Строительство уникальных зданий и сооружений. ISSN 2304-6295. 4 (19). 2014. 11-20

Construction of Unique Buildings and Structures

journal homepage: www.unistroy.spb.ru

Experimental analysis of load-bearing timber-glass I-beam

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ARTICLE INFO

Type: original research article

Article history

Received 2 March 2014
Received in revised form 20 April 2014
Accepted 29 April 2014

Keywords

timber;
glass;
I-beam;
adhesive;
bending test;

ABSTRACT

Nowadays modern architecture demands more transparent building elements. The composite elements allow the best of the characteristics of two different materials to be brought together for a common purpose. This was one of the major reasons for carrying out the presented experimental research. This paper focuses on the analysis of experimental test of timber-glass I-beam on four–point bending tests.

The work is being carried out as part of the EU Wood Wisdom-Net research project, with participants from Austria, Brazil, Chile, Germany, Turkey, Sweden and Slovenia.

Contents

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1 Introduction

In the last few decades several projects focused on combining glass with other material have been started. The basic problem of glass as a structural material is its unpredictable and brittle failure behavior. Glass composite I-beam have been studied in previous work because it is believed that this structural bonding system could be the best way of enhancing the performance of the two very different elements in a unitary set. There are many ways of improving the strength of glass. Research at the Faculty of Civil Engineering, University of Maribor, focuses on the development of composite I-beam structures, with glass web and with flanges made of timber. We can found several projects of combining glass with other materials. At Graz University of Technology [1] are researched glass-concrete composite beam, with a fully tempered glass web with reinforced concrete flanges. Palumbo [2] has research the behavior of annealed float glass beams reinforced with carbon fibre, in the tensile zone of the glass beam. We can also found studies of hybrid steel-glass beams where steel flanges are bolted to steel L-sections which are adhesively bonded to a laminated glass beam web [3-5], [6], [7]. Timber-glass composite I-beams are researched first Hamm [8], Kreher [9,] and Natterer [10], where was wooden flanges adhesively bonded to a single layer glass web. This concept have been applied in a roof structure in hotel Palafitte in Switzerland, where the upper flanges of the beams were designed for fire-resistance, with dimensions sufficient to carry the load in case of glass failure. Also Cruz and Pequeno [11] studied this I-beams with flanges of two separate wooden parts. Blayberg and Serrano [12] tested timber-glass I-beams with diferent type of flanges, which were made from laminated veneer lumber (LVL). They use diferent type of flanges with groove inside. The similar study is from Hulimka, Kozlowski [13] and also from Linnaeus University and Glafo Institute in Sweden [14]. The paper present results of the first stage of ongoing research project including experimental test on timber-glass composite beam. We use the same principal as in [11], but we have different cross-section. At the beginning is described the main characteristics of used materials, furthermore it includes the presentation of the manufacturing of beams and test set-up. At the end of this article are presented results of four points bending test.

2. Glass in timber buildings

Natural lighting is one of the most important factors in our lives [15, 16]. This was the main reason for the increased use of glass as a structural material in timber buildings [17, 18]. The basic problem of glass is its unpredictable and brittle failure behavior. It is strong in compression, but week in tension. Ordinary annealed float glass has the highest remaining load-carrying capacity after failure. This type of glass fails at relatively low stresses and in large shards. Large shards offer the highest remaining load carrying potential since these shards can still transfer compression force due to interlocking effect. The post-cracked load capacity is largely dependent on the quality of the used glass. This statement is supported by the experimental research of K. Kreher [9]. Glass has no built-in warning mechanism; it can only deform elastically or fracture. Upon overloading, the glass will crack, but proliferation will be limited due to dissipation of fracture energy by deformation of the timber flanges. Glass failure should never lead to complete collapse of the structure.

Timber is natural material, which structure, characteristics and properties are more complex as concrete or steel, because the properties vary in different directions. The main idea was to connect these two materials together to provide the best properties of the composite. [21 - 24] Cruz and Pequeno [11] say that the main characteristic of this composite system is that timber provides ductility and glass offers resistance and stiffness. This statement is also confirmed by other researchers [8-10, 12-14, 25 - 27]. The bonding system is also very important, because the adhesive brings together strength and flexibility. When the glass cracks, the adhesive bond transfers the tensile force. The adhesive has to service under all conditions and for a significant period of time.

3. Experimental study

3.1. Test configuration

Dimension of the specimen

The beams were designed with a cross section according to the drawing shown in Figure 1. All composite beams are 4800 mm long and 240 mm high. The thickness of the glass web was 8 mm and the height was 190 mm. The timber webs have a cross section 30/45 mm.

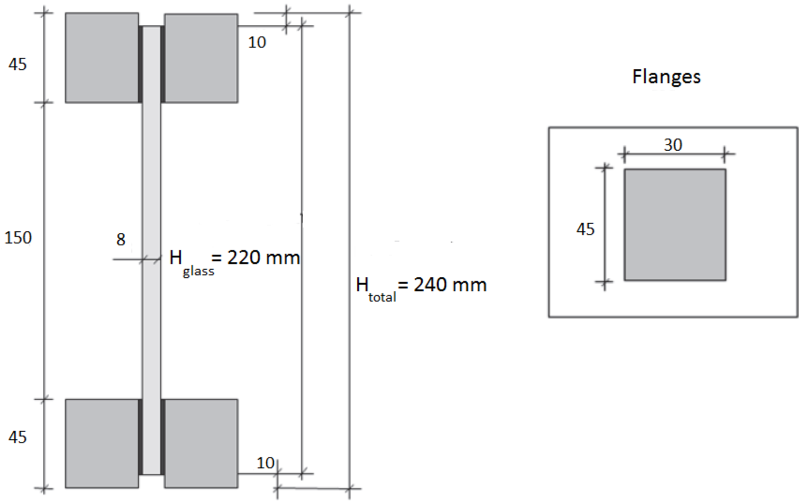

Figure 1. Cross section of beam and flanges types

Timber

We use for timber webs spruce C24– finger joint, because for this type of composit we must use quality wood, without any defects – especially knots. In table 1 are given the main characteristics of C24. [20]

Table 1. Material properties of timber

	E_0,mean N/mm^2	G_m N/mm^2	$f_{m,k}$ N/mm^2	$f_{t,0,k}$ N/mm^2	$f_{c,0,k}$ N/mm^2	ρ_k N/mm^2	ρ_m N/mm^2
C 24	11 000	690	24	14	21	350	420

Glass

The glass of the I-beams webs of specimen was float glass, according to the European standard EN-572 [19], with a thickness of 8 mm. The most important physical properties of this type of glass are in Table 2.

Table 2. Material properties of annealed float glass

ρ kN/m^3	E MPa	G MPa	μ	Tensile strength MPa	Compressive strength MPa	α K^{-1}
25	70 000	28 000	0,23	45	800	$9\cdot10^{-6}$

Adhesive

We use silicone SikaSil SG-500 [21]. This is a two-component silicone sealant. One of the main applications of this adhesive is structural glazing. The thickness of the adhesive was 2-3 mm.

Table 3. Material properties of adhesive

Adhesive type	E MPa	G MPa	Tensile strength MPa	UV-resistance
2-C Silicone A - soft	1 MPa at 100%	0,8	2,2	Excellent

Manufacturing of beam

In this set 12 beams were produced, but for now we have tested only one. The adhesive was applied manually. The glass must be clean, dry, and free from all traces of dust. Contaminated areas must be thoroughly cleaned before proceeding – Sika recommends the use of Sika ADPrep-5901. To ensure that the adhesive does not pass outside of the intended area, was used double-sided tape. To guarantee the right thickness of the adhesive was used skewers.

Figures 2, 3 and 4. Preparation of specimen

Testing procedure

Bending tests was performed in an electro-mechanical machine as four-point bending tests with lateral supports along the beam, with a symmetric setup [28-31]. Loads and global deformation were monitored.

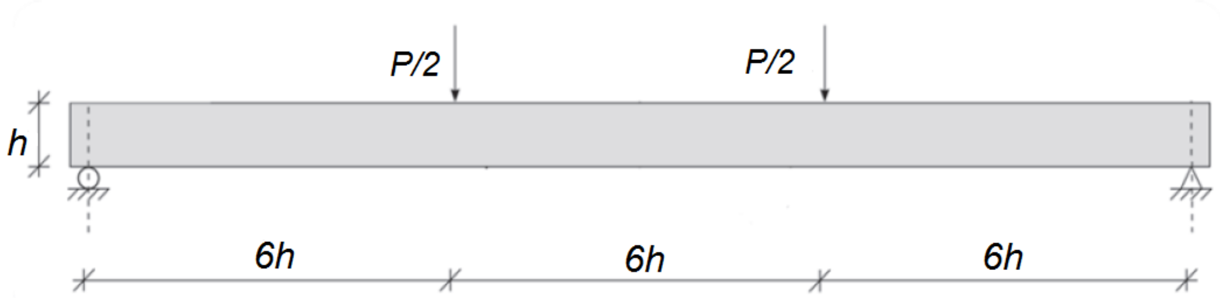

Figure 5. Setup for 4-point bending

We used in total 18 measuring device, 10 strain gages (6 on wood and 4 on glass) and 8 inductive displacement sensors (2 sensors at the end of the beam and 6 in the middle). Also a set of strain gages was attached to the piston.

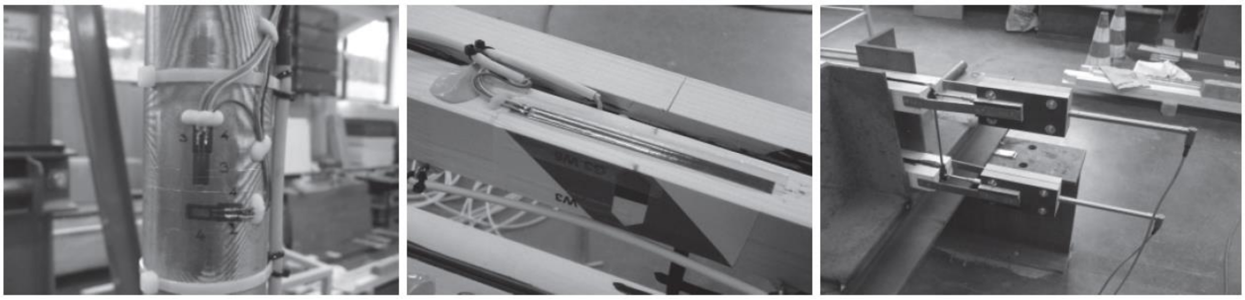

Figure 6. a), b) strain gages on piston and on wood and glass c) inductive displacement sensors at the end of the beam

The specimen has been tested within three weeks after production. It was loaded at constant rate of 1kN per 100s. Loading was continued until total destruction. The bending stiffnes, EI, can be calculated from the test.

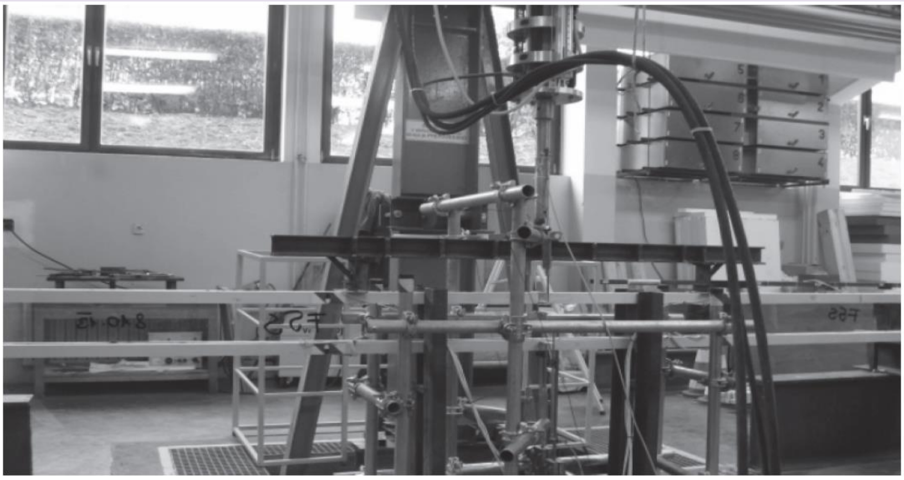

Figure 7. Test set up

3.2. Results

Table 4. Results

crack	first	second	third	Total collapse of the beam
force	3,2 kN	3,8 kN	8,9 kN	10,45 kN

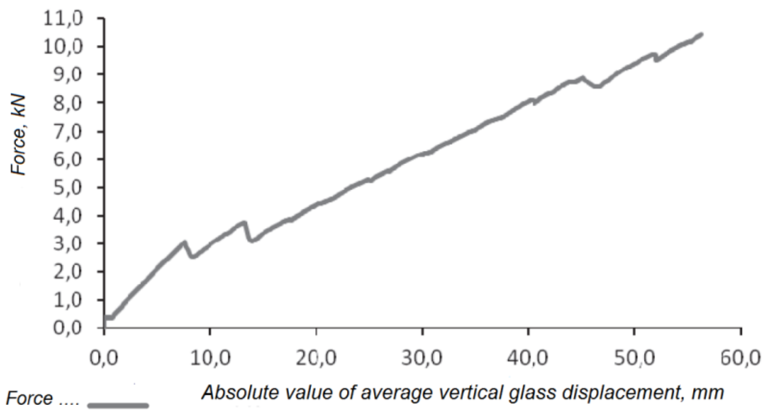

Figure 8. Force versus absolute value of average vertical glass displacement

3.3. Analysis of the test results

On figure 8 we can see the relationship between the load and vertical displacement was liner until the first crack started forming at 3,2 kN. This was followed by a sudden change of bending stiffness and increase of vertical displacement. After glass faliure bottom flange acted as a crack bridge which together with an uncracked compression zone of the web and top flange allowed the beam to still carry load. As loading is continued, bending stiffness is slightly decreased. In the next stage the existing crack grew and new crack formed in another part of the web at 3.8 kN. The existing cracks start to propagate horizontally and start to grow towards each other. At the force 8.9 kN third large crack appears. Bending stiffness slightly decreases gradually until final failure at 10.45 kN occurs.

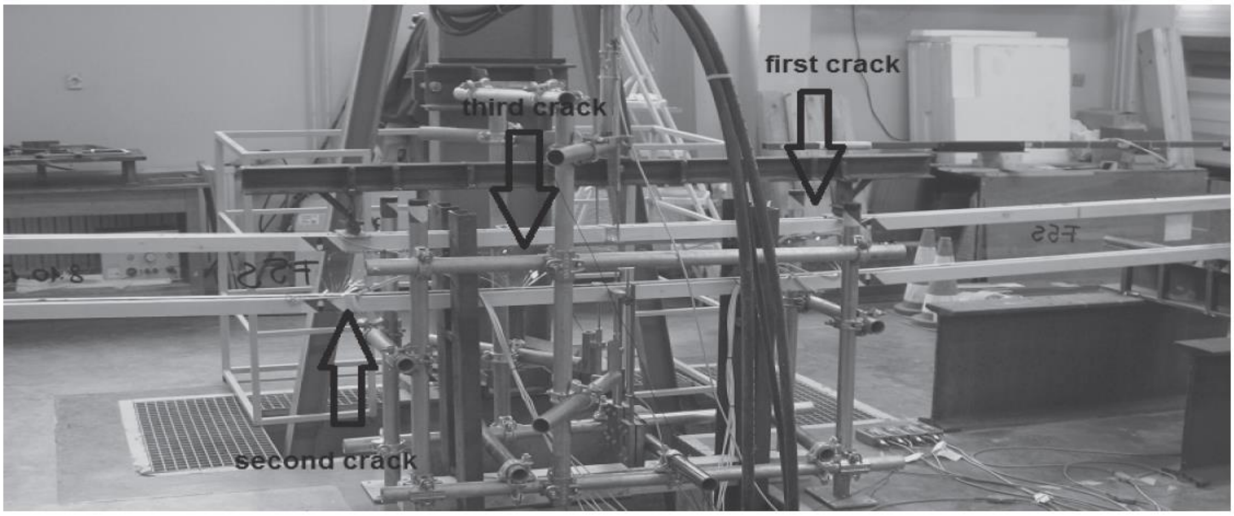

Figure 9. Force versus absolute value of average vertical glass displacement

4. Conclusions

Glass in this composite behaves as a structural reinforcement. Timber provides ductility and glass offers resistance and stiffness. We can see that this timber-glass beam with only 240 mm height carries a lot of load. The next stage of ongoing research project will be tested 17 specimens, 5 with silicone, 6 with acrylate and 6 with epoxy adhesives. The behavior of these beams is going to be studied also by developing analytical models and numerical models.

5. Acknowledgments

The support of the companies Kager hiša, Reflex and Sika Slovenia who donated the materials needed for the experiments is gratefully acknowledged. The research work is part of the project LBTGC selected on the international Wood Wisdom-Net and funded by the MIZŠ.

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Экспериментальный анализ несущей деревянно-стеклянной двутавровой балки

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Информация о статье

Научная статья

УДК: 69.04

История

Подана в редакцию 2 марта 2014
Оформлена 20 апреля 2014
Согласована 29 апреля 2014

Ключевые слова

стекло;
дерево;
двутавровая балка;
клей;
испытания на изгиб.

АННОТАЦИЯ

В настоящее время современная архитектура все более ориентируется на использование прозрачных строительных элементов. Объединение двух различных материалов для достижения общей цели позволяет использовать лучшее из характеристик этих материалов. Такой подход стал одной из главных причин проведения данного экспериментального исследования.

Данная статья сосредоточена на анализе свойств деревянно-стеклянной двутавровой балки, выполненного на основании проводимого экспериментального исследования. Работа ведется в рамках «WoodWisdom-Net», исследовательского проекта ЕС, с участием представителей Австрии, Бразилии, Чили, Германии, Турции, Швеции Словении.

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