EXPERIMENTAL DETERMINATION OF OUT OF PLANE ELASTIC SHEAR MODULUS BY THREE POINT BENDING TEST WITH VARYING SPAN: APPLICATION TO COMPOSITE LAMINATES AND PARTICLE WOOD PANELS.

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Abstract:
By subjecting an orthotropic material, like a composite laminate, to a series of three point bending tests with varying span between the supports, it is possible to determine the out of plane shear modulus. The method exploit the principle that the smaller the span, the larger the influence of shear deformation upon total deflection. By proper optimization algorithms, it is possible to obtain the values of the relevant elastic constants, i.e. the flexural modulus and the out of plane shear modulus. The method we propose can be applied to any orthotropic material. In this work, we present the application of this identification method to particleboard panel considered as composite material like a sandwich panels.

1. Introduction

The bending performance for wood-based materials like particleboard panels is a very important characteristics to take in to account in various applications, especially for the design of pieces of furniture. Considering particleboard as a sandwich panel made of orthotropic skins and core, the deflection of the beam-shaped specimen is mainly related to the in-plane flexural modulus E and out of plane shear modulus G. The simpler way to determine these mechanical quantities it is exploit the three point bending test with varying span (TPBT) as done for the laminate composite in [1], [2] or for wood [3]. In this work, we want to apply the (TPBT) to particleboard panels and present a calculation method for the relevant elastic constants, i. e. the flexural modulus and shear modulus, based on optimization algorithms.

Particleboard is a wood-based material used to produce panels of different size, normally used in furniture and building industries. This material is very common because it is economic, offers good mechanical performances, it is a multipurpose material and it is very suitable to be produced using

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recycled wood from wood-waste. The panels made of particleboard are mainly used for furniture frames (in this case the boards are usually ennobled with decorative paper), interior lining, floors or modular walls.

Figure 1: Particleboard panels having different thicknesses.

The manufacturing process to reach the final panel is the same for raw and ennobled ones, and nowadays it is generally performed consuming wood waste as a raw material. Normally the process starts with the washing and the grinding of the wood rejections to reduce these, sometimes very big parts, to the right dimension particles. After having dried and cleaned the wood particles from metal, stones, papers, plastic, sand and all the material not suitable to the boards production, it is possible to reach two different particle sizes: coarse (the range of the dimensions of the particles is 1.5mm) and fine (0.25mm) both with moisture content equal to 2.5 – 5%.

At this point, the workflow require to wet the particles with resin, spreading an urea-formaldehyde based adhesive. Then, fibres are deposed on the bed of a continuous press, following the size sequence: fine – coarse – fine, to give to the panel the required mechanical characteristics and hot pressed. The manufacturing process is complete after appropriate panel trimming and smoothing. The raw particleboard panels of 38mm thickness studied in this work, are produced following this manufacturing process. Figure 1 show the final product of different thicknesses. Fig. 2 shows the vertical density profile measured from X-Ray diffraction wood scanner of the particleboard of 38mm of thickness as a result of deposition scheme fine – coarse – fine.

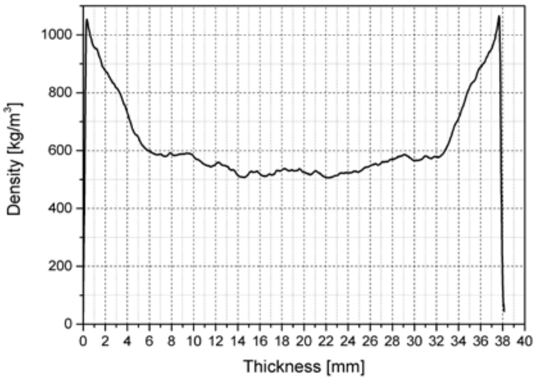

Figure 2: Vertical density profile of 38mm particleboard.

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2. Experimental

From square panels of 500 x 500 mm size we have extracted 5 samples 50mm wide and 500mm long. It is very important to underline that is possible to define three zones in the thickness of the sample: two skins and one core. The skins are considered symmetric with respect to the panel's mid-surface; the density from the maximum value at the outer surface decreases linearly to a constant value in the core, thus forming a quasi-layered structure. Moreover the wood-particles have a planar distribution, which, combined with the layered structure, makes out of plane elastic constants differ from in-plane ones, like in composite material laminates. By assuming that in-plane elastic longitudinal modulus is proportional to the local value of density [4], it is possible to consider each particleboard panel as a composite laminate and as a sandwich panel. In particular, the skins (with high density) are stiffer than the core, whose low density, and hence low stiffness, is controlled in order to make it suitable to separate the skins and prevent their sliding (shear stiffness effect) under the applied loads. Table 1 lists the geometrical dimensions of the samples and mean density.

Table 1: Geometrical dimensions of the samples and mean density

Board thickness (mm)	Skin thickness (mm)	Core thickness (mm)	Mean density (kg/m^3)
38	6	25.8	620.06

As mentioned before in the introduction of this article, exploiting three points bending test with variable span between supports and considering particleboard panels as a orthotropic material, like composite laminates, the out of plane shear modulus of the core layer can be determinate. To perform (TPBT) it was followed EN 310 standard [5] without take in to account the influence of load nose radius on elastic constant calculation as shown in [6]. The experimental set-up shown in Fig. 3, is composed of:

- Multipurpose MTS test machine Alliance RT-100 (maximum capacity of 100kN),
- Additional Load Cell MTS 4501055 with the capacity of 10kN,
- MTS 632.06H-30 Opt.003 & 005 Deflectometer with ±12.5mm travel,
- MTS 642.10B variable span supports with maximum total load supported equal to 100kN.
- Roller supports diameter 15mm
- Load nose diameter 30mm

Figure 3: Three points bending set-up with variable span

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The test procedure followed to perform three point bending test with varying span, is derived from EN 310 standard. This standard prescribes that the flexural elastic constants of the panel are determined in the linear range in the load-deformation graph, as defined by two force limits (F_1 and F_2) proportional to the ultimate load F_{max} [5], See Eq.1 and Eq.2:

$$F_1 = 0.1F_{max} \tag{1}$$

$$F_2 = 0.4F_{max} \tag{2}$$

Considering as a limit F_2 reached with the maximum span, we have calculated the bending moment reached in the highly stressed section. The next tests executed using shorter span, were performed maintaining the moment constant (increasing F_2 and reducing the span). Thus, it was possible to use the same sample for each span, without damaging the samples. The speed of the crosshead was adjusted to reach the maximum load F_{max} in 60 ± 30s, in agreement with the standard [5].

3. Results

Figure 4 reports the three point bending test results with varying span applied to a particleboard sample of thickness equal to 38mm.

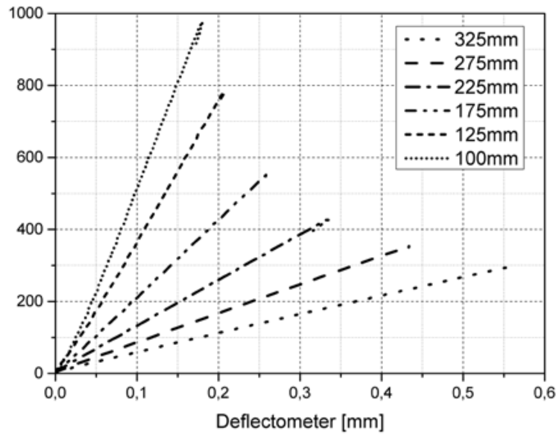

Figure 4: Three points bending test results with varying span

Results of the tests were analysed with two different models, in order to derive the values of the elastic constants, as described in the following section

4. Modelling

4.1 Two Constants Model

To calculate the elastic constants of the board, considering the particleboard as a sandwich panel with geometry shown in Figure 5a, it is first necessary to express the flexural stiffness D using (Eq. 3).

$$D = 2 * \frac{E_f * b * t^3}{12} + 2 * \frac{E_f * b * t * d^2}{4} + \frac{E_c * b * c^3}{12} \tag{3}$$

Then, we minimized the difference between the experimental deflection, measured in the middle of the sample using the deflectometer, and the analytical one (Eq. 4). The minimization algorithm works varying the value of in-plane elastic modulus of the skins and core, and out of plane shear modulus of the core, to reach the optimum solution and determine elastic constants of the particleboard. Moreover

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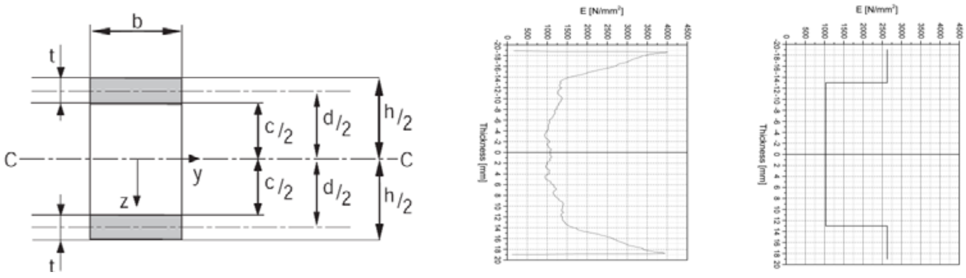
reducing the distance between the supports, the shear effect is amplified, thus making it possible to increase its contribution to the total deflection, expressed by

$$f = f_{fl} + f_{sh} = \frac{P*l^3}{48*D} + \frac{P*l}{4*G_{12}*A} \quad (4)$$

where E_f and E_c are the in-plane elastic longitudinal modulus of the skins and core, respectively. The dimensions b, t, d and c are shown in Fig. 5a. The analytical deflection f is the result of flexural contribution f_{fl} and shear contribution f_{sh}. P is the vertical load applied in the middle of the sample during the test. L is the distance between the two supports, A is the orthogonal surface of the core and G_{12} is the out-of plane shear modulus of the core.



a) b) c)

Figure 5: Particleboard as a sandwich panel: a) Geometry; b) Elastic modulus profile; c) Two-Constant elastic modulus profile.

This method is largely applied to the sandwich panel to determine the elastic constants in agreement with standard ASTM D7250. However is clear that this method not reproduce the real trend of the E modulus in the skins (Fig. 5b), because the expected relationship between E modulus and density should be of the type

$$E = A * \rho + B \quad (5)$$

An example of a relationship of this type, obtained using particleboard panels made of virgin material, can be found in [4], as

$$E = 5494.2 * \rho - 1845.4 \quad (6)$$

By the two constants model, we are assuming a step wise variation of the E modulus through the thickness (Fig. 5c), whereas in the real case it has a linear trend. This observation suggest that this method could be improved by introducing a more realistic linear trend.

Table 2 report the elastic constant results of the particleboard samples studied using Two-Constants model to model it as a sandwich panel with the E modulus in the skins and in the core equal to constant value.

Table 2: Elastic constant results from Bi-Constant model

Board Tick. (mm)	E Skins (N/mm²)		E Core (N/mm²)		G12 Core (N/mm²)	
	Mean	St. Deviation	Mean	St. Deviation	Mean	St. Deviation
38	2630.9	42.7	1034	5.1	138,6	11.1

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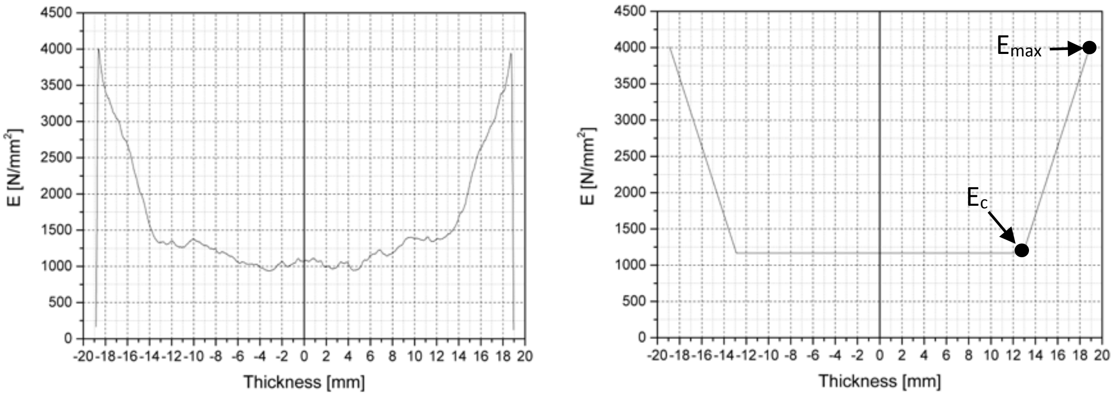
4.2 Bi-Linear Model

Knowing the density profile shape (Fig. 2) and using Eq. 6 [4] to visualize the expected shape of the elastic modulus – position through the thickness function (Fig. 6a), we have assumed a bi-linear, symmetric relationship between the Young modulus and the position through the thickness. Considering this assumption, the elastic modulus trend in the particleboard skins now becomes linear, as a reported in Fig. 6b.



a) b)

Figure 6: Bi-Linear model: a) Elastic modulus profile; b) Bi-Linear shape.

To implement this model, it is necessary to re-define the flexural stiffness $D_{Bi\text{-}Lin}$ to represent the linear variation of E modulus through the thickness of the skins. It is then necessary to express the linear equation between the elastic modulus in the core E_c (still constant), and maximum elastic modulus in the skins E_{max}. The new mathematical expression of $D_{Bi\text{-}Lin}$ becomes:

$$D_{Bi-Lin} = \frac{1}{12} * E_c * c^3 * b + 2 * b * \int_{\frac{c}{2}}^{\frac{h}{2}} (q + my) * y^2 dy \tag{7}$$

where q is the intercept and m is the slope of the linear equation between E_c and E_{max}. The free coordinate along the skins thickness is y and $\frac{c}{2}$ and $\frac{h}{2}$ are two extremes that represent the skins' thickness. Three mechanical constant E_f, E_c and G_{12} are calculated using the same optimization algorithm as a before, but using the new expression of flexural stiffness $D_{Bi\text{-}Lin}$. Table 3 shows the particleboard elastic constant refined using Bi-Linear model. Results referring to values of the Young's moduli are in agreement with the expected values (shown in Fig. 6b). As for values of the shear modulus of the core, comparison could be performed with results obtained from full field methods [7] as a Digital Image Correlation performed on shear Iosipescu tests [8].

Table 3: Elastic constant results from Bi-Linear model

Board Tick. (mm)	E Skins (N/mm²)		E Core (N/mm²)		G12 Core (N/mm²)	
	Mean	St. Deviation	Mean	St. Deviation	Mean	St. Deviation
38	2337.3	69.5	1424.4	164.4	137.3	9.6

5. Conclusions

The identification method to characterize particleboard panel elastic constants derived from composite materials featuring is proposed as an alternative methods compared to [9] and [7]. This method consider

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the particleboard as a sandwich panel and models the in-plane skins' Young modulus with a linear relationship in agreement with the E modulus –density relationship proposed by in the literature [4]. To derive the in-plane E modulus of the skins, that of the core and the out of plane G modulus of the core, three point bending tests with variable spans were conducted keeping bending moment constant and reducing the distance between the supports. Knowing the experimental deflection of the particleboard samples, is possible to obtain the E modulus of the skins, the core and the G modulus of the core.

Further development expected regard the exploration of this method on others type of particleboard thicknesses mostly diffused (8mm and 18mm), to derive their skins and core elastic constants. This further step could make it possible to derive a now relation between the density and elastic modulus, valid for particleboard material obtained from recycled wood.

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