

THE CLT PANELS IN STRUCTURAL RESTORATION: CHARACTERISTICS AND TECHNICAL REGULATIONS

PROF. ING. GIORGIO FRUNZIO^{1*}, ING. LUCIANA DI GENNARO² ING. LUIGI
MASSARO³ AND ING. FABIO D'ANGELO⁴

^{1*} Department of Architecture and Industrial Design
Univesità degli Studi della Campania "Luigi Vanvitelli"
Abbazia di San Lorenzo ad Septimum 81031 Aversa (CE), Italy
e-mail: giorgio.frunzio@unicampania.it - Web page: <https://www.unicampania.it>

² Department of Engineering
Univesità degli Studi della Campania "Luigi Vanvitelli"
Via Roma 29 81031 Aversa (CE), Italy
e-mail: luciana.digennaro@unicampania.it

³ Soc. M. & P. s.a.s. di Massaro Cesare & C.
Via Ovidio 2 - 81033 - Casal di Principe (CE), Italy
e-mail: ing.luigi.massaro@gmail.com

⁴ TECNOLAB srl
Via S. Maria del pianto, 80 – 80143 - Napoli, Italy
e-mail: info@tecnolabnapoli.it - Web page: <http://www.tecnolabnapoli.it>

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Abstract. *Wood can represent a valid and important alternative to the most commonly used structural materials for the restoration of masonry buildings, with a view to efficient, effective and "conscious" renovation. Today, the modern technologies allows to overcome the structural limits of solid wood due to its own anisotropy. The use of composite wood elements makes possible to obtain excellent mechanical performances that consent to evaluate aspects such as the use of low environmental impact retrofit strategies. The aim of this work is the analysis of mechanical parameters related to CLT (cross laminated timber) panels in order to determine their possible use in the structural restoration of masonry buildings. The CLT panels consist of solid wood planks superimposed so that each layer has the fibres rotated ninety degrees with respect to the adjacent layer. The layers (always in odd number and at least three) can be connected by discrete joints, pins and nails, or glued together. This configuration enables to product large structural elements with considerable thickness. Two different experimental test campaigns were carried out on samples of panels with three and five glued layers. The purpose of experimentation activities was to evaluate the bending deformation of the wooden elements and shear strength of the bonding sections. All the tests were processed according to the provisions contained in the UNI standards. The test results were then compared with different theoretical calculation models to determine the one that best represents the tested material. The tests outcomes have shown that some characteristics of the material, such as the remarkable ductility, open different scenarios of use for the CLT panels in the field of structural restoration of masonry buildings.*

1. INTRODUCTION

The purpose of this work is to provide some assessments of the possibility of using structural wood-based products such as CLT panels, for the restoration of existing masonry buildings both ordinary that monumental ones. The CLT panels consist of a series of layers of solid wood lamellas placed with the fibres rotated by 90° with respect to the adjacent layers, therefore by their own nature these elements are suitable for interventions to reinforce of the structures in their own plan. It is also considered that these elements can be a valid solution to the reinforcement of the structural elements for actions out of their own plan in order to increase both their resistance than their ductility, using for example prestressing techniques such as PressLam® [2,4], performing fully reversible interventions.

In this note, we intend to study the possible applications of CLT panels in the restoration of masonry buildings both in relation to the techniques used to date than in relation to other future perspectives.

These structural wood-based panels are to date widely used in the structural reinforce of the timber floors in order to increase their strength to the actions that operate in their own plan [5,6,7,8,9,10,11,12,13]. It is considered essential to better know the mechanical properties and laws that govern the behaviour of this material subjected to stress, in order to evaluate the possibility of extending its use to other field of application.

The working group conducted a campaign of tests on CLT panel taking as reference the technical regulations to evaluate the bending resistance (UNI EN 408:2012) and the sliding resistance of the gluing sections (UNI EN 392:1997).

The results of these campaigns are summarised in the following paragraphs.

2. TECHNICAL REGULATIONS

Laminated wood and CLT panels have long since provided a new way of using wood in structures. This means, as with other structural materials, that specific product standards must be drawn up. These standards define the types of structural material, their mechanical properties and establish how to determine them.

Below are the regulations in force which seem to be relevant in this case.

2.1. Strutture

- UNI EN 1995-1-1:2014 - Eurocodice 5 - Progettazione delle strutture di legno - Parte 1-1: Regole generali - Regole comuni e regole per gli edifici. (Design of wooden structures - Part 1-1: General regulations - Common regulations and regulations for buildings)
- ETAG 007 - GUIDELINE FOR EUROPEAN TECHNICAL APPROVAL of TIMBER BUILDING KITS
- Norme tecniche per le costruzioni (NTC 2018). D. Min. Infrastrutture e Trasporti 17 gennaio 2018 (Technical standards for construction (NTC 2018))
- CNR-DT 206/2007 Istruzioni per la Progettazione, l'Esecuzione ed il Controllo delle Strutture di Legno (Instructions for Design, Execution and Control of Wooden Structures)

- Circolare 21 gennaio 2019 n.7 ” Istruzioni per l’applicazione dell’«Aggiornamento delle “Norme tecniche per le costruzioni”» di cui al decreto ministeriale 17 gennaio 2018” (Circular January 21, 2019 n.7 ”Instructions for the application of the «Update of the “Technical standards for construction”» referred to in the Ministerial Decree of 17 January 2018)
- Direttiva del Presidente del Consiglio dei Ministri 9 febbraio 2011 Valutazione e riduzione del rischio sismico del patrimonio culturale con riferimento alle Norme tecniche per le costruzioni di cui al D.M. 14/01/2008. (Assessment and reduction of seismic risk of cultural heritage with reference to the Technical Standards for constructions referred to in D.M. 14/01/2008.)

2.2. Materials

- ISO 16572:2008 Timber structures -- Wood-based panels -- Test methods for structural properties
- ISO 16696-1:2019 Timber structures -- Cross laminated timber Component performance, production requirements and certification scheme
- UNI EN 13017-1,2 :2001 - Pannelli di legno massiccio - Classificazione in base all’aspetto delle facce - Conifere/Latifoglie; (Solid wood panels - classification according to face appearance - coniferous/hardwood)
This standard is the official Italian version of the European standard EN 13017-1 (edition November 2000). The standard specifies general requirements and appearance classes for both single-layer solid wood panels and multi-layer solid wood panels, the latter having a minimum thickness of the outer layers of 3,5 mm, made from coniferous/hardwood.
- UNI EN 12775:2002 - Pannelli di legno massiccio - Classificazione e terminologia (Solid wood panels - Classification and terminology)
This standard is the official Italian version of the European standard EN 12775 (January 2001 edition). The standard provides a classification for solid wood panels and defines the terms used.
- UNI EN 13353:2011 - Pannelli di legno massiccio (SWP) – Requisiti. (Solid wood panels (SWP) – Requirements)
This standard is the official English version of the European standard EN 13353:2008+A1 (May 2011 edition). The standard specifies the requirements for solid wood panels as defined in UNI EN 12775, with a maximum thickness of 80 mm, for use in dry, humid and outdoor environments, as defined by service classes 1, 2 and 3 of UNI EN 1995-1-1.
- UNI EN 14081-3:2012 - Strutture di legno - Legno strutturale con sezione rettangolare classificato secondo la resistenza - Parte 3: Classificazione a macchina; requisiti aggiuntivi per il controllo di produzione in fabbrica. (Structural wood with rectangular cross-section classified according to strength - Part 3: Machine classification; additional requirements for factory production control)
- UNI EN 14080:2013 - Strutture di legno - Legno lamellare incollato e legno massiccio incollato – Requisiti (Wooden structures - Glued lamellar wood and glued solid wood – Requirements)

- UNI EN 14081-2:2013 - Strutture di legno - Legno strutturale con sezione rettangolare classificato secondo la resistenza - Parte 2: Classificazione a macchina - Requisiti aggiuntivi per le prove iniziali di tipo. (Wooden structures - Structural wood with rectangular cross-section classified according to strength - Part 2: Machine classification - Additional requirements for initial type tests.)
- UNI EN 14081-1:2016 - Strutture di legno - Legno strutturale con sezione rettangolare classificato secondo la resistenza - Parte 1: Requisiti generali (Wooden structures - Structural wood with rectangular cross-section classified according to strength - Part 1: General requirements)
- UNI EN 338:2016 - Legno strutturale - Classi di resistenza (Structural wood - Resistance classes)
- UNI EN 14358:2016 Strutture di legno - Calcolo e verifica dei valori caratteristici (Wooden structures - Calculation and verification of characteristic values)

2.3. Laboratory Tests

- ISO 8375:2017 Timber structures -- Glued laminated timber -- Test methods for determination of physical and mechanical properties.
- UNI EN 313-1:1997 - Pannelli di legno compensato. Classificazione e terminologia. Classificazione. (Plywood panels. Classification and terminology. Classification.)
- UNI EN 392:1997 - Legno lamellare incollato. Prova di resistenza a taglio delle superfici di incollaggio. (Glued laminated wood. Resistance to shear test of gluing surfaces.)
- UNI EN 314-1:2005 - Pannelli di legno compensato - Qualità dell'incollaggio - Parte 1: Metodi di prova (Plywood Panels - Gluing Quality - Part 1: Test Methods)
This standard is the official version of the European standard EN 314-1 (December 2004 edition). The standard specifies the methods for determining the quality of gluing of plywood with veneers, planing boards and lamellar panels by cutting test. The relevant requirements are specified in UNI EN 314-2.
- UNI EN 408:2012 - Strutture di legno - Legno strutturale e legno lamellare incollato - Determinazione di alcune proprietà fisiche e meccaniche. (Structural wood and glued lamellar wood - Determination of certain physical and mechanical properties.)
- UNI EN 384:2016 - Legno strutturale - Determinazione dei valori caratteristici delle proprietà meccaniche e della massa volumica (Structural wood - Determination of characteristic values of mechanical properties and density)
- Linee Guida per la certificazione dell'idoneità tecnica all'impiego di materiali e prodotti innovativi in legno per uso strutturale (DM 14.01.08 – Norme Tecniche per le costruzioni paragrafo 11.1, lettera C) - Guidelines for the certification of technical suitability for the use of innovative wood materials and products for structural use
- UNI EN 16351:2015 Strutture di legno - Pannello di tavole incrociate – Requisiti (Wooden structures - Cross board – Requirements)
- EN 13354:2008 - Solid wood panels (SWP) - Bonding quality - Test method;
This European Standard specifies a test method for determining the bonding quality of single-layer and multi-layer solid wood panels by a shear test.

From the analysis of the regulations losted above, in order to know the mechanical parameters of the CLT panels, it was considered appropriate to apply the following standards:

- UNI EN 392:1997 - Glued lamellar wood. Trimming resistance test of gluing surfaces.
- UNI EN 408:2012 - Wood structures - Glued structural wood and glulam wood - Determination of certain physical and mechanical properties.

It should be noted that the standards chosen for the tests are not specific for CLT panels.

3. APPLICATIONS

The overcoming of the problems related to the anisotropy of the raw material, and the possibility of reaching remarkable thicknesses and dimensions, have made these panels an important business reality which is forcefully emerging in various construction sectors.

Willing to investigate the possible applications in the structural restoration field, was noted that these panels have often been used for the refurbishment and reinforcement of existing wooden floors and roofs [5,6,7,8,9,10,11,12,13].

Verifications carried out on masonry buildings located seismic areas often reveal a criticism about the timber ceilings, because in order to guarantee a uniform transfer of the loads to the lateral resistant elements, it should be ensured a diaphragm behavior of floors and inclined rooftops. But instead the real condition is that the wooden horizontal structures had a remarkable deformability, and therefore their behavior is clearly far from a diaphragm one. Consequently there is a need to intervene with reinforcement and stiffening measures on these structures. Clearly the possibility of operating on ancient structures carrying out as possible by reversible and dry interventions, becomes increasingly important in structural retrofit strategies.

With this perspective the CLT panels provide an innovative solution to the problem while matching the reinforcement needs with those related to a philosophy of reversibility and low invasiveness of interventions. Numerous scientific studies, experimentations and realizations have demonstrated the effectiveness in terms of reinforcement in the own plan of the structures. This allow therefore to consider at date these panels as a valid alternative to the traditional techniques of reinforcement.

In the literature, several research groups have shown that for CLT-reinforced horizontal structures, increasing loads applied, the crisis of the system is reached with the crisis of the connection sections. So it were obtained resistance values 7 times higher than the traditional slabs. The reinforcement of wooden roofs both planar or inclined, represent another possible application of CLT panels in structural restoration. In the literature there are several studies about this topic, in particular in order to evaluate the different possibilities of modelling these kind of structures in relation to the potential dissipative effects that the reinforcements with these panels determine. A plausible modelling hypotesis is to consider the connections between panels and trusses as springs characterized by linear or not linear propreties according on the type of analysis carried out [9]. Regardless of whether the dissipative effects are evaluated, also in this case this reinforcement strategy is effective both in terms of seismic response and in terms of reversibility and low invasiveness.

However, studies conducted on other plausible interventions involving the use of CLT panels are very rare.

This type of panels could probably be used for the consolidation of the masonry walls by operating a sort of tackle inside the walls themselves [3]. This type of intervention would allow the original appearance of the buildings to be preserved by operating with an almost complete reversibility perspective in full compliance with the buildings both from the aesthetic that from the constituent materials point of view .

4. EXPERIMENTAL TESTS

4.1. Bending Resistance

In order to investigate the behaviour of the panels, several tests were carried out on samples of panels consisting of 3 and 5 lamellas layers. The 3-layer panels have a height of 100 mm and consist of external lamellae of a height of 25 mm, while the inner layer is made up of a lamella of a height of 50 mm. The 5-layer panels have a height of 120 mm with slats of equal thickness of 24 mm. In both types of panels the lamellae are 300mm long. The results of the experiments were compared with theoretical calculation models. All tests were carried out according to UNI EN 408:2012. The panels used for the tests are made of wood classified C24 according to UNI EN 338 with the following mechanical characteristics:

$$E_0 = 110000 \text{ N/mm}^2; E_{90} = 3700 \text{ N/mm}^2; G = 690 \text{ N/mm}^2$$

The tests were performed by placing the samples on two known centre distance supports by progressively applying the load in the centre.

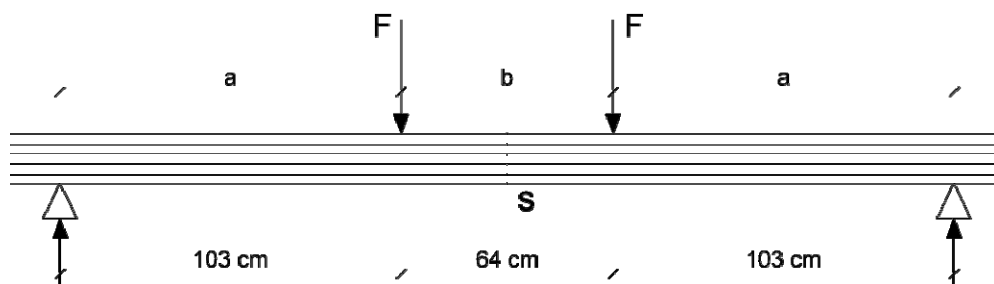


Figure 01: Test load scheme (UNI EN 408:2012)



Figure 02: Load test

Below one of the Force-Displacement diagram is shown:

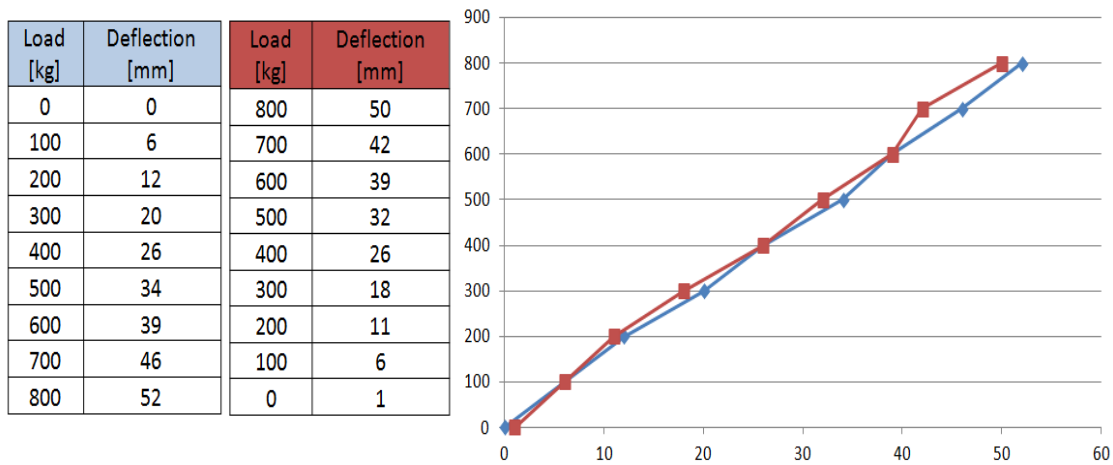


Figure 03: 3-layer panel force-displacement diagram

When the test phase are finished, the theoretical displacement in the centre was calculated using three different models:

- Model 1: the calculation of the maximum displacement was performed by neglecting the contribution of the transverse layers, but giving them the transfer of the shear effort to the adjacent layers while preserving the flat sections;
- Model 2: in compliance with the technical regulations, the calculation of the maximum deflection has been calculated taking into account the cooperation of the transversal elements;
- Model 3: The calculation was performed taking moderately into account the contribution of the transverse layers with their shear deformability.

The following table summarizes the values obtained from the test (with subscript sp) and from the 3 different calculation models (with subscript t):

Table 1: Bending test results

	3-LAYER PANEL			5-LAYER PANEL		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
EI	2,40625E+11	2,41781E+11	2,37537E+11	3,72557E+11	3,72685E+11	2,37537E+11
V_t	24,67	24,55	24,99	13,28	13,28	13,44
V_{sp}	50,5	50,5	50,5	27	27	27

The comparison between the experimental values and the theoretical ones show that the displacements values found during the tests are much higher than those obtained from all the theoretical calculation models. This could be due to an incorrect attribution of the EI value to the material in the three calculation models considered. If it was, starting from the experimental data found, it would be necessary to create a model of the CLT material more responsive to reality. The experiments shown in this work have been carried out on a specific standard for lamellar wood which does not necessarily apply well in this case, it should be

noted.

4.2. SLIPPING

In order to investigate the behavior of the gluing surfaces of the CLT panels, and in the absence of specific technical regulations (ref. § 2), several tests were carried out on different specimens in according to the provisions contained in the UNI EN 392: 1997 standard "Wood glued lamellar. Shear strength test of gluing surfaces".

This standard doesn't contain specific provision for the orientation of the fibres in relation to the direction of application of the load. That because the field of application of the regulation, is exclusively laminated wood which as is known, is made with lamellas oriented in the same direction.

In order to considerate the mutual 90 degrees rotation of the lamellas, that is of the fibres, constituting CLT panels, the working group carried out the tests by dividing the samples into two families: the first characterized by the central panel fibres oriented parallel to the direction of load application (SAMPLES TYPE A), the second one with the central panel fibres orthogonal to the direction of application of the load (SAMPLES TYPE B).

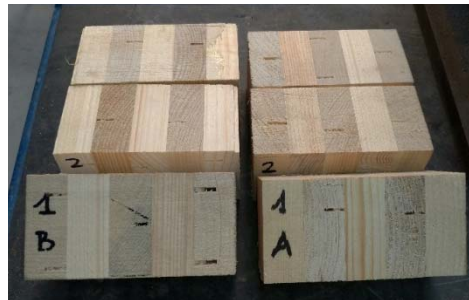


Figure 04: Specimens type A (central layer fibers parallel to the load direction) and type B (central layer fibers orthogonal to the load direction)

The test was carried out on the basis of the scheme described in the standard as shown in the figure below.

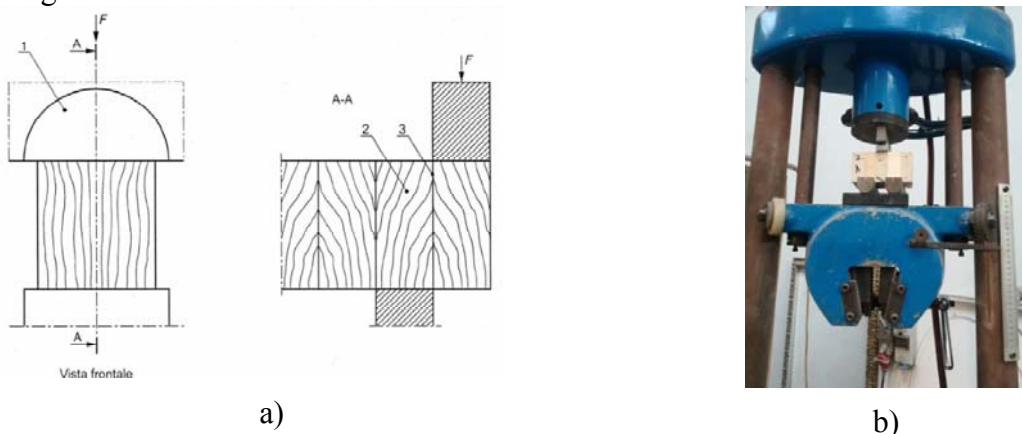


Figure 05: a) Representation of the performed test (UNI EN 392:1997) - b) Laboratory test

Ten tests were performed, five for each samples family. The results are shown in the table below:

Table 2: Slipping test results

Specimen	Basis [mm]	Width [mm]	Height [mm]	Mass [Kg]	Specific Weight [Kg/m ³]	Thickness [mm]	Breaking load [KN]	τ [N/mm ²]
1A	60	119	60	0,178	415,500	3	15,273	4,243
2A	60	119	59	0,185	439,159	6	20,223	5,713
3A	60	119	59	0,175	415,420	5	10,888	3,076
4A	60	119	60	0,176	410,831	5	12,512	3,476
5A	60	119	56	0,179	447,679	4	14,987	4,460
1B	60	119	59	0,174	413,047	3	7,464	2,108
2B	60	119	58	0,180	434,657	6	10,928	3,140
3B	60	119	60	0,185	431,839	3	7,709	2,141
4B	60	119	59	0,179	424,916	8	15,934	4,501
5B	60	119	60	0,184	429,505	9	13,769	3,825

Analysis of results indicates that samples B resistance values are clearly lower than those of A family. It means that the τ value for the group A samples are 33% higher than the B group ones.

By studying the breakage mechanisms of the individual specimens, we can observe that while for the A samples the crisis occurs with the failure of the gluing surface, for group B the crisis occurs with the failure of the central layer of the panel and not of the bonding surface. The results described are clear in the figure below



Figure 06: Post test specimens

All in all, we can affirm that from the tests carried out it is clear that the individual layer orientation assumes considerable importance both in terms of strength, Than in terms of "quality" of breakage, when we want to analyze the parameters that govern breakage by stressing the bonding surfaces.

5. CONSIDERATIONS AND CONCLUSIONS

The need to carry out structural restoration interventions that operate according to a philosophy of maximum reversibility and low invasiveness is becoming increasingly important.

In this perspective, the use of wood-based structural products and in particular CLT panels could represent a valid alternative solution to traditional structural restoration methods. In order to meet this requirement, in our opinion, it is necessary to introduce specific technical From the results of the tests shown in this work, it is clear that to date there are still numerous uncertainty factors linked both to the correct choice of the mathematical model to be used to better describe the behavior of the material, than to the presence of a poor regulatory framework related to the tests to be carry out on CLT panels. This work shows therefore that CLT panels cannot be actually tested in the same way as laminated wood.

That is especially in the case with we have to consider the use of CLT panels in the structural restoration for out of their own plan actions

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