Rational design of a new reflection photoelastic coating

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Introduction

Reflection Photoelastic Stress Analysis (RPSA) is an experimental technique used in industries to assist in a variety of design and manufacture processes. Users can benefit from immediate qualitative and quantitative information, for example, about maximum shear strains in complex geometries. Recent developments, and commercial availability, in automated collection and analysis of photoelastic data has given potential for RPSA to be a truly effective method. However, current RPSA methods are hindered by complicated coating application processes, a need for skilled engineers and large timescales for data collection. These issues all stem from one vital component – the photoelastic coating material. This research has demonstrated the possibility of improving upon these drawbacks by designing a new coating material that is thinner (~50 µm), easy-to-apply, and curable in a matter of minutes. Furthermore, this new coating has been shown to be comparable to commercially available photoelastic materials in its response.

Photoelastic coating

Common reflection photoelastic materials utilise thermoset resins as either an adhesive for a polycarbonate sheet or as a mouldable coating for use on complex geometries. Application processes are difficult to perfect and often produce undesirable qualities that affect a coating's photoelastic response. Such effects include non-uniform adhesive layers creating residual stresses or air bubbles in transparent coating, distorting captured photoelastic images. Another inconvenient attribute of thermoset resins is their long cure times, often upwards of twenty-four hours.

This research investigated the potential of UV curable resins to produce rapid, energy efficient and low-cost chemical reactions when compared to thermosets. A variety of resins were chosen and combined in different quantities to form thirty formulations. After initial photoelastic testing, the resin compositions of formulations that presented ideal properties (low residual birefringence, high sensitivity to strain, curing performance etc.) were analysed further using a Design of Experiments (DOE) statistical package, utilising a mixture design, to optimise the resin blend.

Photoelastic analysis and experimental setup

To investigate a formulation's photoelastic performance, coatings were cured onto aluminium beams at a thickness of approximately 50 µm. The beams were subjected to various cantilever deflections with a consistent location chosen for photoelastic analysis. Photoelastic analysis was used to measure the induced retardation between two mutually perpendicular components of light that interacted with the coating. The formulation's normalised retardation data were compared directly to beams coated with a commercially available polycarbonate sheet, Micro-Measurements' PS-1E sheet adhered with PC-10 two-part adhesive[1].

A GFP1600 grey-field polariscope[2] was used, in conjunction with the DeltaVision image and acquisition software, to provide automated full-field magnitude and directional data with a sub-fringe resolution of better than 0.1 nm, figure 1. Once the formulation composition was finalised, its strain-optic coefficient can be calculated and inputted into the software to translate retardation data into micro-strain with a 20 micro-strain resolution.

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[1] www.micro-measurements.com

[2] www. stressphotonics.com

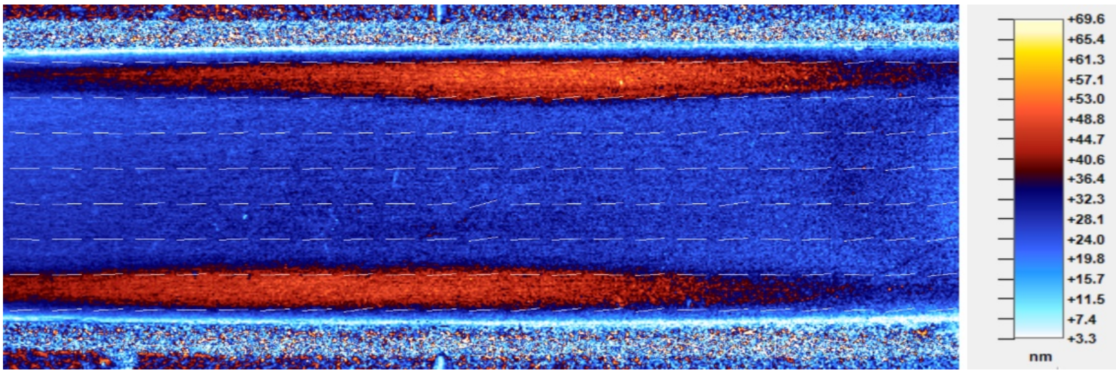

Fig 1: Photoelastic analysis of an aluminium beam at a maximum cantilever deflection of 20.32mm. Directional vectors represent the orientation of the first principal strain. Orange regions represent the edges of the beam where a meniscus has formed increasing coating thickness.

Experimental results

The coatings must first be calibrated in order to convert induced retardation into principal strain difference ($\varepsilon_1 - \varepsilon_2$). Strain gauges were used to measure the principal strains, at the point of measurement, which were inputted into the strain-optic law, eq. 1,

$$(\varepsilon_1 - \varepsilon_2) = \frac{N\lambda}{2dK} \tag{1}$$

where N is the fringe order, λ is the wavelength of captured light, d is the coating thickness and K is the strain-optic coefficient. To finalise calibration, eq. 1 was rearranged to determine K for the UV curable coating. The formulation's strain-optic coefficient was calculated to be 0.042 which demonstrates a suitable sensitivity for use in photoelastic analysis. Figure 2 compares the principal strain difference determined using strain gauges and the two coatings and demonstrates that the UV curable coating is linear throughout the deflection whilst the PS-1E sheet's strain limit is breached beyond a 0.8 mm deflection.

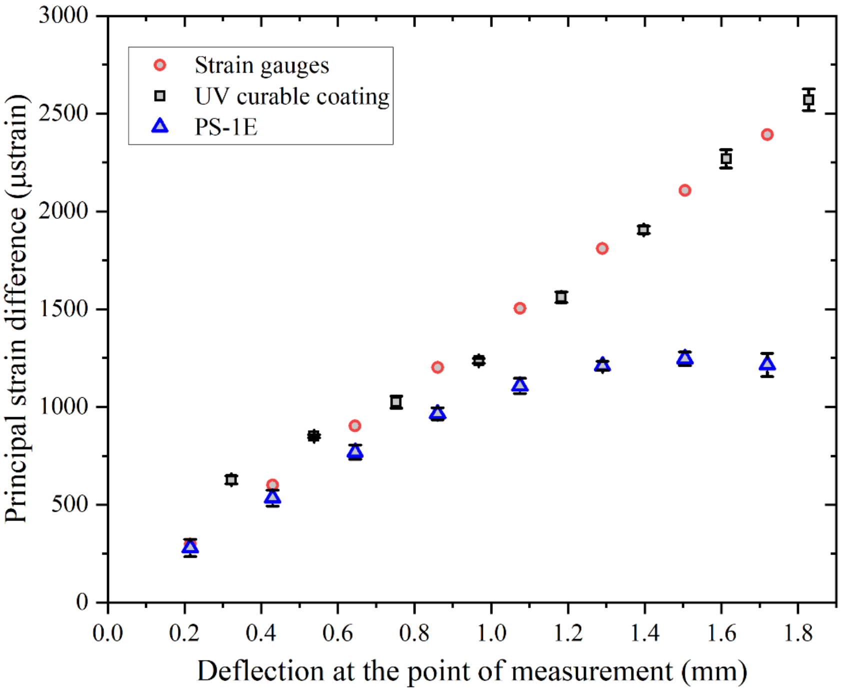

Fig 2: Comparison of principal strain difference of the cantilever beam

Conclusion

It is concluded that this new coating shows great potential in comparison to existing technologies. Through rational design, a potential photoelastic UV curable coating was established. It's response to cantilever deflections was linear and it possessed only a small initial residual birefringence, comparable to the PS-1E sheet.