Evaluation of Pin Penetration Probing Technique for the Assessment of Basic Density in Air-dried Wood

Ebrahim Khosravi,[a] Mehran Roohnia,[b,]* Amir Lashgari,[c] Ahmad Jahanlatibari,[b] and Ajang Tajdini [c]

Fast and accurate evaluation of the physical and mechanical properties of engineering materials is of particular importance. The *in situ* semi-destructive and non-destructive tests *versus* the static tests for determining the time-consuming physical properties have replaced many traditional methods with reasonable accuracies. Determining the density as one of the most important qualitative and quantitative parameters in the inspection of wood and wood-based products is of great importance. For this purpose, 33 wood specimens from 11 species with varying densities were tested by pin penetration probing. Results were compared with those from the basic density values from traditional methods. The results showed an exponential relationship between the pin penetration depths and the basic density considering the moisture conditions but without any problems. The coefficients of determination while estimating the equality of the basic density *via* pin penetration probing with the actual basic density for both the testing specimens and the control samples were always over 0.8. Henceforth, this methodology suggested that the density evaluation could inspire higher precision than what has been achieved in previous efforts.

Keywords: Density; Exponential relationship; Non-destructive; Pin penetration; Wood

Contact information: a: PhD candidate, Department of Wood and Paper Science, Faculty of Agriculture and Natural Resources, Karaj Branch, Islamic Azad University, Karaj, Iran; b: Professor, Department of Wood and Paper Science, Faculty of Agriculture and Natural Resources, Karaj Branch, Islamic Azad University, Karaj, Iran; c: Associate Professor, Department of Wood and Paper Science, Faculty of Agriculture and Natural Resources, Karaj Branch, Islamic Azad University, Karaj, Iran;
** Corresponding author: mehran.roohnia@kiau.ac.ir*

INTRODUCTION

This study was initiated because the density of wood has been identified as an important irreplaceable physical parameter for *in situ* nondestructive evaluation of the residual mechanical strengths of wood inside standing structures, *e.g.*, wooden members in buildings or railway sleepers, *etc*. It is clear that one cannot pull out the wood member to directly calculate the mass and volume and then return it to the structure and re-embed it. Therefore, an indirect methodology for evaluating the density of wood is inevitably necessary. Assessing the dynamic modulus of elasticity without knowing the density of wood is impossible *via* Euler-Bernoulli's elementary theory or the Timoshenko's complicated theory of the flexural vibration or even for the longitudinal vibration method and stress wave velocity approach (Brancheriau and Bailleres 2002; Beall 2007; Roohnia *et al.* 2010, 2013; Roohnia 2014). The timber grading in the strength classes also uses the density of the specimen (EN 338 2003; Divos and Kiss 2010; Bailleres *et al.* 2012). There exists a successful approach for the dynamic evaluations of wood without knowing the density (Kubojima and Sonoda 2015; Kubojima *et al.* 2016, 2021). However, this approach is novel but still being effective only for a both ends free bar, which is out of the structural frame. This means that the density identification still remains as an unsolved problem, at least for *in situ* evaluations. Iniguez-Gonzalez *et al.* (2015) demonstrated that there is still a gap between laboratory tests and the *in-situ* assessment of timber inspection. The main problem is the evaluation of precise density.

Long ago, wood scientists attempted to indirectly evaluate precise density using the X-ray, Gamma, and other similar nuclear techniques (Mothershead and Stacey 1965; Divos *et al.* 1996; Beall 2007; Kruglowa 2012). Unfortunately, these efforts involved only small-scale research without good luck for the commercial large-scale projects because of severe risks and high expenses, especially in outdoor evaluations. This implies that the methods were applicable to the outdoor projects with lesser risks and the costs. In order to develop a nondestructive or semi-destructive evaluation for wood density, methods, such as core drilling and obtaining a core to measure the local density (Iniguez-Gonzalez *et al.* 2015), infra-red spectroscopy (López *et al.* 2013; Majdabadifarahani *et al.* 2019), screw withdrawal test (Cai *et al.* 2003; Kasal and Anthony 2004; Iniguez *et al.* 2015; Ribeiro *et al.* 2018), and pin probing test (Cown 1978; Hall 1988; Hansen 2002; Kasal and Anthony 2004; Makipaa and Linkosalo 2011; Fukatsu *et al.* 2011; Wu *et al.* 2010 and 2011; Kruglowa 2012; Hasnikova and Kuklik 2014; Warrier and Venkataramanan 2014; Chen *et al.* 2015; Iniguez-Gonzalez *et al.* 2015; Gao *et al.* 2017), were explored that are comparatively cheaper and safer technologies to evaluate the density indirectly.

After all, the density itself is defined in different contexts within which the operator must be aware of these variations. The basic density, the oven-dried density, the apparent density, local and global densities, *etc.*, have been previously introduced thoroughly (Tsoumis 1991), but unfortunately their dependence on the moisture content always contributes to deviations of the calculations of mechanical parameters in terms of the density to some amounts of error. Therefore, increasing the moisture content of wood increases the mass as the volume increases due to the swelling, but at different rates. Here, the basic density is an isolated parameter that might remain unchanged in some ranges of moisture contents, because it is derived from the oven-dried mass divided by the green volume. The basic density always demonstrates the lowest possible density of a sample in all levels of the moisture contents. The basic density is the one demonstrating the dry mass of the wood without any moisture in commercial purchases. It shows the dead load dedicated by the wood itself without any addition of the water to its original weight. Therefore, it would be promising to continue the investigations focusing on the basic densities of the wood specimens.

Among the above-mentioned nondestructive and semi-destructive methodologies, the thin pin probing method has been found to be cheap, safe, and lesser invasive to the building members. It is considered as a nondestructive method because it only makes the smallest pin-hole, which causes no significant damage to timber or living plants (Iniguez-Gonzalez 2015). This technique has been introduced for the standing trees and the sawn timber but has been found to be more promising in green wood from the standing trees. Its results for the sawn timber were always poor, but it is emphasized that such measurements should not be undervalued, because it was always simple and quick to apply and useful as a first approach to the question of *in situ* assessment.

This study aimed to highlight the developing possibility of this method even for the sawn timber, either *in situ* or removed from the building structures, benefiting the calibrated energy for pin penetration and considering the basic density of the samples (oven-dried mass divided by the green volume).

EXPERIMENTAL

Materials and Methods

A total of 33 cubic pieces of 11 different wood species with slightly different dimensions but showing full perfect radial, tangential and cross-sectional planes, were selected after air-drying regardless of their actual moisture content. The test samples were selected based on their density from the wood archive of the Wood-NDT laboratory at Islamic Azad University, Karaj, Iran, so that light to moderate and heavy density ranges are covered. Balsa, boxwood cypress, paulownia, ash, mulberry, poplar, beech, pine, oak, and maple were found among the test samples. An additional 15 specimens were also selected and kept as control samples.

Density measurements

The specimens were first dried to 0% moisture content (MC) in an oven at 62 °C for 72 h. They were then immersed in deionized water for three weeks to complete the swellings. The exact mass and dimensions of the specimens in the oven-dried, air-dried, and green conditions were collected. The apparent density (D_{mc}, Kg/m^3) in each of the moisture content conditions was calculated using the Eq. 1,

$$D_{\text{mc}} = \frac{m}{(b \times h \times l)}, \text{ mc} \geq 0 \tag{1}$$

where m is the mass of the specimen (kg), b, h, and l are the dimensions (m) and mc denotes the percentage of moisture content in the specimen, which varies from zero for the oven-dry condition to over the fiber-saturation point for the green specimens.

The basic density (D_b) was calculated from the oven-dried mass divided by the maximum swelled volume in green condition, as per Eq. 2,

$$\begin{aligned} D_{\text{b}} &= \frac{m_0}{(b \times h \times l)_{\text{g}}} \\ D_{\text{bmc}} &= \frac{m_{\text{mc}}}{(b \times h \times l)_{\text{g}}} \end{aligned} \tag{2}$$

where m_0 is the mass of the specimens at the 0% MC, while m_{mc} shows the mass at the particular moisture content (kg), b, h, and l with a subscript g, are the maximum swelled dimensions (m) at the green condition.

The apparent density in 12% moisture content (D_{12}) is rebuilt according to ISO-13910 (2005) standard that is substituted with similar definitions step by step in Eq. 3,

$$\begin{aligned} D_{12} &= D_{\text{mc}}\left(\frac{112}{100 + mc}\right) \\ D_{\text{b12}} &= D_{\text{bmc}}\left(\frac{112}{100 + mc}\right) \\ D_{\text{b}}(calculated) &= D_{\text{b12}}\frac{100}{112} \end{aligned} \tag{3}$$

where D_{b12} is introduced as an intermediate calculation step that will sometimes be needed to compensate some variations within the moisture contents, while the calculations in accordance with ISO 13910 (2005) are introduced in terms of the density at the 12% moisture content. It resembles the mass at 12% moisture content divided by the green volume of the specimens. Meanwhile, a D_b is also calculated to rebuild the basic density for the specimens other than the oven-dried samples. D_{bmc} is a similar definition of density that is presented here for the air-dried mass of a specimens, divided by its green volume.

Pin penetration probing

Pin penetration probing is a procedure in which a constant energy is employed to shoot a pin into the wood. The test correlates the hardness with the pin penetration depth to estimate the local density of wood. In current pin shooting devices, the constant shooting energy is provided by the potential energy of a compressed spring. As far as the spring potential and kinetic energies are attenuated during the repeated working, a simple setup to use the height potential energy is developed creatively. The height potential energy is much more reliable than the other sources of its available forms for this particular study . However ,this is not so convenient for horizontal measurement as is likely to occur for *in-situ* structural members. This disadvantage might be neglected, using the spring potential energy again, resembling the height potential energy, thereafter in industrial purposes.

Figure 1 demonstrates the pin penetration setup. A steel ball is released from a certain height in a tube and provides the kinetic energy required to drive a pin into the specimens. A narrow guide hole under the tube is also provided to ensure an absolutely straight penetration of the pin.

The potential energy of the steel ball ($E_p = Mgh$) can be converted to kinetic energy during the falling until it hammers the pin with the highest possible energy ($E_k \leq E_p$), which remains constant with the least observed repeatability error. In this case, the mass of the steel ball (M) was 0.1738 kg, it was released from a constant height (h) of 2 m, fell down with 9.81 m/s^2 of the gravity acceleration ($E_p = 0.1738 \times 9.81 \times 2 = 3.41$ J), and hammered a flattened tip pin in a uniform diameter of 1.6 mm, into the specimen.

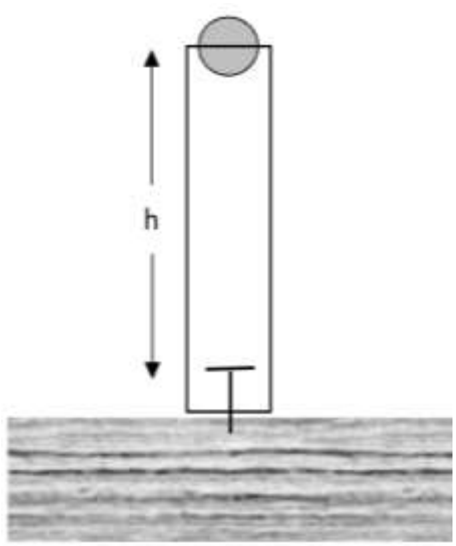

Fig. 1. Schematic view of the pin penetration test. The conical tip of the pin has been flattened to ensure a unique diameter across the pin length.

Because the provided setup operates by penetration, there is a suspicion that its action may be affected by the hardness of either the latewood or the earlywood bands encountered on the radial surface, as latewood density is appreciably greater. Iniguez-Gonzalez *et al.* (2015) and Karlinasari *et al.* (2021) showed no sign of the influence of reading direction (radial or tangential), but ensuring the uniformity of the tests, the pin penetrations were applied only on two opposite tangential surfaces in two or more replications for each sample. The maximum penetration depth for each sample was recorded for further analysis.

Considering the pin penetration depths *vs* basic and apparent densities of the first 33 specimens, a best-fitted regression model was developed using Microsoft Excel 2003 (Microsoft Corp., Redmond, WA, USA), which was re-evaluated using the 15 control specimens.

RESULTS AND DISCUSSION

Figure 2 shows the penetration depths in two opposite tangential faces of the specimens. They appear a bit different but indicated a high correlation coefficient; however, the extremely minor variation might be negligible. Ensuring a uniform set of data, even these small differences were not neglected where the maximum penetration depths in each replication were recorded for further analysis.

The basic density was illustrated as an exclusive diversity among the density varieties that might remain unchanged in different moisture contents, because it is always the oven-dried mass divided by the green volume. This parameter is based on the mathematical calculations from Eq. 3. Figure 3 shows no need to dispute this mathematically established claim. Either the calculated or the actual basic densities are the same for the specimens at the different moisture contents.

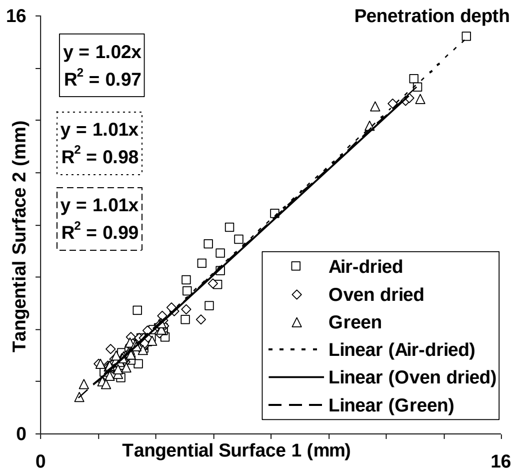

Fig. 2. Comparison of the penetration depth replications in two opposite tangential surfaces

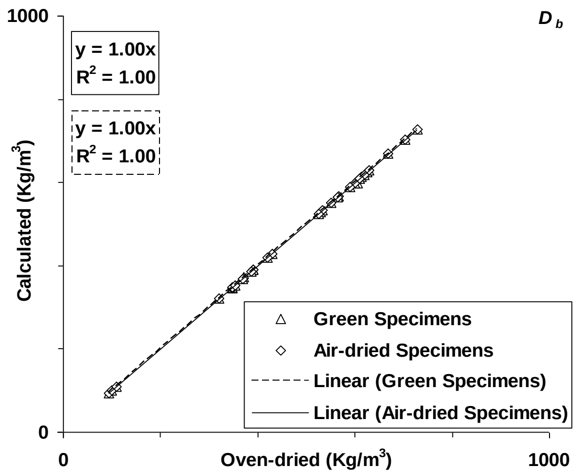

Fig. 3. Comparison of the equality of the re-built basic density (D_b) in different specimens with various moisture contents

The apparent and basic densities *vs.* the penetration depths are shown in Fig. 4 (a and b). The exponential relationship was the best-fitted model in both the scatter plots. It was noteworthy that the moisture contents of the specimens varied in a wide range, above zero, under the fiber saturation point. The moisture contents of the air-dried commercial sawn timbers are often within this range. The good correlation coefficients establishes the sufficiency of the fitted model where the exponential formula might estimate the density of the wood *via* pin penetration technique, as it is an approved methodology.

A problem occurs when the moisture content variations deviate from the estimated results. Previous studies (Iniguez-Gonzalez *et al.* 2015; Karlinasari *et al.* 2021) do not report any substantially good correlation coefficients in this subject. Therefore, Fig. 4b was preferred for D_{bmc} and D_{b12} estimations, because the basic density was calculated mathematically from D_{bmc} and D_{b12} in terms of different moisture contents of the specimens. It does the required moisture correction automatically, better than any statistical moisture modification. Based on Eq. 3, the basic density, D_b, must be calculated from D_{b12}, and D_{b12} itself must be calculated from D_{bmc}. In fact, the fitted model for the D_{bmc} took into account first, then D_{b12} or after that, D_b was evaluated for extra controls.

Considering the best-fitted correlation in terms of D_{bmc} and the moisture contents, the basic densities were re-estimated *via* pin penetration depths (d) in 33 original test specimens (Fig. 5a) and thereafter in extra 15 specimen controls (Fig. 5b), (Eq. 4):

$$
\begin{aligned}
D_{\text{bmc}}(estimated) &= 1162.67e^{-0.16d} \\
D_{\text{b12}}(estimated) &= D_{\text{bmc}}\frac{112}{100+mc} \\
D_{\text{b}}(estimated) &= D_{\text{b12}}\frac{100}{112}
\end{aligned}
\tag{4}
$$

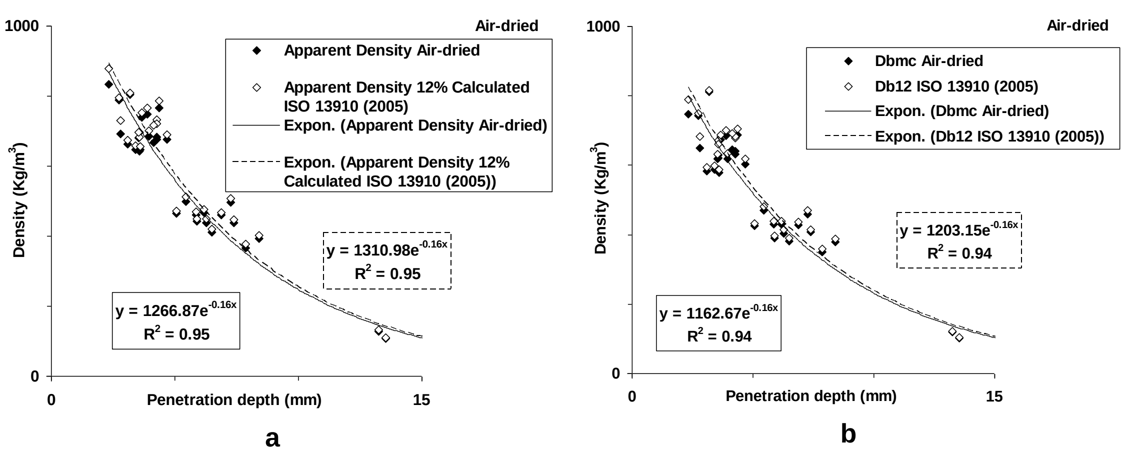

Fig. 4. The best-fitted regression models for the estimation of a - apparent and b - basic densities from the penetration depths

As indicated, the re-estimation *via* exponential model was sufficiently successful to estimate the basic density of the wood pieces with air-dried moisture conditions.

Regarding the importance of the *in situ* density estimation in structural members, the pin penetration methodology was chosen in this study because of its easy availability, simplicity, and low cost operation in comparison with the other non-destructive density evaluations. That is why this methodology ought not to be undervalued despite the fact that the estimation precisions were not high in previous work. To name a few poor determination coefficients reported between the estimated and the actual apparent densities, Iniguez-Gonzalez *et al.* (2015) ($R^2 = 0.3$) and Karlinasari *et al.* (2021) ($R^2 < 0.5$) are considered. These studies have often reported a poor linear correlation, while the exponential model might be fitted better on their scattered points of data, too.

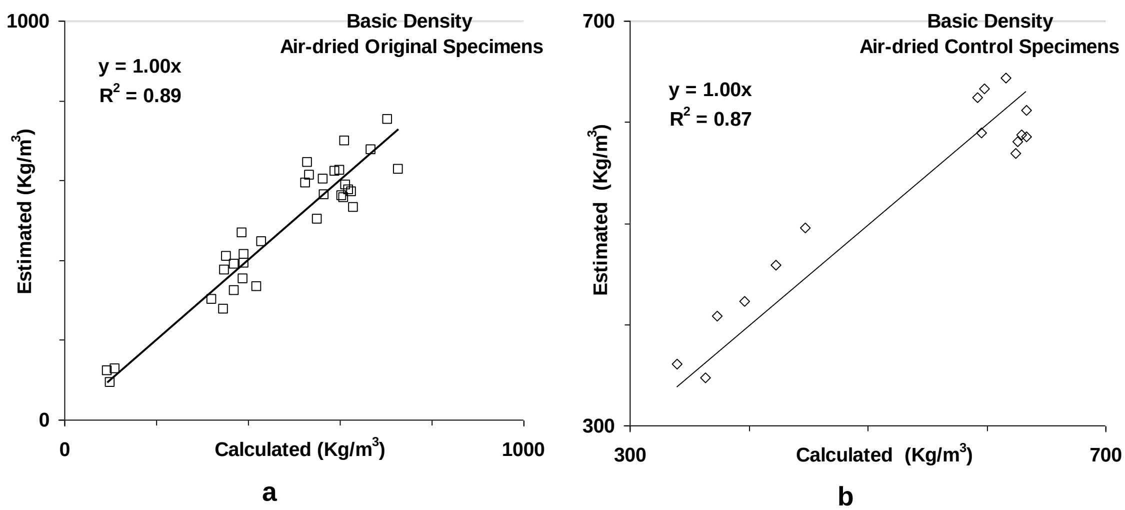

Fig. 5. Estimations of the basic densities through the best selected regression model (Eq. 4.): a: Original specimens and b: Control specimens

So, the authors assume the situation where users need to estimate the wood density for such wide range shown here in real usage of the method. Using a wide range of the densities from balsa to heavier species, the presented relationship and parameter are suggested to be utilizable in all industrial uses, and the low estimated error (at least a great step forward) would improve its industrial usage than what the older existed pin penetration methodology was.

The effect of the moisture content is also important in various applications where the specimen mass and the dimensions are affected. Thus, the exploitation of the basic density in terms of the oven-dried mass *vs* the green volume is considered promising. However, the higher determination coefficients for the green wood of the standing trees were also previously reported (Wu *et al.* 2011).

This fitted exponential model presented in this study was considered for the air-dried structural wood members. Meanwhile, the moisture contents of the original and control specimens were all within this range.

Considering the nature of the basic density, the application of this developed exponential model might be effective even for green specimens. The green wood is not the majority material in the structural wood members. That is why this topic is not followed or discussed in this particular research work. However, it is predicted that the deviations of the pin penetration depths due to the moisture content would be compensated using the density correction in accordance with ISO-13910 (2005) in Eq. 3.

CONCLUSIONS

Pin penetration probing technique was undertaken to estimate the basic densities of a variety of lightweight to heavy air-dried wood specimens. The following conclusions were attained in this study:

1. An exponential relationship was the best-fitted model while the density correction in terms of the moisture contents was the only modification applied.
2. The basic density estimation *via* pin penetration test showed higher determination coefficients ($R^2 = 0.94$) than what has been previously reported in the literature.
3. Considering the higher determination coefficients, beside the sufficient equality of the actual and estimated results, this introduced procedure inspires a bit higher precision than what was illustrated in previous efforts.

ACKNOWLEDGEMENTS

This study was part of the PhD thesis entitled: "*In situ* Timber Assessment for Residual Density and Mechanical Strength," performed at the Islamic Azad University, Karaj branch. The authors would like to express their sincere gratitude to Darkoob non-destructive testers Co., Ltd. for sharing the idea of this study.

REFERENCES CITED

Bailleres, H., Hopewell, G., Boughton, G., and Brancheriau, L. (2012). "Strength and stiffness assessment technologies for improving grading effectiveness of radiata pine wood," *BioResources* 7(1), 1264-1282. DOI: 10.15376/biores.7.1.1264-1282

Beall, F. (2007). "Industrial applications and opportunities for nondestructive evaluation of structural wood members," *Maderas. Cienc. Tecnol.* 9(2), 127-134. DOI: 10.4067/S0718-221X2007000200003

Brancheriau, L., and Bailleres, H. (2002). "Natural vibration analysis of clear wooden beams: A theoretical review," *Wood Sci. Technol.* 36, 347-365. DOI: 10.1007/s00226-002-0143-7

Cai, Z., Hunt, M., Ross, R., and Soltis, L. (2003). "Screw withdrawal – A means to evaluate densities of *in-situ* wood members," in: *Proceedings of the 13th International Symposium on Nondestructive Testing of Wood*, Berkeley, CA, USA, pp. 277-281.

Chen, Z. Q., Karlsson, B., Lundqvist, S. O., Gil, M. R. G., Olsson, L., and Wu, H. X. (2015). "Estimating solid wood properties using Pilodyn and acoustic velocity on standing trees of Norway spruce," *Ann. For. Sci.* 72, 499-508. DOI: 10.1007/s13595-015-0458-9

Cown, D. J. (1978). "Comparison of the Pilodyn and torsiometer methods for the rapid assessment of wood density in living trees," *N. Z. J. For. Sci*. 8(3), 384-391.

Divos, F., and Kiss, F. S. (2010). "Strength grading of structural lumber by portable lumber grading - effect of knots," in: *Proceedings of the Future of Quality Control*

for Wood and Wood Products, The Final Conference of COST Action E53, Edinburgh, UK, pp. 1-7.
Divos, F., Szegedi, S., and Raics, P. (1996). "Local densitometry of wood by gamma back-scattering," *Holz. Roh. Werkst.* 54, 279-281. DOI: 10.1007/s001070050183
EN 338 (2003). "Structural timber - Strength classes," European Committee for Standardization, Brussels, Belgium.
Fukatsu, E., Tamura, A., Takahashi, M., Fukuda, Y., Nakada, R., Kubato, M., and Kurinobu, S. (2011). "Efficiency of the indirect selection and the evaluation of the genotype by environment interaction using Pilodyn for the genetic improvement of wood density in *Cryptomeria japonica*," *J. For. Res.* 16, 128-135. DOI: 10.1007/s10310-010-0217-6
Gao, S., Wang, X., Wiemann, M., Brashaw, B., Ross, R., and Wang, L. (2017). "A critical analysis of methods for rapid and nondestructive determination of wood density in standing trees," *Ann For. Sci* .74(27), 1-13. DOI: 10.1007/s13595-017-0623-4
Hall, P. J. (1988). "Using the Pilodyn tester in selecting plus trees," *Northern Journal of Applied Forestry*. 5(3), 170-171, DOI: 10.1093/njaf/5.3.170
Hansen, C. P. (2002). *Application of the Pilodyn in Forest Tree Improvement - Danida Forest Seed Centre*) Technical Note No. 55), Danida Forest Seed Centre, Humlebaek, Denmark.
Hasnikova, H., and Kuklik, P. (2014). "Various non-destructive methods for investigation of timber members from a historical structure," *Wood Res-Slovakia* 59(3), 411-420.
Iniguez-Gonzalez, G., Monton, J., Arriaga, F., and Segues, E. (2015). "*In-situ* assessment of structural timber density using non-destructive and semi-destructive testing," *BioResources* 10(2), 2256-2265. DOI: 10.15376/biores.10.2.2256-2265
ISO 13910 (2005). "Structural timber - Characteristic values of strength-graded timber - Sampling, full-size testing and evaluation," International Organization for Standardization, Geneva, Switzerland.
Karlinasari, L., Fredisa, Y., Adzkia, U., Fauziyyah, S., Dwiyanti, F. G., and Siregar, I. (2021). "Use of a pin-penetration wood density meter to determine the density of 25 Indonesian species," *BioResources* 16(2), 3032-3045. DOI: 10.15376/biores.16.2.3032-3045
Kubojima, Y., Kato, H., Tonosaki, M., and Sonoda, S. (2016). "Measuring Young's modulus of a wooden bar using flexural vibration without measuring its weight," *BioResources* 11(1), 800-810. DOI: 10.15376/biores.11.1.800-810
Kubojima, Y., and Sonoda, S. (2015). "Measuring Young's modulus of a wooden bar using longitudinal vibration without measuring its weight," *Eur. J. Wood Wood Prod.* 73, 399-401. DOI: 10.1007/s00107-015-0884-2
Kubojima, Y., Sonoda, S., and Kato, H. (2021). "Measuring density and Young's modulus of a log through the vibration test without measuring its weight," *J. Wood Sci.* 67(6), 1-13. DOI: 10.1186/s10086-020-01929-5
Kasal, B., and Anthony, R. (2004). "Advances in *in situ* evaluation of timber structures," *Prog. Struct. Engin. Mater.* 6, 94-103. DOI: 10.1002/pse.170
Kruglowa, T. (2012). *In-Situ Assessment of Density and Material Properties in Timber Structures by Nondestructive and Semi-Destructive Testing*, Ph.D. Dissertation, Department of Civil and Environmental Engineering, Chalmers University of Technology, Gothenburg, Sweden.

López, G., Basterra, L. A., and Acuna, L. (2013). "Estimation of wood density using infra-red thermography," *Constr. Building Mater.* 42(2), 29-32. DOI: 10.1016/j.conbuildmat.2013.01.001

Majdabadifarahani, P., Roohnia, M., and Lashgari, A. (2019). "Thermography as a non-destructive method in the evaluation of oak and beech wood density," *Iranian Journal of Wood and Paper Science Research* 34(1), 89-99. DOI: 10.22092/IJWPR.2019.124574.1511

Makipaa, R., and Linkosalo, T. (2011). "A non-destructive field method for measuring wood density of decaying logs," *Silva Fenn.* 45(5), 1135-1142. DOI: 10.14214/sf.91

Mothershead, J. S., and Stacey, S.S. (1965). "Applicability of radiography to inspection of wood products," in: *Proceedings of the 2nd International Non-destructive Testing of Wood*, Pullman, WA, USA, pp. 307-331.

Ribeiro, M. L., Del Menezzi, C. H. S., Siqueira, M. L., and Melo, R. (2018). "Effect of wood density and screw length on the withdrawal resistance of tropical wood," *NativaSinop* 6(4), 402-406. DOI: 10.31413/nativa.v6i4.5638

Roohnia, M. (2014). "An estimation of dynamic modulus of elasticity in cantilever flexural timber beams," *Drvna Industrija* 65(1), 3-10. DOI: 10.5552/drind.2014.1229

Roohnia, M., Yaghmaeipour, A., Kubojima, Y., and Tajdini, A. (2013). "Free vibration of both-ends clamped wooden beams: Is it potentially applicable as an *in situ* assessment method?," *Turk. J. Agric. For.* 37, 121-125. DOI: 10.3906/tar-1111-22

Roohnia, M., Yavari, A., and Tajdini, A. (2010). "Elastic parameters of poplar wood with end-cracks," *Ann. For. Sci.* 67(409), 1-6. DOI: 10.1051/forest/2009129

Tsoumis, G. (1991). *Science and Technology of Wood*, Van Nostrand Reinold, New York, NY, USA.

Warrier, K., and Venkataramanan, K. S. (2014). "Use of Pilodyn for rapid and reliable estimation of wood basic density in clones of *Casuarina equisetifolia*," *Int. J. Curr. Res.* 6(9), 8269-8272.

Wu, S., Xu, J., Li, G., Risto, V., Lu, Z., Li, B., and Wang, W. (2010). "Use of the pilodyn for assessing wood properties in standing trees of *Eucalyptus* clones," *Journal of Forestry Research.* 21, 68-72. DOI: 10.1007/s11676-010-0011-5

Wu, S., Xu, J., Li, G., Risto, V., Lu, Z., Li, B., and Eang, W. (2011). "Estimation of basic density and modulus of elasticity of eucalypt clones in Southern China using non-destructive methods," *J. Trop. For. Sci.* 23(1), 51-56

Article submitted: May 16, 2021; Peer review completed: July 18, 2021; Revisions accepted: July 30, 2021; Published: August 4, 2021.
DOI: 10.15376/biores.16.4.6577-6586