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Glass, timber and adhesive joints – Innovative load bearing building components

Louise Blyberg [a], Maria Lang [b], Karin Lundstedt [b], Matilda Schander [b], Erik Serrano [a], Magnus Silfverhielm [a], Christina Stålhandske [b,*]

[a] Linnaeus University, Department of Building- and Energy Technology, SE-351 95 Växjö, Sweden
[b] Glafo, PG Vejdes väg 15, SE-351 96 Växjö, Sweden

HIGHLIGHTS

- A glass/timber beam has a rather ductile failure.
- A shear wall unit of glass and timber could be used in 3–4 storey buildings.
- Environmental impact of a glass/timber wall unit is similar to a triple pane IGU.
- A glass/timber wall unit could fulfil passive house criteria.

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ABSTRACT

Structural glass–timber composite beams and shear wall elements were investigated in terms of their mechanical behaviour, energy performance and their LCA performance. The load bearing components were manufactured using annealed float glass which was adhesively bonded to the timber with different adhesives. The results show, among other things, that is is possible to join the two materials glass and timber and obtaining a non-brittle failure of the beams. The shear wall elements have the potential of being used as stabilising elements and load bearing walls in buildings of up to 4 storeys height. It is possible to combine glass and timber in a load bearing shear wall without loss of energy performance of a building or without loosing LCA performance. In addition to these benefits, the timber glass composite wall has, of course the benefit of being transparent.

1. Background and introduction

1.1. Aim and background

The current paper gives an overview of a Swedish research project "Glass and timber in innovative components with added value". The project aim was to increase the knowledge of using timber–glass based components (TGCs) as structural parts, and to produce a few prototypes in order to demonstrate the practical possibilities for the building sector and possible future manufacturers of the products.

Today's architecture places higher demands than ever on the materials and components used. The trend is towards more slender structures, with increased demand on the components, including load bearing capacity, acoustic and energy performance, as well as lower climatic impact. By the use of wood and wood-based products, wood being the only truly renewable building material, these demands can be met in an eco-efficient way.

Another trend is the increased use of large glazed areas, seeking solutions allowing the creation of large transparent rooms. From a structural point of view glass can have very appealing properties, although its use in construction as a load bearing material has been very limited. Glass is indeed a strong (in compression), but brittle material. As such the design of glass structures is truly challenging. As a consequence glass today is in general not used as an integrated part of the load bearing or stabilising structure of our buildings.

The user of architecture expects the sensory perception of house and room to be that of safe and pleasant surroundings. It is essential to look at glass constructions and get a visual feeling

* Corresponding author. Tel.: +46 105166363; fax: +46 470767459.
E-mail address: christina.stalhandske@glafo.se (C. Stålhandske).

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of intelligent transparency with load bearing capacity. The design must include reliability for the user as a consumer of architecture. An advantage for the integrated design of glass and timber is the credibility wood construction has won. Wood based components can also be interconnected without major problems.

A great possibility with the innovative components discussed in this paper is the potential to convey more light into the houses. The presence of daylight is a classic asset in architecture and is becoming more essential for the future. The passive house applications for the shear wall of glass and timber gives good performance and shows possibilities for application.

1.2. Previous work

The structural properties of timber–glass composites have been researched in previous studies, as reported in e.g. [1–4]. Those studies have dealt with mainly beams and wall elements (shear walls). The present study differs from previous ones in terms of the approach chosen to assure a sufficient shear resistance for the shear walls. In contrast to previous work, and in contrast to the tradition in window manufacturing, this work includes the use of a stiff structural adhesive to joint the timber and the glass. The basic idea is that the stiff adhesive (stiff in comparison with the very soft adhesive sealants such as silicones, that are normally used) will act as a continues shear media along the perimeter of the glass pane. In traditional approaches, the glass pane is mounted using a soft rubbery material and load transfer is assured by introducing stiff contact elements at the pane's corner. The effect of the window on energy consumption and indoor temperature is a complex issue [5–7] related to the specific configuration. The winodws can be considered as net energy gainers if rightly introduced [5,8]. There are quite some Life Cycle Analysis performed on passive houses or low energy houses [9,10] but few that consider glass in windows [11,12] or as a façade [13,14] and these do not use glass as a load bearing element.

Hopefully, new components are about to be conquered for architectural design. Both the glass timber beam and the shear wall will find purposes for use in architecture. Engineered products have been developed with glass and timber in intelligent compositions with the help of high strength adhesives, and a new component can be put in the toolbox for architecture and design.

2. Adhesive joints and mechanical behaviour of TGCs

The study of adhesive joints and load bearing components included experimental and theoretical investigations of small specimens in tension and in shear, of I-beams with webs of glass and flanges made of laminated veneer lumber (LVL) and of shear walls.

The tests performed on small scale specimens are not reported in detail herein, but reference is instead made to Blyberg [15,16]. Three main aims were considered: (a) to characterise a number of adhesives in terms of their strength and stiffness properties, (b) to develop appropriate test methods for the characterisation and (c) to develop evaluation methods making it possible to obtain detailed and localised information (on the scale of <1 mm) about the deformation behaviour of the adhesive joint. In order to fulfil the latter aim, it was decided that during the experimental investigations, a contact-free deformation measurement system was to be used in combination with finite element analyses (FEA).

The present paper gives only an overall overview of an extensive research project. Therefore, in-depth discussions on results and methods used are not given here. Instead reference is made to earlier work by Blyberg [15,16], where e.g. detailed finite element analyses of the behaviour of the tested timber–glass shear specimens are presented.

2.1. Wood–glass components – I-beams

2.2.1. Materials and methods

Fourteen I-beams with glass webs and LVL-flanges were manufactured and tested using three different adhesives and two slightly different designs of the flange-to-web joint. For some of the beams, the glass had roughly polished edges, for other beams, no special treatment of the glass edges was used. The adhesives used in the beam manufacturing were Sikafast (mainly Sikafast 5221), Sikasil SG-500 and Sikamelt 9676 OT. These are a two-component acrylic, a two-component silicone and a one-component polyurethane-based reactive hot-melt, respectively.

The beams were designed with a cross section according to the drawing shown in Fig. 1. All beams were 3500 mm in length and were tested in 4-point bending with the test set-up schematically shown in Fig. 1.

2.1.2. Results

Both the bending stiffness and the load bearing capacity of the beams were evaluated. The bending stiffness was approximated by the slope obtained from straight lines fitted in a least squares sense to data in 4 kN load intervals. The load–displacement curves obtained in the load capacity test are shown in Fig. 2. On average, the failure load was in the range of 250% of the initial crack load, indicating a large amount of redundancy. Thus, several cracks appeared in the glass before the ultimate load of the beams was reached, see Fig. 3.

Table 1 presents the test results in numeric format: the load at which the first crack appeared and the ultimate load. The load at first crack is estimated to be at the "first bump" on the load–displacement curve, as this was observed to be typical during the tests. The ultimate load bearing capacity of the beams is comparable with that of wooden I-joists of similar height and flange width.

The bending stiffness of the beams is in the range of 30% higher than for comparable traditional wooden I-joists. In the serviceability limit state it would be necessary to check not only the stiffness of the beam but also the risk of cracking. Even if the beam has a relatively high degree of redundancy after cracking has started, deformations might be too large and, in addition, a cracked glass component will probably be perceived as unpleasant.

2.2. Wood–glass components – shear wall prototypes

2.2.1. Materials and methods

A prototype for a shear wall component was designed. The prototype consists of a load bearing core made from a 10 mm glass pane glued to a LVL-frame with an acrylic adhesive (Sikafast) or silicon adhesive. On both the inner and outer sides, additional glass panes are connected, although these are not designed for taking part in any load transfer. The outer glass is intended as a climate shield, and also as a protective layer to prevent sabotage of the load bearing core. On the inside a double insulating glass unit, IGU, is used. The prototype and the test set-up used are shown in Fig. 4.

In the load capacity tests of the load bearing core, three different types of loading were applied: vertical loading, horizontal loading of the top chord and, finally, a combination of vertical and horizontal loading, see Fig. 5. For the horizontal loading, the vertical position of the top chord was kept constant by the vertical loading device. The deformation of the shear wall was measured by the use of potentiometers and by the use of a contact free deformation measurement system (Pontos). This system makes it possible to track the position of discrete points (stickers) on the shear wall during the course of loading.

Two scattered light polariscopes, SCALP-04, monitored stresses during vertical line loading of one shear wall element using loads of 0, 10, 30, 60 and 80 kN. One polariscope was fixed horizontally in the centre of the glass pane and the other was transferred manually between bottom corners and the bottom centre position measuring both in horizontal and vertical direction near the edge. In the bottom corners 45° measurements were also performed.

2.2.2. Results

Table 2 presents the maximum loads obtained for all the shear wall elements.

The load–displacement curves for all specimens are presented in Fig. 6. Vertical and horizontal displacement was measured with the potentiometers denoted as p1 and p2, respectively, in Fig. 5.

Out-of-plane displacements measured by the potentiometers are shown in Fig. 7 together with the displacements obtained from the non-contact measuring system. The results include one specimen from each load case.

As opposed to the results for the I-beams, there is no cracking of the glass before the failure of the entire elements. Instead, the failure of the shear wall elements occurs suddenly by cracking of the entire glass sheet and a large portion of the cracked glass falls out of the frame. In Fig. 8 the maximum load values obtained are plotted together with a fit to the super-ellipse equation, $(V/V_{\max})^m + (H/H_{\max})^m = 1$, which is a common approach to fit interaction formulae of this kind.

Measurements at 45° showed that the main stress directions are almost perpendicular to the glass edges in the bottom corners. The stresses in the centre position are proportional to the amount of load, see Fig. 9, but were just measured in one direction and are therefore not corrected for anisotropy. In the centre bottom position the increased load is clearly influencing the vertical stress component which is also proportional to the load just as for the centre position, see Fig. 9. This is not seen in the corner positions where the stresses are almost identical and there is just a linear increase with the applied load up to 30 N inline with the restricted mobility of the corners. Thus the results are in agreement with the displacement analysis and could be used for measuring stresses in load bearing glass components in buildings.