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Beech as construction wood

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Sažetak

Bukva je rijetko korištena kao građevinski materijal. U posljednje se vrijeme razmatra učestalije korištenje u građevinarstvu budući da ima visoka mehanička svojstva i da je zabilježen porast zaliha - posebno u srednjoj i jugoistočnoj Europi. U radu su uspoređeni njemački, francuski i britanski standardi za vizualno ocjenjivanje skupa uzoraka iz lokalne pilane. Prema njima, relativno mali udio dasaka je ocijenjen najvišom ocjenom, a većina je dasaka negativno ocijenjena. Nakon provedenog vlačnog testa nad istim skupom dasaka, otkriveno je da daske imaju visoku vlačnu čvrstoću. Kako bi se poboljšao sustav vizualnog ocjenjivanja, korištena je metoda stabla odlučivanja. Novi sustav ocjenjivanja povoljnije je ocijenio daske nego opisane nacionalne norme.

Ključne riječi: Bukva, vizualno ocjenjivanje, ocjena čvrstoće, stablo odlučivanja, ocjenjivanje svojstava

Bukva kao drvena građa

Abstract

Beech is rarely used in construction. Due to the high mechanical properties and increase of beech stock, especially in Central and South-eastern Europe, beech wood became an interesting resource also for the construction sector. A comparison has been made of the German, French and British standard for visual grading of a sample from a local sawmill. A relatively small portion of boards was graded into the highest grades, and the majority of the boards were graded as a reject. Tension tests of the same boards revealed high strengths, and an attempt of more efficient visual grading was made. We used the decision tree method. With assessment of only three visual parameters, we were able to grade the majority of the boards into higher grades than established visual standards from Germany, France and United Kingdom.

Keywords: beech wood, visual grading, strength grade, decision tree, grade determining property

1. Introduction

In the countries in central Europe, including Slovenia, the stock of hardwoods is increasing. In the last twenty years, the standing stock of softwoods in Slovenia decreased by 5 % whereas the stock of hardwoods increased. Due to bark beetle outbreaks that are the most damaging agent of mature spruce forests, we can expect this trend to continue and the demand for hardwoods to rise. In 2016 hardwoods accounted for approximately 55 % of standing stock [1]. Compared to softwood, the mechanical properties values of hardwoods are higher. Despite that, hardwoods have rarely been used in the construction sector. The lack of standardisation and regulation also contributes to the limited usage of structural hardwood.

Beech is the most common wood species in Slovenia, accounting for about 32 % of the forested areas [1], hence our research focused on this species. Within the Gradewood [2] and EU Hardwood projects data for spruce, oak and beech were obtained. Beech showed a higher natural strength potential than spruce and even oak.

2. Material

208 beech (*Fagus sylvatica*) logs were randomly picked from a local Slovenian sawmill. The logs were visually inspected and graded into four (A – D) grades according to the EN 1316-1 standard. During visual grading, the logs' dynamic modulus of elasticity ($E_{\mathrm{dyn,log}}$) was determined through the 1$^{\mathrm{st}}$ eigenfrequency of the log, using a laser vibrometer (Polytec PDV-100) to measure the vibration from a hammer impact. Although there are small differences between the $E_{\mathrm{dyn,log}}$ values between the different grades, a pattern can be seen where the highest (A) grades have higher values than the lower grades. Using the $E_{\mathrm{dyn,log}}$ values, we can allocate the logs that will potentially have a low tensile strength.

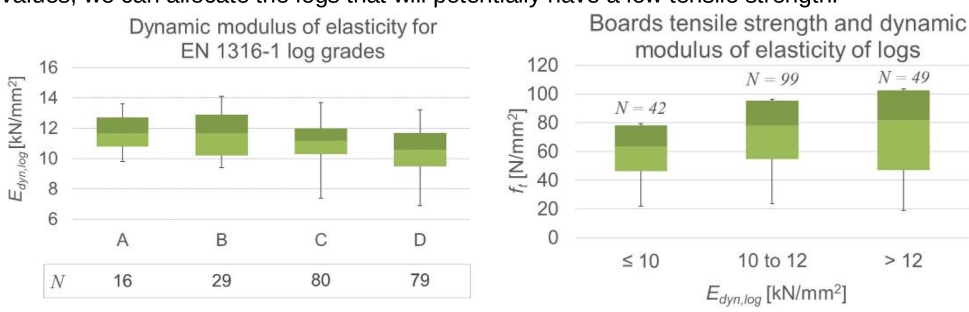


Figure 1. Measured dynamic modulus of elasticity for logs graded according to EN 1316-1 (left) and tension strengths of the boards with dynamic modulus of elasticity of logs (right).

3. Visual grading of beech boards

From each log, only one board was sawn and used for further analysis. For 191 boards out of 208 all visual parameters, defined in the German [3] and British [4] standard, were measured. The rest of the boards were either not measured correctly or lost during testing.

Some additional parameters, that are included in the French [5] standard for visual grading, were acquired only for 167 boards. The comparison between the three standards was made and is shown in Table 1.

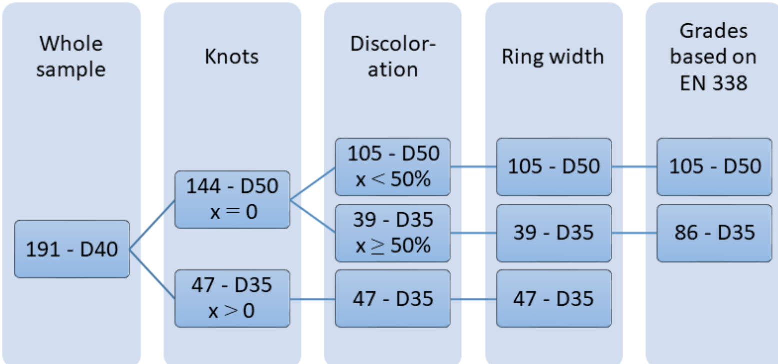
Table 1. Strength grade yields for visual grading according to three European standards.

Standard	D40	D35	D24	Reject
DIN 4074-5	24	10	19	114
NF B 52 001-1	31	/	17	119
BS 5756	50	/	31	86

The results show the conservativeness of all the standards. Most of the boards were graded as a reject, and in the case of the German standard little more than 10 % of the boards were graded into the highest strength grade LS 13. In the standard EN 1912 [6] the assignments to the EN 338 grades are made. LS 13 grade can be translated to the D40 (Table 1). More favourable results were obtained using the British standard where 50 boards were graded as TH1 (D40). Since coniferous wood is mostly used in construction it is logical that visual grading rules were primarily designed to the physical characteristics of softwood, mostly spruce. When a need for grading hardwood species arose, rather than creating new standards from scratch, softwood standards were adopted. Since there are fewer data available for hardwoods, hardwood standards may still be changed after sufficient data for hardwood is available.

4. Decision tree method

The decision tree method was chosen in order to construct an alternative procedure for visual grading rules for beech. Decision trees are a useful way of visually displaying the problem and then organising the programming of making decisions. This approach is especially helpful if a sequence of decisions has to be made [7]. Decision trees provide a modelling technique that is easy to understand and comprehend and simplifies the classification process [8, 9]. Standards for visual grading [3, 4, 5] require measurements of multiple parameters which results in a highly time-consuming process of grading. On 191 beech boards, we measured proposed visual characteristics of the boards and evaluated their correlations with the tension strength, modulus of elasticity in bending and density. In general, the results showed the best correlation of visual parameters with tension strength. We calculated the correlation factor between tensile strength and knots, discolouration, the slope of grain and ring width, respectively. Since the slope of grain is difficult to measure, an effort was made to avoid these measurements during grading. Therefore, in the decision tree algorithm, only knots (0 or larger than 0 mm), discolouration (less or more than half of the board width) and ring width (less or more than 2 mm) were included. In the first two steps, more than half of the boards obtained the characteristic strength corresponding to a very high-grade D70 and the rest corresponded to D35 or more. There was no reject. If all grade determining properties were included, 105 boards were sorted into D50 and 86 boards into D35, still with no reject (Figure 2).



Slika 2. Figure 2. Decision tree algorithm results with grades based on all three grade determining properties from EN 338

The results of the decision tree approach are very encouraging. At this point, it is important to emphasise, that EN 14081-1 requires visual override for visual grading, which was not included in the decision tree algorithm. These requirements are mostly given for the feasibility of the postproduction process, i.e. features like wane, fissures, warp and rot should be limited in order to be suitable for later use. Nevertheless, we were able to recognise boards with high strength properties using only three observed visual parameters that can be determined easily and quickly. No measurements were needed.

Table 2. Strength grades for the grade determining properties separately and overall as a result of the decision tree algorithm

No.	$f_{t,k}$	E_t	ρ	$f_{t,k}$ [N/mm^2]	E_t [N/mm^2]	ρ [kg/m^3]
24	D80	D55	D50	48.5	16100	626
81	D65	D55	D50	40.9	16200	647
86	D35	D50	D55	22.0	14800	662

In Table 2 grading by all three grade determining properties is presented separately. If strength would be the only grade determining property, we could allocate the boards into D80, which is the highest possible strength grade for hardwoods defined in EN 338 [10]. Although the boards had a similar density to those in other research [11, 12], it was the acting grade determining property, and it was not possible to grade into higher grades than D50. There was no single board, which would exceed the requirement for the characteristic value of the density for the highest grade.

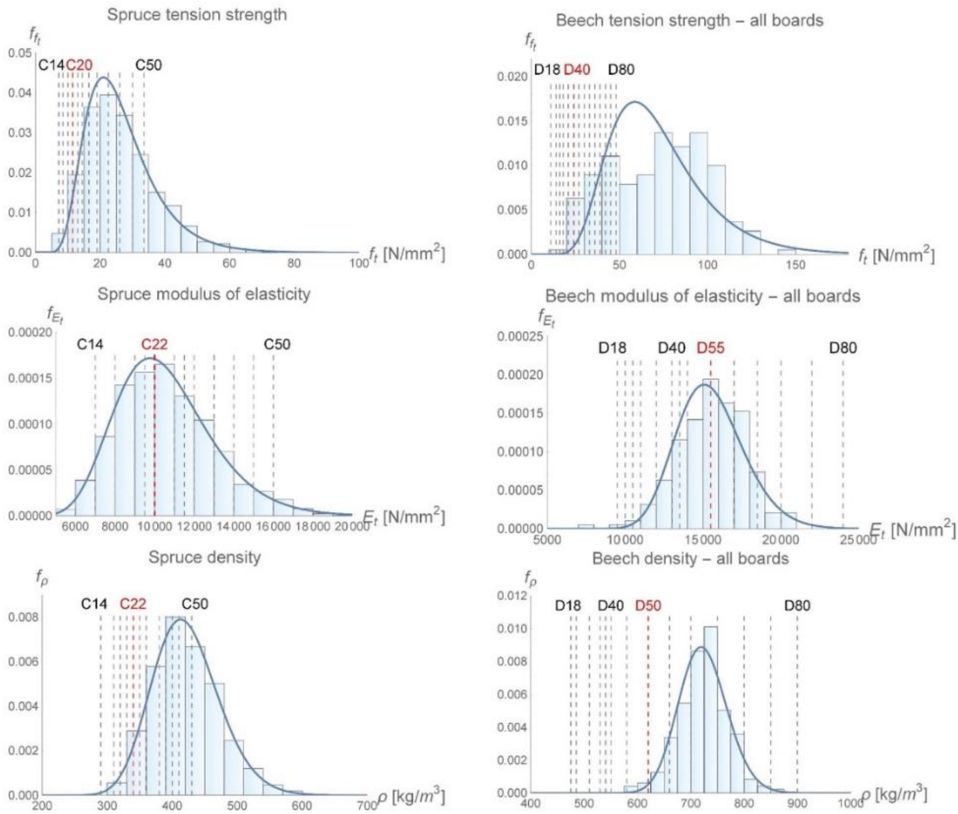


Figure 3. PDF of fitted lognormal distribution for grade determining properties and requirements according to EN 338 for spruce (left column) and beech (right column) boards.

Therefore, further investigation and comparison of the requirements for all the grade determining properties were made. In Figure 2, probability distribution functions (PDFs) of fitted lognormal distribution for grade determining properties together with the histograms of actual data are shown. The dashed lines illustrate the requirements for all grades. A comparison to the data of 1493 spruce boards from the Gradewood project was made [2]. Although the acting grade determining property for all boards is the strength (C20) as in the case of beech, the other two properties show just slight deviation since the characteristic values of elastic modulus and density correspond to grade C22. It is also clear that higher grades are not hindered by any grade determining property. We can see that we could grade a specific subsample of high-quality spruce to a very high grade. According to EN 338 requirements for hardwood and experimental data from our research grading of beech in higher grades (D65 and higher), it is just impossible, although the strength characteristics of beech clearly indicate that beech could be graded higher.

5. Conclusions

Beech shows high mechanical properties, and it has good potential as construction material. According to the current standards for visual grading, the highest possible grade that beech can be allocated to is D40. Our research proposes a method of strength grading using the decision tree algorithm. The results showed very high strength values, and if strength had been the only grade determining property, Slovenian beech would have been graded into D80 too. The requirements for the modulus of elasticity and density are stricter, and it is not possible to grade higher than D50. According to our analysis, the requirements of the standard EN 338 for modulus of elasticity and density are not in accord with the general characteristics of the mechanical properties for beech. In our opinion, additional research is required, and the grade requirements re-evaluated.

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