Modulus of elasticity assessment of glass-fibre reinforced bark-based panels by acoustic resonance vibration non-destructive test

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Modulus of elasticity assessment of glass-fibre reinforced bark-based panels by acoustic resonance vibration non-destructive test

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Abstract: One of the main properties of solid materials are their stiffness. Acoustic vibration non-destructive tests have been successfully used to predict the stiffness, i.e. Young's modulus or modulus of elasticity (MOE) values of solid wood and wood-based panels. In this work, there was an attempt to evaluate the relationship of dynamic MOE longitudinal and static MOE values, of low-density panels produced from bark particles reinforced with various length glass fibres. The findings of the results and the observed strong coefficients of determination suggest the possibility of the proposed Non-Destructive Test (NDT) method as a prediction tool for the MOE estimation of similarly produced bark-based panels. By means of this non-destructive method can be tested the materials without breaking the material and the results available right after the test.

1. Introduction

Wood based panels are essential and common raw materials suitable for engineering applications in the building construction and furniture industry. These represent a variety of products in the shape of panels in which various species of wood is bonded with structural and non-structural adhesives. Wood-based panels are made in the form of veneers (plywood, laminated veneer lumber), particles (particleboards, oriented strandboards) and fibres (fibreboards). Wood-based panels such as particleboards make use of low grade logs, thinning, and recycled wood and wood residues as raw materials during their manufacturing [1].

Each year large amounts of bark are remained as waste in the forest or sawmills. The disposal of bark waste has traditionally been used as biomass for energy production. Several, past research efforts have studied the feasibility of making particleboards from bark residues. The results have shown the successful replacement of wood particles from bark particles up to a range of 30 to 50%. Beyond this percentage, the physical and mechanical properties of the bark-based particleboards are substantially decreasing and usually not fulfil the standard minimal requirements even for furniture manufacture [2,3]. Although, under certain conditions and due to the inherent low thermal conductivity value of bark, particleboards made of bark particleboards, it was shown that could be used as thermal insulation panels where the mechanical properties are not in priority [4,5].

One of the main mechanical properties of solid materials, such as wood panels, is the determination of Young's modulus, also referred as modulus of elasticity, which depicts the bending stiffness or resistance of the material, i.e. how much a wood panel would deflect under load in the elastic range. However, worldwide research efforts have been focused on the development of non-destructive tests to be used in the forestry sector. Ross in [6] defines non-destructive evaluations as 'the science of identifying the physical and mechanical properties of a piece of material without altering its end-use capabilities and then using this information to make decisions regarding appropriate applications'. It is further stated that such evaluations rely upon various appropriate non-destructive tests and their selection depends by the particular performance or interest quality characteristic. Among them non-destructive tests include sound vibration, acoustic or stress wave tomography, ultrasound and X-ray [7].

Acoustic tools are a non-destructive method of predicting the physical and mechanical properties of timber and wood-based materials. The principle of this method is based on the speed at which an induced sound or stress wave travels through a sample of wood. These changes in the acoustic velocity will cause the wood sample to vibrate as its resonant frequency [8]. As stated [9] the spreading velocity of sound waves depends on the elastic properties and moisture content of the material and it is possible to determine the modulus of elasticity using longitudinal waves. Dynamic tests based on resonant frequency have shown strong correlations between the longitudinal and static modulus of elasticity values of small wood specimens and also in structural timber and logs [10]. Further, stress-wave vibration technique have been successfully used to determine the modulus of elasticity of wood-based panels [11-13].

The objective of this work was to receive some preliminary results i) for the estimation of elastic properties (modulus of elasticity) of low-density bark-based panels reinforced with glass fibres, based on sound vibration (resonant frequency) non-destructive test (NDT) and ii) to assess if the existence of correlation between the dynamic and static bending stiffness of the proposed panels. Glass fibres in different lengths were mixed with the bark particles, to investigate their potential feasibility as reinforcement materials in the proposed bark-based panels.

2. Materials and methods

2.1. Materials

The whole bark samples used in this research were directly collected from the debarking units of a wide diameter range harvested poplar logs stored in a local sawmill at the area of Sopron, Hungary. The E-glass fibres roving (EC 14-300-350) used for this study was supplied by Tolnatext company (Tolna, Hungary). The investigated lengths of 12 mm (GF_12), 18 mm (GF_18), 24 mm (GF_24) and 30 mm (GF_30) were manually cut from the obtained fibreglass roving cylindrical packages. The commercial UF resin and hardener used in this work was purchased by DUKOL Ostrava s.r.o.

2.2. Bark panels manufacturing

Initially, the various thicknesses bark slices, comprising of inner and outer bark were collected and dried below 20% into a chamber. Consecutively, the inner and outer bark, were cut into small pieces and chipped into particles using a hammer mill equipped with an 8-mm screening holes. The granulated bark particles sized from 0.5 mm to 8 mm fractions were used as raw material for the manufacturing of bark panels. The moisture content of the bark particles was reduced the range of 6% to 9% before further processing.

The randomly oriented, chopped glass fibres with the prepared dimension lengths were placed and homogenized with the bark particles in a laboratory type blender for five minutes, before pressing. A 8% urea formaldehyde (UF) adhesive stirred with a 35% aqueous solution of ammonium sulfate $(NH_4)_2SO_4$ as catalyst, was sprayed on the mixture of bark particles and glass fibres.

Forthwith, the glued mixtures were manually layered and formed in a wooden frame into a mat. Thereafter, the frame was removed, and the mats were pre-pressed by hand to compact the materials without heat transfer. Following, the mats were transferred to a single-opening hydraulic hot press machines (Siempelkamp). The pressing temperature was set at 180 ℃ with a pressing time of 18 seconds per thickness millimetre at a maximum pressure of 2.86 MPa. Constant weight of bark particles and glass fibres were weighted to obtain the target density of 350 kg m^{-3}. Control panels at the target density of 350 kg/m^3 (C_350) were used as reference. Single-layered boards with dimensions of 500 mm x 500 mm x 20 mm were produced using approximately 1.6 ±0.5 kg of dried bark particles and 50 g glass fibres for each composite.

2.3. Measurements

All the composites panels were kept at standard climate conditions (20 ℃ and 65% relative humidity), until equilibrium moisture content (EMC) was achieved, prior to experimental measurements. The density and moisture content of each panel were determined according to the European standards EN 323:1993 and EN 322:1993, respectively.

2.3.1. Modulus of elasticity in static bending. The modulus of elasticity (MOE_{sb}) as well as modulus of rupture determination of obtained bark composite panels were characterized by a 3-point bending test (figure 1a), with a universal testing machine Instron 5506, in compliance with the appropriate European Standards EN 310 (1993) at a crosshead speed of 8 mm min^{-1}. MOE were calculated on specimen dimensions of 450 mm x 50 mm x 20 mm, according to the following equations:

$$MOE_{sb} = \frac{\Delta F}{\Delta \alpha}\ x\ \frac{L^3}{4 \cdot b \cdot d^3} \tag{1}$$

L is the span between supports (mm), *b* is the width of the specimens (mm), and *d* is the thickness of the specimens (mm), *ΔF* is the load increment and *Δα* is the deflection increment rate. Young's modulus was calculated from the elastic region of the stress-strain curves, corresponding to strains between approximately 10% and 40%.

2.3.2 Dynamic modulus of elasticity in longitudinal vibration. In this work, vibration non-destructive tests through resonant frequency signals were performed on the glass fibre reinforced bark-based panels using the 'Stress Wave Vibration Equipment' developed by Fakopp Enterprise Bt, Hungary. The setup is simple and accompanied with the necessary software which based on a Fast-Fourier Vibration analyser, that directly displays the maximum peak frequency intensity. The determination of the longitudinal (figure 1b) was conducted according to the manufacturer's manual instructions.

The calculation of dynamic modulus of elasticity in longitudinal vibration (MOE_{lv}) was performed according to the following equation:

$$MOE_{lv} = \rho\ (2\ L\ f)^2 \tag{2}$$

where ρ is the density, *L* the length of the specimens and *f* is the longitudinal vibration frequency.

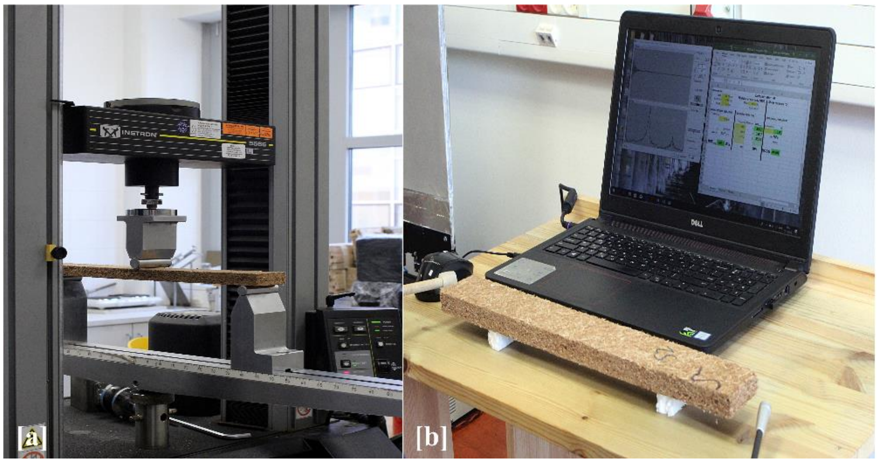

Figure 1 Determination of MOE through the desctructive [a] and non-destructive tests [b]

Regression analysis measurements were conducted to evaluate the correlation relationship between the static MOE_{sb} values as a function of dynamic longitudinal MOE_{lv} of the reinforced bark-based panels.

3. Results and discussion

For the determination of dynamic MOE_{lv}, the first vibration mode which represents its stiffness under compressive stress was measured, in consequence with the study on scantlings originating from *Eucalyptus* plantations [10]. Table 1 shows the mean density, MOR, MOE_{sb}, MOE_{lv} values of the results obtained from the investigated bark-based panels. Ratio values were determined from the division of MOE_{lv} by the MOE_{sb}. Coefficient of determinations (R^2) were linearly calculated to evaluate the correlation dependence of static MOE_{sb} as a function of the dynamic MOE_{lv} on the specimens in each group of panels.

Table 1 Reported mean values of the measured properties in this study. Standard deviations values are in brackets

Bark-panels	Density (kg/m^3)	MOR (MPa)	MOE_{lv} (MPa)	MOE_{sb} (MPa)	Ratio	R^2
C_350	372.11 (± 25.57)	1.20 (± 0.52)	398.05 (± 98.78)	200.15 (± 69.63)	2.09 (± 0.65)	0.50
GF_12	371.17 (± 19.49)	0.99 (± 0.32)	335.39 (± 59.02)	193.45 (± 48.58)	1.76 (± 0.16)	0.97
GF_18	385.01 (± 14.11)	0.93 (± 0.22)	323.56 (± 44.72)	166.45 (± 21.03)	1.94 (± 0.12)	0.84
GF_24	376.00 (± 14.77)	0.69 (± 0.24)	277.03 (± 65.95)	143.30 (± 30.98)	1.93 (± 0.17)	0.85
GF_30	373.54 (± 11.87)	0.68 (± 0.16)	295.20 (± 30.69)	285.43 (± 24.85)	1.03 (± 0.04)	0.89

As shown by the results the bark-based panels density was in the range of 350-400 kg/m^3. A possible explanation for the increased mean density of the produced panels related to the target density of 350 kg/m^3 could be the compression of bark particles during the hot pressing. Further, it was found that the addition of glass fibres exhibited opposite outcome, instead of the theoretically expected reinforcement on the mechanical properties of the bark panels. Additionally, the modulus of rupture was gradually decreasing by increasing the length of the glass fibres from 12 mm up to 30 mm. However, it seems that glass fibres did not occur any significant influence in the MOE, i.e. the stiffness of the investigated panels.

As illustrated by the results, the R^2 values in each group of panels were above 0.8 indicating strong correlation between the static and dynamic MOE measurements. The coefficients of determination resulted to be from 0.84 to 0.97. The only exception was in the case of control bark boards, in which the R^2 was defined as 0.50.

As it is generally expected, the estimated MOE_{lv} are higher than the calculated MOE_{sb}. This trend was verified for all the measured specimens. The mean averages of the ratio values of the C_350, GF_12, GF_18, GF_24 and GF_30 panels were relatively high compared to an investigation on commercial wood-based panels [14].

4. Conclusion

In this study, there was an attempt to assess the calculation of MOE values of bark based panels with a common and simple set-up non-destructive test method. The predicted R^2 indicated comparatively strong correlations between the dynamic and static modulus of elasticity values. Therefore, determination of MOE low density reinforced bark-based panels through acoustic (resonance frequency) tests could potentially be feasible. However, higher amount of specimens is necessary to enhance and further verify the MOE_{lv} and MOE_{sb} relationship through regression analysis statistics measurements. Results show the non-destructive testing for determination of mechanical properties needs further investigation. Testing method developed for structural material needs more sophisticated settings of parameters, but correlation could be found between tasting methods.

5. References

[1] Irle M and Barbu MC 2010 Wood-based panels: An introduction for specialists Thoemen M, Irle M and Sernek M (eds) Cost Action E49, Brunel University Press chapter 1 p 1
[2] Blanchet P, Cloutier A and Riedl B 2000 *Wood Sci. Technol.* **34** 11
[3] Muszynski Z and McNatt JD 1984 *Forest Prod. J.* **34** (1) 28
[4] Kain G, Güttler V, Barbu MC, Petutschnigg A, Richter K and Tondi G 2014 *Eur. J. Wood Prod.* **72** (4) 417
[5] Pásztory Z, Mohácsiné IR and Börcsök Z 2017 *Constr. Build. Mater.* **147** 733
[6] Ross RJ 2015 *Nondestructive evaluation of wood: second edition.* General Technical Report FPL GTR-238, Madison WI, USA, chapter 1 p 1
[7] Cavalheiro RS, De Almeida DH, De Almeida TH, Christoforo AL and Lahr FAR 2018 *CJAST* **26** (1)
[8] Mochan S, Moore J and Connoly T 2009 *FCTN18* Technical Note Forestry Commision
[9] Niemz and Mannes 2012 *J. Cult. Herit.* **13S** S26
[10] Hein PRG, Lima JT, Gril J, Rosado AM, Brancheriau L 2012 *Wood Sci. Technol.* **46** (4) 621
[11] Han G, Wu Q and Wang X 2006 *Forest Prod. J.* **56** (1) 28
[12] Bobadilla I, Arriaga F, Esteban M, Iñiguez G and Blázquez I 2012 *Forest Prod. J.* **62** (1) 69
[13] Ross RJ and Pellerin RF 1988 *Forest Prod. J.* **38** (5) 39
[14] Poggi F 2017 *MSc Dissertation* Linnaeus University Sweden

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