Bubble growth in thin layers of polymer

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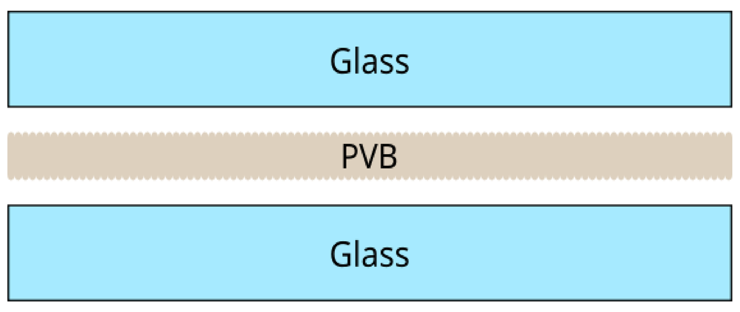
Introduction

In laminated safety glass, bubbles can appear during its elaboration or lifetime, hindering the view. An objective for Saint Gobain is to prevent the apparition of these bubbles. To do this, it is necessary to know the conditions in which they appear and the pressure inside the bubbles. Can birefringence, usually used for unconfined materials, be a non-invasive probe of these bubbles?

1. Bubble in laminated glass. Taken by Claire Schune.

Laminated safety glass

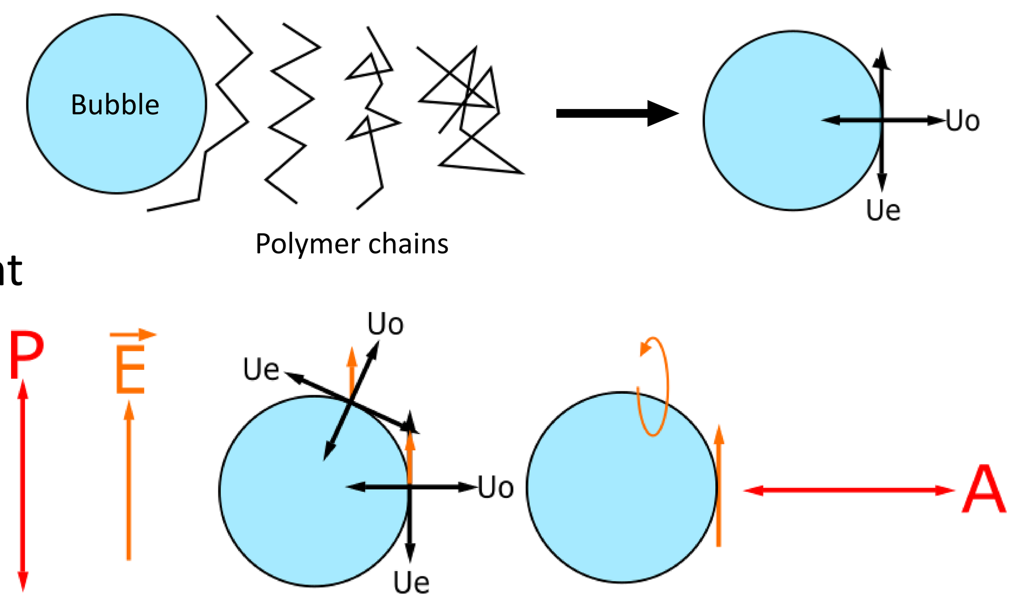
- « Sandwich » of glass and polymer.
- Resistant to impact
- PVB: PolyVinylButyral



Birefringence model

Polymer chains stress by bubble
→ radial and tangential birefringent axes

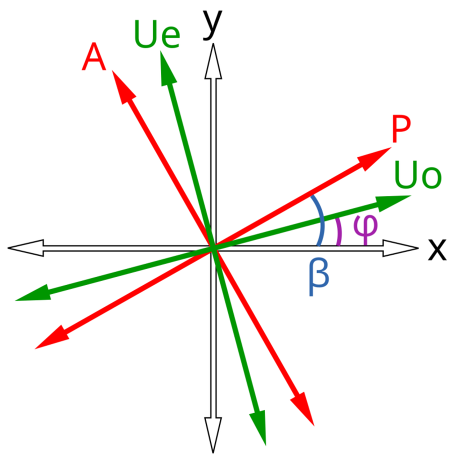
→ Polarisation change differently around a bubble.

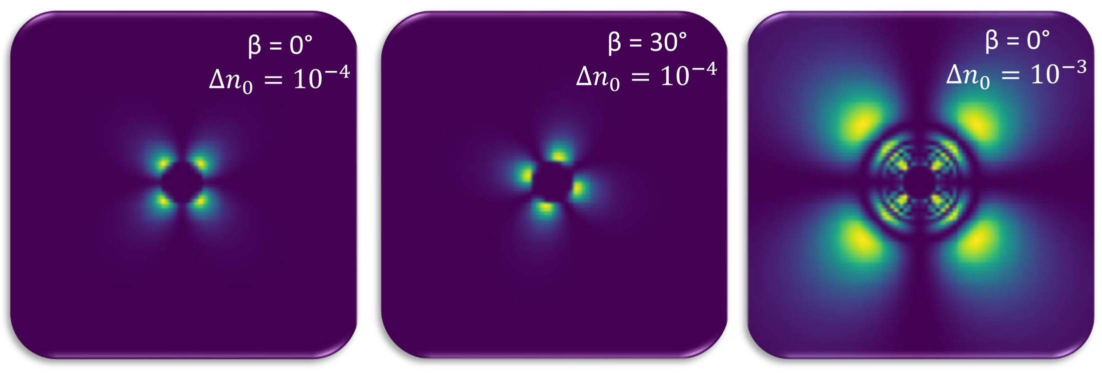


Received intensity

$$I_r = I_0 . \sin^2[2(\beta - \phi)].(1 - \cos(\Delta n.k.e))$$

Received intensity; Emitted intensity; Angle between ordinary axis and laboratory; Wave vector; Angle between polarizer and laboratory; Birefringence; PVB thickness



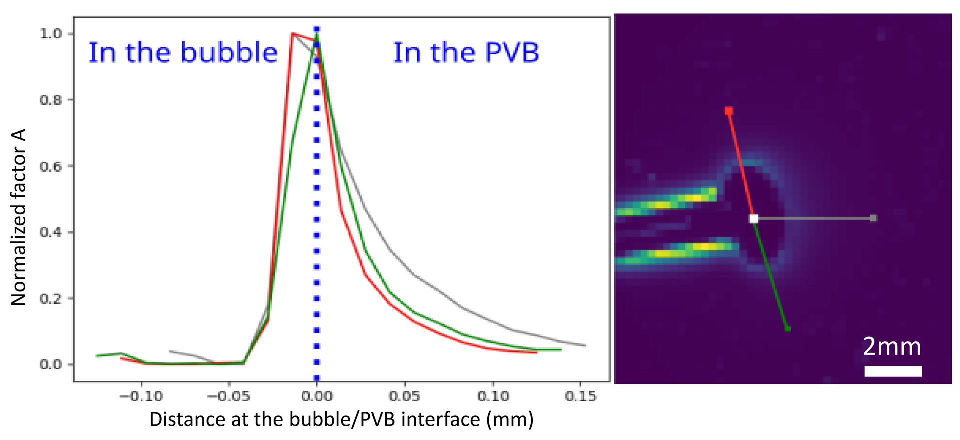


3. Simulations of the mathematical model for different angles β and different initial birefringence Δno with a bubble at the center. Assumption of birefringence decreasing as $\Delta n = \frac{\Delta n_0}{r^2}$

Analysis

Amplitude factor A extracted from the result measurements.

$$A = I_0.(1 - \cos(\Delta n.k.e))$$



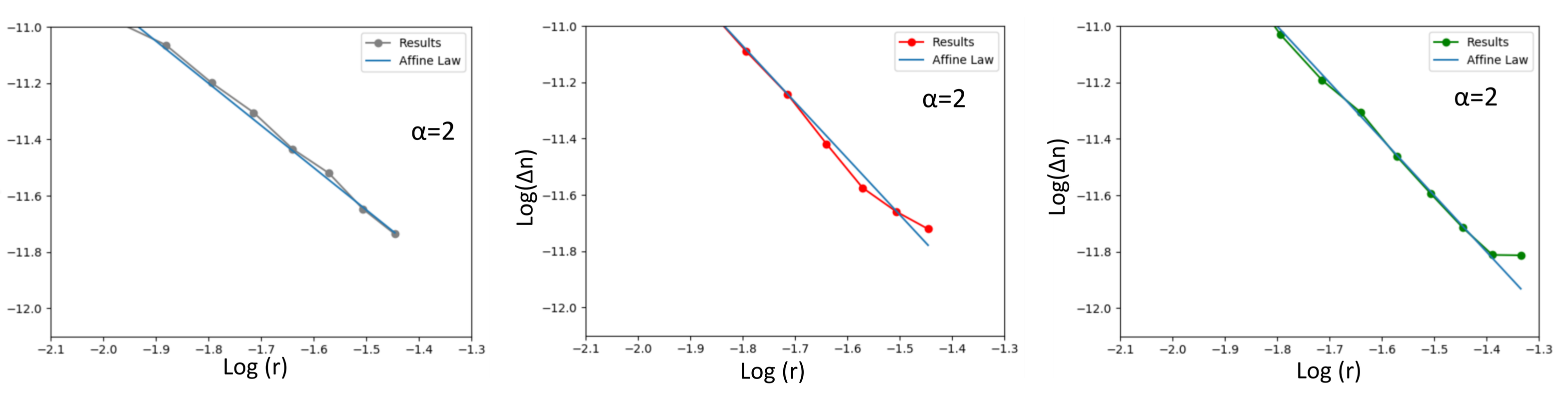
7. Evolution of factor A with the distance at the bubble/PVB interface.

From the A factor, the evolution of birefringence as a function of the radial axis is determined.

The birefringence follows a power law and decreased in $\frac{1}{r^2}$.

$$\Delta n = \frac{\Delta n_0}{r^\alpha}$$

Initial birefringence; Radius (distance to bubble center)



8. Evolution of birefringence with the distance at the bubble center in log-log scale.

Conclusion

- A non-invasive optical method has been developed for confined systems
- Measurement of the stress field has been done with a PID analysis.

Perspectives

- Determination of the stress-optic coefficient.
- Birefringence as a marker of bubble history?

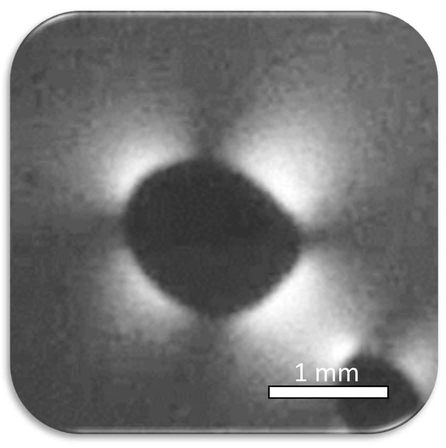
Cloverleaf pattern

Bubble between crossed polarizers: cloverleaf pattern around bubble due to PVB birefringence.

$$n_1 - n_2 = c(\sigma_2 - \sigma_1)$$

Refractive index; Stress-optic coefficient; Stress field

[1] William F. RILEY James W. DALLY. Experimental stress analysis. McGraw-Hill Inc

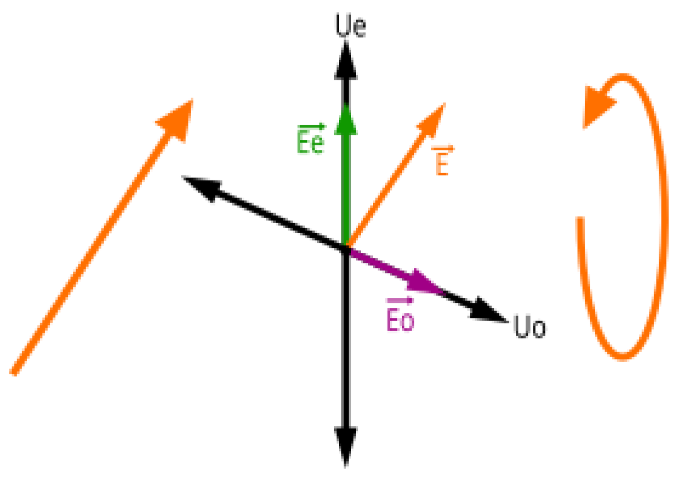


2. Bubble in laminated glass placed between crossed polarizers.

Birefringence

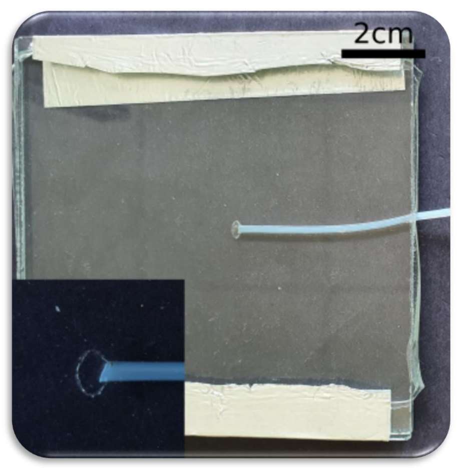
In a birefringent material:
- 2 axes: ordinary and extraordinary axes
- 2 refractive indexes

Light propagates at different speeds along each axes → phase shift → polarization change



Sample

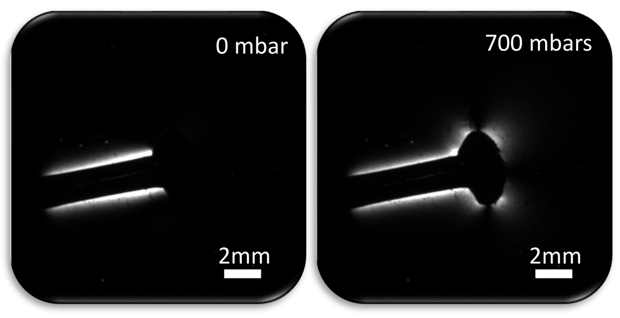
- A tube is incorporated to control bubble pressure.
- Composed of 2 PVB sheets and 2 glass plates.
- Bubble created by doing a hole in a PVB sheet.
- Thickness : PVB = 0,76mm / Glass = 2mm.



4. Picture of the sample used. Square of 10 by 10 cm.

Images between crossed polarizers

- Higher the bubble pressure, the more intense the light signal around the bubble.



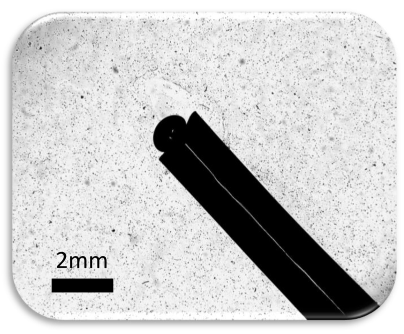
5. Picture of the sample between crossed polarizers for different bubble pressure.

6. Picture of the sample between crossed polarizers for different angles between the first polarizer and laboratory axis. Pressure set at 700 mbars.

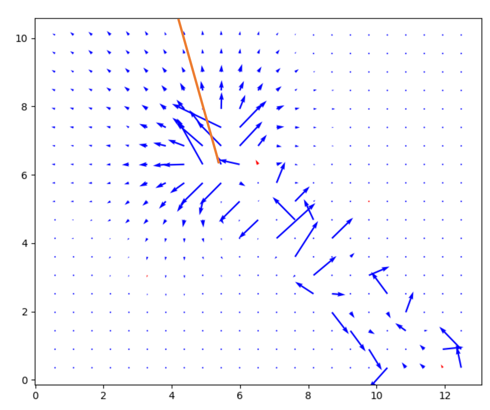
Cloverleaf pattern rotates with the angle between the polarizer and the laboratory.

Particle Image Displacement (PID) Analysis

2 bars pressure onset.
80°C.



9. Example of an image used for PID. PID analysis is made by using dust in the sample.



10. Example of PID. Arrows size increased by a factor of 1000. The biggest arrows are caused by tube presence. Orange line is the profile used for fig.11.

The difference of stress field between radial and tangential axes is deduced from radial displacement

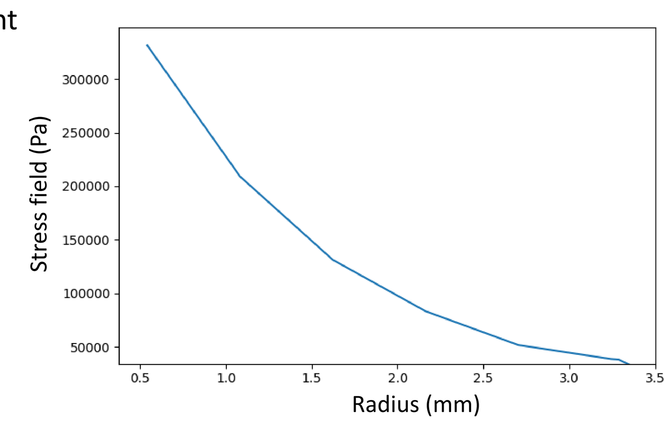
$$\varepsilon_{rr} = \frac{dU_r}{dr} \qquad \varepsilon_{\theta\theta} = \frac{U_r}{r}$$

Radial strain field; Tangential strain field; Radial displacement; Radius

$$\sigma_{rr} - \sigma_{\theta\theta} = 2G(\varepsilon_{rr} - \varepsilon_{\theta\theta})$$

Radial stress field; Tangential stress field; Shear modulus

Analysis reveal a decreases of stress field in $\frac{1}{r^2}$.



11. Evolution of stress field along orange axis (on fig.10).

Aknowledgment

- LIPhy
- Saint Gobain

- Elise Lorenceau
- Irène Wang
- Carlos Arauz