A combined experimental and numerical approach to the investigation of the influence of geometry on residual stresses in structural glass

MITHILA ACHINTHA[1*], BOGDAN BALAN[1]

[1]Faculty of Engineering and the Environment, University of Southampton, United Kingdom
[*] Corresponding author. E-mail: Mithila.Achintha@soton.ac.uk; Tel: +44 2380 59 2924

This paper reports selected findings from a combined experimental and numerical analyses of the influence of geometry on residual stresses in commercially-available float and tempered glass. The effect of residual stresses is critical for the performance of structures; unexpected premature failure may occur because residual stresses can critically combined with applied stresses [1]. Despite the potential consequences of ignoring the effects of residual stresses, the current design guidelines of glass structures [2] do not explicitly take into account the effect of residual stresses.

The misfit strains (i.e. eigenstrains) developed due to the cooling of glass during the manufacturing process generate residual stresses. The authors have previously [3] developed a contour method–eigenstrains hybrid model to predict the residual stresses present in commercially available float glass. This paper extends the hybrid model to investigate the interaction between the geometry and residual stress in both float and tempered glasses.

Contour method experiments have been used to construct the residual stress depth profile, and then the results validated using scattered-light-polariscopic experiments are used to devise eigenstrains – i.e. the misfit strains that generated due to differential cooling during the manufacturing process. The full 3D residual stress distribution is then devised by incorporating the eigenstrain as a misfit strain in an appropriate finite element (FE) model. The results show that in both float and tempered glass, the residual stress depth profile has a parabolic distribution with ~20 % of thickness surface compression zone on each side balanced by a mid-thickness tension zone. The model predictions agree well with residual stresses measured using scattered-light-polariscopic experiments. Surface compressive stress of ~100 MPa has been determined in tempered glass, while that in float glass is ~8 MPa.

Once the underlying eigenstrain depth profile has been determined residual stress in new geometries (e.g. stress concentrations features) and/or during subsequent loading applications, are determined from FE models by simply using the knowledge of eigenstrain depth profile. For instance, results of a glass plate with a central hole shows that the presence of the hole affects the stress distribution, and the results also suggest that change in stress is not proportional to the magnitude of applied stresses. Furthermore, investigations have shown that the negligence of the effect of residual stress can significantly underestimate critical design stresses.

A further application of the eigenstrain method has been explored. Eigenstrains generated in float glass depends on differential cooling that takes place during manufacturing, and this means that eigenstrain depth profiles in glass of different thickness are different. The results show that by combining the knowledge of eigenstrain depth profile in float glass of known thickness and a “thickness effect”, which indirectly takes into account of different rates of cooling experienced by glasses of different thicknesses, eigenstrains in other thicknesses and subsequently the stress distributions can be determined.

The study suggests that the hybrid contour method/eigenstrain approach is particularly effective in predicting residual stress distribution in different glass geometries. The approach has been used to model the interaction between the geometry and the residual stresses.

References

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