ADVANCED, AESTHETIC, DURABLE, CHALLENGING AND RELIABLE NEW TIMBER STRUCTURES: THE ITALIAN TRADITION BY ARCHLEGNO

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ABSTRACT: a preliminary 40 flexure tests on Cross-laminated timber (CLT) are presented and briefly discussed in this paper. CLT is a panel-shaped engineered wood product, assembled of layers of lamellas (mostly softwood) with perpendicular orientation of the grain direction. CLT is not used as a component of structural elements, but, more frequently, as load bearing plates and shear panels. Predicting the behaviour of such panels requires accurate information about their elastic properties. With the aim of determining the global elastic properties and bearing capacity of CLT, around 120 CLT panels and beams with different dimensions, layer sizes and loading schemes will be tested under flexure and shear at the Structural Engineering Laboratory of the University of Brescia, simulating both plate and panel stress flow. The first part of the experimental results are herein reported.

KEYWORDS: Cross-laminated timber, serviceability, shear panels.

1 INTRODUCTION

The design of timber structures is often governed by serviceability criterions like maximal deflections and vibration susceptibility. Due to its micro and macro structure, timber shows a strong anisotropic elastic behaviour. Parallel to the grain, moduli of elasticity E are significantly higher than perpendicular (radial and tangential) to the grain. Therefore, timber structures are mostly assembled using beam or rod-like elements [1-2]. Furthermore, timber is a heterogeneous material with many natural defects like knots or sloped grain. Such inhomogeneities result in a high local variation of mechanical properties and stress concentrations which are taken into account in design codes by allowing only for low admissible stresses. To overcome these disadvantages, the wood industry is fabricating laminated beam and plate elements where major defects are cut off and remaining minor defects are distributed over a large volume, resulting in a homogenization of the material. With this technique, high quality structural members can be produced using normal quality timber. The crosswise perpendicular orientation of the strong fibre direction of the layers results in a composite plate element with "tuned" stiffness properties in different directions, as shown in Figure 1.

Cross-laminated timber (CLT) is becoming more and more important in timber structures. Typically, plates of 3 to 12 cm thickness are produced and are used as load carrying walls and slabs in houses.

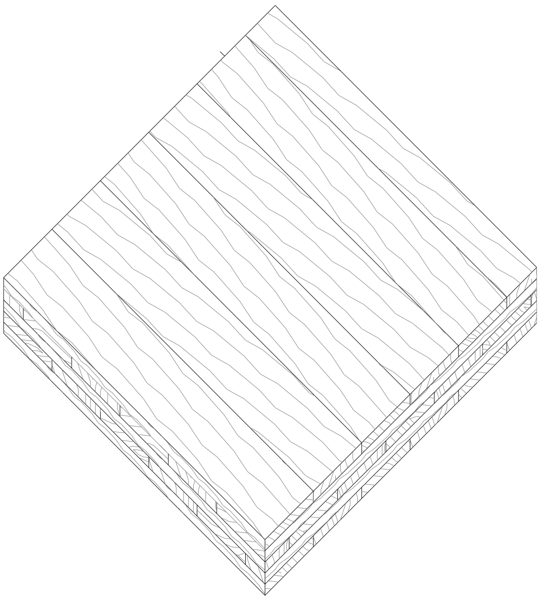

Figure 1: *A typical 5 layer CLT panel.*

Strips of lumber stacked on top of each other at a 90° angle are glued together under high pressure to become large-sized solid cross-laminated boards. In general, the board have three, five or seven layers, depending on the bearing capacity and/or deflection limit demand. The strips vary in thickness between 19 and 40 mm. As for the glue-laminated technology, cross-laminated boards

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can be fabricated using low-grade lumber within the core of the boards and with higher grade pieces on the outside. This has the advantage that a wider range of board densities can be used for this engineered wood product [3].
Cross-lamination of the strips minimises shrinkage and swelling while increasing static strength and shape retention properties. The loads can be transferred on all sides, as a true plate and sheet action. Some forms of cross-laminated boards are fabricated using aluminium nails to permit machining without damaging the cutting tools. The separate layers of lumber are glued using interior/exterior polyurethane adhesives. The glues are formaldehyde and solvent free adhesives.
The fabrication of large elements and the prefabrication of wall segments in factories protected from the weather are requirements that can also apply to timber construction. These boards have the advantage that they can be delivered to the construction site easily and quickly and ready for finishing.
The mechanics behind the cross-laminated technology are not different from beam and plate theories. However, one has to take into account the reduced stiffness of the laminations that are laid at 90°. The cross layers result in increased deflections for a given element depth. As well, rolling shear, as for plywood, becomes important and must be verified.
Most of the research has been done in Germany and Austria. It is already accepted within the German design code. Research has shown that the cross-laminated board elements includes the laminating effect of the glue-laminated beams and the system effect observed for equally spaced similar members [4-5]. More research on various connections techniques is being undertaken presently.
Among the principal Italian investigation, it is worth mentioning a seven storey building using cross-laminated components, fabricated and shipped from Italy to Japan for a shaking table test [6]. In this test, the cross-laminated technology proved to be adequate in resisting the seismic actions imposed. The fact that none of the cross-laminated boards were damaged significantly in a 100% Kobe earthquake test, and that the whole structure was dismantled, shipped back and re-used in Italy is a proof that wood structures can be used efficiently in structures and that they can be recycled.
In this paper, following the extensive application of the CLT technology after the L'Aquila's strong earthquake in April 2009, a preliminary 40 flexure tests on Cross-laminated timber panels are presented and briefly discussed. Aim of this ongoing research is to develop a consistent and reliable technology toward an intensive utilization of the product in the field.

2 EXPERIMENTAL PROGRAMME

At the laboratory of Structural Engineering of the University of Brescia, under the supervision of Prof. Ezio Giuriani and Prof. Fausto Minelli, 40 CLT samples were tested toward a characterization of the flexure behaviour, both at service and ultimate limits states (SLS and ULS) of this quite new technology, especially as far as the Italian market is concerned.
Tests were performed according to EN 408 [7] and EN 789 [8], as shown in Figure 2.
All tests were performed under displacement-control to ensure stability during any possible unstable branch with sudden load drops. An electromechanical screw jack was adopted, having a capacity of 500 kN and a total displacement of 300 mm.
All tests were conducted, according to EN 408 [7], in order to achieve the collapse in 5±2 minutes. This led to a screw jack rate of 250 μm/min up to failure for all tests herein reported.
Concerning the instrumentation, vertical displacements at midspan, point loads and supports, both in the front and back side were monitored by means of LVDTs. Local and global deformation, according to EN 408 [7] were then measured (Figure 3 and Figure 4).

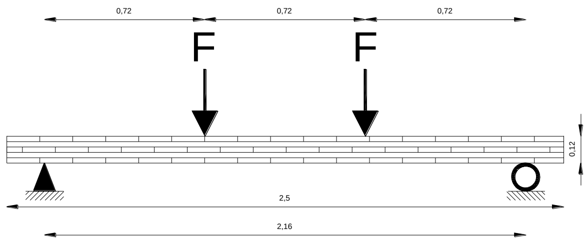

Figure 2: *Tests set-up for BTOD flexure tests*

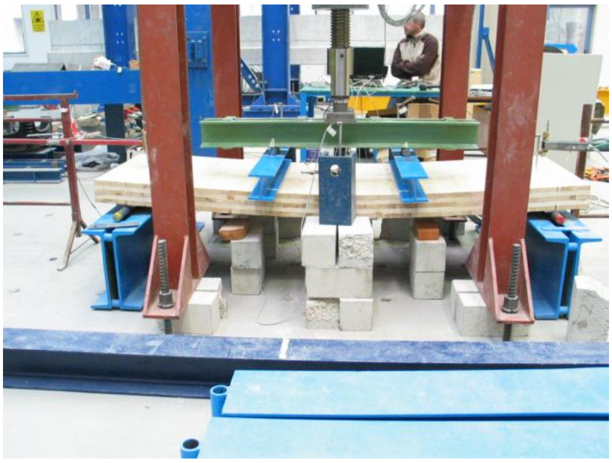

Figure 3: *Tests set-up for BTOD Flexure tests*

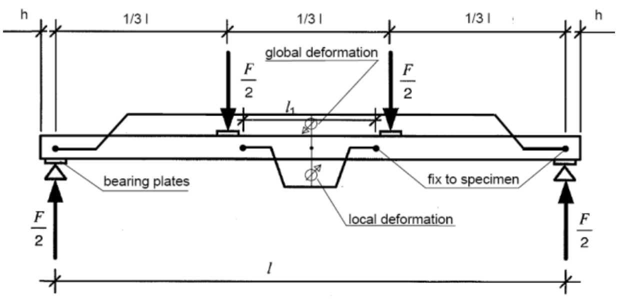

Figure 4: *Loading scheme and measuring set-up [7].*

The main experimental results concern the overall load-displacement curve, the maximum bearing capacity, the flexure strength and the elastic modulus. They concerns two test typologies, the so-called BTOD (5 layer panels, length of 2.5 m, effective length of 2.16 m, depth of 0.12 m, width of 0.8 m, distance between load points of 0.72 m, see Figure 2) and STLD specimens (5 layer panels, length of 3.2 m, effective length of 3 m, depth of 0.12 m, width of 0.8 m, distance between load points of 1 m).
Data are presented in Figure 5 and Figure 6 and in Table 1, Table 2 and Table 3.
In BTOD specimens, only two layers were built in the direction of the flexure strength (the second and the fourth in depth) whereas, in the STLD samples, the first, third and fifth strip were placed in the longitudinal direction. This fact of course had a quite strong influence in the experimental results concerning flexure strength and stiffness.

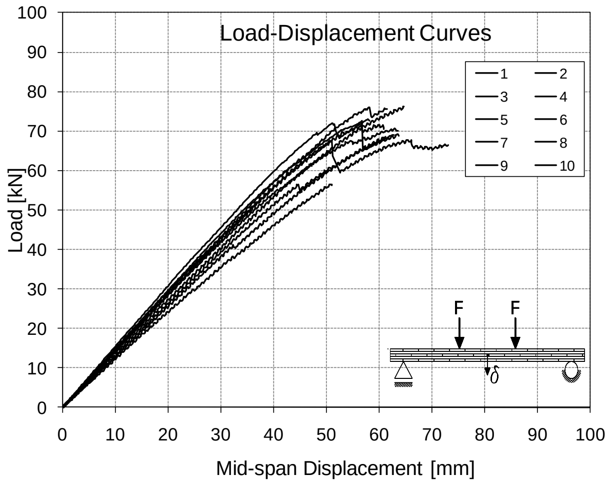

Figure 5: *Experimental results for all 10 BTOD specimens*

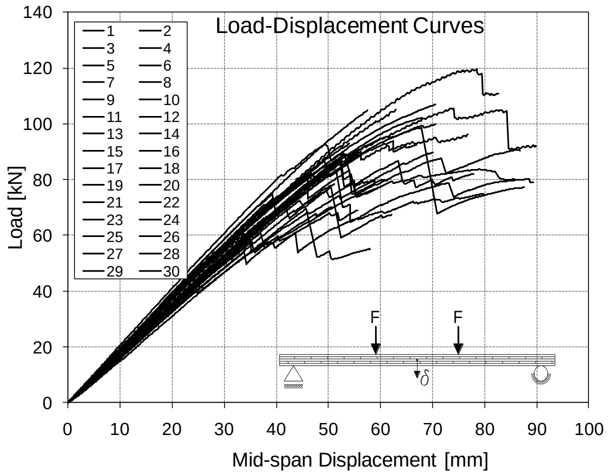

Figure 6: *Experimental results for all 30 STLD5 specimens*

Concerning BTOD specimens, it is possible to report a quite good dispersion of results. All 10 specimens reached the full flexural capacity without any significant strip slippage, except for specimen BTOD5-7, which still reached a rather good structural performance. The maximum load prior collapsing F_{max} and the flexural strength f_m had an average value of 72.46 kN and 13.75 MPa and, more importantly, a coefficient of variation (standard deviation over average value ratio) of 8% and 7%, respectively.
In Table 1and Table 2 the length *l*, the width *b*, the depth *h*, the two force values of $F_1=0.1F_{max}$ and $F_2=0.4F_{max}$ and the corresponding displacement w_1 and w_2 (relative displacement between midspan and load point deflection, see Figure 4), the elastic secant modulus *E*, the section modulus *W*, the distance between support and point load *a* and the collapse modes are also reported. F_1 and F_2 are defined, according to EN 408 [7] for the evaluation of the secant elastic modulus *E*.
Figure 7 reports a picture of a typical CLT panel collapse under flexure.

Table 1: *Geometry and experimental measurements for BTOD specimens*

SPECIMEN BTOD5	l	b	h	F_1	F_2	w_1	w_2	E
	[mm]	[mm]	[mm]	[kN]	[kN]	[mm]	[mm]	[MPa]
1	2495	800	120	7.38	28.08	0.49	2.08	2645
2	2498	801	118	7.11	28.17	0.41	1.87	3063
3	2502	800	121	7.04	28.05	0.80	2.90	1979
4	2497	799	118	7.26	28.02	0.85	2.57	2580
5	2501	799	120	7.01	28.08	0.60	2.62	2120
6	2495	800	117	7.20	28.05	0.60	2.62	2264
7	2499	798	119	7.11	28.39	0.61	2.36	2531
8	2502	799	119	7.17	28.05	0.58	2.09	2870
9	2501	800	119	7.11	28.02	0.74	2.03	3357
10	2498	830	118	7.07	28.30	0.51	2.46	2234
AVERAGE								2564
Standard Deviation								437
Coefficient of Variation								0.17

With regard to STLD5 specimens, as plotted in Figure 6 and reported in Table 3, a higher dispersion of results can be reported, ranging from 12 to 14%. 5 out of 30 specimens experienced a delamination failure among adjacent layers whereas 2 other samples showed a flexure failure along with a significant plank slippage. Space restriction did not allow the authors to report all single data.
Note that, as already mentioned before, the different orientation of wood strips determined a rather higher stiffness and flexure strength in STLD5 specimens compared to BTOD samples. Having three strips with stronger fibers in the longitudinal direction allowed STLD5 elements to achieve a modulus of elasticity 3 times higher and a flexure strength 1.73 times greater. The enhanced stiffness would allow for an easier serviceability check (deflection and service stresses) whereas the improved flexure strength would help

checking the resistance of the member at ultimate limit states.

Table 2: *Geometry and experimental measurements for BTOD specimens*

SPECIMEN BTOD	W [mm^3]	a [mm]	F_{max} [kN]	f_m [MPa]	Collapse mode
1	1920000	720	72.93	13.63	Flexure, midspan
2	1858854	720	69.97	13.51	Flexure, load point
3	1952133	720	71.45	13.13	Flexure, midspan
4	1854213	720	78.43	15.18	Flexure, midspan
5	1917600	720	70.76	13.24	Flexure, load point
6	1825200	720	58.79	11.55	Flexure, midspan
7	1883413	720	73.85	14.07	Flexure and significant shear slippage
8	1885773	720	74.76	14.23	Flexure, midspan
9	1888133	720	78.37	14.90	Flexure, midspan
10	1926153	720	75.33	14.03	Flexure, midspan
AVERAGE			72.46	13.75	
Standard Deviation			5.6	1.0	
Coefficient of Variation			0.08	0.07	

Table 3: *STLD5 specimens*

SPECIMEN STLD5	E [MPa]	F_{max} [kN]	f_m [MPa]
AVERAGE	7910	91.3	23.77
Standard Deviation	964	12.8	3.38
Coefficient of Variation	0.12	0.14	0.14

Figure 7: *Flexure collapse mode for BTOD-3 specimen.*

3 CONCLUSIONS

In this short paper, 40 preliminary tests on CLT panels were tested under flexure up to failure: elastic stiffness, bearing capacity and flexure strength were measured.
A maximum 14% dispersion of results was reported and more than 90% of specimens had the predicted flexure failure without any significant shear slippage.
Further 100 panels will be tested under different loading condition to verify and demonstrate that this technology is reliable, repeatable and can be safely applied to structures both for plate and in-plain loading conditions.

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