Hybrid contour method/eigenstrain model to predict residual stress in glass

B. A. Balan, Supervisor: Dr Mithila Achintha

UNIVERSITY OF Southampton

Current issues

- Glass has the potential to overcome the challenges in reducing carbon footprint.
- Design of glass elements is challenging due to its brittle nature.
- Current design guidelines are based on rules of thumb which focus mainly on external loading.

Aims

- Develop a simple analytical/numerical tool to accurately characterise residual stress in glass.
- Efficiently incorporate the stress results to analyse the structural response of glass elements.

Method

Original glass sample

↓ Cut sample in half and measure surface displacements

Displacement contour of the cut plane

↓ Finite element analysis

Residual stress

↓ Inverse eigenstrain analysis

Eigenstrain distribution

↓ Finite element model

Residual stress in new geometries/during applied loading

Results

1. Residual stresses using contour method and validation

The contour method was used to determine the residual stress profile – analytically, the opposite of the measured contour (arisen due to stress relaxation) along a newly cut plane is forced back to its original position (i.e. before the cut). The stress results are validated using a scatter light polariscope that makes use of the glass birefringence.

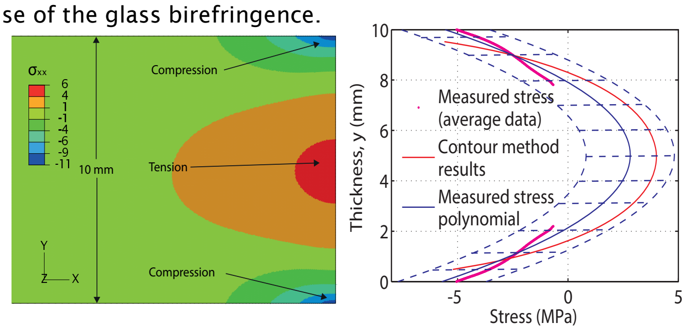

Fig.1. Residual stress (σ_{xx}) using contour method (left). Comparison of stresses (σ_{xx}) computed and experimental (right).

Results (cont.)

2. Determination of eigenstrain profile

Although the contour method can be used to model residual stress in a given glass specimen, a new experiment is required to predict the stress distribution in a new glass specimen or glass structural element.

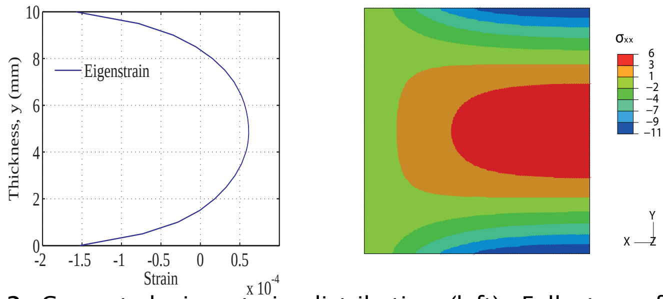

Fig.2. Computed eigenstrain distribution (left). Full stress field (σ_{xx}) using eigenstrain method – 10 mm thick sample (right).

Practical applications

The stress field around a complex geometry (e.g. hole) is constructed using the present method (Fig. 3a).

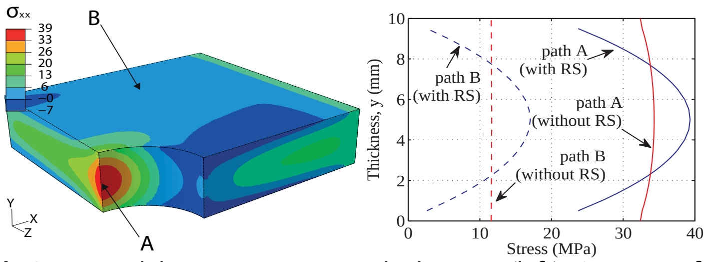

Fig.3. FE model incorporating residual stress (left). Stress profile (σ_{xx}) along path A and B at 10 MPa remote tensile stress (right).

Conclusions

The current method enables modelling residual stress in new geometries (e.g. stress concentrations around hole) and/or during subsequent loading.

The eigenstrain distribution depends only on the manufacturing process, this allowing to analytically compute the eigenstrain profile for samples with different thicknesses.

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Email: b.a.balan@soton.ac.uk

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HYBRID CONTOUR METHOD/EIGENSTRAIN MODEL TO PREDICT RESIDUAL STRESS IN GLASS

B.A. Balan[1], Dr M. Achintha[1]

[1]Infrastructure Group, Engineering and the Environment, University of Southampton, UK

INTRODUCTION

The use of glass as a load bearing structural material within buildings (e.g.: stair cases in Apple stores) has become increasingly common over the last 25 years. While aiming to offer a permissible stress design philosophy for glass elements current guidelines are mostly based on inadequate rules of thumb which are focused on the external loading action on elements. Although this is important, no focus has been given to other loading contributory factors such as residual stresses. They have a high influence on the stress distribution near the connections of the glass elements, known to be the core component when designing structures made of glass.

The misfit strains (i.e. eigenstrain) developed during cooling of the glass in the manufacturing process generate residual stresses. Due to non-crystalline microstructure of the glass, conventional methods (e.g.: X-ray or neutron diffraction) cannot be used to determine the residual stress.

The current work presents a validated method to characterise the full residual stress field in glass. The contour method [1] was used to determine the residual stress profile in the glass sample. Experimental validation of the computed stresses was done using a scattered light polariscope. The validated results were used to determine the eigenstrain profile, which is used to model residual stresses in new glass elements [2].

METHODOLOGY

Construction of residual stresses using contour method

The deformations caused by the relaxation of the stresses in a glass sample after is cut in half (Fig. 1) are used in an appropriate finite element (FE) model to compute the initial residual stress.

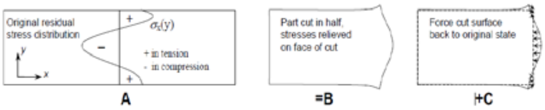

Figure 1: Contour method principle [1]

The birefringence of glass makes possible the use of a scattered light polariscope to validate the computed results (Fig. 2). The predicted parabolic stress distribution (Fig. 2) agrees with what is reported in the literature.

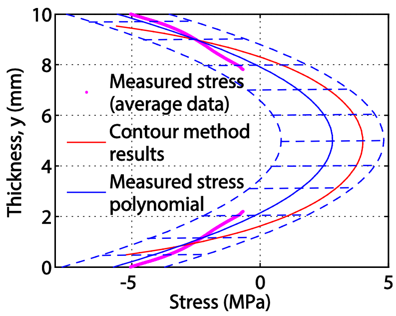

Figure 2: Comparison of the experimental results with the contour method results (Dotted line: ± 2MPa polariscope error)

Determination of eigenstrain profile

In an inverse eigenstrain analysis [3], the experimental results were matched in a least-square sense to determine the original eigenstrain profile. Once the eigenstrain distribution is known the residual stress field in new glass geometries can be simply determined [2].

PRACTICAL APPLICATIONS

Incorporating the determined eigenstrain in a FE model of a new glass sample having a 20 mm diameter hole at centre (only quarter of sample modelled), allowed constructing the full residual stress field in the sample (Fig. 3a). The stress distribution fulfils the overall equilibrium requirements.

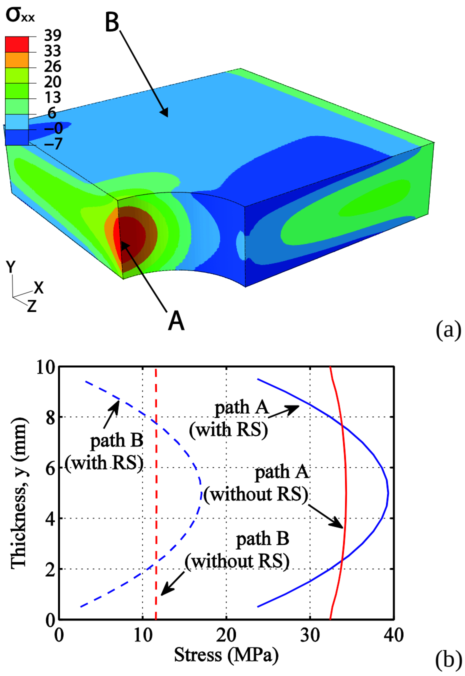

Figure 3: (a) FE model incorporating residual stress subjected to a 10MPa tensile stress. (b) Stress distribution (σ_{xx}) comparison at 10 MPa tensile stress of the sample.

The negligence of residual stresses (RS) results in a significantly different stress distribution (Fig. 3b) than is developed in the real glass specimen (i.e. when RS are taken into account). Due the brittle nature of glass, modelling residual stresses in glass elements is a crucial prerequisite in correctly predicting the structural response of glass elements.

CONCLUSIONS AND FUTURE WORK

Once the eigenstrain of a glass sample is established based on validated results of contour method, it can be simply incorporated in FE model to determine the residual stress in new geometries and/or during subsequent loading.

The eigenstrain distribution of glass depends only on the manufacturing process, this allows to analytically compute the eigenstrain profile for samples with different thicknesses.

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REFERENCES

1. Prime, M.B., 2000. *6th International Conference on Residual Stresses*, pp. 617-624.
2. Balan, B.A., Achintha, M, 2014, *5th International Conference of Computational Methods*, ID 400.
3. Achintha, M., Nowell, D., 2011. *Journal of Materials Processing Technology*, 211, pp.1091-1101.