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COMPARATIVE STUDIES OF VISUAL AND MACHINE STRENGTH GRADING OF PINE STRUCTURAL SAWN TIMBER

In the EU countries structural timber used in construction have to comply with regulations arising from the Regulation No 305/2011 of the European Parliament and of the Council. One of the basic requirements for structural timber is the need for strength grading which can be performed either by visual or machine method. The paper presents the results of visual and machine grading of structural pine timber originated from Masovian-Podlaska natural forest region of Poland. Obtained results extend the database of mechanical properties of Polish structural pine timber necessary for introduction of Polish visual grades into the standard EN 1912.

Keywords: structural timber, visual grading, machine grading, bending strength

Introduction

For safety reasons, in accordance with legal regulations, only timber with guaranteed strength, that is CE marked, may be used as structural members in construction in the EU. Permission for CE marking is granted to the

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manufacturer of sawn timber who meets all the requirements resulting from the construction materials control system 2+ (in accordance with the Regulation No 305/2011 of the European Parliament and of the Council). One of the basic requirements for structural timber is the need for strength grading [Baltrušaitis and Pranckevičienė 2003] which can be performed either by visual or machine method.

The visual method is based on visual assessment of size and distribution of wood defects, shape defects and defects resulting from machining. Then sawn timber is classified to a specific grading class [Dzbeński et al. 2005; Noskowiak 2011]. In Poland, visual grading rules are covered by the standard PN-D-94021:2013 "Visual strength graded coniferous sawn timber for structural use". This standard defines three classes (KW, KS, KG) and reject. There are similar national standards for visual grading in each EU country. All these standards must comply with the standard EN 14081-1:2016 "Timber structures – Strength graded structural timber with rectangular cross section – Part 1: General requirements". Due to variety of visual grades throughout the Europe, unification of these classes is needed. It consists in the assignment of visual grades from different countries to the strength classes included in the standard EN 338:2016 "Structural timber – Strength classes". This assignment for most EU countries can be found in EN 1912:2012+AC:2013 "Structural Timber – Strength classes – Assignment of visual grades and species". There is still lack of Polish visual grades in that standard. It is currently practiced in Poland to assign visual grades according to the standard PN-D-94021:2013 to strength classes according to the standard EN 338, in accordance with the table NA 2 in the national annex to the standard PN-EN 1995-1-1:2010 "Eurocode 5: Design of timber structures – Part 1-1: General – Common rules and rules for buildings". According to this table, the grades KW, KS and KG correspond to the strength classes C35, C24 and C20, respectively.

The method of machine grading involves the use of specialized device which determines in a non-destructive way the characteristics of timber correlated with bending strength [Glos 1982; Ranta-Maunus 2007; Ranta-Maunus 2009; Ranta-Maunus et al. 2011; Rohanova 2010; Rohanova 2014]. The rules of machine strength grading, machine control methods and their admittance for use are regulated by a group of European standards EN 14081-1, 2 and 3. Individual machines obtain approval for use for specific species of timber and specific countries of origin. Approved machines perform strength grading of timber into strength classes C or other special classes (L, T). Currently, there are many types of such machines in use on the European market [Denzler et al. 2005]. Most of them operate on the basis of the measurements of static or dynamic modulus of elasticity [Krzosek 2009].

Structural timber in Poland is almost exclusively visual graded. Only few sawmills have already purchased or are preparing to buy devices for machine grading of structural timber [Bekas 2016]. Hence, knowledge about correlations between the results of machine and visual grading is of great practical importance.

The goal of this study is to extend the database of mechanical properties of Polish structural pine timber necessary for introduction of Polish visual grades KW, KS and KG into the standard EN 1912. In addition, machine grading of timber was performed.

Materials and methods

Pine sawn timber [*Pinus sylvestris* L.] with nominal dimensions of 50 mm × 150 mm × 5000 mm as typical for structural applications (e.g. for the production of trusses jointed with connector plates) was chosen for testing. One sample consisting of 50 pieces of timber was obtained from Masovian-Podlaska natural-forest region. Sample size was 50 pieces. The timber was kiln dried to moisture content of (18 ± 3)%.

Visual grading of the timber was carried out in accordance with the standard PN-D-94021:2013. This standard meets all the rules set out in Annex A of the standard EN 14081-1. It introduces three grades: KW, KS and KG, for which the main grading criteria are indicators of knot area ratio (Table 1).

Table 1. Criterial values of knot area ratio of the timber according to PN-D-94021:2013

Knot Area Ratio	Visual grade				
	KW	KS		KG	
		Option 1	Option 2	Option 1	Option 2
margin KAR	≤1/4	≤1/4	≤1/2	≤1/2	>1/2
total KAR	≤1/4	≤1/3	≤1/4	≤1/2	≤1/3

Machine grading was carried out using Mobile Timber Grader (MTG 920) by Brookhuis Microelectronics BV. MTG operates on the principle of determination of dynamic modulus of elasticity by measuring the natural frequency of tested board. The vibrations are generated by a dynamic impact on one end of the board. The device has already been used for machine grading of Polish sawn timber in earlier studies [Krzosek et al. 2008; Krzosek 2009; Noskowiak 2013]. As a result of grading with the use of MTG, tested sawn timber was graded into strength classes C according to the settings adopted by the manufacturer for Scandinavian pine timber. So far, the device has not yet been approved for Scots pine from Poland.

The tests of bending strength and local modulus of elasticity in bending were carried out according to the standard EN 408:2010+A1:2012 “Timber structures

– Structural timber and glued laminated timber – Determination of some physical and mechanical properties”. Deflection measurements were made in the pure bending zone (local deflection).

Density, moisture content and width of annual rings were determined according to the standards ISO 13061-2:2014 “Physical and mechanical properties of wood – Test methods for small clear wood specimens – Part 2: Determination of density for physical and mechanical tests”, EN 13183-1:2004 “Moisture content of a piece of sawn timber – Part 1: Determination by oven dry method”, EN 13183-2:2004 “Moisture content of a piece of sawn timber – Part 2: Estimation by electrical resistance method” and EN 1309-3:2018 “Round and sawn timber - Methods of measurements – Part 3: Features and biological degradations” respectively.

Modulus of elasticity, static bending strength and density were adjusted in accordance with the rules specified in the standard EN 384:2016 “Structural timber – Determination of characteristic values of mechanical properties and density”.

Results and discussion

Results of visual and machine strength grading are shown in Tables 2 and 3 respectively.

Table 2. Visual grading of the timber according to PN-D-94021:2013

Grading class	Reject	KG (C20)	KS (C24)	KW (C35)
Quantity [pcs]	1	5	11	33
Percentage [%]	2	10	22	66

Table 3. Machine strength grading of the timber (MTG 920)

Strength class	Reject	C18	C24	C30	C35	C40
Quantity [pcs]	0	3	12	16	15	4
Percentage [%]	0	6	24	32	30	8

Based on the results presented in Tables 2 and 3, it was not clearly confirmed for the tested sample, that for Polish pine sawn timber better yield of higher strength classes is obtained for machine grading than for visual grading according to PN-D-94021:2013,. In the tested sample 66% of the pieces were classified to the class C35 for visual grading while 38% of the pieces were classified to the classes C35 and C40 for machine grading. Therefore, the relations observed in previous studies was not confirmed [Krzosek 2009; Noskowiak et al. 2010]. Machine grading resulted in reduction in the amount of sawn timber classified as reject, which contributes to more rational use of wood in construction. With machine grading it is possible to obtain higher strength classes, e.g. C40, which is not possible with visual grading.

As part of further analyses of the results, relationship between static local modulus of elasticity in bending and dynamic modulus of elasticity (determined using the MTG device) was established (Fig. 1). Relationships between bending strength and density in relation to both moduli of elasticity (Fig. 2-5) were also determined.

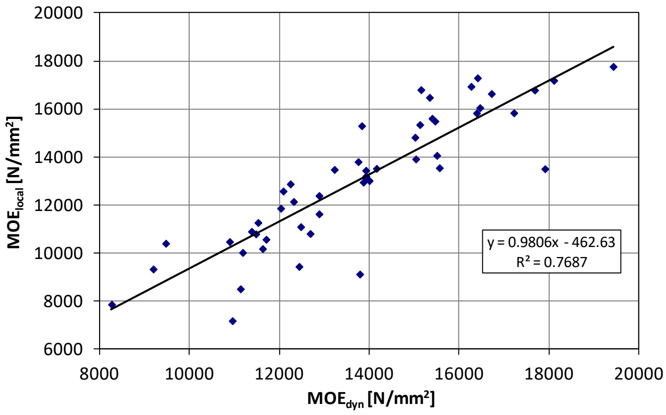

Fig. 1. Relationship between local modulus of elasticity in bending (MOE_{local}) and dynamic modulus of elasticity (MOE_{dyn})

Quite high coefficient of determination (0.7687) between static and dynamic modulus of elasticity was obtained for the tested timber sample. This indicates high reliability of the results of timber testing using the MTG device. A similar value of the coefficient of determination (0.7744) for the dependence between the local static modulus of elasticity and the dynamic modulus of elasticity was obtained from previous studies on pine structural timber originating from various natural-forest regions of Poland [Krzosek et al. 2008; Krzosek 2009; 2011].

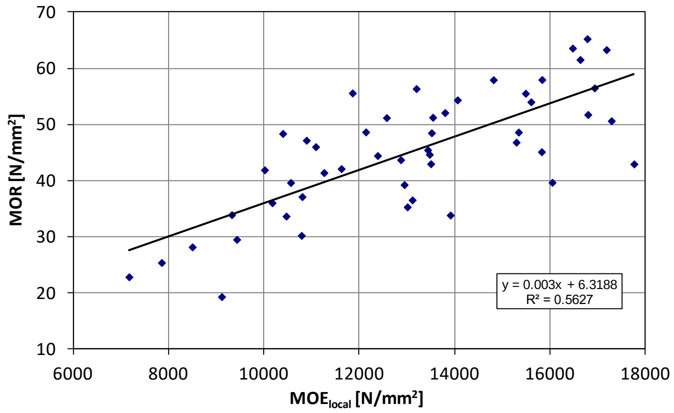

Fig. 2. Relationship between bending strength (MOR) and local modulus of elasticity in bending (MOE_{local})

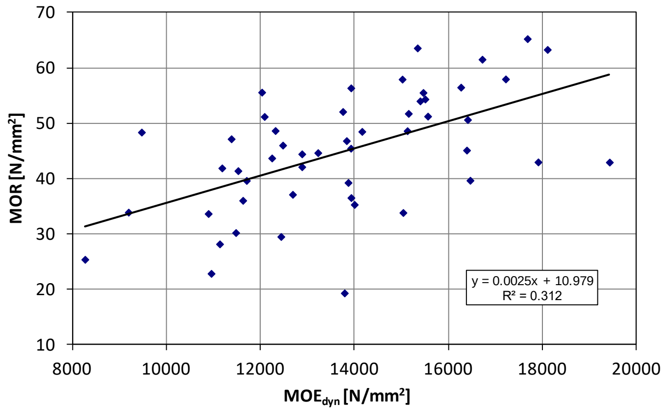

Fig. 3. Relationship between bending strength (MOR) and dynamic modulus of elasticity (MOE_{dyn})

The dependences presented in Fig. 2 and Fig. 3 show that for the tested timber sample the correlation between bending strength and static modulus of elasticity (R^2 = 0.5627) was clearly higher than correlation between bending strength and dynamic modulus of elasticity (R^2 = 0.312). The results of R^2 obtained from earlier studies for Polish pine timber were 0.64 and 0.62 respectively [Krzosek 2009]. Higher coefficients of determination from those tests could be explained by larger sample of tested sawn timber (766 pieces). Above results confirm that timber grading based on testing the static modulus of elasticity is a proven and reliable method.

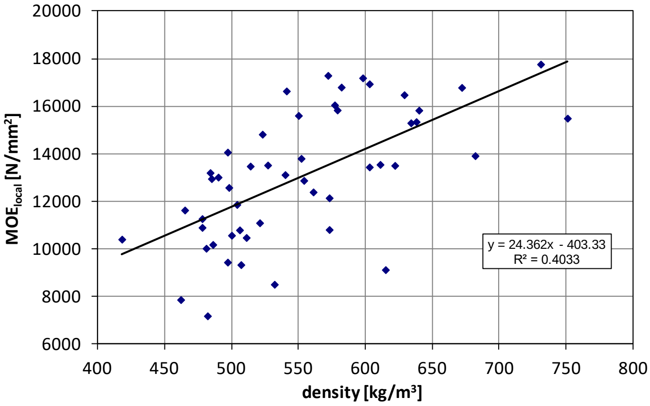

Fig. 4. Relationship between local modulus of elasticity in bending (MOE_{local}) and density

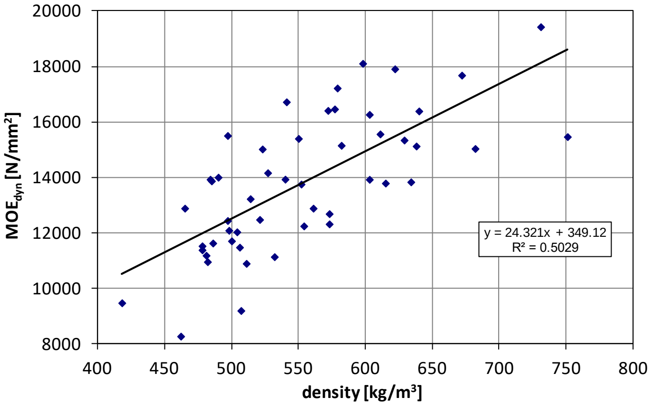

Fig. 5. Relationship between dynamic modulus of elasticity (MOE_{dyn}) and density

On the basis of further analyses, it was found (Fig. 4 and 5) that coefficient of determination of dependence between static modulus of elasticity and density (0.4039) was lower than the coefficient of determination for relationship between dynamic modulus of elasticity and density (0.5029). Coefficient of determination for relationship between static modulus of elasticity and density achieved in previous studies of pine timber of Polish origin was equal to 0.5329 [Krzosek 2009].

Figure 6 shows relationship between bending strength and density of tested timber.

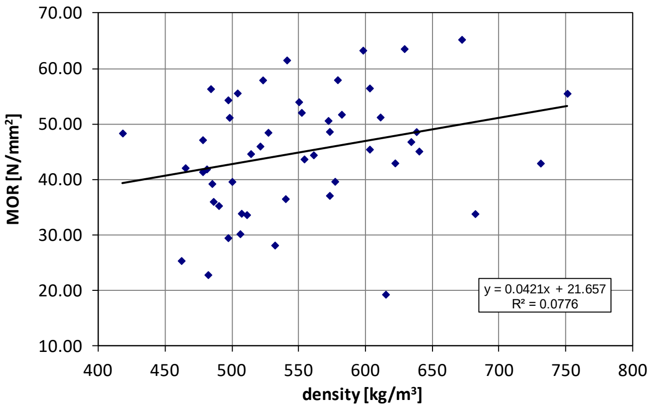

Fig. 6. Relationship between bending strength (MOR) and density

The R^2 coefficient for dependence between bending strength and density of tested pine timber was 0.0776 and it was the lowest value of all presented relationships. It may be concluded that density cannot be used as a predictor of bending strength. Bending strength of pine structural timber is determined by other features of wood, especially knots. Density could only be treated as an approximate indicator of the strength properties of pine wood, possibly considered jointly with other wood features. Coefficient of determination for relationship between density and bending strength achieved from previous research carried out on larger number of pieces of pine timber was 0.4225 [Krzosek 2009].

Further analyses of the results included influence of width of annual growth rings on bending strength, modulus of elasticity in bending and density. Low coefficients of determination between the analysed relations were obtained, e.g. 0.1188 for the relationship between the bending strength and the width of annual growth rings, and only 0.054 for the relationship between the static local modulus of elasticity and the width of annual growth rings.

Conclusions

As a result of the tests carried out on pine timber, it was found that:

1. In the tested sample, a significant number of pieces of sawn timber (8%) were classified by machine grading in the strength class which could not be obtained by visual grading (C40).
2. The clear advantage of the machine grading over the visual grading has not been confirmed with regard to the amount of Polish pine sawn

timber classified to the strength class C35, which indicates the need to continue similar research in terms of improving the methods of both machine and visual grading.

3. High coefficient of determination (0.77) known from the literature for the relationship between the static local modulus of elasticity in bending and dynamic modulus of elasticity was confirmed, and therefore a high usefulness of this relationship in machine grading.
4. Density and width of annual rings of tested pine timber were poorly correlated with bending strength. It is impossible to conclude about strength classes of sawn timber based on these characteristics of pine wood.

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