Structural Timber-Glass Adhesive Bonding

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In order to fully benefit from composite timber-glass structural solutions, an adequate bonding between these two elements is essential. Uniform distribution of forces, reduction of materials fragilization by avoiding drilling, averting of high peak stresses and aim at the ductility in the unity of the set were the criteria behind the decision of using adhesive as structural bonding system. With the purpose of achieving the ideal balance between strength and stiffness for each specific situation, an extensive set of experimental tests is being carried out at the University of Minho.

Keywords: Glass, Timber, Adhesives, Joints, Structural bonding.

1. Introduction

The structural utilization of glass is always a challenge [1] [2] – either alone or combined with other materials. In the case of timber, its utilization in building structures has been increasing in the last years, partly due to technological developments in this field. New tectonic concepts such as prefabricated and industrialised systems arose [3] [4], though very different from the ones presented by traditional solutions. The structural combination of different constructive materials is emerging. Glass, composite materials or steel can be combined with timber [5] [6] [7], in order to obtain resistant products, highly typified, standardised and with low behavioural variation.
At a structural level, glass compression capacity and timber tension resistance must be enhanced [8], the same way that accumulated and tensile stresses must be avoided on glass surfaces [9]. Simultaneously, the specificities of natural behaviour of timber have to be assumed, understood and contextualised [10].
It is crucial that the adhesive brings together strength and flexibility. That is the path to its structural employment, necessarily subject to transmission of heavy loading. However, it must also allow bending, expansion and timber free movements, according to loading and humidity variations. Given the basic difference of characteristics between glass (brittle) and timber (ductile, in compression), it is believed that this structural bonding system [11] [12] [13] could be the best way of enhancing the performance of the different composite elements in a unitary set.
This paper focus on the analysis of results regarding shear stress, temperature and water saturation tests with timber-glass bonding, using adhesive as structural bonding system. In these tests, twenty different adhesives were applied, including several trades and adhesive types such as silicones, methacrylates, polyurethane, epoxy, acrylic, superflex polymers and MS polymers.

2. Experimental Studies

2.1. Laboratorial tests

This paper is based on the results of 248 experimental tests on shear stress compression, involving different types of adhesives and several variables such as presented in Table1, and exemplified in Figures 1 and 2.

Each specimen is made up of a glass plate fixed between two timber boards of *Pseudotsuga Menziessi*.

Table 1: Shear stress tests carried out – 248 specimens

Lab. Test Type	Shear Stress Compression Test													
Test Specification	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Adhesive	Laboratory Tests [•]													
A Sika® polyurethan	•••	•••	•••	•••	•••	•••	•••	•••	•••					
B Sika® silicone		•••	•••	•••										
C Sista® polymer		•••	•••	•••	•••	•••	•••	•••	•••	•••	•••	•••		
D Sika® methacrylat.		•••	•••	•••	•••	•••	•••	•••						
E 3M® acrylic 2c		•••	•••	•••										
F 3M® acrylic tape		•••	•••	•••										
G DLChemicls® MS		•••							•••					
H Teroson® MSilane		•••			•••	•••	•••	•••	•••	•	•			
I Teroson® polyurt1c		•••												
J Teroson® polyurt2c		•••												
K Loctite® silicone		•••												
L Loctite® silicone		•••												
M DLChemical® MS		•••												
N Butiral	•													
O DLChem® polyurt		•••												
P 3M® epoxy		•••												
Q 3M® polyrtreactiv		•••			•••	•••	•••	•••	•••					
R 3M® epoxy		•••			•••	•••	•••	•••	•••		•••	•••		
S DC® slicone		•••			•••	•••	•••	•••		•••		•••	••	••
T 3M® epoxy		•••				•••								
U Pattex®					•	•••								
V Sista® polymer						•••						•••		
Timber											•••			
Lam.Glass											•••			
Temp.Glass											•••			

01 – Specimen dim. 400x100 mm; without primers; temp. glass 5 mm; contact surf. area (c.f.a.): 40000 mm^2.
02 – Specimen dim. 400x100 mm; without primers; laminated glass 5+5 mm; contact surf. area: 40000 mm^2.
03 – Specimen dim. 400x100 mm; within primers; tempered glass 5 mm; contact surface area: 40000 mm^2.
04 – Specimen dim. 400x100 mm; within primers; laminated glass 5+5 mm; contact surf. area: 40000 mm^2.
05 – Temperature: - 10ºC; specimen dim.100x100 mm; without primers; lam.glass 5+5 mm; cfa: 10000 mm^2.
06 – Temperature: + 20ºC; specimen dim.100x100 mm; without primers; lam.glass 5+5 mm; cfa:10000mm^2.
07 – Temperature: + 40ºC; specimen dim.100x100 mm; without primers; lam.glass 5+5 mm; cfa:10000 mm^2.
08 – Water Saturation (1 month); spec. dim. 100x100 mm; without prim.; lam.glass 5+5 mm; cfa:10000 mm^2.
09 – Shear stress bending test; spec. dim. 300x300 mm; without prim.; lam. glass 5+5 mm; cfa: 20000 mm^2.
10 – Load/Unload cyclic test; spec. dim. 400x100 mm; without prim.; lam. glass 5+5 mm; cfa: 40000 mm^2.
11 – Reinforced with parallel glass plates; dim.300x100mm; without prim; lam.glass5+5 mm; cfa:30000mm^2
12 – Reinforced with transv. glass plates; spec.dim 300x100 mm; without prim.; lam glass 5+5; cfa:6000 mm^2.
13 – Timber/timber adhesive bonding test; Specimen dimensions 400x100 mm; without primers utilization.
14 – Glass/glass adhesive bonding test; Specimen dim. 400x100 mm; without prim.; laminated glass 5+5 mm.

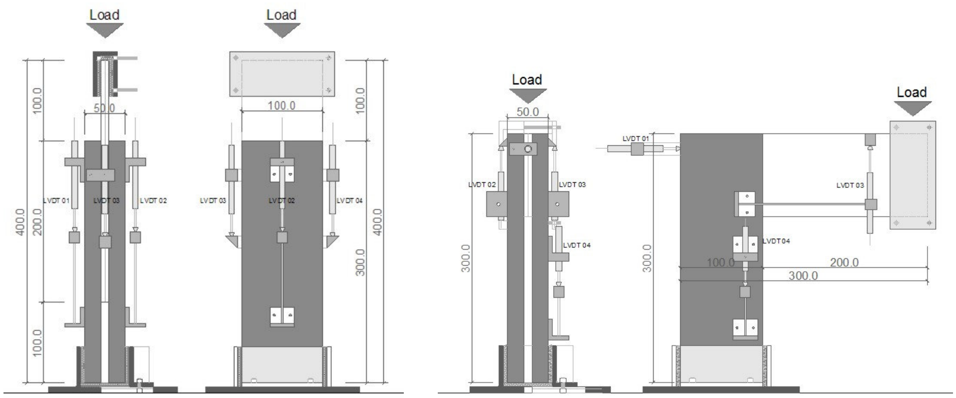

Figure 1a and b: Set-up of tests 01, 02, 03, 04 (a) and 09 (b) – instrumentation and load application.

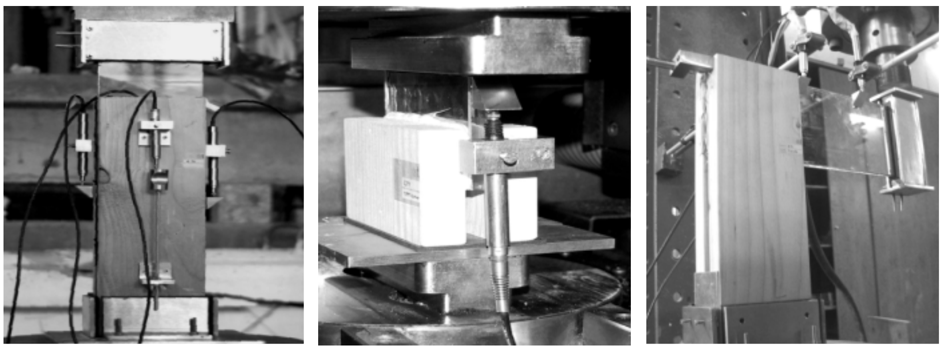

Figure 2a, b and c: Pictures of three types of tests carried out - 02 (a), 05 (b) and 09 (c).

3. Results

3.1. Reference data

The results obtained in these tests gave way to conclusions on various important aspects, such as strength and relative timber-glass displacement; timber deformation and its consequences; failure modes; variations due to surface treatments and primers utilization; glass type influence and also safety precautions that must be assured.
Table 2 summarizes shear stress tests results.

Table 2: Summary of the shear stress tests results

Lab. Test Type	Shear Stress Compression Test							
Test Specification	01	02	03	04	05	06	07	08
	Maximum Load – Average [kN]							
A Sika® polyurethan.	38	68	39	15	15	11	11	1.9
B Sika® silicone		16	20	20				
C Sista® polymer		60	45	55	14	11	10	2.4
D Sika® methacrylat.		72	50	62	19*	15	11	4.5
E 3M® acrylic 2c		88	57	73				
F 3M® acrylic tape		02	01	03				
	Relative Displacement Timber-Glass – Average [mm]							
A Sika® polyurethan.	4.7	5.1	5.8	4.3	1.9	1.5	1.6	1.1
B Sika® silicone		3.9	4.8	4.9				
C Sista® polymer		5.0	3.8	5.2	2.5	2.6	1.8	0.6
D Sika® methacrylat.		0.1	0.1	0.2	0.1	0.4	0.7	0.5
E 3M® acrylic 2c		0.1	0.0	0.1				
F 3M® acrylic tape		9.6	10.	10.				
	Failure Mode*[1]							
A Sika® polyurethan.	○●	○	○	♦●	■	■●	♦■●	●
B Sika® silicone		♦■●	♦■●	♦■●				
C Sista® polymer		○	○	♦○■	■	♦■	♦■	■
D Sika® methacrylat.		○	○	○	○	○■□	♦○■	■
E 3M® acrylic 2c		♦○●	○	♦○■				
F 3M® acrylic tape		♦■	♦■	♦■				

* Maximum Load Capacity of Equipment achieved. Specimen kept on resisting.

*[1] Failure Mode:

○-Glass failure; □-Wood failure; ● -Glass adhesion interface; ■-Wood adhesion interf.; ♦-Adhesive cohesion.

3.2. Strength and relative timber-glass displacement

Based the analysis of Figure 3a, it is possible to identify three distinct groups in this context:

- Adhesives highly resistant and insufficiently flexible;
- Highly flexible adhesives, yet insufficiently resistant;
- Adhesives that balance both key factors in this research: strength and ductility.

In this third group, and regarding behavioural variability, it is possible to observe in Figure 3b that superflex polymers – adhesive C –, contrary to polyurethane – adhesive A –, present, in all circumstances, uniformity convergent with safety criteria. Variation in polyurethane fundamentally results from already mentioned variables applied to the tests.

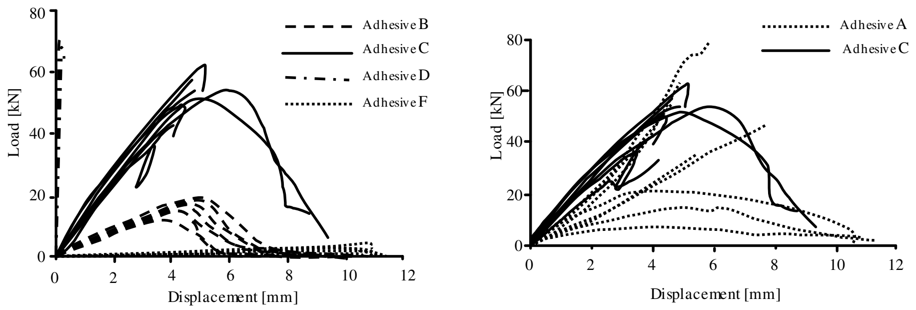

Figure 3a and b: Curves load vs timber-glass relative displacement obtained in Tests 02, 03 and 04.

3.3. Deformation of timber: consequences

The greater the loading endured by the adhesive, the greater the strength to which both timber and glass will be submitted. A comparison between Figures 4a and 4b, both regarding a rigid adhesive – two-component acrylic –, shows that longitudinal deformation of timber is higher than timber-glass relative displacement. This fact brings consequences to the specimen behaviour. Longitudinal deformation of timber has repercussions in its tangential expansion. This represents precisely the occurrence that must be minimised, as it is responsible for the application of tensile stress on the glass surface directly in contact with timber, as shown in Figure 5.

Even a highly resistant adhesive – tolerating stresses up to 15/20 MPa – under certain circumstances, easily fail due to the particular characteristics of the materials under study. Limiting the tangential dimension of timber in contact with glass surely represents a valid solution for this situation.

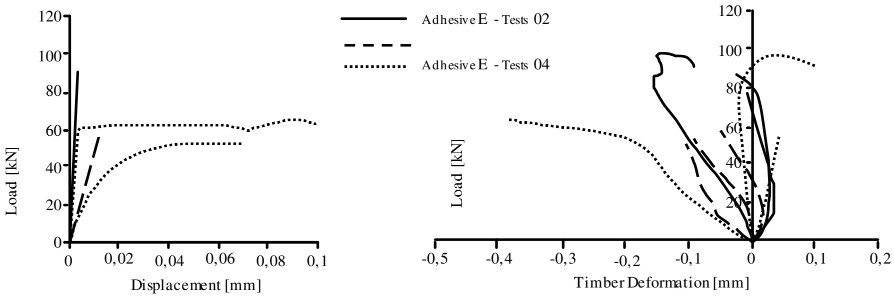

Figure 4a and b: Load/ Timber-glass displacement (a) and Load/ Timber deformation (b) – Tests 02, 03, 04.

Figure 5a and b: Consequences of timber tangential expansion on glass – Tests 02, 03, 04.

3.4. Failure modes and primers utilization

Different failure modes were observed depending on the type of adhesive and variables implemented. It was possible to conclude that surface treatment – Figure 6 – has a decisive influence in the adhesive bonding failure. In Figure 7, relating to the same product – adhesive E, two-component acrylic – it is possible to observe two different types of collapses, through timber adhesion – primers applied – and through glass adhesion – without primers –, respectively.

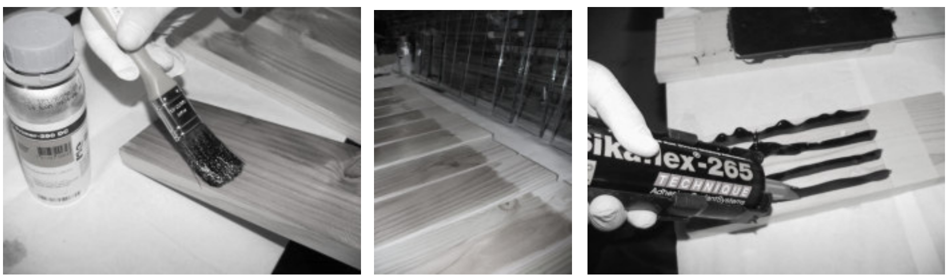

Figure 6a, b and c: Some pictures of the primers employment process.

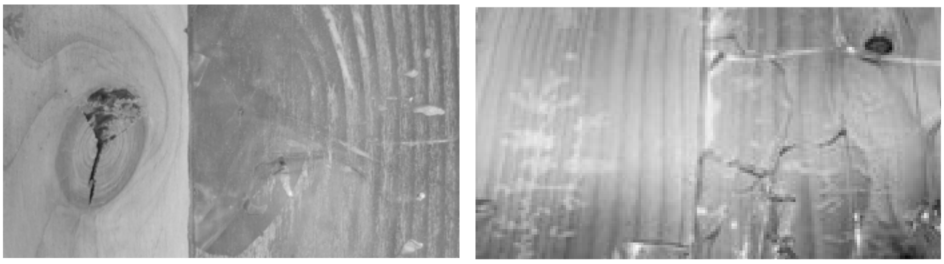

Figure 7a and b: Different failure modes of the same adhesive, depending on primers application.

3.5. Glass type influence

Tempered glass, though more resistant to superficial stresses than laminated glass, presents two considerable and decisive disadvantages, such are brittle behaviour and an irregular surface – Figure 8b. Repercussions of these characteristics are shown in Figure 8a. With some products – adhesive F, bi-component acrylic tape - , the difference is of less than half the effectiveness, due to the incapacity for compensating superficial imprecision.

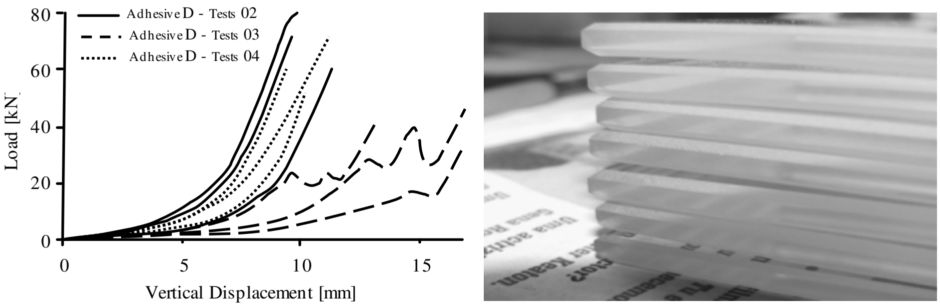

Figure 8a and b: Load-vertical displacement curves comparing laminated glass, utilized in Tests 02 and 04, with tempered glass utilized in Tests 03 (a); Tempered glass irregular surfaces (b).

3.6. Temperature and water saturation

Tests performed under the influence of temperature – Figure 9 – led to the conclusion that this factor will not hinder the accomplishment of the structural bonding system under analysis. Though there is a substantial increase of the loading capacity when temperature decreases to negative values of -10ºC, there is also the confirmation that the decrease occurring while temperature rises up to 40ºC is not worthy of note.

Regarding water saturation over long periods – Figure 10 –, there is a considerable loss of capacity at the level of the structural bonding and the elasticity of adhesives itself. This constituted an extreme test, based on circumstances that will not actually take place. However, it shows that it is important to bear in mind this question. The solution must ponder having control over the phenomenon of humidity migration on the interface with wood, with recourse to the employment of specific primers.

Figure 9a, b and c:Temperature tests –Tests 05, 06, 07(a)(b); Practical example of specimen load capacity (c).

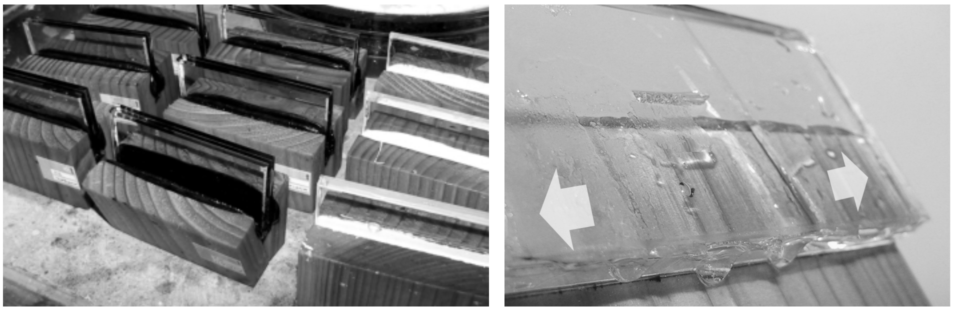

Figure 10a and b: Water saturation tests – Tests 08.

3.7. Timber reinforced with glass

In this set of tests, one of the approached questions was precisely the possibility of reinforcing timber through bonding with glass. Parallel reinforcement – Figure 11 – and transversal reinforcement – Figure 12 – were tested. Particularly in transversal reinforcement, an increase in the loading capacity of the specimens was observed, especially because collapse is geometrically displaced towards the edge of the reinforcement area, as shown in Figure 11c and 12b.

Figure 11a, b and c: Timber reinforcement with parallel glass plates – Tests 11.

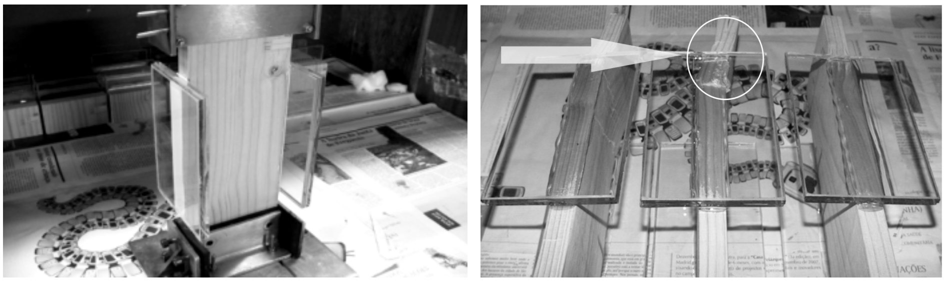

Figure 12a and b: Timber reinforcement with transversal glass plates – Tests 12.

3.8. Aesthetics and UV radiation

Especially due to the utilization of glass, solar radiation is a decisive aspect when choosing the adhesive, not only for functional and structural reasons –UV resistance –, but also for aesthetic reasons – Figure 13. Silicone is the product that best responds to this type of necessities.

Figure 13a, b and c: Effects of solar radiation on wood surface with different colours – pictures before (a) and after solar exposure (b) –; and on initially transparent adhesive (c).

3.9. Adhesive drying

It is necessary to devote special attention to the glass-glass structural bonding, due to its imperviousness to air. This aspect may hinder the process of drying of the adhesive and consequent loss of capacity of the bonding system – Figure 14. In the case of timber-glass structural bonding, this issue is minimized by the porosity of timber.

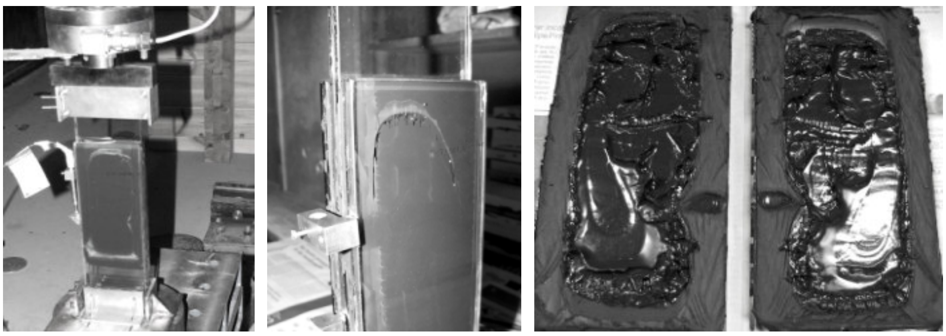

Figure 14a, b and c: Effect of adhesive drying on the outer perimeter of the structural glass-glass bonding.

3.10. Safety precautions

Safety is a crucial and indispensable aspect. It implies deformability or ductility criteria, instead of brittle characteristics, which are unable to absorb tensions, usually much resistant but easy to suddenly and unexpectedly collapse.

The behaviour of the structural elements in periods ranging from the first cracking to the maximum loading resistance, and from this to collapse, is of essential importance.

4. Conclusions

The bonding solution pointed out in the present research can be a practical system regarding the structural use of several timber-glass composite elements. Depending on the geometry of the composite cross section, the specific mechanical characteristics of its components and the loading involved, it may be necessary to apply a more rigid or ductile adhesive.

The results obtained, concerning strength and ductility, demonstrate a wide range of mechanical behaviours - from extremely rigid to significantly ductile – and support the feasibility of this solution to the applications envisaged.

This solution, however, must be subject to other tests in order to be accepted as a structural constructive solution: relative humidity variation, UV radiation, ageing and applicability are considering aspects. The work hereby presented is a stage in a long path towards the technical and scientific validation that is intended to be achieved. Its main purpose is the practical, safe and generalised implementation of an innovative, daring and promising constructive system.

5. Acknowledgements

A grateful acknowledgement is due to FCT, Fundação para a Ciência e a Tecnologia, for the PhD grant with the reference SFRH/BDE/15538/2005, conceded to José Pequeno. DST, S.A., is also gratefully acknowledged for the commitment and support.

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