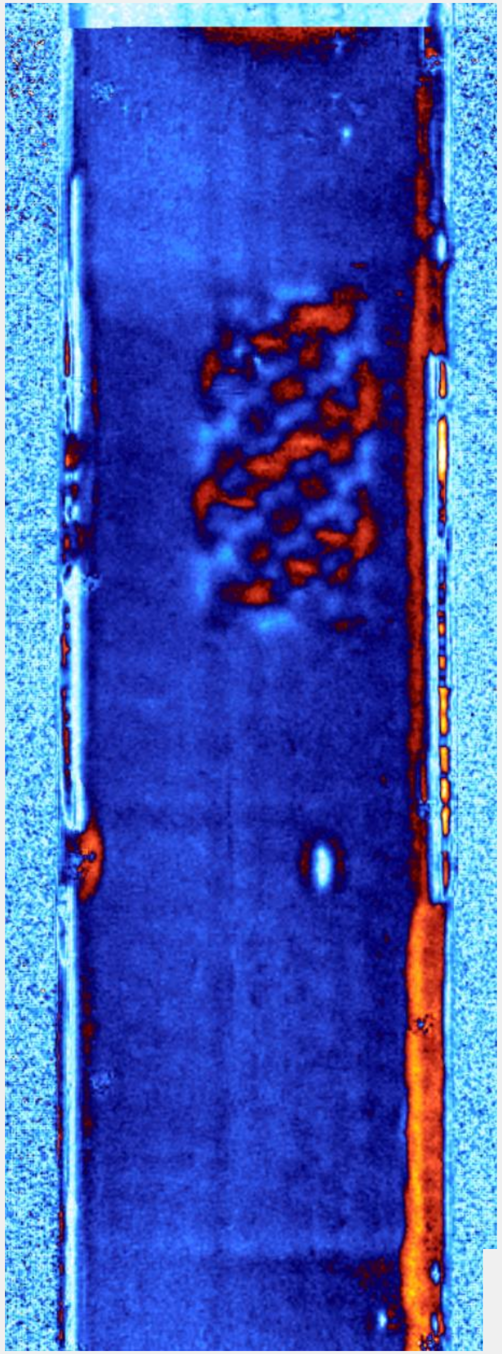
Photoelasticity:
Past, Present and Future Challenges

William Fraser[1] and Rachel Tomlinson[2]

Arkema UK Ltd[1], Wetherby
School of Mechanical, Aerospace and Civil Engineering[2]
The University of Sheffield



Overview

- Fundamentals of Photoelasticity
- Past History
- Present Technologies, Drawbacks and Solutions
- Future Challenges

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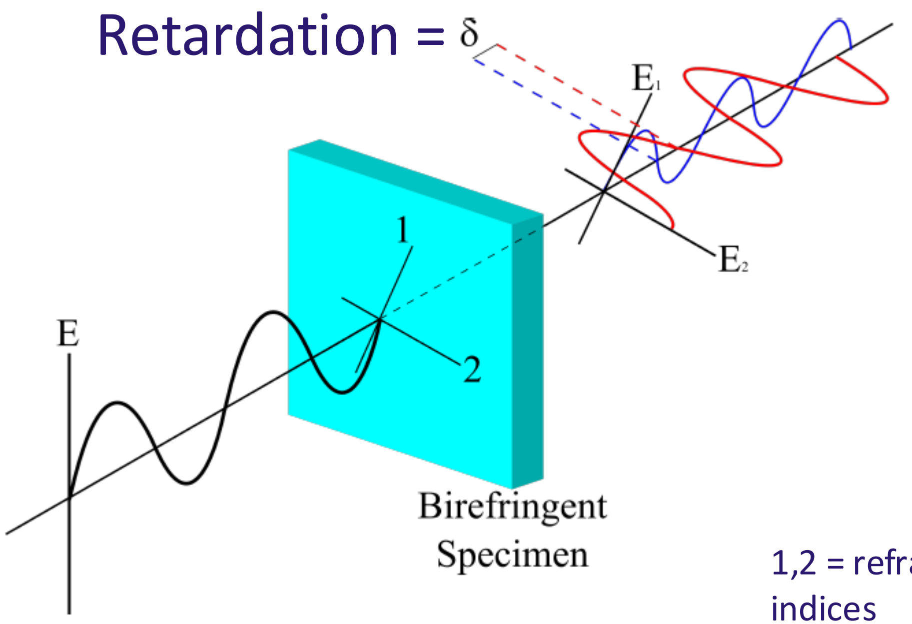
Fundamentals

- Photoelasticity utilises an anisotropic optical property – birefringence.
- Birefringent materials possess two perpendicular refractive indices.

1. A single 'wave' of light passing through a birefringent material will 'split' into two components that travel through at different speeds.

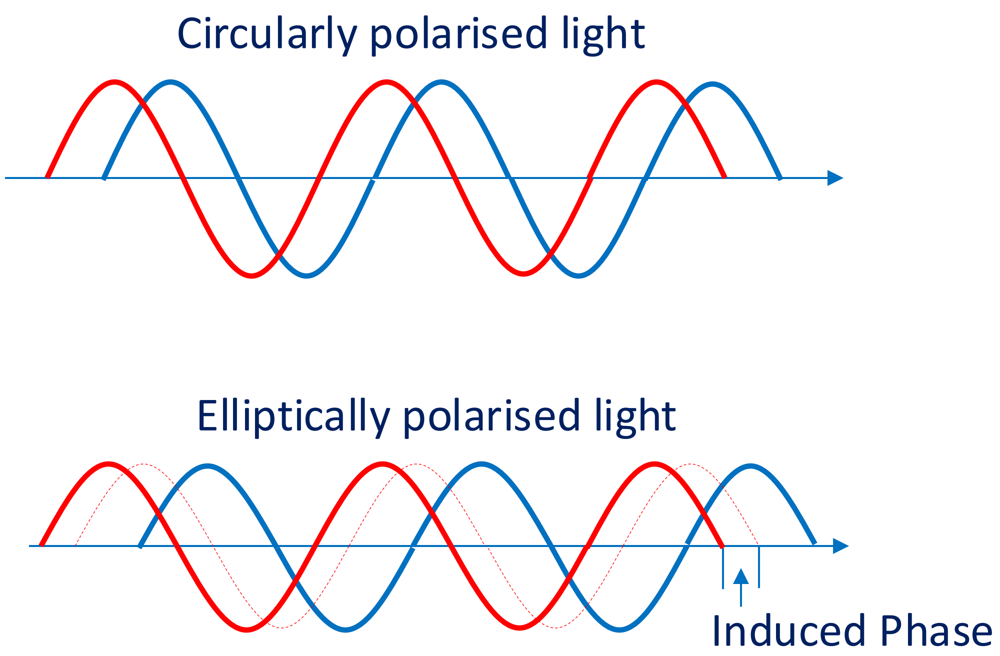
2. Circularly polarised light will emerge elliptically polarised due to a shift in phase.

1



1,2 = refractive indices

2



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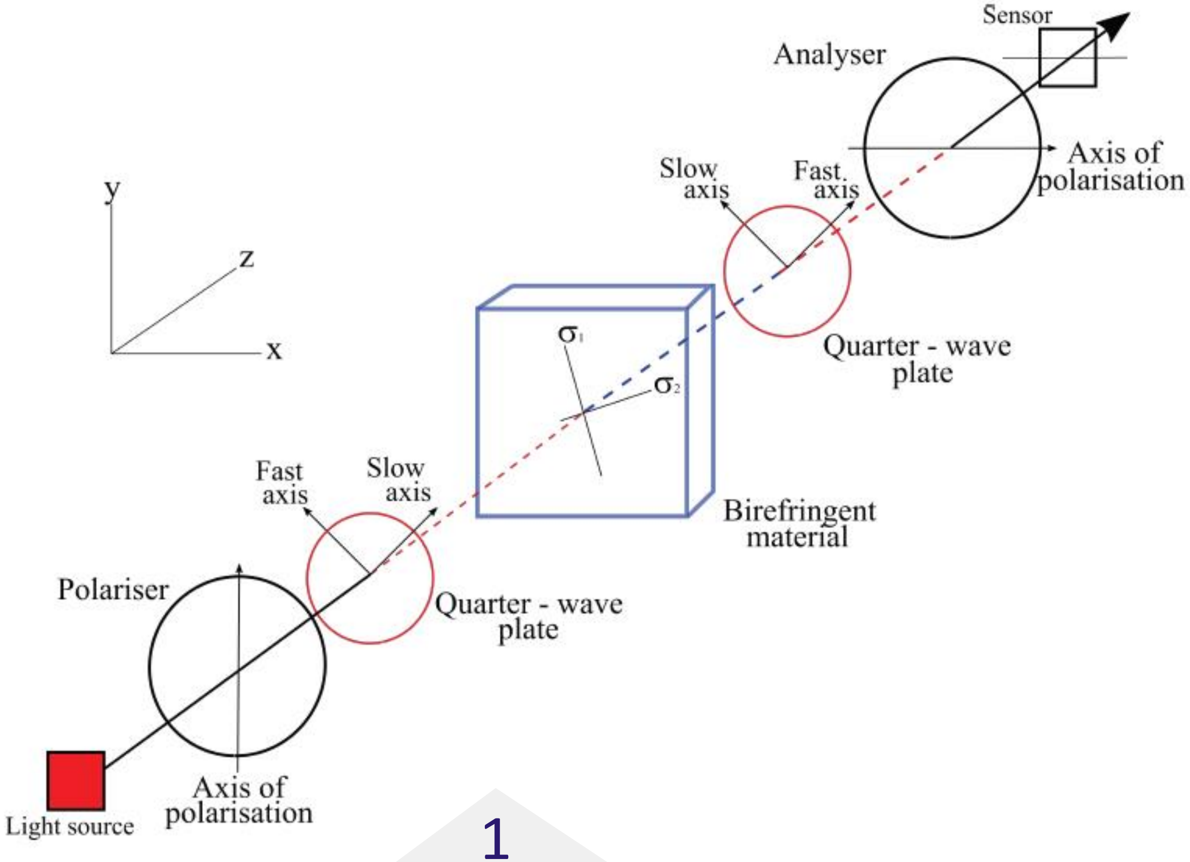
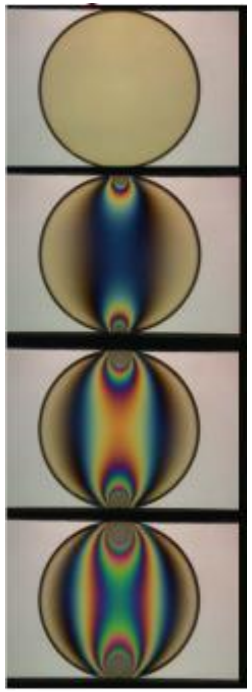
Fundamentals



1

Circular polariscope

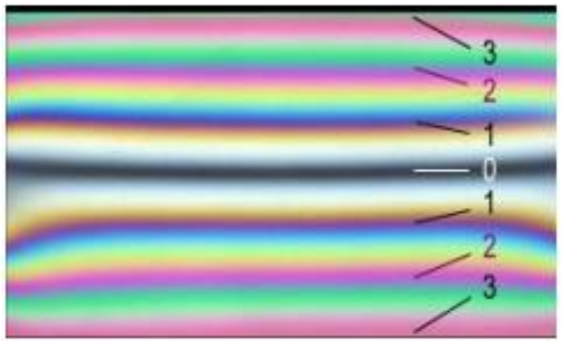
2



0 N

3 N

Development of fringes upon increasing load



$$(\sigma_1 - \sigma_2) = \frac{NF_\sigma}{d}$$

$(\sigma_1 - \sigma_2)$ = principal stress difference (MPa)
N = Fringe order
d = Thickness (mm)
F_σ = Material stress fringe value (N/mm/fringe)

3

Ordering of fringes to calculate principal stress difference

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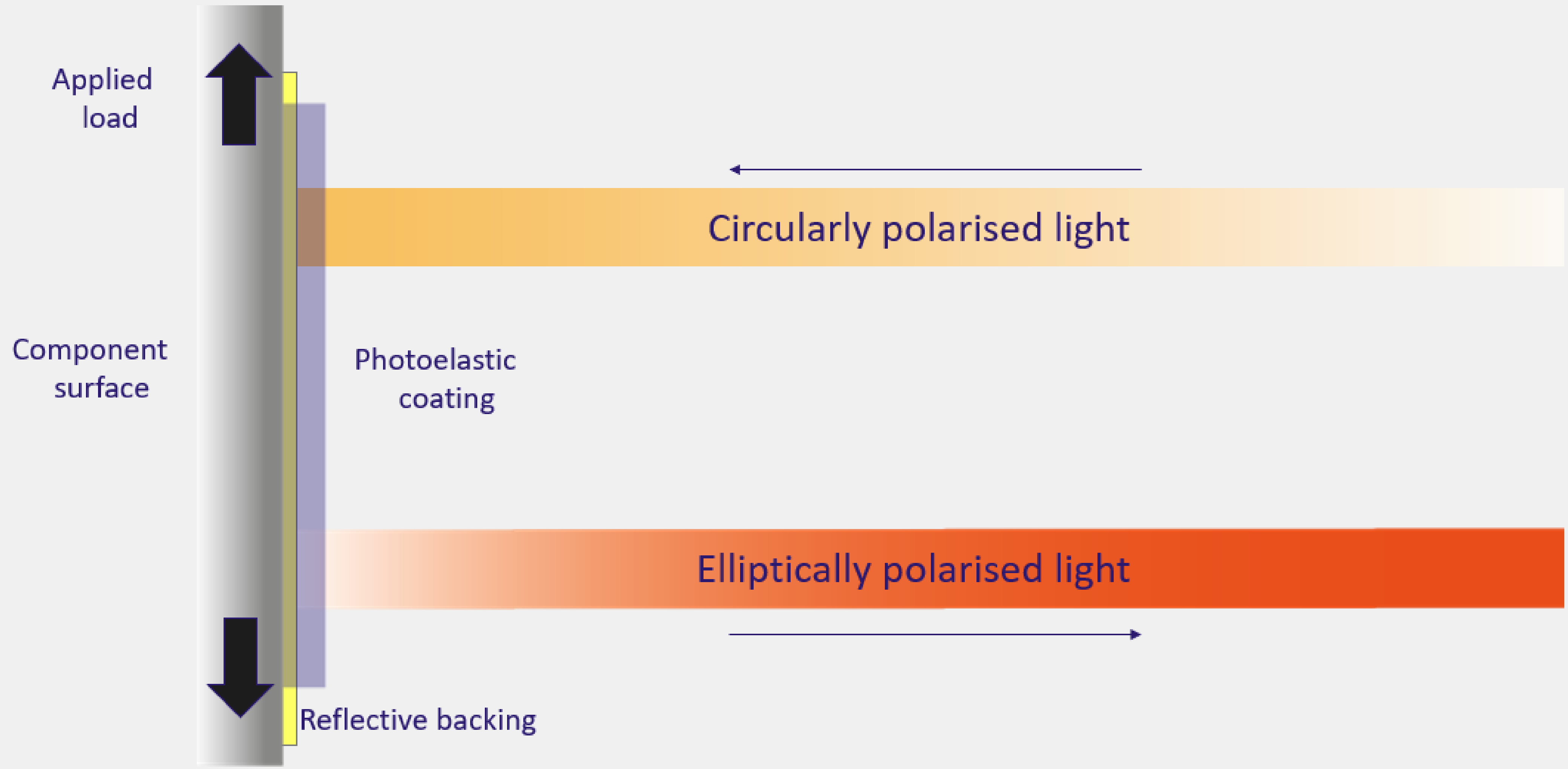
Reflection photoelasticity



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Reflection photoelastic stress analysis (RPSA)

RPSA is used to assist in a variety of design and manufacture processes.

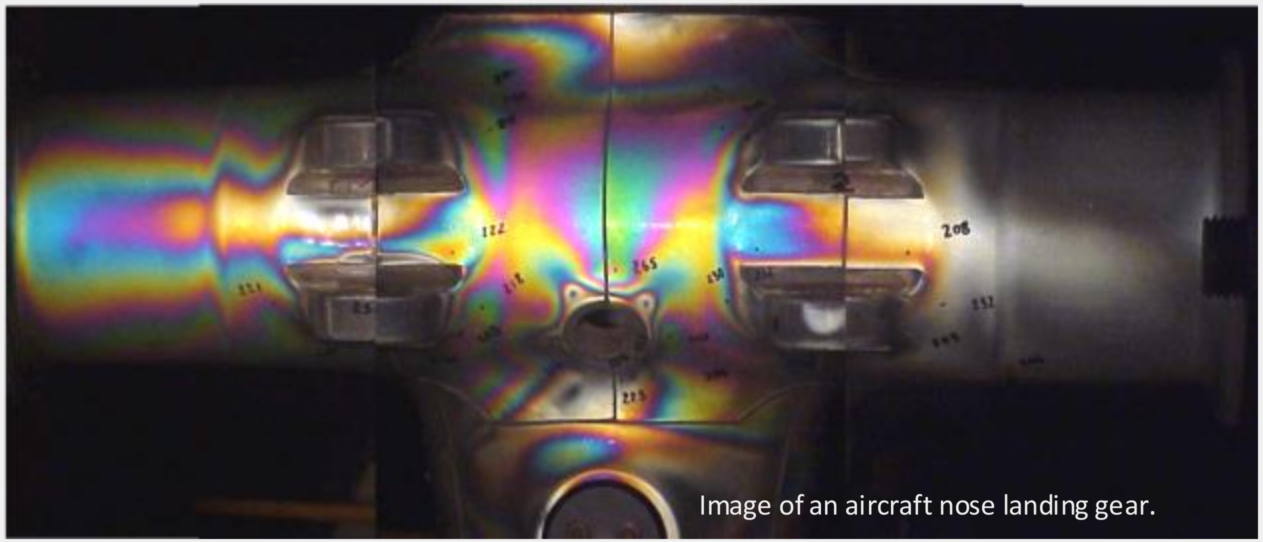
Image of an aircraft nose landing gear.

This provides users with 'real' stress information allowing for:

- Information regarding maximum shear strains in complex geometries.
- Correction and validation of Finite Element Analysis (FEA).
- Instant identification of critical areas.

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History – Transmission Photoelasticity

- 1816 Temporary Double Refraction observed by Sir David Brewster
- 1822 Fresnel confirmed by experiment Brewster's findings
- 1853 Maxwell publishes the Theory of photoelasticity
- 1931 "Treatise on Photoelasticity" by Coker and Filon
- 1940s Publications by Neumann; Frocht

Subsequent development of polariscopes, materials, methodologies, for static and dynamic applications

- 1990s Digital photoelasticity technological developments

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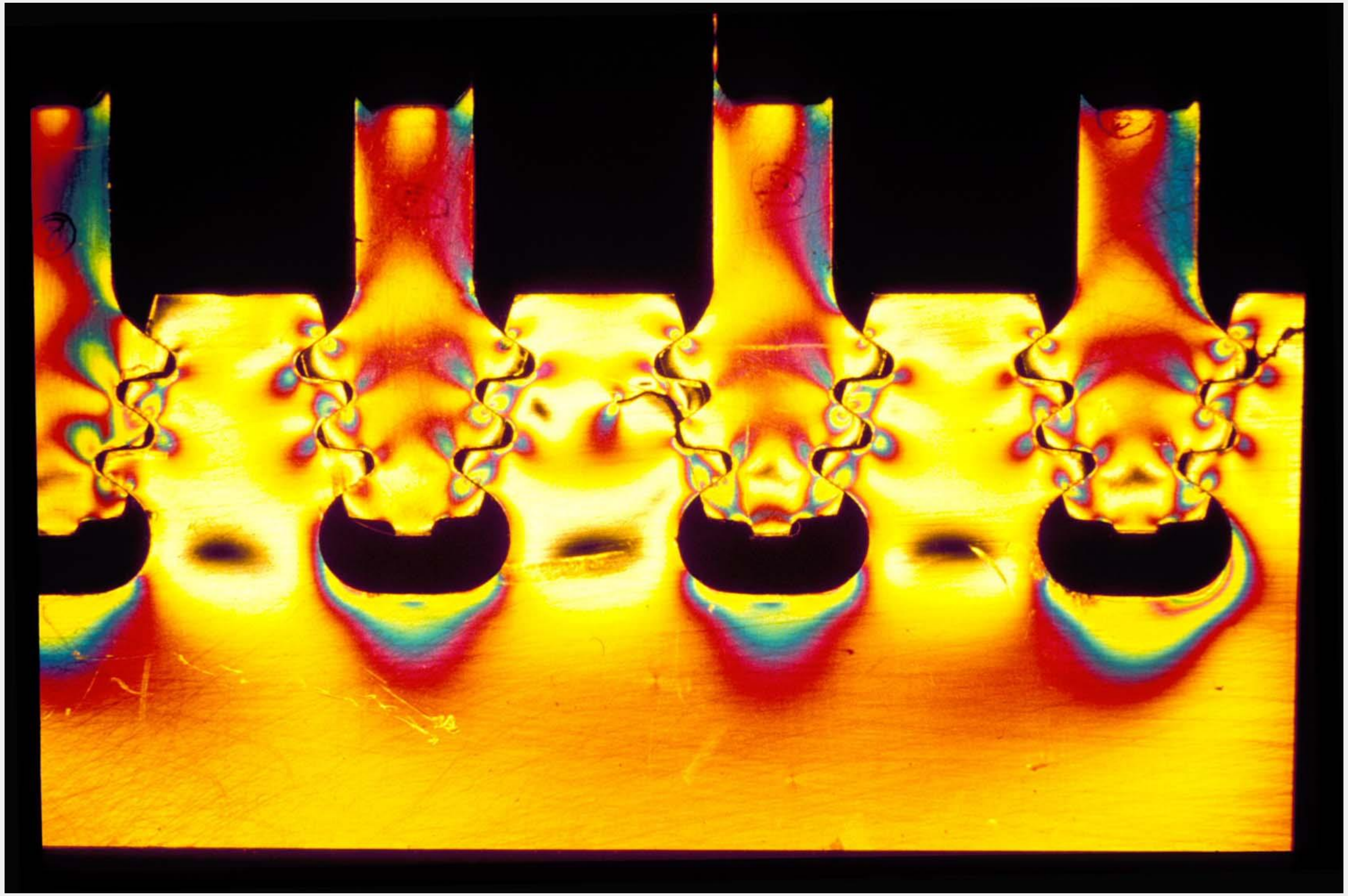

Model of an aeroengine fir-tree root connecting blades and disc

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Residual stresses in an uncut diamond

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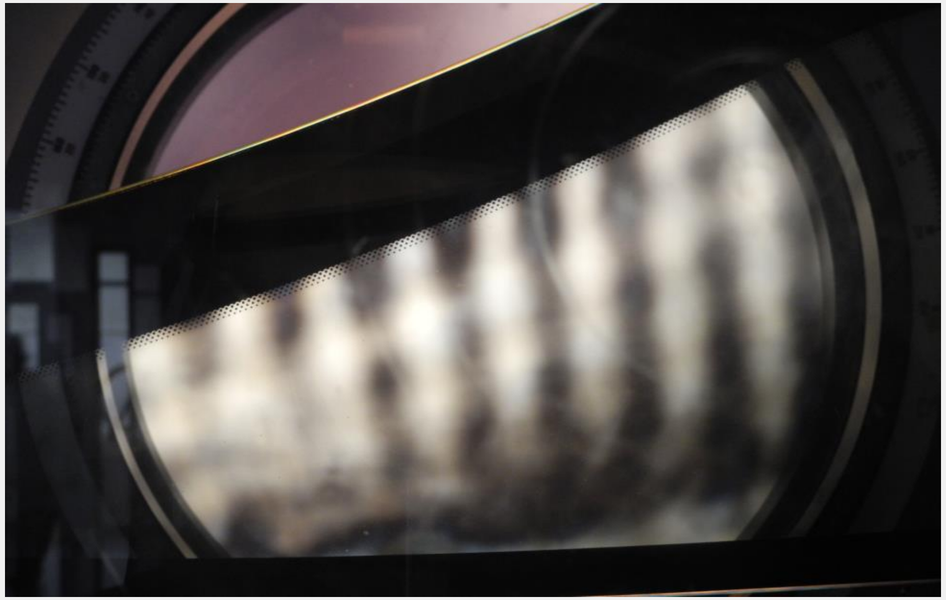
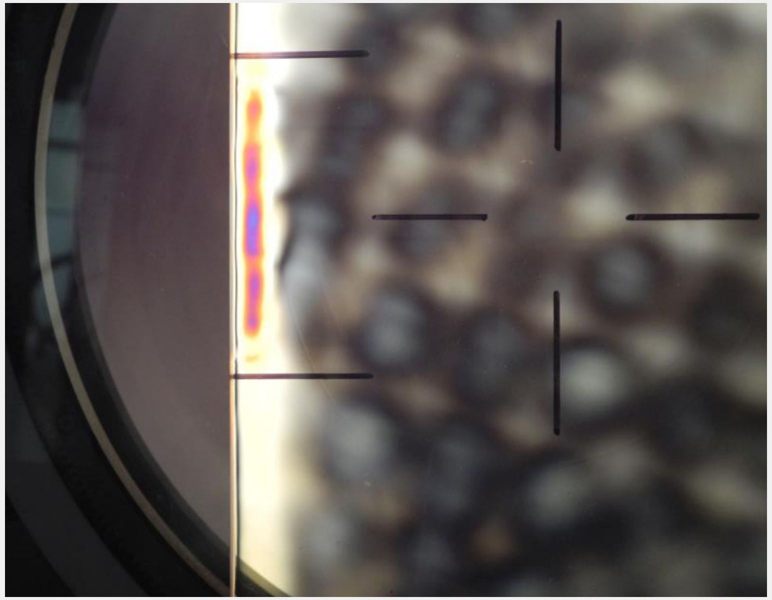
Residual stresses in glass products





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History – Reflection photoelasticity (RPE)

Birefringent Coatings

- 1930 Mesnager used glass fragments as photoelastic coating

  Sensitive to changes however impact of reinforcement problematic
- 1950 Availability of epoxy resins contributed to development of RPE
- 1960s Zandman developed a contourable photoelastic sheet which was applied on complex structures in industrial settings.

↓

- 2000s Hubner developed an experimental luminescent PE coating based on UV curable materials.

  Required conditions limited practical use
- 2019 – 2023

  Development of thin and efficient PE coatings for industrial applications

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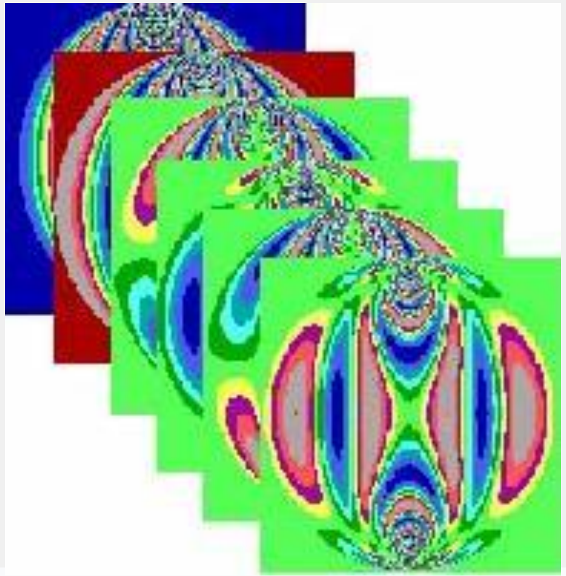
History – Reflection photoelasticity (RPE)

Acquisition and analysis

Direct observations utilising polariscopes and manual manipulation of optics

1980 – 1990s:

- Hecker and Morche (1986) introduced phase stepping for automated photoelasticity
- Developments of phase stepping methodology,
  e.g. six step phase stepping; Patterson and Wang (1991)



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1997-2003:

- Developments of digital image acquisition and processing for RPE. Both static and dynamic capture.
  - 1997 advent of the grey field polariscope
  - 2002 advent of the poleidoscope for dynamic capture

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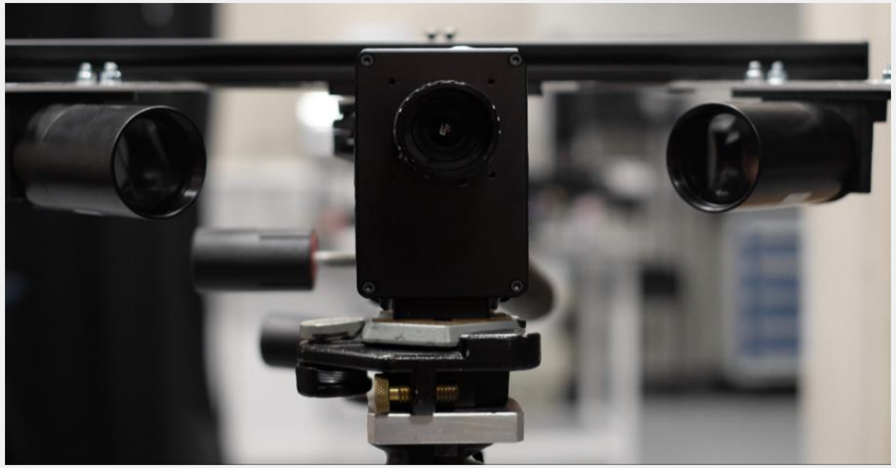
Present - Technologies

Imaging and processing

Stress Photonics' polariscope and poleidoscope:

- Commercially available
- Ease of use
- Sub-fringe resolution of better than 0.1 nm
- 20 micro-strain resolution
- Automatic thickness correction*

*Tinted coating required



GFP1600: Grey field polariscope for static RPSA

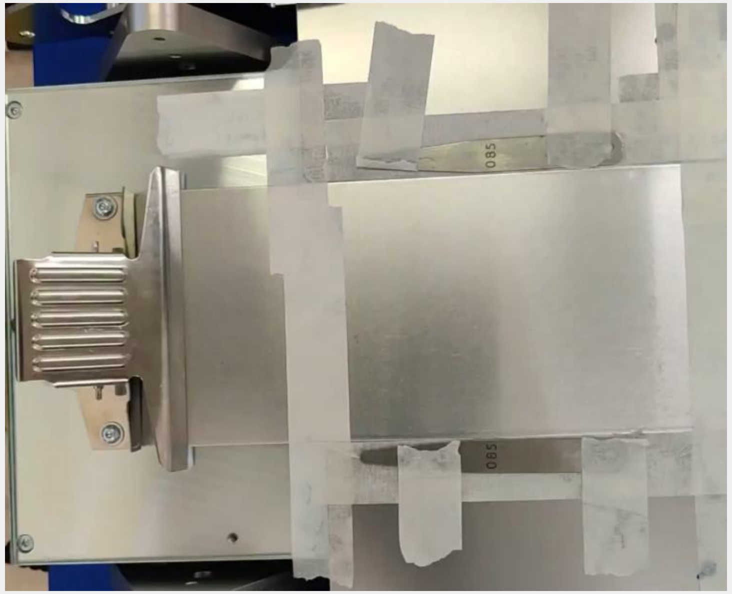
Coating materials

Micro-measurements' photoelastic sheets:

- Flat sheets for basic geometries.
  - Range of thicknesses and sensitivities.
- Mouldable plastics for complex geometries.

$$(\varepsilon_1 - \varepsilon_2) = \frac{\delta}{2dK}$$

$(\varepsilon_1 - \varepsilon_2)$ = principal strain difference
δ = Retardation (nm)
d = Thickness
K = Strain-optic coefficient



Video playback 32x speed:
30 minute coating preparation

24 hours cure

6 minute protective coating removal

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Present - Drawbacks of RPSA

Three main issues exist

1. Complicated coating application processes.
2. A need for skilled engineers.
3. Large timescales for data collection.

The photoelastic coating material

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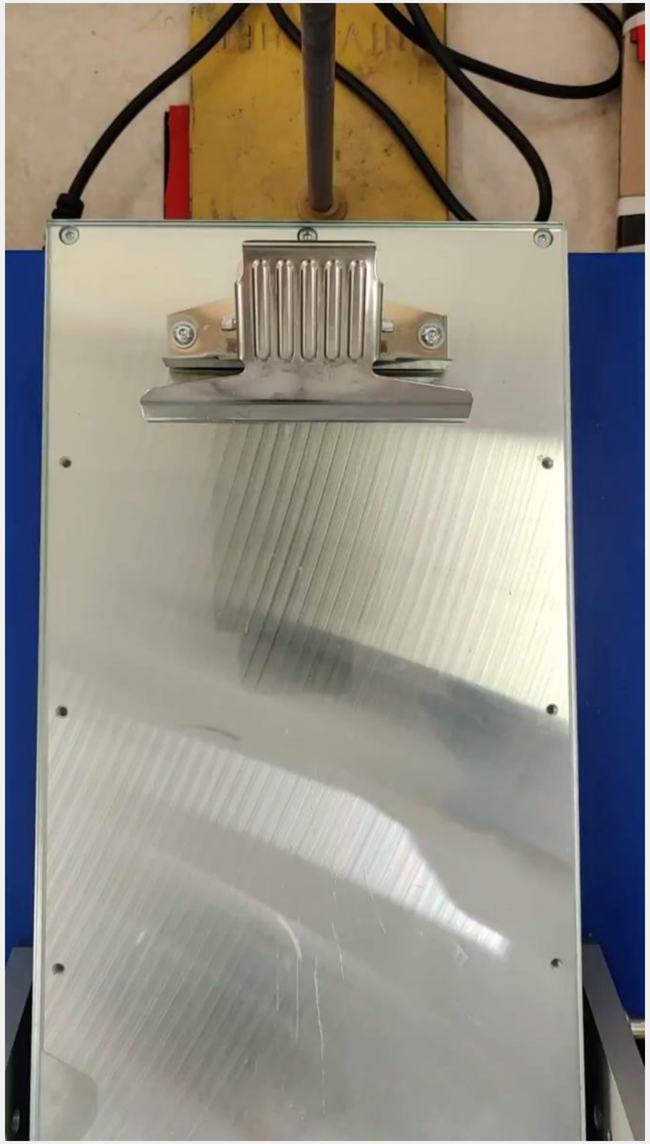
Present - Developing a new coating

Properties of a potential new coating

- Thin (~50 μm)
- Easy-to-apply (sprayable)
- Curable in a matter of seconds (UV curable)



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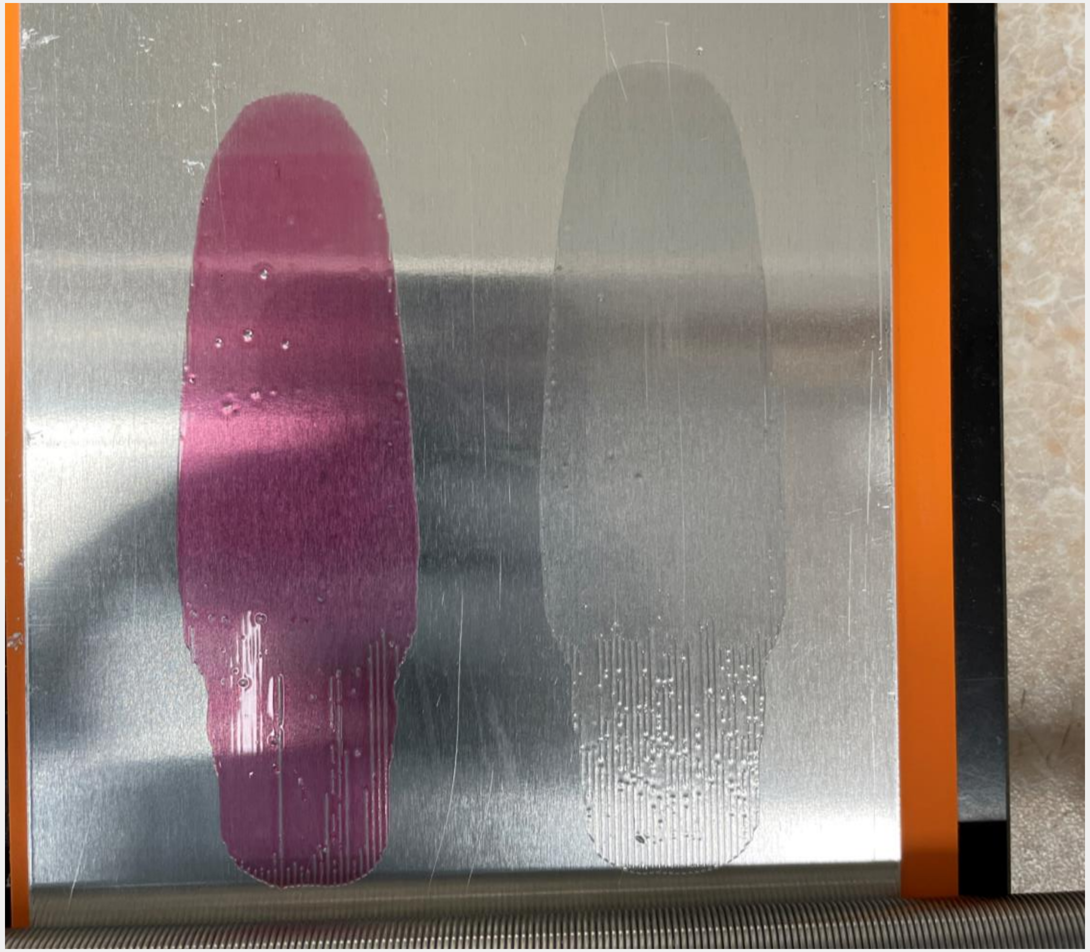
Application concerns:
Thickness control

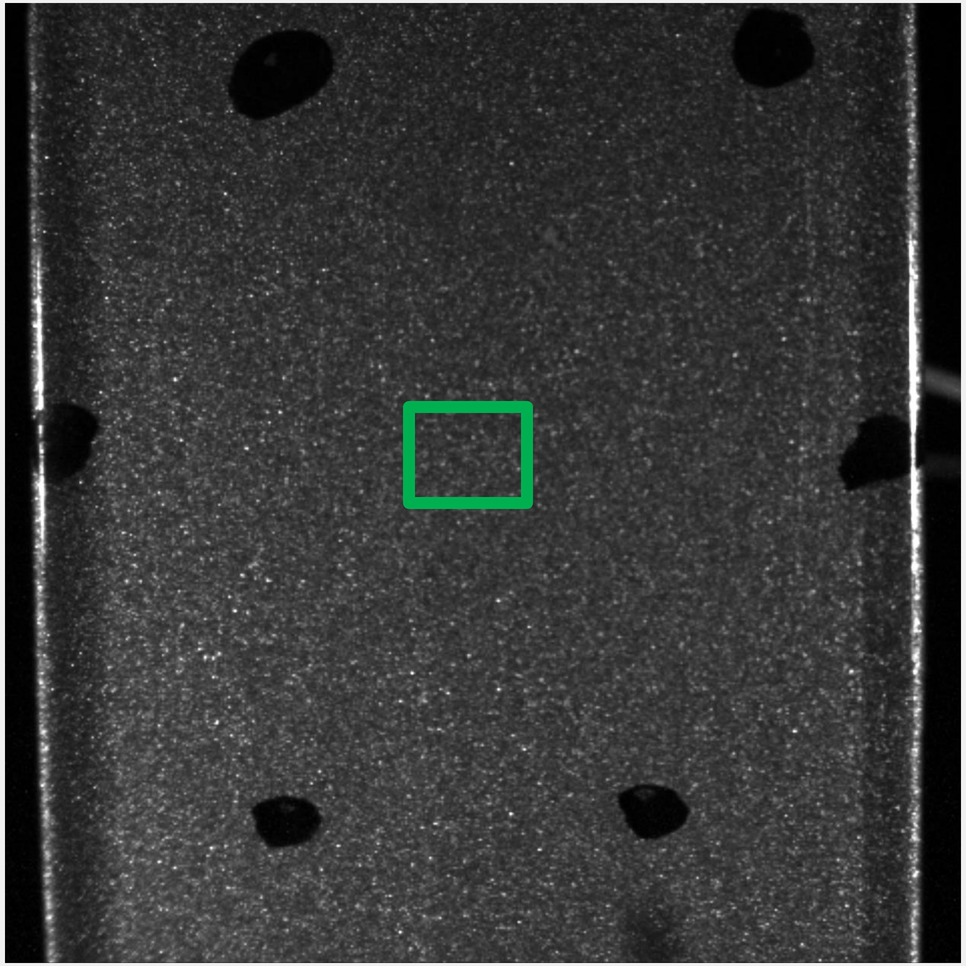
We can't control; but…we can measure

- Use of a tinted coating.
- 1.5 wt% of a red epoxy dye.
  - Balance of cure performance, PE sensitivity and signal.
- A red coating will transmit red light whilst absorbing blue light.
- The ratio between captured red and blue light can be translated into a thickness measurement.



102 mm

Application concerns:
Thickness control



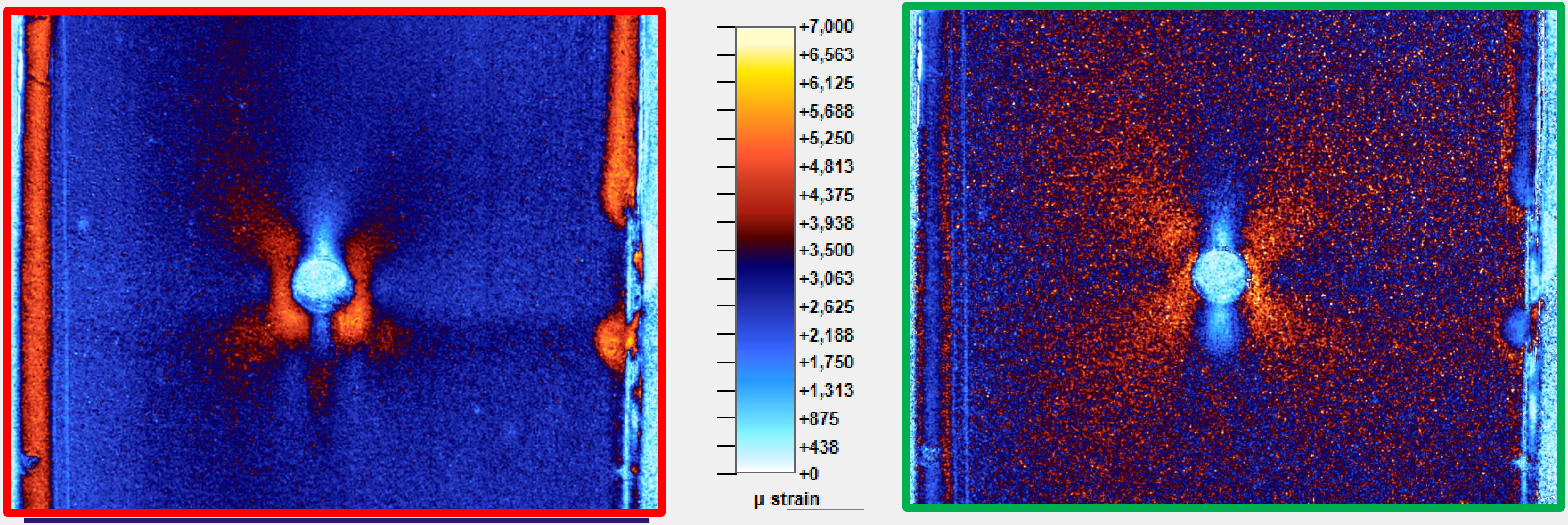
25 mm

Calculated thickness: **0.046 ± 0.007 mm**

Measured thickness: **0.046 ± 0.004 mm**

Application concerns:
Thickness control

Thickness correction on a Glass Laminate Aluminium Reinforced Epoxy (GLARE) sample – Load applied: 9 kN



38 mm

Corrected

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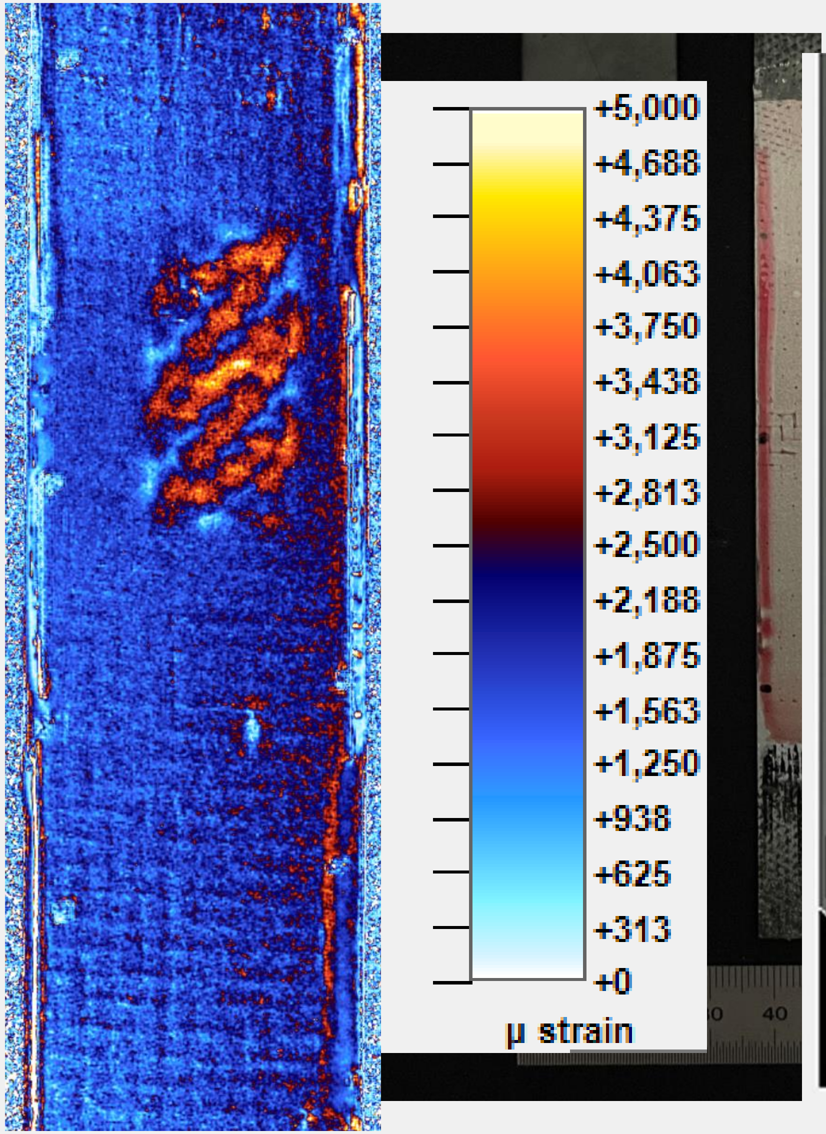
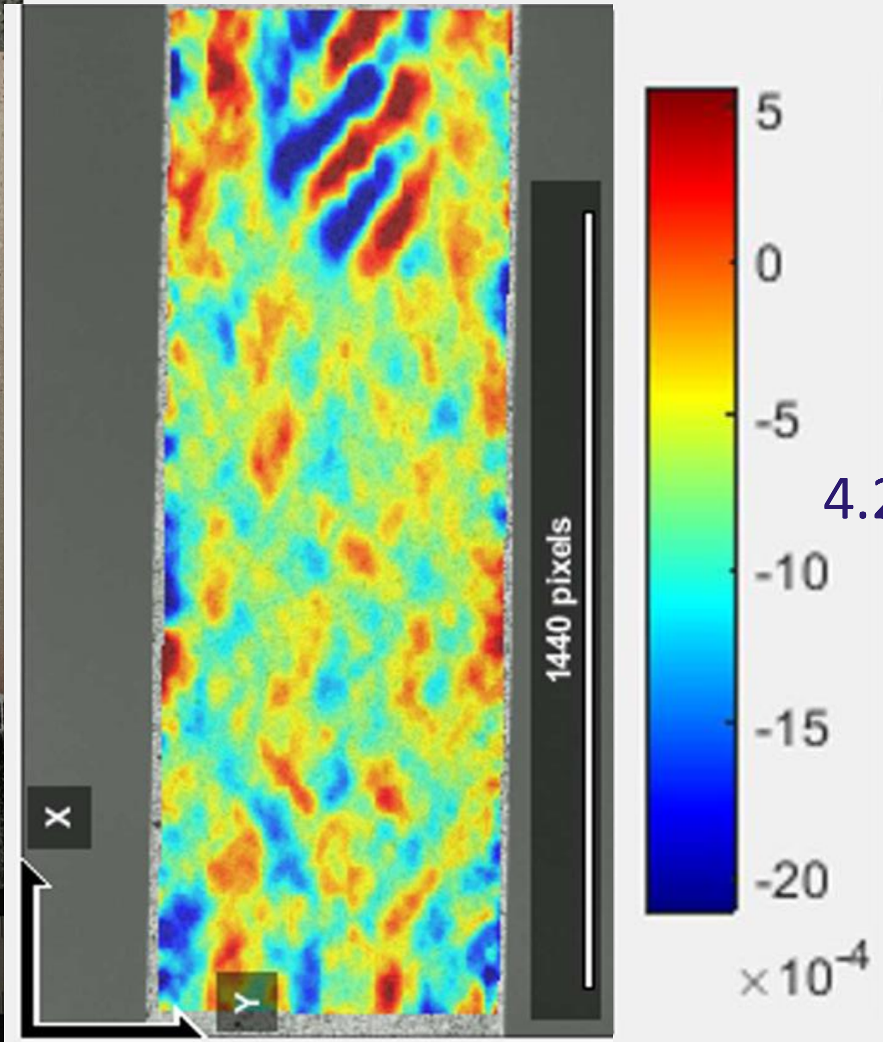
Present - An industrial focused application

The identification of critical areas.

RPSA

2 kN Load





DIC

4.25 kN Load

ε_{yy} plot

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Future of Reflection Photoelasticity

- Sprayable
- Formulation optimisation
  - LED curable for safe and easy application within industrial settings
  - Focused chemistry on PE sensitivity – go thinner
- Ease of use with computional techniques e.g. FEA for validation.

Thank you for listening

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