

# Structural Glass – New opportunities for an old material

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**Abstract:** To use laminated glass as a structural building material, a better understanding of its mechanical properties is necessary. To gain a better insight in the influence of the viscoelastic interlayer (PVB and SGP) on the mechanical behaviour of glass laminates, the Laboratory for Research on Structural Models is performing experimental tests and numerical simulations. Among others, the study determines the resistance taking account of the time- and temperature dependent behaviour of the laminate.

For this research, an optimised torsion test set-up has been built based on numerical simulations with different support types. Also three- and four-point bending tests are being executed in a climatic chamber where temperature and humidity are controlled. Further comparison of these test results at different temperatures should lead towards a complete image of the stiffness of laminated glass, which could be used as a basis for safe but economic design recommendations for laminated glass components.

**Keywords:** Glass, Laminated Glass, Ionoplast interlayer, Viscoelasticity, Post-failure

## I. INTRODUCTION

### A. History of the material glass

Already in the Stone Age, naturally found glass was treated for sharp and strong utensils such as spearheads or cutting equipments. Despite this glass was black and non-transparent, it already had a similar composition as the glass known today.

The first self-made glass products found in graves date from about 3500 BC. Around the beginning of the Common Era the Syrian discovered they could process the molten glass by the use of a blowpipe.

The first flat glass was produced around 1300 AD with the Crown method. With this, an opened glass bulb is whirled around until a flat disk is obtained (Fig 1). Because of the weight of the material (the relative density of glass is  $2500 \text{ kg/m}^3$ ) only relatively small glass plates could be made.



Fig 1: First flat glass with the Crown method.

With the cylinder blown sheets method, some larger plates could be made, but the true revolution in flat glass came at the beginning of the 20<sup>th</sup> century with the industrial revolution. In 1904 large glass plates were pulled out of a molten glass bath with the Fourcault-process. During a period of 50 years this process was refined until Pilkington developed in 1959 the until now most used float glass process. With this, the melted glass mass is poured on a tin bath which results in an extremely smooth glass plate.

### B. Structural Glass

During centuries, architecture is influenced by these developments in its wish for light and transparency. The small plates, produced by the glassblower with the Crown technique, were composed in multi-coloured leaded windows. The larger cylinder blown sheets could be combined in a wooden frame. The quality and the size of the industrial glass sheets lend itself for the use of large windows without subdivisions.

It took the building industry till the early 90's of the previous century to discover the load bearing capacities of this material. Through this, the structures - which carry the glass windows - could themselves be transparent. It did not take long before architects started to explore the possibilities of structural glass and designed full glass transparent structures such as for example the glass bridge of architect Dirk Jan Postel in Rotterdam (Fig 2), [1 and 2].



Fig 2: Glass bridge, Rotterdam.

This evolution was not only possible by the quality improvement of the flat glass, but certainly also by the development of renewing safety concepts. For this reason, most of the structural glass elements consist of multiple glass plates, mutually linked with a soft interlayer across the complete surface. It so happens that the interlayer prevents crack growth from one plate to the other and glass fragments stick to the interlayer after glass breakage of a glass plate instead of falling down.

## II. RESEARCH AT LMO-UGENT

### A. Objectives

Whether it concerns a glass staircase, glass stiffeners in a showroom or a fully glass construction, an exact knowledge of the material is essential for an optimised design. In contrast to traditional construction materials, such as steel and concrete, this knowledge cannot be found in current standards. Especially by the growing quantity of interlayer materials, even the producers themselves often do not know the exact behaviour of their products. To fill this gap, the Laboratory for Research on Structural Models at Ghent University started up a theoretical, experimental and numerical research on one of the most promising interlayer for structural applications: SentryGlas® Plus.

### B. Approach

In literature, there are many test methods proposed to investigate the material properties of laminated glass and its components - glass and interlayer. All of them are interesting for certain aspects, but none of them are useful for all possible kinds of structural problems. Therefore, this research started with the determination of an optimal test programme for divergent loading cases.

The combination of three- and four-point bending tests and rotational tests with FEM-simulations and theoretical approaches should lead to a full image.

## III. EXPERIMENTAL PROGRAMME

### A. Three point bending tests

Three point bending tests are one of the simplest tests to define the bending stiffness of a material. For the multi-layered material laminated glass, test series must be executed around the weak as well as around the strong axis, because the influence of the interlayer is totally different for these two loading cases.

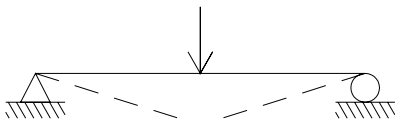


Fig 3: Principle of a three point bending test

### B. Four point bending tests

Because the glass strength is determined by the amount of cracks on the surface - due to the fabrication process, the installation and other natural scratching - the glass strength depends, among others, on the size of the maximum loaded zone. Therefore, three point bending tests are inadequate to define the strength of laminated glass. Four point bending tests, with a fixed maximum loaded zone, are more suitable. With these tests, it is also possible to define the remaining strength and stiffness of laminated glass with one or more broken glass plates [3 and 4].

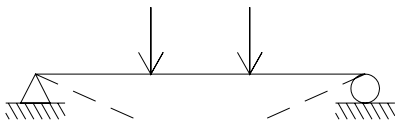


Fig 4: Principle of a four point bending test

### C. Torsion tests

Although these tests seem to resemble most real-life loading cases, there is still an important property unknown: the rotational stiffness. In literature, there has been only little research done in this field, although it is an important parameter when investigating the buckling instability of slender glass beams [5]. For this reason, an optimised torsion test set-up has been built.

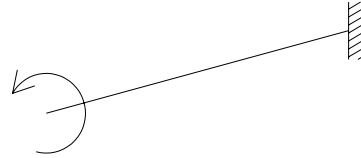


Fig 5: Principle of a torsion test

### D. Temperature control

Because it is known that the mechanical behaviour of the interlayer is time and temperature dependent - the so called viscoelastic behaviour - it is possible to simulate long term loads by increasing the temperature [6]. This means that a ten year test at room temperature can be replaced by for example a one day test at elevated temperature.

At the Laboratory for Research on Structural Models, the temperature of the laminated glass test specimens can be controlled with adjustable IR-heaters and with a climatic chamber. The comparison between these two methods should define if the relatively cheap IR-heaters provide an adequate temperature control.

## IV. NUMERICAL SIMULATIONS

The experiments will be used to validate finite element models. These models will be used for a safe extrapolation of the test results to other glass dimensions and loading cases.

## V. PERSPECTIVES

At this moment, experiments are executed in the climatic chamber and basic FEM simulations are started. Further comparison of these test results at different temperatures with the numerical simulations should lead towards a complete knowledge of the mechanical behaviour of laminated glass. This knowledge will be used as a basis for safe but economic design recommendations for all kinds of laminated glass components.

## ACKNOWLEDGEMENTS

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