EXPERIMENTAL ANALYSIS OF LOAD BEARING TIMBER-GLASS I-BEAMS WITH SILICONE ADHESIVE

[1]**Mateja Zlatinek**
[1]**Miroslav Premrov**
[1]**Andrej Štrukelj**
[1]University of Maribor, Faculty of Civil Engineering, Transportation Engineering and Architecture; Department of Building Structures

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 experiment. This paper focuses on the analysis of experimental tests of timber glass I-beams with silicone adhesive on four-point bending tests. The main goal of the research is using glass as loadï bearing element and research for industry to produce these composites for the market.
This work is being carried out as a part of EU WoodWisdom-Net research program with participants from Austria, Brazil, Chile, Germany, Sweden, Turkey and Slovenia.

Key words : timber-glass composites, I-beams, silicone adhesive, bending test

EKSPERIMENTALNA ANALIZA GREDA I-PROFILA OD NOSIVOG DRVETA-STAKLA SA SILIKONSKIM LJEPILOM

Sažetak: Suvremena arhitektura danas zahtijeva transparentnije graĽevinske elemente. Kompozitni elementi omoguĺuju da se najbolje od karakteristika dvaju razliļitih materijala spoje za zajedniļku svrhu. Ovo je bio jedan od glavnih razloga za izvoĽenje predstavljenog pokusa. Ovaj rad je usmjeren na analizu pokusnih ispitivanja greda I-profila od drveta-stakla sa silikonskim ljepilom na ispitivanjima savijanjem u ļetiri toļke. Glavni cilj istraģivanja je koriģtenje stakla kao nosivog elementa i istraģivanja za industriju kako bi se ovi kompoziti proizveli za trģiģte. Ovaj rad se provodi kao dio istraģivaļkog programa EU WoodWisdom-Net sa sudionicima iz Austrije, Brazila, Ļilea, Njemaļke, Ģvedske, Turske i Slovenije.

Ključne riječi : kompoziti drvo-staklo, grede I-profila, silikonsko ljepilo, ispitivanje savijanjem

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 present 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. There can be found several projects of combining glass with other materials. At Graz University of Technology (Freytag [1]) are researched glass-concrete composite beam, with a fully tempered glass web with reinforced concrete flanges. The length of such beams was 7.8 m. Palumbo [2] investigated the behavior of annealed float glass beams reinforced with carbon fibre, in the tensile zone of the glass beam. Studies of hybrid steel-glass beams (Ungermann [6], Weller [7]) where steel flanges are bolted to steel L-sections which are adhesively bonded to a laminated glass beam web (Wellershoff [3], Finterhoff [4], Grotepass [5]) were also carried out.

Timber-glass composite I-beams were first investigated by Hamm [8], Kreher [9, 10] and Natterer [10], where wooden flanges were 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 these I-beams with flanges of two separated wooden parts. All composite beams were 550 mm high with 3200 mm of span. Blayberg and Serrano [12] also tested timber-glass I-beams with different type of flanges, which were made from laminated veneer lumber (LVL). They use different type of flanges with groove inside. The similar study was carried out by Hulimka, Kozlowski [13] and also by 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. At the beginning the main characteristics of used materials is described. The presentation of the manufacturing of beams and test set-up is also presented. At the end of this paper results of four-point bending test are presented.

2 GLASS IN TIMBER BUILDINGS

Natural lighting is one of the most important factors in our lives. This was the main reason for the increased use of glass as a structural material in timber buildings. 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 its properties vary in different directions. The main idea was to connect these two materials together to provide the best properties of the composite. The main characteristic of this composite system is that timber provides ductility and glass offers resistance and stiffness (Cruz and Pequeno [11]). The bonding system is also very important, because the adhesive brings together strength and flexibility. When glass cracks, the adhesive bonding transfers the tensile force. The adhesive has to service under all conditions and for a significant period of time.

3 EXPERIMENTAL STUDIES

3.1 Test configuration

Beams were designed with a cross section according to the drawing shown in Figure 1. All composite beams were 4800 mm long and 240 mm high. The glass web were 220 mm high, the edges were polished to avoid influence of edge quality. Two types of glass were used: annealed float glass and fully tempered glass, according to the European standard EN-572, with a thickness of 8 mm. The most important physical properties of glass are shown in Table 1.
For timber flanges a spruce C24ï finger joint was applied, because for this type of composite it is obvious to use the wood of good quality, without any defects ï especially knots. The timber flanges have a cross section 30/45 mm. The material properties of timber are shown in Table 2.

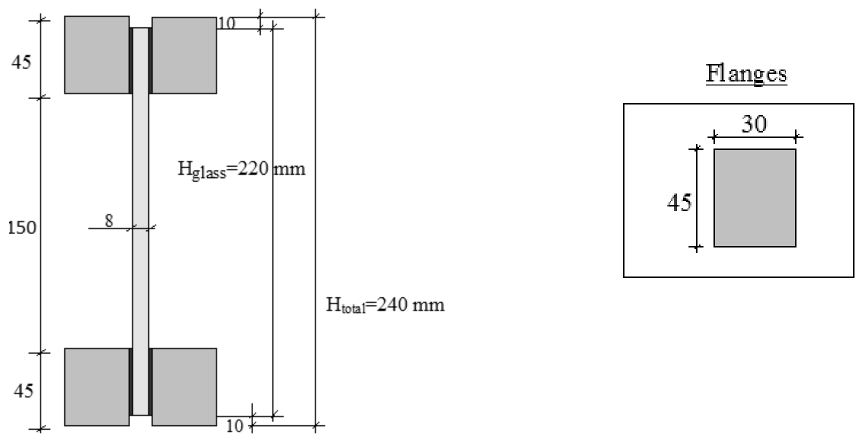

Figure 1. Cross section of beam and flanges types

Table 1. Material properties of glass (EN-572)

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	$9{\cdot}10^{-6}$

Table 2. 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	11000	690	24	14	21	350	420

For the conection we use silicone SikaSil SG-500 [19]. This is a two-component silicone sealant. One of the main applications of this adhesive is structural glazing. Material properties of adhesive are shown in Table 3.

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% elongation	0,8	2,2	Excellent

In this set 6 beams were produced. The adhesive was applied manually. The glass must be clean, dry, free from all traces of dust. Contaminated areas must be thoroughly cleaned before proceeding ï 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.

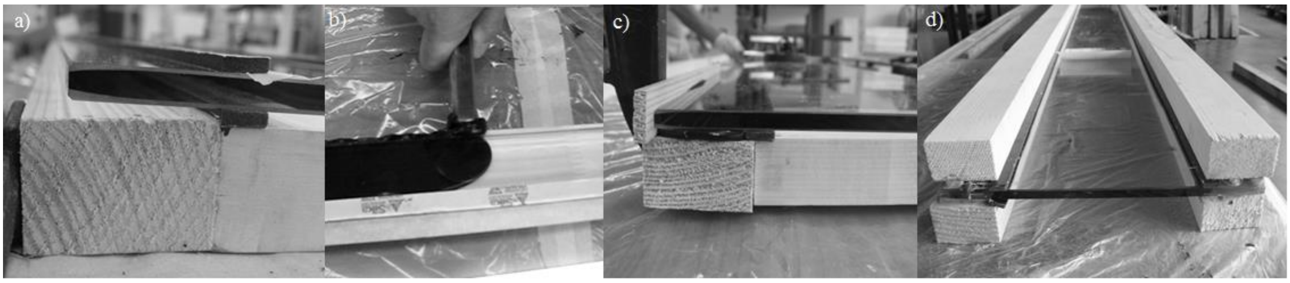

Figure 2. a), b) and c) Preparation of specimen; d) Final look of the beam

3.2 Testing procedure

Bending test were performed as four-point tests, with symmetric set-up. According to EN 408 the distance between the supports should be 18 h (4320 mm) and the loading points should be positioned at one third of the span (Figure 3).

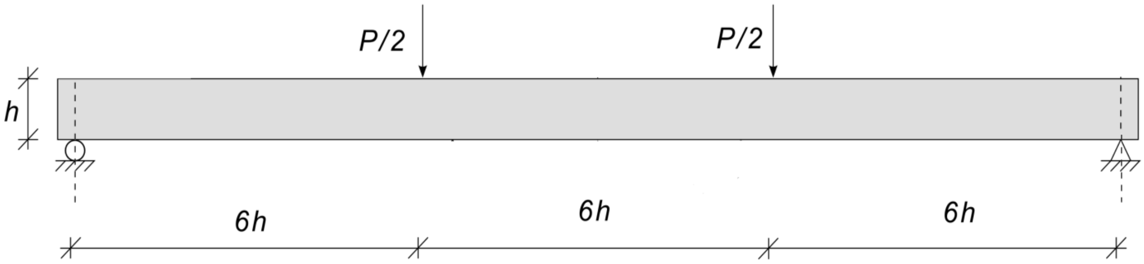

Figure 3. Setup for 4-point bending

On the first of 6 samples strains on glass web and wooden flanges as well as vertical and relative displacements between glass and wood were simultaneously measured. On the glass web the strain measuring points were positioned on its upper and lower edge, where the highest values of strains were expected (Figure 4a). The strain measuring points on timber were distributed on lower side of upper flange and on lower and upper side of lower flange (Figure 4b). All strain measuring points have been equipped with strain gauges produced by manufacturer HBM (for measurements on glass the length of strain gages measuring grids was 6 mm and for strain measurements on wood strain gages with 100 mm long measurement grids were used). All strain gages on specimen were connected as a quarter Wheatstone bridge with four wire connection (Hoffmann [18]). All vertical displacements in the middle of the span were measured by inductive displacement transducers (Figure 4c).

They were also used to measure relative displacements between glass and timber in the horizontal direction at one end of the composite beam (Figure 4d). The measurements were made using data acquisition system HBM MGCPlus, which was controlled by a laptop computer with licensed software Catman 4.5. The intensity of the load was measured directly on the hydraulic piston (Figure 4e). with a group of four strain gages connected in full Wheatstone bridge. To obtain the intensity of the load from measured strains the analytical and experimental calibration were performed.

Figure 4. strain gages on glass a) on wood b) and piston e); inductive displacement transducers at the middle c) and at the end of the beam d)

The specimens have been tested within three weeks after production. They were loaded at constant rate of 1 kN per 100 s. Loading was continued until total destruction. The bending stiffness, EI, can be calculated on the basis of test results.

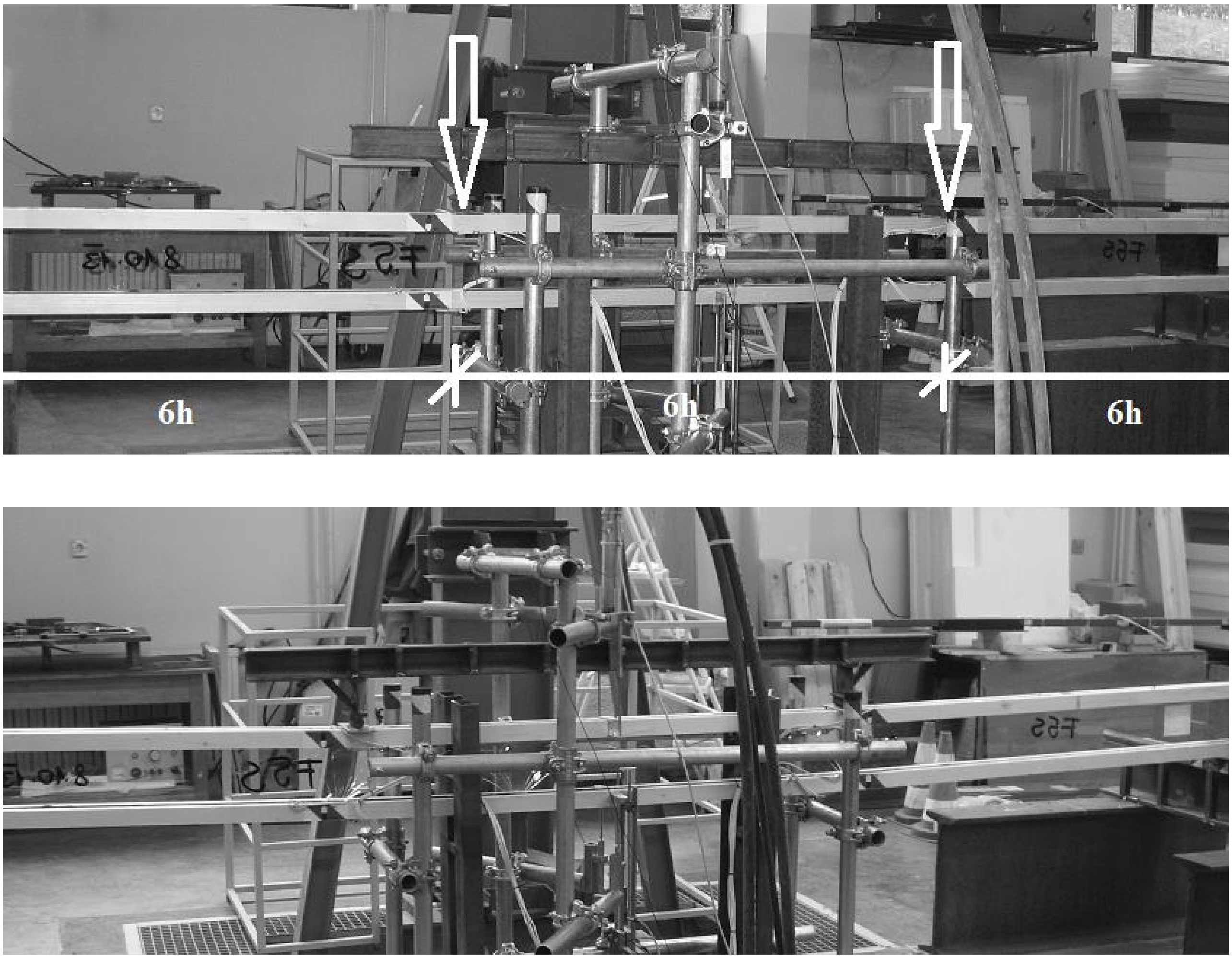

Figure 6. Test set up and testing

3.3 Results and discussion

Table 4. Results

Annealed float glass			
Specimen	**Load at first crack [kN]**	**Maximal load [kN]**	**Deflection [mm]**
S_AF_01	4,6	15,3	54,8
S_AF_02	4,1	18,2	69,11
S_AF_03	5,3	15,6	59,5
Mean values	**4,7**	**16,4**	**61,1**
Fully tempered glass			
Specimen		**Maximal load [kN]**	**Deflection [mm]**
S_FT_01	/	20,01	47,4
S_FT_02	/	18,5	43,9
S_FT_03	/	19,8	52,8
Mean values	**/**	**12,2**	**185**

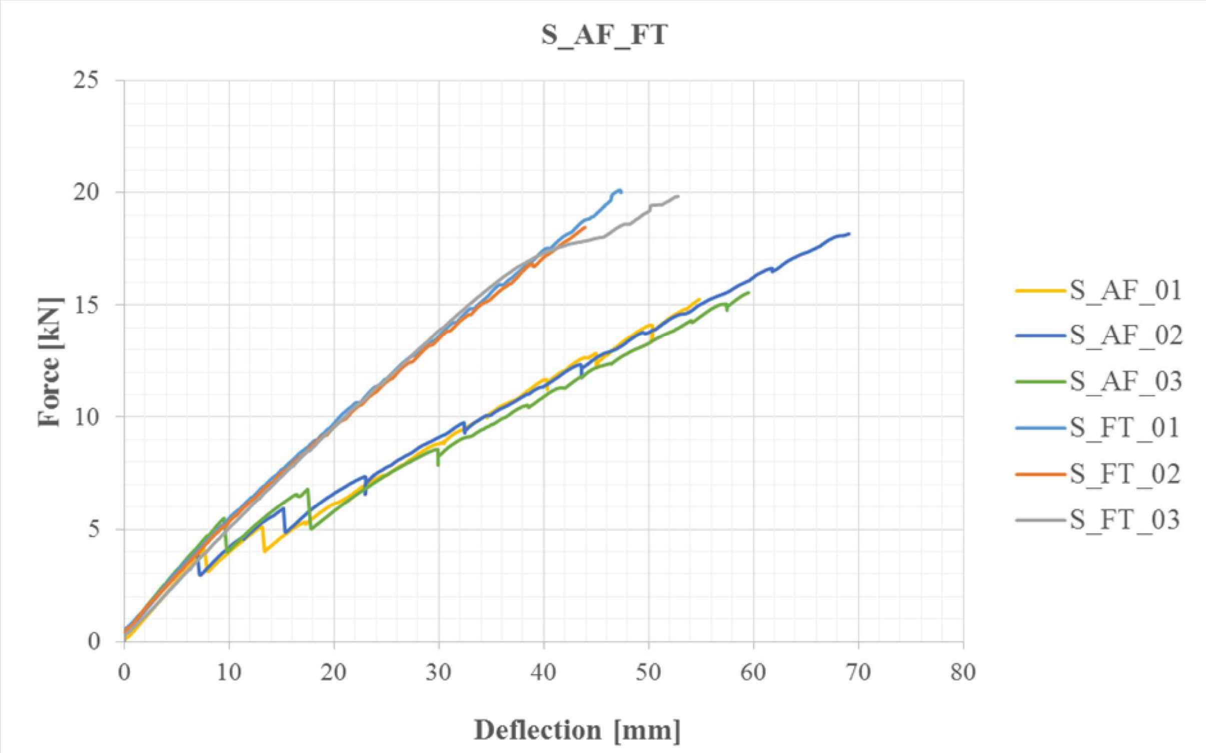

Figure 7. Force versus absolute value of average vertical glass displacement

In Fig. 7 the relationship between the load and vertical displacement for annealed float glass and fuly tempered glass are presented. For all specimens of AF glass the stiffness was liner until the first crack occurred. This was followed by a sudden change of bending stiffness and increase of vertical displacement. This is most evident on silicone specimens. After glass failure bottom flange acted as a crack bridge which together with an uncracked compression zone of the web and top flange allowed the beam to continue of carrying the load. In the next stage the existing crack grew and new crack formed in another part of the web. The existing cracks start to propagate horizontally and start to grow towards each other. Bending stiffness slightly decreases gradually until final failure occurred. This is a typical pattern for the annealed float glass. Very surprising are the results of the increasing of ultimate loads than the loads at first cracking.
Beam with FT glass fail immediately, but with higher total load in comparison to beams with annealed float glass

4 CONCLUSIONS AND FUTURE WORK

Glass in such composites behaves as a structural reinforcement. Timber provides ductility and glass offers resistance and stiffness. It can be seen that this timber-glass beam with only 240 mm height could carry quite high loading. The next stage of ongoing research project will be developing analytical as well as numerical models for this type of beams.

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