

Early-Stage Prediction and Modelling Strength Properties of Lithuanian-Grown Scots Pine (*Pinus sylvestris* L.)

ANTANAS BALTRUŠAITIS¹ AND MARIUS ALEINIKOVAS²

¹ Kaunas University of Technology, Faculty of Design and Technologies, Department of Wood Technology, Studentų St. 56, LT-51424 Kaunas, Lithuania. antanas.baltrusaitis@ktu.lt

² Institute of Forestry, Lithuanian Research Centre for Agriculture and Forestry, Department of Forest Resources, Economics and Policy, Liepų 1, Girionys, Kaunas distr., Lithuania. m.aleinikovas@mi.lt

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Abstract

The aim of this article is to determine the distribution of Lithuanian pine wood according to the international strength classes and to establish correlations of roundwood and sawn timber viscous-elastic properties. At least 6 model trees from Scots pine (*Pinus sylvestris* L.) stands were selected in seven forest regions of Lithuania, representing typical growing sites. Comparative non-destructive methodology was used for the analysis of sawn timber taken from the model logs focused on modulus of elasticity, strength and the distribution into strength classes. The non-destructive tests were done using the Timber Grader MTG and Metriguard, used for measuring the log and sawn timber mechanical properties and bending machine. After performance of non-destructive log and sawn timber tests the static 4 – point bending test was done for boards out of tested logs. The comparison of modulus of elasticity of all static and dynamic devices with the actual timber bending strength was done after all the testings.

Key words: Scots pine, wood strength, modulus of elasticity, nondestructive methods.

Introduction

Timber properties and their dependence on various factors are quite extensively studied worldwide. The analyses on the distribution of coniferous timber to the strength classes are becoming more and more sophisticated. The objective of the studies is to create the databases on the distribution of the main commercial tree species in each European country to the standardized strength classes. The integrated European base will allow the tenders of wood industry to be oriented in raw wood market and to be competitive in furniture and, particularly, in the timber building and construction industry. As for the design of load-bearing structures, it is necessary to supply wood of reliable strength characteristics.

In addition, it is very important to determinate the roundwood stiffness-strength characteristics and the correlations with the sawn timber strength and stiffness. It is also essential that the roundwood for structural use could be pre-graded at earliest possible stage.

The aims of this article were to determine the distribution of Lithuanian pine wood according to the international strength classes and to establish the correlations between roundwood and sawn timber viscous-elastic properties.

Materials and methods

At least 6 model trees (in total 42 trees) from Scots pine (*Pinus sylvestris* L.) stands were selected in seven forest regions of Lithuania representing typical growing sites. Three logs (2.4-3.0 m long) - but log, middle log and top log - were sampled from each tree. There were 8 - 12 model logs from each site (total 78 logs) taken for testing.

Integrated comparative non-destructive methodology was used for the analysis of saw timber taken from the model logs focused on modulus of elasticity, strength and the distribution into strength class according to the LST EN 338-2004 (Miseikyte et al. 2008). The non-destructive tests were done using the following devices:

1. The Timber Grader MTG, used for measuring the timber strength and stiffness (*Brookhuis Microelectronics BV*, Holland). Log dynamic modulus of elasticity was calculated according the natural frequency, average wood density and moisture content of the log.
2. For sawn timber bending machine - Metriguard (USA) and Timber Grader MTG.

After performance of non-destructive logs and sawn timber tests the static 4 – point bending test accordingly EN 408: 2006 procedure was done for

boards out of tested logs (Baltrusaitis et al. 2011). The comparison of modulus of elasticity of all static and dynamic (non-destructive) devices with the actual timber bending strength was done after all the testing.

Disks without defects have been used for the determination of the average wood density and moisture content in logs. This way, each log modulus of elasticity was calculated testing natural frequency at the real density and moisture content of separate log.

Results and discussion

After the performed analyses the database on the moisture content, density and variation in the moisture content and density along the tree stem, distance from the pith and cambium age, ring width, early-late-wood proportions was proceeded.

Some data on the log parameters are presented in Table 1.

average density and moisture content typical of the country or forest site (Aleinikovas 2007, Edlund et al. 2006, Ridley-Ellis et al. 2009) are not so convincing, as also the hypothesis, that the variations in moisture compensate the variations of logs densities (Ross et al. 1996, Rajeshwar et al. 1997). Such assumptions, of course, significantly simplify the investigations, but for estimation of log elastic category and plastic properties, the moisture and density are influencing factors. This affects also early-stage pre-grading sawlogs especially for the constructions.

The relationship between logs MOE and log cambium ages (a) and logs MOE and MOE of green ex-logs boards are presented in Fig. 2.

Recent cambium age-related measurements has broken the stereotypes on the models of density distribution in the tree stem; even the decrease of the density in the direction from the pith to sapwood was discovered (Grekin and Verkasalo 2009, Verkasalo et al. 2008).

Table 1. Geometrical parameters of tested logs

Log index	But-end diameter D _{but-end} , mm	Top-end diameter D _{top-end} , mm	Length, l, m	Volume, V, m ³	Taper, mm/m	Ovality, mm	Sweep, mm	Twist, mm
Average	265.52	206.60	2.92	0.14	13.75	10.20	7.33	10.61
min	190.00	143.00	2.40	0.05	3.50	0.30	2.00	5.10
max	417.40	306.60	3.11	1.11	33.50	32.30	19.30	23.50

The modelling on the log dynamic modulus of elasticity (DMOE) was performed according to the main influencing parameters. Initially the relationship between log top-end diameter (Fig.1,a) and logs density (Fig.1,b) with the dynamic modulus of elasticity (DMOE) was tested.

Some detections show the trend of decreasing log dynamic MOE during maturing of the stand (Reynolds 2007). Of course, the estimated evidences cannot be considered as the final and require further investigation. However, the given data hypothesize that the interrelations between wood density and stiffness is

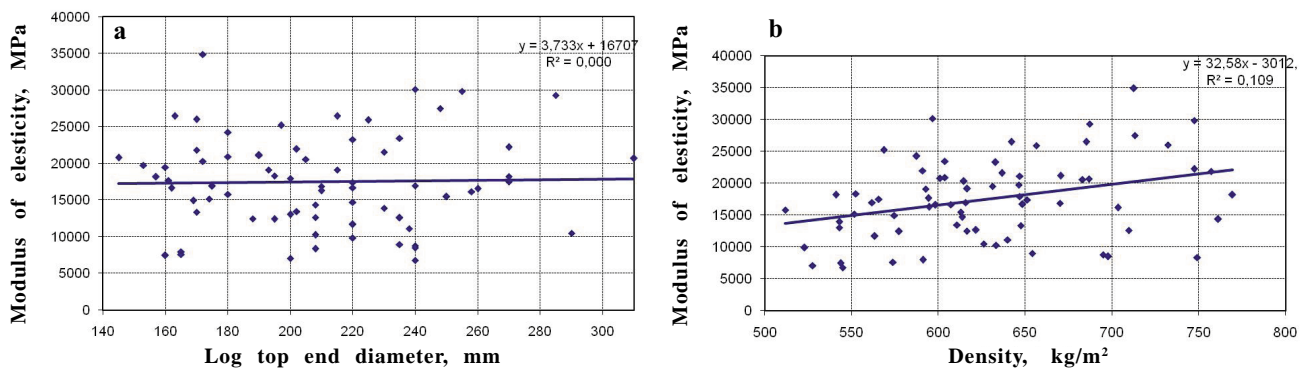


Figure 1. Dynamic MOE by log top-end diameter (a) and density (b)

As our results show, the modulus of elasticity was not dependent on log diameter. The obtained results are not unusual or controversial. However, the DMOE of wet logs significantly correlated with the density. Therefore, the assumptions of many authors about the possibilities to evaluate log elasticity properties by the

not as homogeneous, and sometimes conversely to the existing opinions.

At least, the obtained mechanical properties of the fresh cut logs have shown more relevant patterns and interpretation possibilities. The tendencies in the changes of DMOE of logs and the DMOE of un-dried

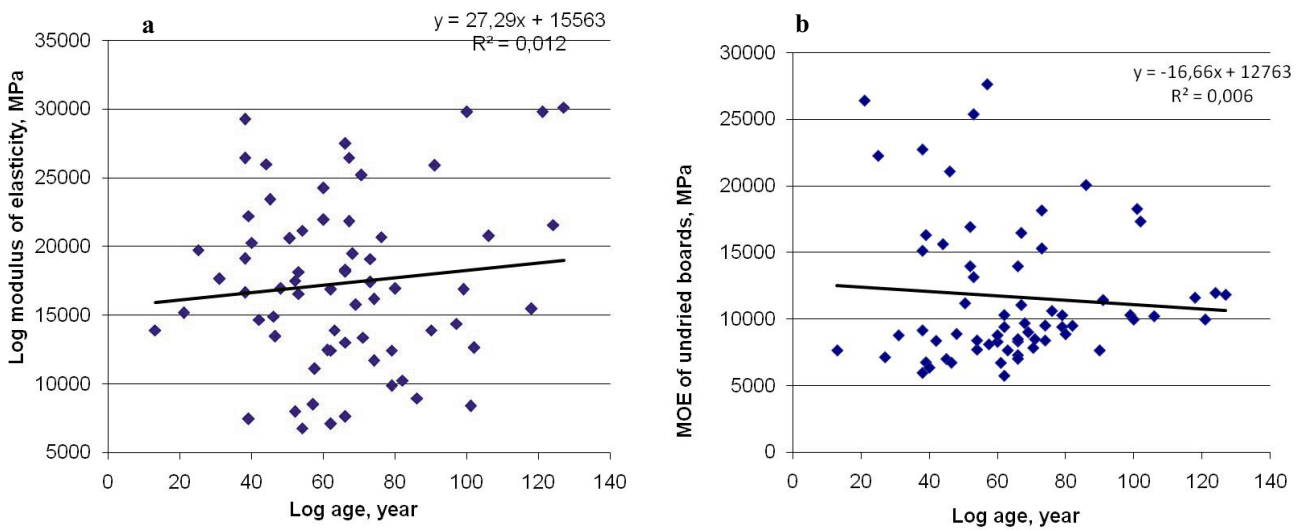


Figure 2. Log dynamic MOE (a) and green board MOE by log age (b)

boards with the cambium age seem convincing, but still require careful validation.

The modelling of all tested log modulus of elasticity was done in consequence of physical parameters and natural frequency of logs. The reliance of the log dynamic modulus of elasticity (E_{log}) on age (A_{log}), early late wood ratio ($Ratio_{E/L}$), density (ρ) at 12 % MC, log top end diameter ($D_{top\ end}$), log moisture content (ω) and natural frequency (f) is described by the model:

$$E_{log} = -29639.6 + 13.6A_{log} + 968.6Ratio_{E/L} + 9.8D_{top\ end} + 35.6\rho + 199.0\omega + 15,3f \quad (1)$$

The coefficient of determination R^2 is 0.67. The adequacy of dispersion 2240640, reproduction variant 61198939, the calculated Fisher criterion $F_{calc} = 0.366$, tabulated Fisher criterion $F_{table} = 1.8171$ (with a probability of 0.99). Since $F_{calc} < F_{table}$, so this model is adequate. Average E_{log} is 21056.76 MPa and standard devi-

ation 7822.98 MPa. The most significant factors are the density, moisture content and the natural frequency.

The reliance of the DMOE of logs and un-dried boards are also controversial. The effects of the moisture content to the dynamic viscous-elastic wood tissue properties are not cleared so far

As our research results have shown, there are no opportunities to relate the elastic properties of logs with the assortments stiffness before drying. Still, summarizing the obtained data it could be noticed that the DMOE of logs significantly correlates with natural frequency ($R^2 = 0.73$) (Fig. 3), what improves the relevance of such measurements for diagnostics of wood properties.

For verification the feasibility of green pre-grad-ing stiffness of un-dried and dried boards was tested. The comparison of dried and un-dried assortment DMOE is presented in Fig. 4.

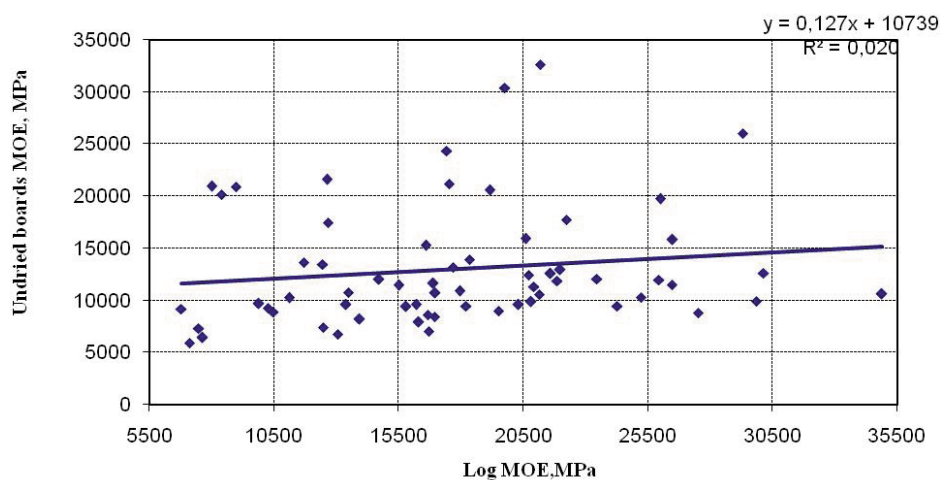


Figure 3. Dependence between DMOE of logs and DMOE undried boards

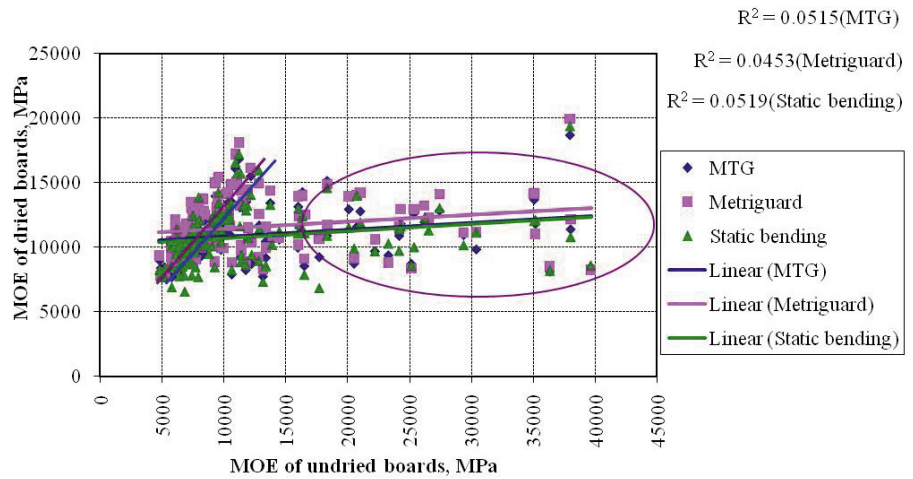


Figure 4. DMOE of boards before and after drying

Following, interdependence of un-dried assortment DMOE with the modulus of rupture (MOR) after the drying is given in Fig. 5.

As it could be seen from the results no significant correlation has been determined. This confirms that the early stage prediction of strength according to the DMOE of un-dried assortment is not presumptive.

The reliance of the dried samples dynamic and static MOE and MOR is presented in Fig.6.

The model below describe interrelation of static bending strength f_m with the log density $\rho_{\log-12}$ at 12% moisture content, the log modulus of elasticity E_{\log} , the log age A_{\log} , the ratio of earlywood/latewood $R_{a-tio_{E/L}}$, log moisture content ω_{\log} and log top end diameter $D_{top\ end}$:

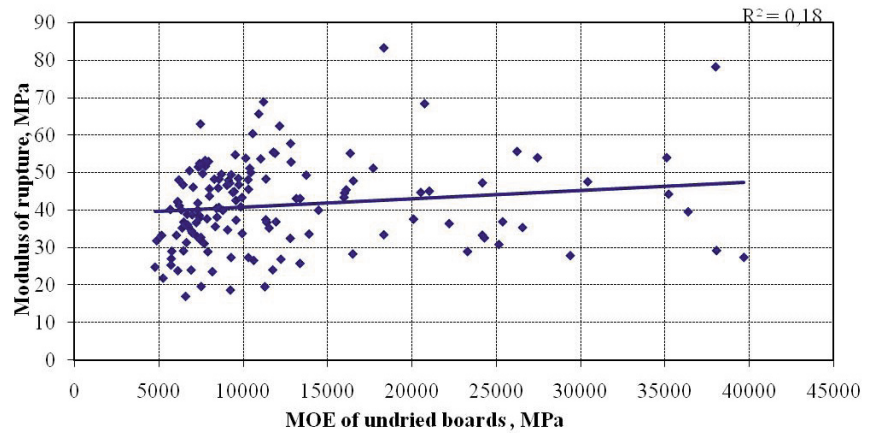


Figure 5. Strength prediction based on DMOE of the un-dried assortment

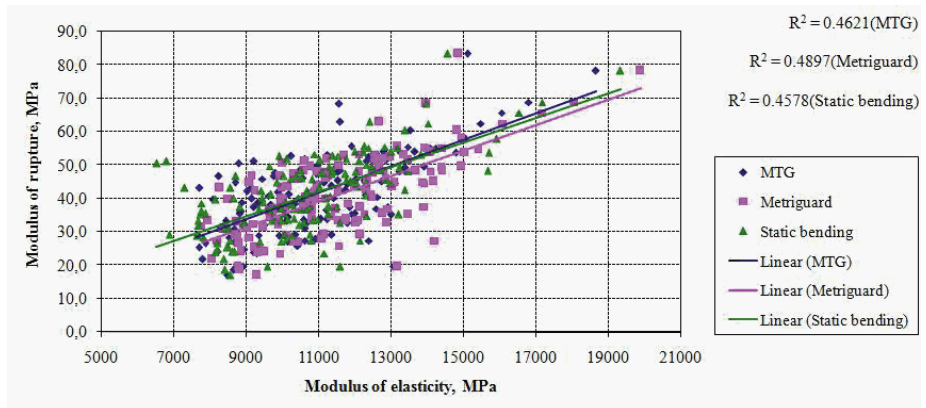


Figure 6. Strength prediction based on MOE of the undried assortment

$$f_m = 24.9788 + 0.0747\rho_{\log-12} - 0.00002E_{\log} + 0.0383A_{\log} - 2.9173Ratio_{E/L} - 0.0603D_{top\ end} - 0.2857\omega_{\log} \quad (2)$$

Determination coefficient R^2 is 0.3144. Adequacy of the variance is 64.74, reproduction variance is 84.67, the calculated Fisher criterion $F_{calc} = 0.7646$, the table Fisher criterion $F_{table} = 1.899$ (with a probability of 0.99). Since $F_{calc} < F_{table}$, the model is adequate. Average of static bending strength is 41.00 N/mm², the standard deviation is 9.201. The most significant factors are moisture content ω_{\log} , log top end diameter $D_{top\ end}$ and log density $\rho_{\log-12}$.

The large variance ($R^2 = 0.46-0.49$) in the tested total sample population was influenced by the variation in the log properties from overall regions in Lithuania. This data is in line with our earlier researches (Baltrusaitis et al. 2011). However, it is acceptable to predict the strength, especially considering industrially applicable strength grading characteristics (Fig.7).

As it could be noticed only 4 % from the total tested samples were not suitable for the structural use. Meanwhile, 23 % boards belong to strength class C18. High quality wood was distributed as following: 45 % of C24, 24 % - C30, 4 % - C35 and 1 % - C40. The selected (C30 and higher grade class) wood presented 33 % respectively, or one-third of total production.

The summarizing assessment of the research is displayed in Fig.8. Thus, it represents the reliant of the regionally tested logs MOE's with the strength classes of the board's ex-logs.

It could be seen that with the increase in the DMOE of logs, the decrease in the C18 and in the non-structural wood is evident. Though, the medium quality timber (class C24) is not relied on log DMOE, i.e. the output of this category remains constant in all quality groups of logs. However, growth of logs MOE obviously increase the share of higher quality (C30 and better) sawn wood.

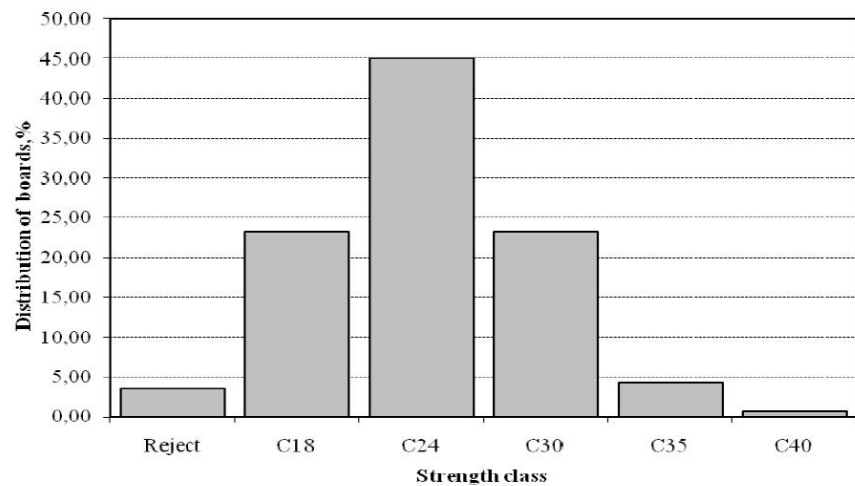


Figure 7. Lithuanian-grown pine wood strength classes

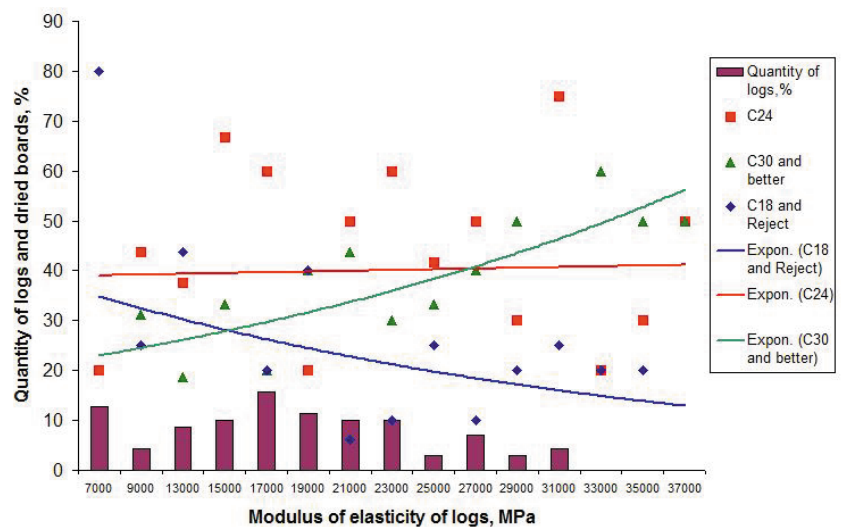


Figure 8. The distribution of strength classes according the log DMOE intervals

This conclusion is particularly important in demonstration that the early stage selection of logs and the dynamic identification according to the elastic properties is very important from the economic and technological point of view, for separating and optimizing of raw material for timber structures and decorative use.

Concluding remarks: basing on received data we come to the hypothesis that decisive factors for pre-grading of logs and green boards is configuration of their densities and moisture contents at the moment of testing. Vast variations of MC and densities along and across the grain superimpose situation even more and due to such complexity intended pre-grading is hardly predictable and reliable on somehow generalized averaging or another simplification. Moreover, even exact weighing of logs during vibrant or acoustic scanning does not exclude specific propagation of stress waves according to the early-late wood ratio or micro-scale characteristics on the fiber or cell and lower levels.

Conclusions

1. The density of fresh cut logs not significantly correlates with dynamic stiffness ($R^2=0.21$) and is not representative evaluating the structural use of raw material.

2. Log top-end diameter as well as the log cambium age could not be related with usage for structural timber.

3. DMOE's of un-dried and dried boards significantly correlates within physically feasible 20000 MPa intervals. Calculated DMOE of wet and dry boards at 20000-25000 MPa are low-confident and the higher values seem to be measurement errors. Thus minimization uncertainties of various dynamic measurements are still a challenge using new and industrial metrological equipment.

4. The modelling of the log dynamic modulus of elasticity could be done using log natural frequency, cambial age, top-end diameter, early-late wood ratio, moisture content and density.

5. Lithuanian grown Scots pine population wood properties vary to a large extent. Essentially, it is dif-

ficult to predict reliably sawn timber stiffness-strength accordingly to the log DMOE.

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ПРОГНОЗИРОВАНИЕ В РАННЕЙ СТАДИИ И МОДЕЛИРОВАНИЯ ПРОЧНОСТНЫХ СВОЙСТВ ДРЕВЕСИНЫ СОСНЫ ОБЫКНОВЕННОЙ (*PINUS SYLVESTRIS* L.) РАЗНЫХ РЕГИОНОВ ЛИТВЫ

А. Балтрушайтис и М. Алейниковас

Резюме

Для исследований были отобраны 42 модельные деревья сосны обыкновенной (*Pinus sylvestris*) (по 6 из каждого региона). От каждого дерева отобрано по три бревна: пневной средний и верхний. Затем проводилось комбинированное неdestructивное исследование модуля упругости, прочности и распределения по классам прочности в соответствии со стандартом EN 338 для досок, выпиленных из модельных древен. После неdestructивных исследований проводился тест 4 – очечного изгиба в соответствии со стандартом EN 408:2006. В статье представлены свойства упругости сосновых бревен, их связь с жесткостью и прочностью вырубленных сортиментов для того, чтобы выбрать крупный лесоматериал для правильного строительного использования на ранней стадии переработки.

Ключевые слова сосна, прочность, модуль упругости, неdestructивные исследования