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Modulus of elasticity as a criterion for strength grading of structural sawn timber

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Abstract: *Modulus of elasticity as a criterion for strength grading of structural sawn timber.* The paper presents an analysis that was performed on sawn timber originating from the Silesian Forest District in terms of parameters related to the elastic properties of the material. As part of the research, static modulus of elasticity (in accordance with EN 408: 2010 + A1: 2012) and dynamic modulus (using a portable device for machine strength grading) were determined. Both elasticity modulus were correlated with the density of the material, and compared with the database developed on the basis of previous research carried out at Faculty of Wood Technology of WULS- SGGW, including the results of strength grading of sawn timber from five natural Polish forest regions.

Keywords: strength grade, static and dynamic modulus of elasticity, wood density

INTRODUCTION

Due to the anisotropic structure and defects existing in wood, it can exhibit very high variability of mechanical properties, even within the same species. In compliance with the legislation currently in force in Poland and the EU countries, only strength graded sawn timber, whose strength is guaranteed, is allowed for use in construction applications. There are two strength grading methods: visual (appearance) strength grading and machine strength grading.

The visual strength grading method consists in a visual assessment of each board and its classification to the respective sorting class based on structural defect of wood, as well as shape and processing defects. In visual grading, the following wood features and defects are taken into account: knots, grain deviation, cracks and fissures, resin pockets, bark pockets, rot and insect tunnels, shape deviations etc. Shape and processing defects are wanes, longitudinal (sides and planes) curvatures, transversal curvatures, twists and other cutting defects, such as mechanical damage or exceeding dimensional tolerances. As a result of visual grading, timber is sorted into specific sorting classes. Each of the EU countries has its own national regulations regarding strength grading of sawn timber by visual method. Following this, there are distinct sorting classes in different countries and there are different methods of assessing timber features, eg knottiness. In PN (Polish standard) and BS (English standard), the knottiness is defined as the ratio of the surface of knots to the cross-sectional area of sawn timber, in DIN (German standard) and ÖNORM (Austrian standard), as the ratio of the corresponding linear dimensions of knots and timber. In Poland, strength grading by visual method is carried out on the basis of PN/D-94021:2013 standard, in Germany: DIN 4074-1:2012-06, in England: BS 4978:2007+A2:2017, in Austria: ÖNORM DIN 4074:2012-09-01 etc. Sorting classes in Poland are: KW - high quality, KS - medium, KG - low, in Germany: S13, S10 and S7, in England: GS and SS, w Austria S13, S10 and S7 (Krzosek 2009). Each class has a specific strength characteristic. Strength grading of timber by visual grading method, as well as by machine method, is classified as non-destructive tests.

When classify full-size sawn timber, only non-destructive evaluating methods can be used. Non-destructive methods of testing polish sawn timber in context of strength grading, even before introduction of European standards, were studied by Dzbenski (Dzbenski 1984, 1990) and Szukala (Szukala 1995). In non-destructive testing of sawn timber the most important factor influencing strength grade is the modulus of elasticity. Modulus of elasticity is highly correlated with other physical and mechanical properties of wood, including bending strength (Table 1).

Table 1. Coefficients of correlation between selected wood features and its strength with respect to boards and logs of European conifers (Glos, 1982).

Property	Correlation with bending strength	tensile strength	shear strength
density	0,5	0,5	0,6
annual ring width	0,4	0,5	0,5
knottiness	0,5	0,6	0,4
fiber deviation	0,2	0,2	0,1
modulus of elasticity	0,7 - 0,8	0,7 - 0,8	0,7 - 0,8
density + knottiness	0,7 - 0,8	0,7 - 0,8	0,7 - 0,8
modulus of elasticity + density	0,7 - 0,8	0,7 - 0,8	0,7 - 0,8
modulus of elasticity + knottiness	> 0,8	> 0,8	0,8

Due to the large variety of strength grades being the effect of visual grading in Europe, there was a need to unify these classes. The unification consists in assigning individual strength grades from different countries to the strength grades C introduced in the EN 338: 2016 standard. The last amendment to this standard comes from 2016 (in Poland PN-EN 338: 2016 Timber structures - Strength classes). The assignment of strength grades from different countries to strength classes C valid in the entire EU can be found in the EN 1912 standard (in Poland PN-EN 1912 Structural Timber. Strength classes. Assignment of visual grades and species). The last amendment to this standard took place in 2013 (EN 1912: 2012 + AC: 2013). Polish strength grades, up to now are not included in this standard. Research on introduction of strength grades KW, KS and KG into EN 1912 standard has been undertaken in Poland for years (Szukala and Szuminski 2003, Dzbenski 2006, Krzosek 2009, Noskowiak and Szuminski 2006, Noskowiak et al. 2010). Similar research on sawn timber of various species has also been carried out in other European countries before (Bacher 2009, Glos et al. 1998, Ranta-Maunus 2007, Ranta-Maunus et al. 2011, Rohanova 2008). Such tests involve grading a batch of timber of a given origin into strength classes KW, KS and KG and then determining for each of the sawn timber piece its MOE (modulus of elasticity), MOR (bending strength) and density. Based on these characteristics in accordance with the procedure given in the standard EN 384:2016 Structural timber. Determination of characteristic values of mechanical properties and density, the characteristic values are determined. Such activities are currently undertaken at the Faculty of Wood Technology SGGW in Warsaw within the BIOSTRATEG 3 project. This paper presents comparison between MOE_{EN-408} (modulus of elasticity) obtained during static bending tests and MOE_{dyn} (dynamic modulus of elasticity) determined using MTG device (Mobile Timber Grader) for pine wood derived from the Silesian Forest Region. MTG device works on the principle of stress wave activating with the fixed quantity of energy and recording the vibration. Strong correlation was observed between modulus of elasticity of sawn timber and stress wave characteristic (Krzosek and Grzeskiewicz 2008, Krzosek et al. 2008, Krzosek 2009).

CHARACTERISTICS OF THE RESEARCH MATERIAL

A batch of sawn pine timber originating from the Silesian Forest Region was the subject of research. Sawn timber was obtained from raw sawmill materials IV and V of the age class, from mixed fresh forest located in Directorate-General of the State Forests in Katowice (Olesno Forest District, Sternalice Forest Region stand 14d). Sawn timber was dried under industrial conditions, in a wood drying kiln, to a moisture content of approx. 12%, and planed. Nominal dimensions of sawn timber after drying and planing were 40 x 138 x 3500 mm. Total number of 210 boards was tested.

SCOPE OF RESEARCH

The scope of research included determination of:

1.sawn timber moisture content

2. sawn timber density

3. MOE_{EN-408} during static bending

4. MOE_{dyn} using MTG device from Brookhuis Electronics BV

RESEARCH METHODOLOGY

1. Determination of timber moisture content was carried out using Tanel resistance moisture meter, type HIT5, with a measurement accuracy of 0.1%. During the measurement, the species of wood tested and the ambient temperature were taken into account. The measurement involved punching electrodes in wood in the area half the length of the board, in a spot free of defects (eg knots). The results are presented in Table 2.
2. The density of each piece of sawn timber was determined by a stereometric method. The VIS electronic caliper with the range of 0-30 cm and a measurement accuracy of 0.01 mm was used, a measuring tape with a length of 5 m and a measurement accuracy of 1 mm and an electronic weighing scale KERN DE60K20N from Brookhuis Electronics BV with a measuring range from 0 to 60 kg and measuring accuracy 0.02 kg. After measuring all three dimensions of sawn timber, it was put on the scale and mass was read on the device's display. With the dimensions and weight of the sawn timber, the necessary calculations were made. The results are presented in Table 2.
3. Determination of modulus of elasticity (MOE_{EN-408}) during static bending was carried out with the use of a 10-ton TIRA Test 2300 testing machine, in accordance to PN-EN 408:2010+A1:2012 Timber structures – Structural timber and glued laminated timber – Determination of some physical and mechanical properties. The results are presented in Table 3.
4. Determination of the dynamic modulus of elasticity (MOE_{dyn}) was performed using the Mobile Timber Grader (MTG) from Brookhuis Electronics BV. The results of the study are presented in Table 3.

RESULTS AND ITS ANALYSIS

The results of moisture and density determination of pine timber are presented in Table 2.

Table 2. Results of moisture and density determination.

Property tested	Moisture content [%]	Density [kg/m^3]
average	11.6	546.8
standard deviation	1.4	61.7
coefficient of variation	12.0	11.3 [%]

The average moisture content of the entire batch of sawn timber was 11.6% and the average density was 546.8 kg/m^3. On the basis of data obtained in previous years at Faculty of Wood Technology of WULS during the study of timber originating from 5 other forest regions, it was found that density of raw material originating from the Silesian Forest Region had a value comparable to the density of timber derived from Baltic Forest Region (524 kg/m^3) and Greater Poland - Pomeranian Forest Region (522 kg/m^3). Density variation coefficient for the tested batch was 11.3% and was comparable to the coefficient of variation on the average density of timber tested at Faculty of Wood Technology of WULS in previous years (13%).

Table 3. Results of modulus of elasticity determination.

Property tested	MOE $_{EN\text{-}408}$ [MPa]	MOE_{dyn} [MPa]
average	11915	13105
standard deviation	2440	2645
coefficient of variation	20 [%]	20 [%]

The average value of MOE $_{EN\text{-}408}$ of the tested timber was 11915 MPa while the average value of MOE_{dyn} was 13105 MPa with a coefficient of variation of 20% for both modules. Compared to the results of a dynamic and static modulus of elasticity of timber originating from five other forest regions (Krzosek 2009), the tested timber derived from the Silesian Forest Region was characterized by the highest average values of both the dynamic and static modulus of elasticity. In previous studies, the highest value of dynamic modulus of elasticity (11958 MPa) as well as static modulus of elasticity (11126 MPa) showed timber originating from the Greater Poland - Pomeranian Forest Region. For a more thorough analysis of the results, the relationship between the density of tested timber and the dynamic and static modulus of elasticity was verified. Obtained dependences are presented in figures 1 and 2.

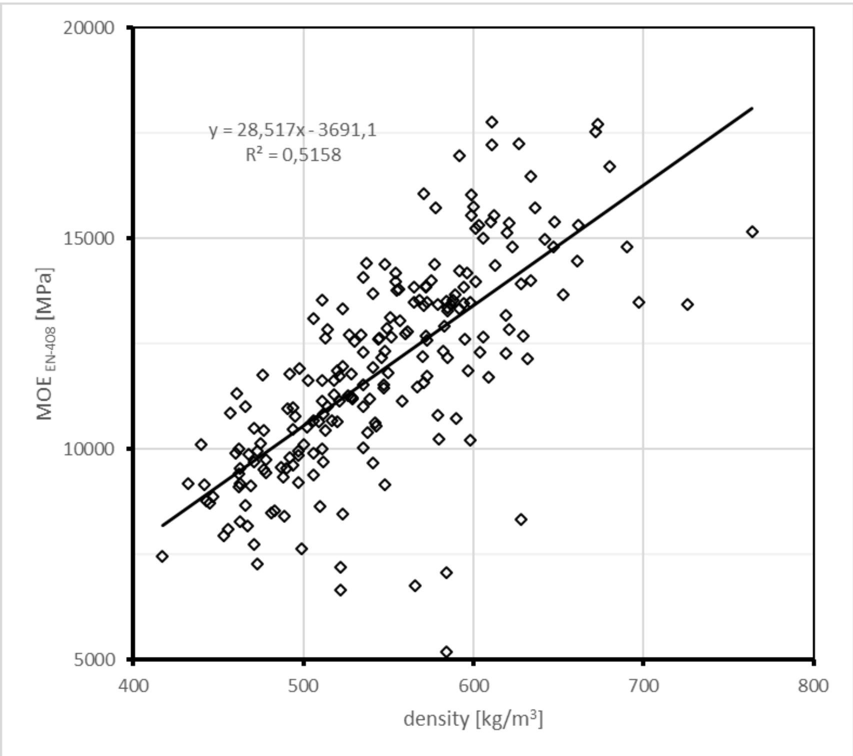

Figure 1. Dependence of the static modulus of elasticity on the density of the tested sawn timber.

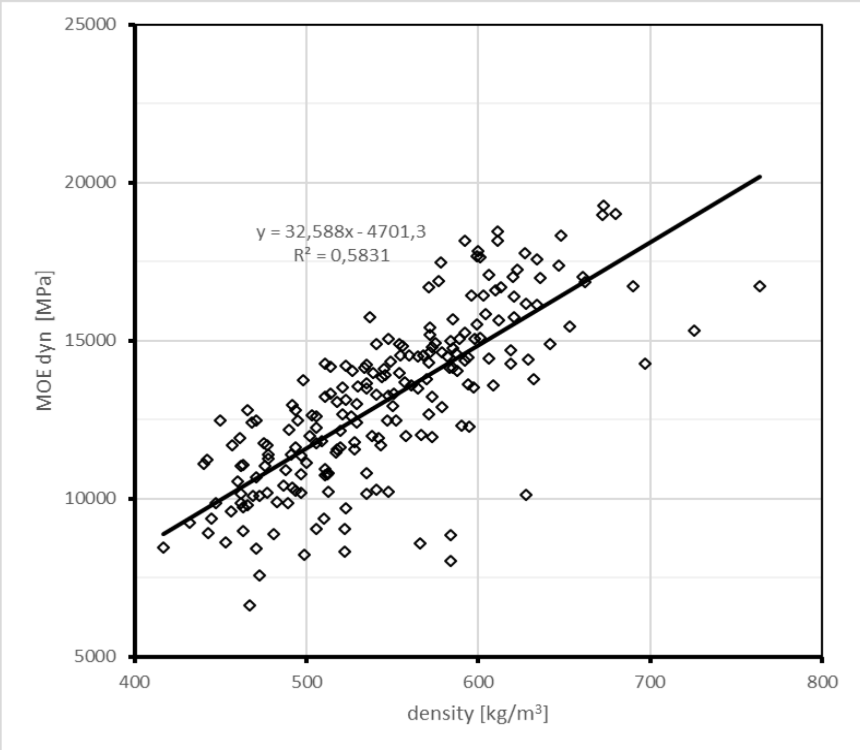

Figure 2. Dependence of the dynamic modulus of elasticity on the density of the tested sawn timber.

For a sawn timber derived from Silesian Forest Region it was found that the correlation coefficient between density and static modulus of elasticity was 0.72 and was lower than the highest correlation coefficient obtained in previous studies for sawn timber from Baltic Forest Region (R = 0.84). The correlation coefficient between density and dynamic modulus of elasticity for sawn timber from the Silesian Forest Region was 0.76. In previous studies, for a entire batch of timber from five other forest regions, the analogous correlation coefficient was 0.78.

CONCLUSIONS

1. Sawn timber from Silesian Forest Region was characterized by the highest average density (546.8 kg/m^3) in relation to average density of timber from five other forest regions tested in the past on Faculty of Wood Technology of WULS.
2. Sawn timber from Silesian Forest Region was characterized by the highest average values of both determined modulus of elasticity (dynamic 13105 MPa, static 11915 MPa) in relation to the average values of modulus of elasticity obtained for timber from five other forest regions tested in the past on Faculty of Wood Technology of WULS.
3. Correlation coefficients between both determined modulus of elasticity and density of timber originating from Silesian Forest Region were comparable to the analogical correlation coefficients obtained in previous studies on timber from other natural forest regions in Poland.

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Streszczenie: *Współczynnik sprężystości jako kryterium sortowania wytrzymałościowego tarcicy.* Praca dotyczy analizy surowca drzewnego pochodzącego ze śląskiej krainy przyrodniczo-leśnej pod kątem parametrów związanych z właściwościami sprężystymi materiału. W ramach badań określono dwa współczynniki sprężystości – statyczny (wyznaczony zgodnie z normą EN 408:2010+A1:2012) i dynamiczny (wyznaczony za pomocą przenośnego urządzenia do wytrzymałościowego sortowania tarcicy metodą maszynową). Oba współczynniki sprężystości zostały skorelowane z gęstością materiału, po czym porównane z bazą danych opracowaną na podstawie wcześniejszych badań przeprowadzonych na WTD SGGW w Warszawie, zawierającą wyniki sortowania wytrzymałościowego tarcicy pochodzącej z pięciu innych krain przyrodniczo-leśnych Polski.

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