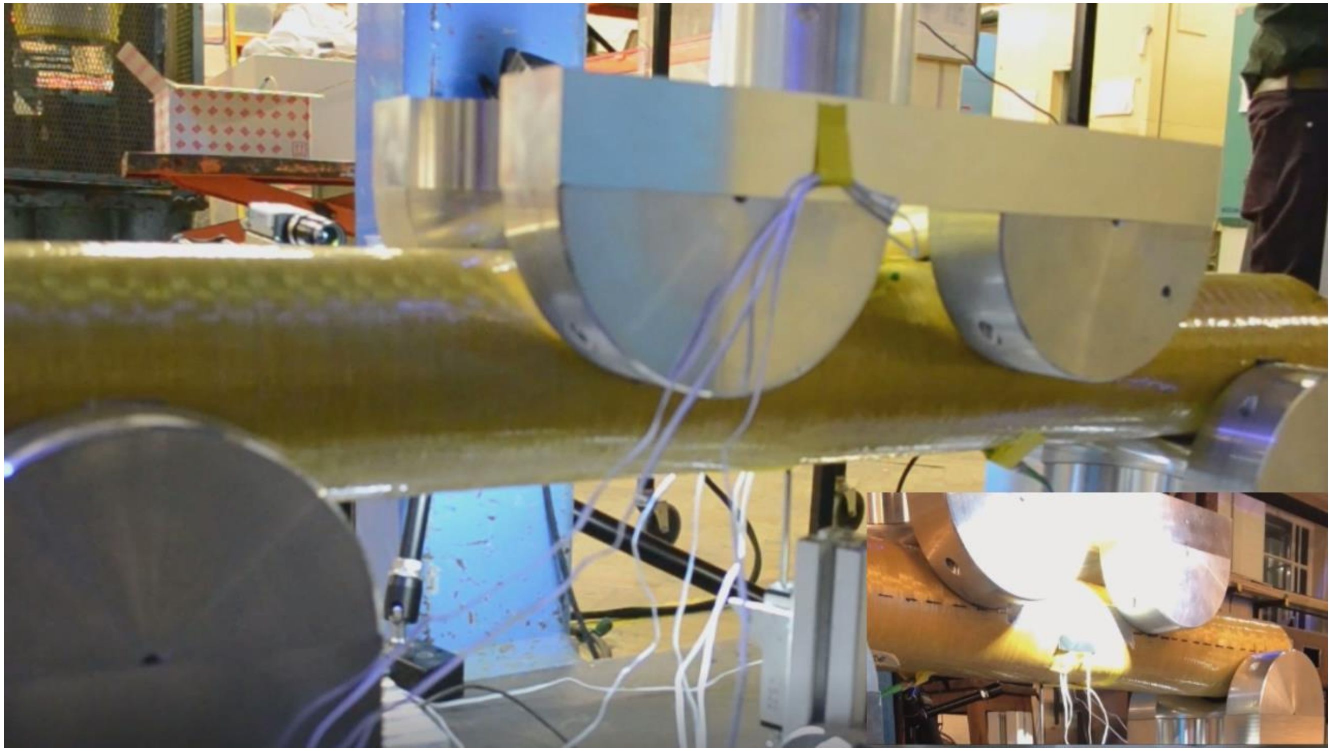


➢ Results

• Tests were conducted using a Dartec load-frame with capacity of 100 kN with piston loading rates in the range of 0.05 to 0.07 mm/sec.

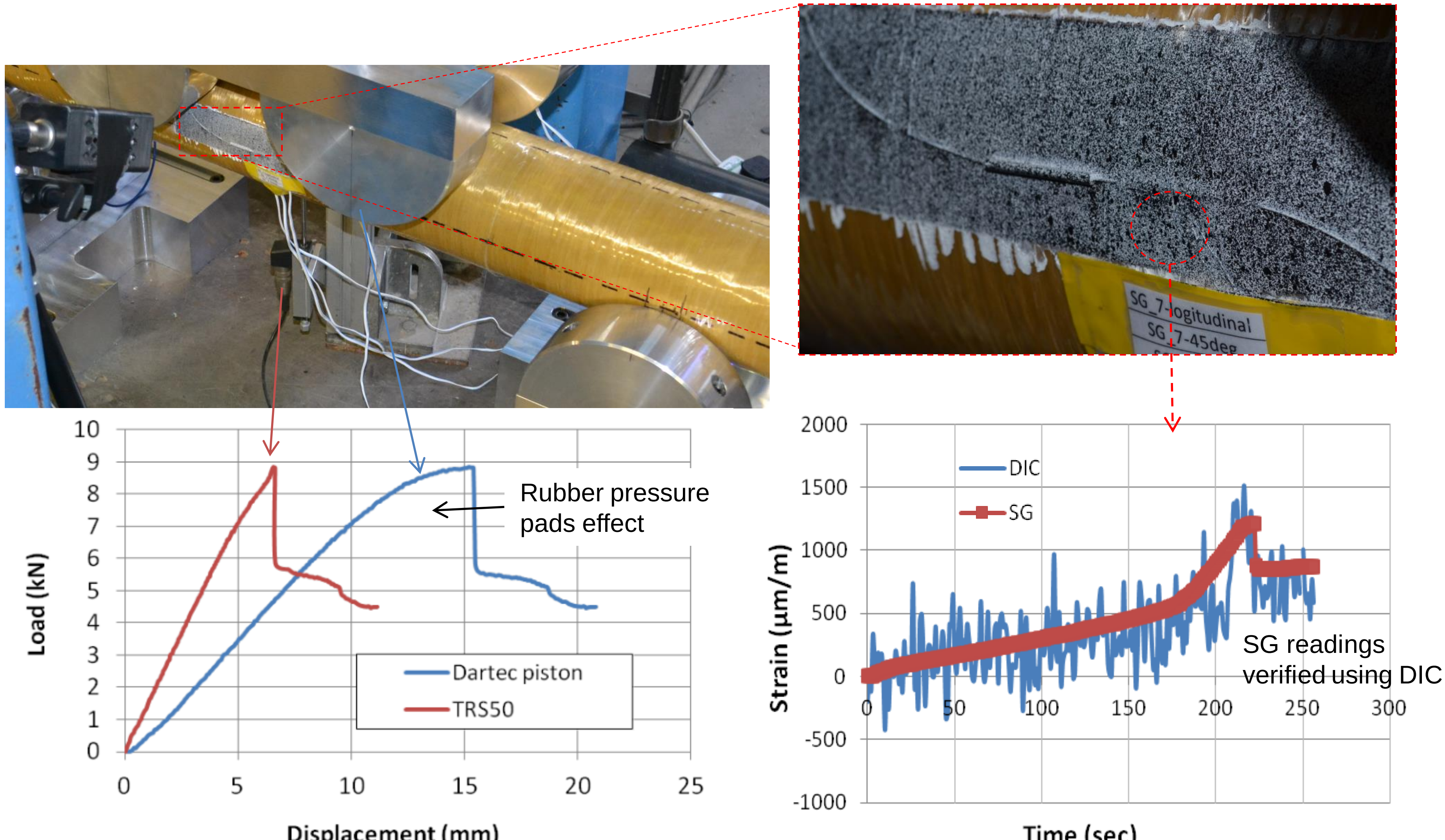
• The majority of the experiments were conducted within the elastic regime (typical service loads) – tests until rupture were also carried out.

• Footage of a 4-point bending canister test until final rupture:



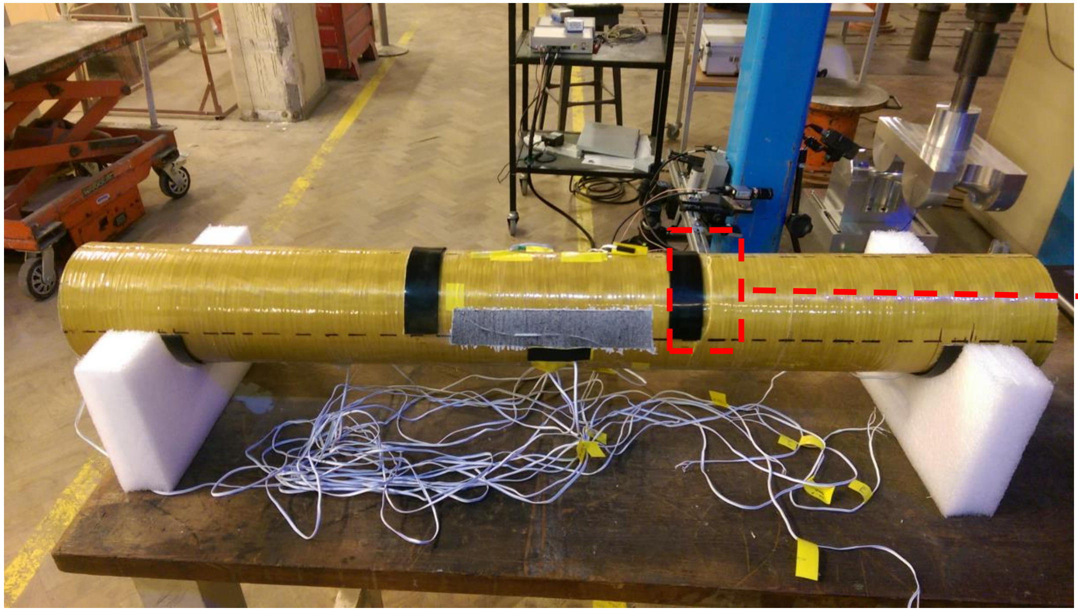
➢ Results

• 4-point bending canister test until final rupture



➢ Results

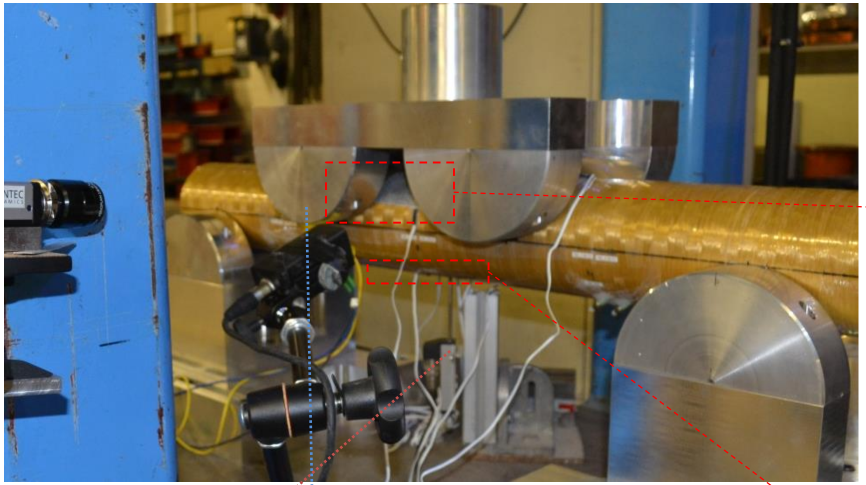
- 4-point bending canister test until final rupture

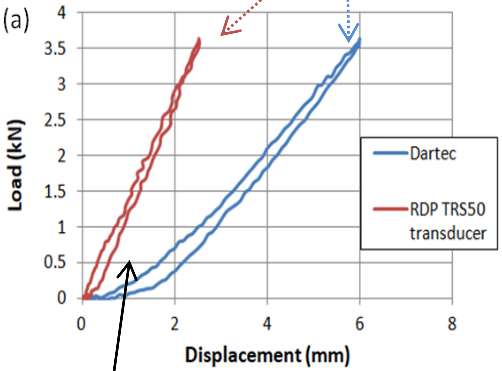


Failure area

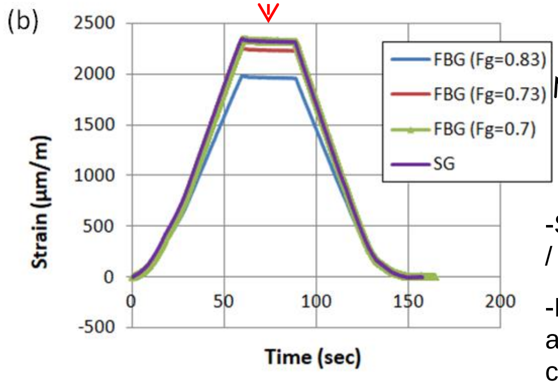
➢ Results

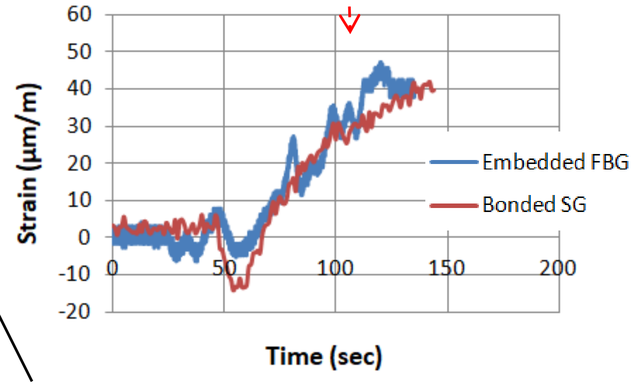
- 4-point bending canister test within elastic regime





Rubber pressure pads effect





-Strain sensitivity coefficient: manufacturer suggested (0.83) / typical values from the literature (~0.7).

-Bonded FBG sensors can be affected by the properties of the adhesive layer, indicating the need for a careful placement and calibration exercise.

➢ Conclusions and future research

• Several filament wound composite cylinders with embedded and surface bonded FBG sensors were tested under four point bending load cases.

• Strain gauges and a DIC camera system were also employed in order to assess the capability of the FOS with respect to strain monitoring.

•The test results indicated that the fibre optic sensors are able to predict the strain fields with very good accuracy.

• Embedded bare FOS can provide without additional actions accurate data using the strain sensitivity coefficient provided by the manufacturer, while bonded FBG sensors can be affected by the properties of the adhesive layer, indicating the need for a careful placement and calibration exercise.

• The FOS capability to capture other loading types (internal pressure, impact) and measurands (temperature, acceleration) will be evaluated in a forthcoming experimental campaign.

Thank you for you attention