Insights and Innovations in Structural Engineering, Mechanics and Computation – Zingoni (Ed.)

Insights and Innovations in Structural Engineering, Mechanics and Computation - Proceedings of the 6th International Conference on Structural Engineering, Mechanics and Computation, SEMC 20162016, Pages 1727-17306th International Conference on Structural Engineering, Mechanics and Computation, SEMC 2016; Cape Town; South Africa; 5 September 2016 through 7 September 2016; Code 179629

DOI: 10.1201/9781315641645-285

Sonic Testing on Cross Laminated Timber panels

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ABSTRACT: Cross Laminated Timber (CLT) panels are used as building construction materials due to their excellent properties. In particular, with this construction technique it is possible to produce high quality structural members by assembling normal/low quality planks. Timber boards should be graded according to the current regulations before their use as structural components. Among grading methodologies, non-destructive Sonic Testing can be applied. Sonic Testing is a non destructive technique widely used for building material quality control. In this paper, the reliability of Sonic Testing in giving information on some mechanical characteristics of Cross Laminated Timber panels is discussed also in relation to wood type, layers number and layers configuration of the panels. For this purpose, both Sonic Testing and destructive bending tests have been carried out on several CLT panels manufactured by using boards of Spruce and Sardinian Maritime Pine. Regression analysis between sonic and mechanical parameters (static modulus of elasticity and bending strength) has been performed and is critically discussed in the paper.

1 INTRODUCTION

In Italy timber and wood products, such as Cross Laminated Timber (CLT) panels, are becoming increasingly used as building construction materials due to their excellent properties: lightness, high strength-to-weight ratio, prefabrication and environmental sustainability. CLT consists of at least three layers of timber planks where the direction of the grain in adjacent layers is perpendicular to each other. The timber planks are finger-jointed and glued on the top and bottom surface with the other layers. CLT panels have several advantages including (i) in-plane isotropy and (ii) the reduced influence of defects and flaws as the production process leads to the removal of major defects and to the distribution of the remaining minor defects over a large volume, resulting in a homogenization of the material. With this technique, high quality structural members can be produced using normal/low quality timber such as Sardinian maritime pine, which is generally low quality due to the presence of defects (knots, clusters knot, resin pockets, deviation of the grain etc.) (Concu, 2012 and 2013).

Before their use as structural components, timber boards should be graded according to the current regulations. Among grading methodologies, non-destructive Sonic Testing (ST), based on measurements of the velocity V of sonic waves propagating through the material, can be applied (Ross, 1999 and 2005, Fortune, 2007). ST are usually carried out by applying the Direct Transmission Technique (DTT), in which the sonic wave is input into the specimen by a transducer and received by a second transducer placed on the opposite side. The signal travels through the volume of the specimen, and it is possible to measure the time T that the wave needs to move from the emitter to the receiver. Assuming that the path corresponds to the distance L between the transducers, the velocity V of the sonic wave can be obtained from the ratio L/T.

As previously stated, non–destructive grading can be used to timber boards. This work reports the preliminary results of an experimental programme aimed to assess the reliability of ST in giving information on mechanical behaviour of CLT panels. Both ST and bending tests have been carried out on several CLT panels manufactured from Sardinian Maritime Pine and Spruce boards in order to measure sonic velocity and to determine the static elastic modulus and the bending strength. Correlation analysis between sonic and mechanical parameters has been performed and critically discussed.

2 EXPERIMENTAL PROGRAMME

2.1 *Cross Laminated Timber Panels*

For the experimental programme, a total of 28 CLT panels have been made by using boards of Spruce (S) and Sardinian Maritime Pine (P) previously visually graded. Spruce boards belong to C24 strength class according to EN 338, while Maritime Pine boards were assigned to C16 and C14 strength classes based on the visual grading rule recently developed by CNR-IVALSA (Riu, 2016). The boards with lower strength were used as inner layers in both combined Spruce and Pine (SP) panels and in Pine (P) panels. Panels have been sorted into four groups, each made of 7 specimens differing in wood type and/or in layers' number and/or geometric dimension (Table 1).

Table 1. Characteristics of CLT panels.

Group	Thickness of boards	N. of layers and wood	Length	Section (BxH)
	m		m	m^2
60 SP*	0.02	3: S-P-S	1.27	0.24x0.06
60 P*	0.02	3: P-P-P	1.27	0.24x0.06
100 P*	0.02	5: P-P-P-P-P	2.00	0.245x0.10
120 P*	0.04	3: P-P-P	2.60	0.24x0.12

* S=Spruce, P=Sardinian Maritime Pine.

2.2 *Sonic Testing*

Sonic Testing has been carried out using a testing equipment, properly developed and assembled, which included (Figure 1):

- an impact hammer with a piezoceramic sensor for generating the signal;
- a piezoelectric transducer (54 kHz resonant frequency) for receiving the signal;
- a Vellemann Instruments digital oscilloscope for signal visualization and preliminary analysis;
- a PC for data storage and signal processing.

A suitable mastic has been interposed between the receiving transducer and the panel in order to reduce energy dissipation due to the different acoustic impedance of the materials. The DTT has been applied, and sonic waves were induced to propagate through the longest dimension of the panel.

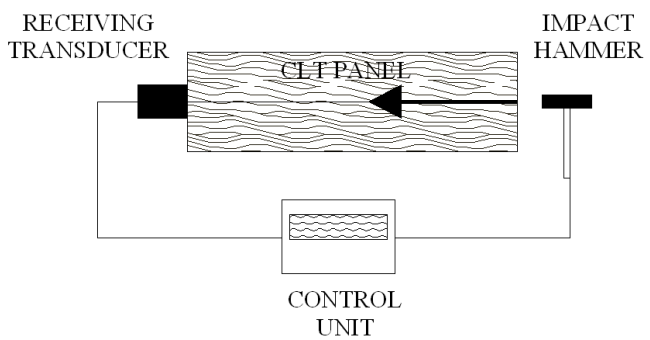

Figure 1. Sonic Testing equipment.

2.3 *Bending Test*

Bending tests have been carried out according to UNI EN 408. Tests have been performed in order to determine the static modulus of elasticity (E), and the bending strength (σ) at failure. The static modulus of elasticity has been determined by recording force and displacement at a level of the applied load approximately equal to 40% of the estimated failure load. Bending test setup is shown in Fig. 2.

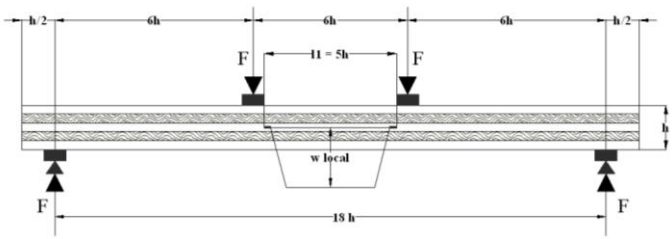

Figure 2. Bending Test setup.

3 RESULTS

Table 2 shows a summary of measured parameters.

Table 2. Statistical distribution of measured parameters.

Parameters	60 SP	60 P	100 P	120 P
V [m/s]	4618	2995	3690	3160
SD* [m/s]	414.50	276.31	212.63	172.79
CoV** [%]	8.98	9.23	5.76	5.47
σ [N/mm²]	42.20	27.35	37.20	30.45
SD* [N/mm²]	6.40	5.75	3.70	3.51
CoV** [%]	15.20	21.02	10.02	11.52
E [N/mm²]	11092	6745	9946	8423
SD* [N/mm²]	875.72	633.21	863.96	1123.38
CoV** [%]	7.90	9.39	8.69	13.34

* SD = Standard Deviation, **CoV = Coefficient of Variation.

Figures 3-5 show how measured parameters V, σ, E varies with wood type, layers' number and layers' configuration.

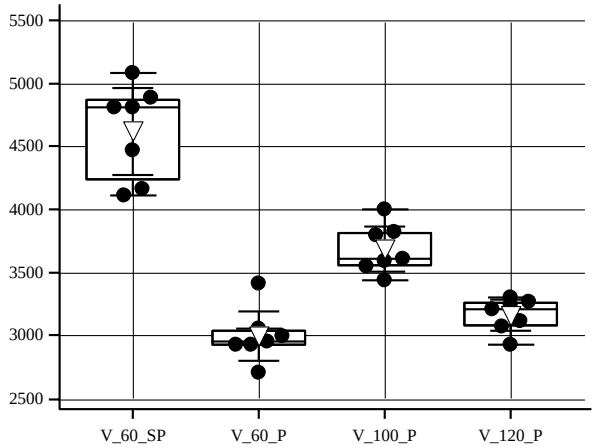

Figure 3. Sonic velocity.

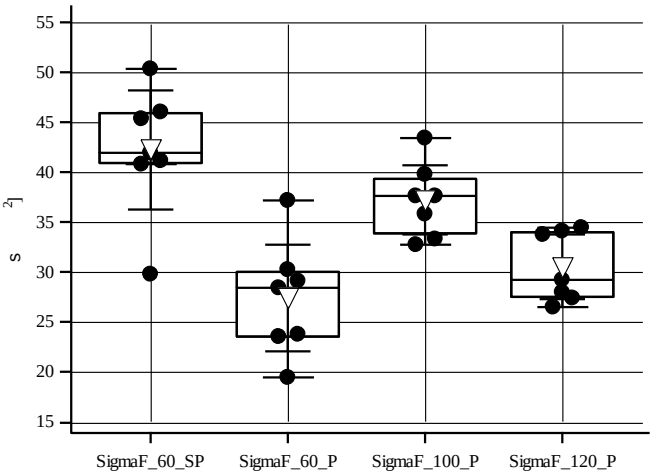

Figure 4. Bending strength.

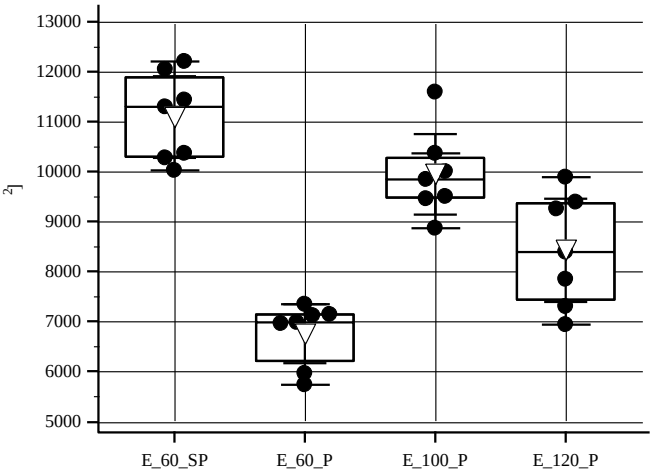

Figure 5. Static modulus of elasticity.

From Table 2 and Figures 3-5 it can be inferred that group 60 SP – three layers' panels made of mixed Spruce-Pine boards 200 mm thick – shows higher mechanical performance than the other groups. In particular, it is worth noting that both bending strength and static modulus of elasticity are higher than those of group 100 P – five layers' panels made of Pine boards 20 mm thick – and of group 120 P – three layers' panels made of Pine boards 40mm thick. Thus, the use of Spruce boards instead of Sardinian Maritime Pine boards as external layers leads to an increase of both σ and E of more than 10% compared to that of Pine panels with more layers. The same quantities increase of more than 30% compared to that of Pine panels with the same number of layers but twice as thick. The group 60 P is characterised by the lowest values of both σ and E. The sonic velocity V follows the same trend, proving to have a close link with the mechanical parameters.

3.1 *Regression analysis*

The possibility of evaluating CLT mechanical properties such as σ and E with non-destructive measurements is based on the existence of a relationship between these properties and some predictor parameters, such as V, that do not directly affect the mechanical characteristics but are good indicators of them. The relationship can be established from empirical observations using mathematical statistical methods, usually regression analysis. In this case the so called coefficient of determination R^2 indicates the portion of the total variation of the predicted variable which is explained by the predictor. In this work, the coefficient of determination R^2 between V and σ and between V and E was calculated. Only simple linear regression analysis has been adopted and R^2 has been used solely as a measure of the ability of V to predict the two mechanical properties. Figures 6 and 7 show the V- σ and V-E correlations, respectively.

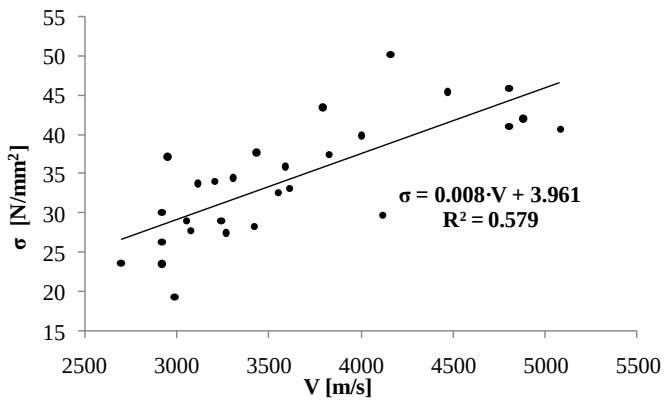

Figure 6. Correlation between sonic velocity and bending strength.

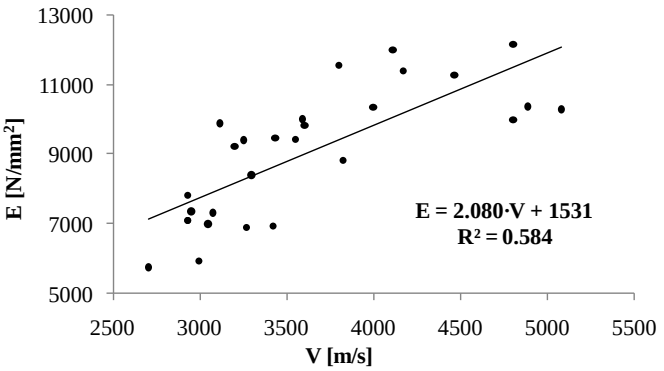

Figure 7. Correlation between sonic velocity and static modulus of elasticity.

It can be noted that in both cases R^2 is approximately 0.58, that means that no more than 58% of the variability of predicted parameters can be explained by sonic velocity. This degree of prediction is consistent with those reported in literature for some types of structural timber (Hanhijärvi, 2005 and 2008, Diebold, 2000, Sandoz, 1989).

4 CONCLUSIONS

An experimental programme has been carried out with the aim of evaluating the reliability of Sonic Testing in predicting some mechanical characteristics of CLT panels. Several CLT panels have been made by using boards of Spruce and Sardinian Maritime Pine. Panels have been sorted into four groups, each made of 7 specimens differing in wood type and/or in layers' number and/or geometric dimension.

Both ST and bending tests have been carried out and the correlation between sonic velocity, bending strength and modulus of elasticity investigated, with special emphasis on wood type, layers' number and layers' configuration of the panels.

Results highlighted that:

– the use of Spruce boards instead of Sardinian Maritime Pine boards as external layers determines an increase of both σ and E with respect to Pine panels with more layers and with the same number of layers but twice as thick;
– the sonic velocity follows the same trend of the bending strength and modulus of elasticity, showing remarkably different values for the various panel groups;
– the regression analysis between sonic velocity and mechanical parameters σ and E gives a coefficient of determination similar to those reported in literature for boards made of various timber species.

Based on these preliminary results, Sonic Testing could be applied not only for grading of timber boards but also for obtaining information on some mechanical parameters of CLT panels such as bending strength and static modulus of elasticity.

ACKNOWLEDGEMENTS

This work is funded and supported by Regione Sardegna, operating programs L. R. 7/2007: "Promotion of scientific research and technological innovation in Sardinia" and PSR 2007/2013 – Misura 124: "Cooperation for development of new products, processes and technologies in agriculture, food and forestry sectors".

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