Strengthening joints in glass with bonded GFRP strips

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Research Aims

The main aim of the current project was: to investigate experimentally and using a Finite Element model the effectiveness of using bonded GFRP strips to strengthen joints in glass. Some of the objectives were: to develop a procedure for testing glass in tension; study the influence of GFRP reinforcement on ultimate load and ductility of glass samples; and to create a Finite Element model to predict stress in reinforced and control glass samples.

The hypotheses of the research were:

1. GFRP reinforcement increases the ultimate breaking load of glass samples.
2. The increase in the ultimate breaking stress of glass samples provided by GFRP is proportional to the area of the reinforcement.

Glass in construction

For the past 25 years the use of structural glass as the main façade element has increased, there is a trend of using sophisticated glass connections to achieve complex forms (Patterson, 2011). Glass can be used as the main material for walls, roofs, floors and stairs. The term 'structural material' can refer to any element that transmits force carried by the structure. In case of glass, the prevalent load types are lateral (wind load) and self-weight load (Vyzantiadou & Avdelas, 2004).

There are several ways of connecting grass to a structure: stud assembly, the Pilkington Planar system, spider connections (Ryan, Otlet & Ogden, 1997). All of these methods require a hole to be made in the glass. Given the brittle nature of glass, high concentration of stress at local points or across holes can easily lead to fractures. Another important factor needs to be considered - the strength of glass depends on the duration of the load, which adds extra complexity to glass design (Brown, 1972).

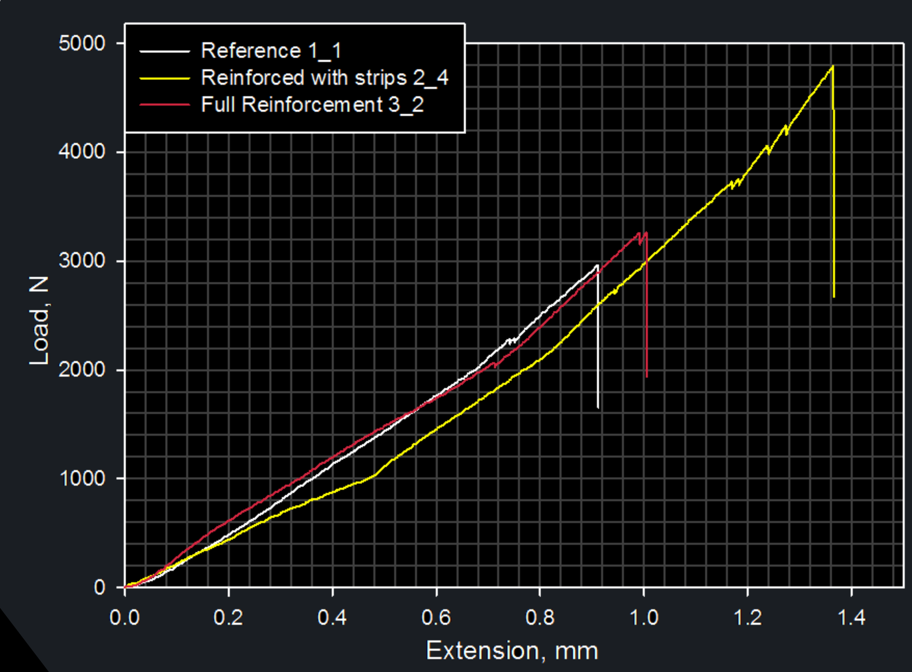
Moor House, London © Andrew Dunn

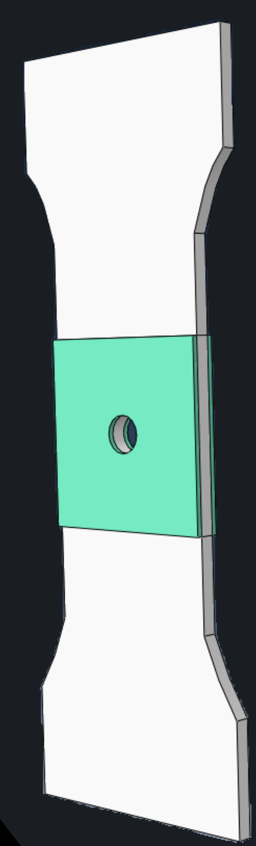
Test Methods

Increase in localised peak stress near holes, grooves, cracks and other variations in the shape is called stress concentration (Boyd et al., 2004). In the present case the hole in the centre of the glass sample acts as a stress raiser. It was decided to study the influence of GFRP reinforcement on the ultimate breaking stress of glass. Float glass samples were used for the experiment.

Unidirectional GFRP strips consisting of two layers of GFRP sheets impregnated with epoxy resin were attached to the samples using structural adhesive Araldite 2020. Both top and bottom surfaces of the GFRP reinforcement were treated with the adhesive to achieve fully bonded conditions between the GFRP strips and the surface of the glass samples. This needs to be done to create an effective stress path. A hole was drilled in each sample, and two different GFRP setup were used: with a GFRP square attached to glass and the hole drilled through it and with individual strips attached around the hole. The samples were carefully checked against cracks that may have developed during drilling. A rectangular sample used in the pilot experiment is shown below. After the pilot experiment failed to serve its purpose and perform in the way it was designed the setup was changed. New dogbone shaped samples were made to achieve desired failure.

The result achieved in the final group of samples showed that the idea of reinforcing holes in glass with GFRP appeared to be working. Strip reinforced sample was the most ductile and achieved the highest failure load value. It could be concluded that GFRP reinforcement provides tension enhancement to glass increasing its ductility. The setup developed in the project could form a basis of a full scale experiment. If the results of such an experiment confirm these findings a number of practical solutions can be developed for the construction industry.

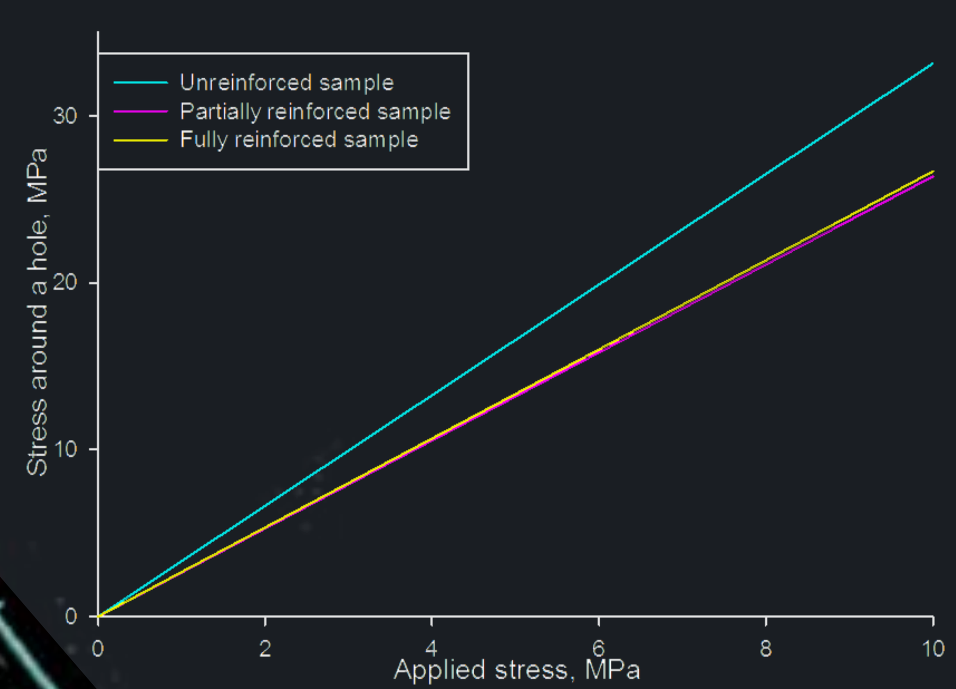


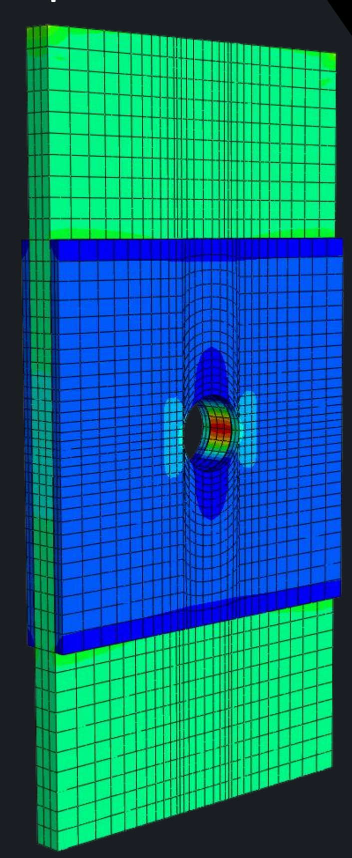


Above – comparison of load vs. extension plots between 3 samples representing different groups; on the right – final experimental sample design.

Finite Element Model

To understand the behaviour and stress distribution of the suggested sample a Finite Element model was created. The model was created using ABAQUS software. It was most important to investigate if there was a reduction in stress amplification factor value in the scenario with GFRP reinforcement as opposed to ones without any reinforcement. For the purposes of the present model purely elastic deformation with critical failure at the end was assumed for glass. It was assumed that there would be no debonding between glass and GFRP. As can be seen from the plot below the stress around the hole for the reference sample was approximately 20% higher than for the reinforced samples.





The graph on the left shows applied stress versus peak stress around the hole for all the samples; the figure on the right shows the model of the glass with GFRP reinforcement subject to tensile load.

Practical Applications

The fragility of glass results in it being weak in tension, mainly because of its non-crystalline structure. Hence, when glass reaches its maximum strength, breakage occurs immediately. The use of GFRP can potentially reinforce glass not only against static load, but also against blast loading At present, the best way of protecting the stress concentration zone against further crack development is the laying of rubber between the glass and the connection GFRP has the following advantages: high strength and lightweight, impact resistance and low thermal conductivity.

Other uses include an increasing application of GFRP systems as an alternative to steel reinforcement for reinforced concrete structures including cast-in-place and pre- and post-tensioned bridges, precast concrete pipes, columns, beams and other components.

References

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