Pre-grading of sawn timber in green condition

Helene Unterwieser [1], Gerhard Schickhofer [2]

[1]holz.bau forschungs gmbh, Inffeldgasse 24, 8010 Graz, helene.unterwieser@holzbauforschung.at

[2]Institute for Timber Engineering and Wood Technology, Inffeldgasse 24/I, 8010 Graz, gerhard.schickhofer@tugraz.at

Keywords: eigenfrequency measurement, green condition, grading, ultrasonic runtime measurement

ABSTRACT

This paper deals with the investigation of the possibilities of timber grading in the green condition and the comparison of the chosen measurement techniques. For this purpose, a total of 310 ungraded spruce boards with different cross sections and sawing patterns were investigated by two methods for determination of the dynamic properties. Based on the green condition of the boards, five test series at different moisture contents were carried out. As result of literature studies and previous investigations, the focus was laid on the method of eigenfrequency measurement, which seems to be best suited for application in an industrial production process. The measurement of the eigenfrequency was carried out with an industrially implemented optical vibration device (ViSCAN, MiCROTEC). For comparison reasons, an ultrasonic runtime measurement with 'Sylvatest' was conducted as well. With these two dynamic parameters and the density it's possible to calculate the dynamic modulus of elasticity, which is a good indicator for the static properties for stiffness and strength. The analysis of a total of 1550 test values for density, eigenfrequency and ultrasonic runtime showed interesting results of their behavior regarding the moisture content. The dynamic modulus of elasticity, determined out from the eigenfrequency measurement, demonstrated no dependence on the wood moisture above the fiber saturation point. A very strong linear correlation between the MoE in green condition and the MoE at a MC of 12 % was found ($r^2 = 0.96$). The dynamic modulus of elasticity, calculated from the ultrasonic runtime measurement in contradiction, did not deliver such a strong correlation between the dynamic values in green and dry condition ($r^2 = 0.88$). It was clearly shown that the ultrasonic runtime was influenced by the existing moisture content. On the basis of the dynamic investigations the dynamic MoE, calculated with the eigenfrequency, seemed more qualified to predict a reliable grading result. To prove the pre-grading with the adjusted dynamic MoE, the static properties in tension and bending of the boards were determined. The series were divided into a lower and a higher quality class by a defined limit value of the static MoE. This separation could be reproduced by the adjusted dynamic MoE; only 5 % of the boards were classified wrong.

INTRODUCTION

In many cases companies buy ungraded sawn timber. After the drying process the boards will be graded prior to the production. Due to the lack of knowledge of the quality, a high percentage of sawn timber accumulates, which cannot be processed any further. This unprocessed sawn timber needs to be used differently and therefore often has to be transported to other plants, which generates further transportation costs. An optimized pre-grading, based on the green state of the timber could ease the situation by a quality assured grading process in the early stages of the production chain. The most important thing is to find a grading method of timber in green condition, which can deliver reliable grading results regarding the mechanical properties of the dried sawn timber. Another point is the practicability of the economical meaningful separation of low-grade and high-grade timber qualities concerning the recovery.

Due to literature studies and pre-investigations, the focus was laid on the method of measuring the eigenfrequency, which seems to be best suited for the application in an industrial working process. The dynamic modulus of elasticity, which is calculated from the eigenfrequency and density, can be determined as grading parameter and shows a strong correlation to material properties like the modulus of elasticity. For comparison the technique of measurement of the ultrasonic runtime will also be carried out.

MATERIALS AND METHODS

The investigation comprised four series of 310 ungraded spruce boards, which were supplied in green condition (MC > 30 %). The sawing patterns were chosen as centercuts (with and without pith) and sideboards. The cross sections were typical cross sections of the project partner and ranged from 202 mm to 98 mm in the width and from 49 mm to 41 mm in the depth (determined dimensions in green condition), whereas the length was 4,500 mm in every case. The material storing took place in a closed hall of the project partner at temperatures between 21°C and 24°C and a relative humidity of approx.

58 %. With these parameters, a slow and gentle drying of the boards could be guaranteed. For the final measurement of the dynamic properties, a moisture content of 12 % was desired. To meet this aim the boards were kiln-dried for 10 days. Samples for kiln-drying of each test specimen were taken before the first and after the last dynamic measurement, to get the information of the moisture content in the different states of measurement.

The investigation was composed of two parts. The first part included the determination of the dynamic properties of the boards in green and dry condition. A total of five measurements of the eigenfrequency and the ultrasonic runtime were accomplished within a period of 12 weeks. The measurement of the eigenfrequency was carried out on an industrially implemented optical vibration device (ViSCAN, MiCROTEC); for the measurement of the ultrasonic runtime the 'Sylvatest' was in use. The mass of the boards was determined at each measurement for calculation of the density. The dynamic modulus of elasticity for both measurement techniques was calculated using the following equations:

$$MoE_{dyn,eigenfrequency} = (2 \cdot L \cdot f)^2 \cdot \rho$$

$$MoE_{dyn,ultrasonic\ runtime} = (\frac{L}{t})^2 \cdot \rho$$

The second part of the investigation deals with the determination of the static properties for strength and stiffness. Each series was split into parts for tension and bending tests according to the standard EN 408. Besides the tension and bending strength, a global modulus of elasticity (reference length = 2,943 mm) and a local MoE in tension (reference length = 5 · b), as well as a local MoE in bending (reference length = 5 · b) were determined.

RESULTS

In the following section the results of the analysis of the dynamic properties, determined from five measurements, will be shown.

The determined mean moisture contents at measurement 1 lay between 48 % and 89 %. The density of the centerboard series decreased by 23 %. The sideboard series showed the highest values for the density, but also the highest decrease (35 %) in ρ, which can be explained with the high moisture content of the sideboards in green condition. The average statistical dispersion decreased from 16 % to 11 %.

Results of the eigenfrequency measurements

The mean values of the eigenfrequency increased by 118 Hz or 26 %. The average statistical dispersion decreased from 12 % to 7.5 %. The calculated mean values of the dynamic modulus of elasticity (MoE_{dyn}) increased by approximately 15 %, whereas the average statistical dispersions stayed nearly constant over all five measurements. During the measurements 1 to 4 no change in the mean values of MoE_{dyn} was noticed.

After the data analysis, a strong correlation between the MoE_{dyn} in the green conditions (measurements 1 to 4) and the MoE_{dyn} at a MC of 12 % was found (Figure 1-le). A linear function could be determind, which allows the calculation of a modulus of elasticity for a wood moisture of 12 % (coefficient of determination $r^2 = 0.96$), based on the MoE_{dyn} at the (unknown) existing moisture content u:

$$MoE_{dyn,12} = 1.09 \cdot MoE_{dyn,u} + 636$$

The observed strong correlation could be explained by the behavior of the input-parameters of the MoE_{dyn}, eigenfrequency f und density ρ concerning the moisture content u. The different effects of the moisture content on these parameters nearly compensated each other in the area above the fiber saturation point ('scissor'-effect, Figure 1-ri).

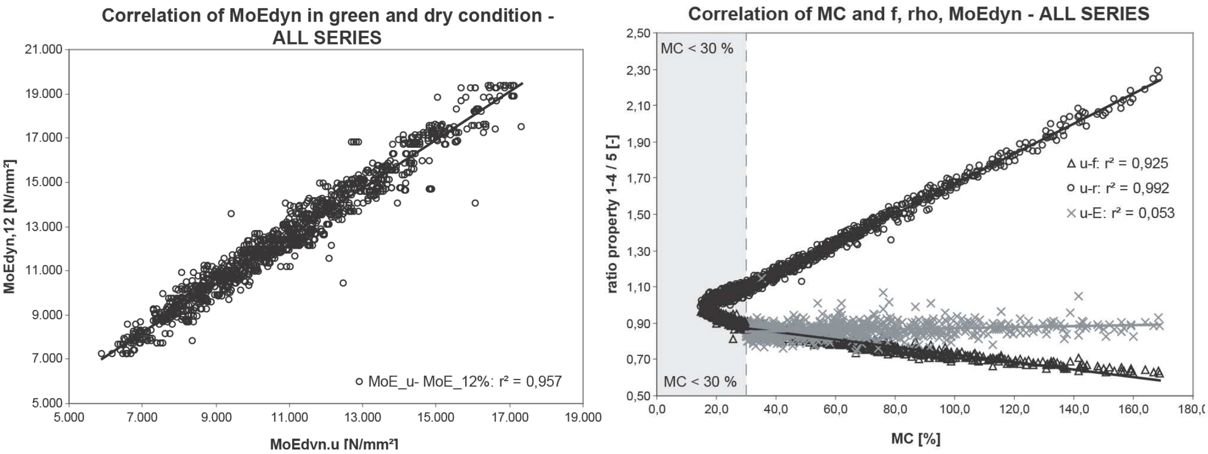

Figure 1. Correlation of dynamic modulus of elasticity in green and dry condition (le); Correlation of moisture content and the ratios of dynamic properties and density (ri)

Figure 1-ri shows the 'quality-free' diagram (ratios, determined by division of the green and dry properties) of the mechanical properties density, eigenfrequency and dynamic modulus of elasticity in respect of the moisture content. The graphs clearly displays the described compensate effects on the dynamic modulus of elasticity, which shows no change of the MoE_{dyn} above the fiber saturation point (r^2 = 0.05). It can also be seen that the ratios of the observed values are different below (gray coloured) and above the area of fiber saturation.

Results of the ultrasonic runtime measurements

The mean values of the ultrasonic runtime *t* decreased by 176 µs or 18 %. The average statistical dispersion decreased from 11.6 % to 6 %. The calculated mean values of the dynamic modulus of elasticity ($MoE_{\mathrm{dyn,US}}$) increased by approximately 8 %; the average statistical dispersions stayed nearly constant over all five measurements.

The analysis of the relation of moisture content and dynamic modulus of elasticity did not offer such a strong correlation between the observed properties in green and dry condition. The calculated coefficient of determination r^2 expresses this fact with a value of 0.88 (Figure 2-le).

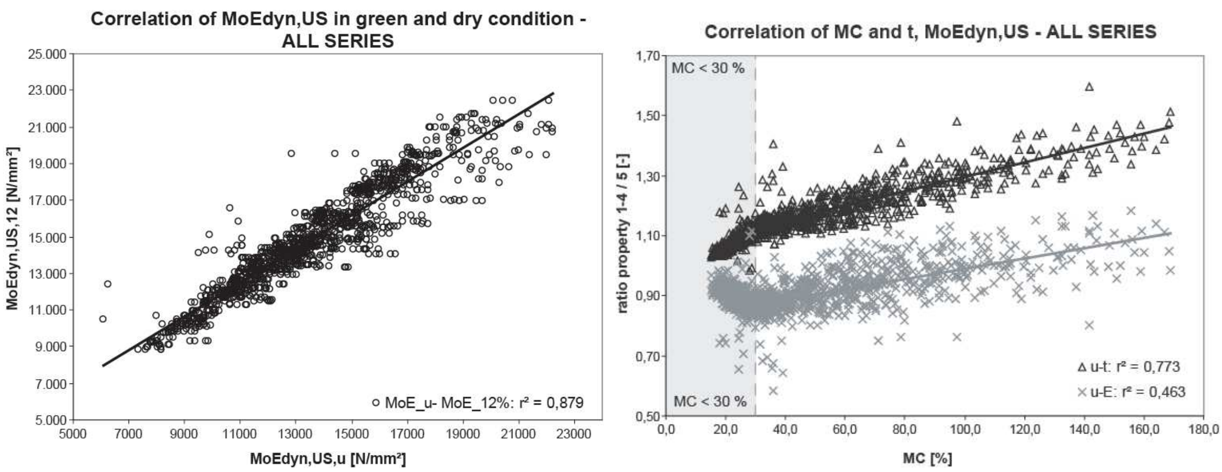

Figure 2. Correlation of dynamic modulus of elasticity (US) in green and dry condition (le); Correlation of moisture content and the ratios of dynamic properties (ri)

An explanation is the influence of the moisture content on the input parameter ultrasonic runtime *t* above the fiber saturation point (Figure 2-ri). It can be clearly seen that the correlation of ultrasonic runtime ratios and moisture content is not as strong as for the determined eigenfrequency *f* shown in Figure 1-ri. This means a dependence of the relative change (ratio) of the dynamic property *t* on the existing moisture content at time of measurement; therefore density and ultrasonic runtime do not compensate the moisture effects in the same way as observed at the eigenfrequency measurements. The graph in Figure 2-ri shows this fact in the relation of moisture content and ratios of $MoE_{dyn,US}$. A linear correlation with a coefficient of determination $r^2 = 0,463$ could be calculated.

Another indication for the potentially better appropriateness of the eigenfrequency measurement and the dependence of the ultrasonic runtime from the wood moisture respectively is shown in Figure 3.

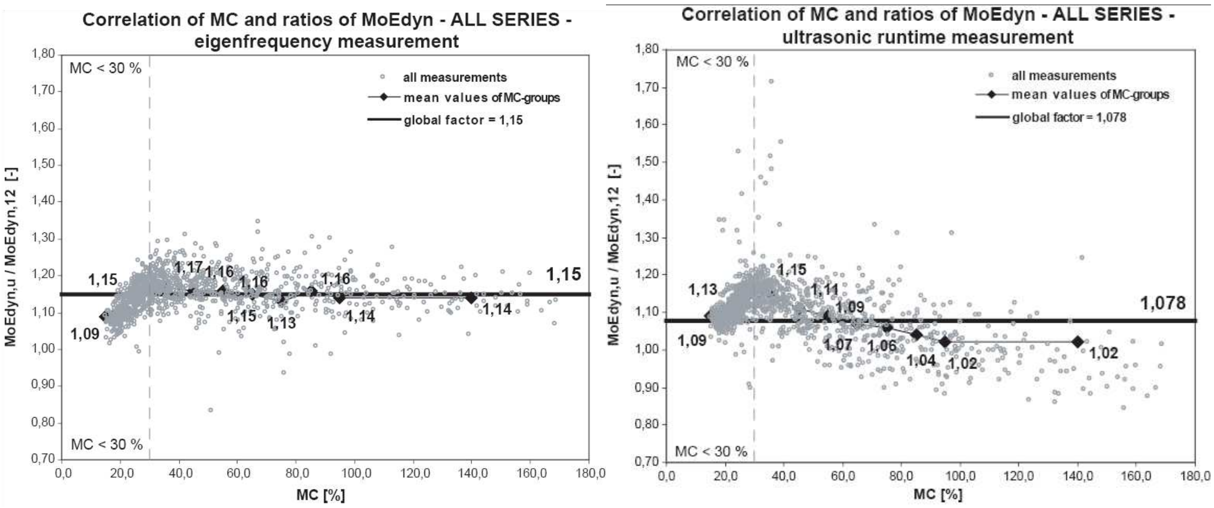

Figure 3. Trends of the dynamic MoE_{dyn} -ratios in relation to the moisture content

The diagrams in Figure 3 contain the ratios of the dynamic modulus of elasticity for both techniques in relation to the moisture content. For this purpose, moisture groups were defined (MC steps: 10 %) for representing a possible trend of the mean values of the relative changes of the dynamic modulus of elasticity. The ratios of the MoE_{dyn} out of the eigenfrequency measurement show no dependence on the moisture content; the average values of the moisture groups oscillate around the global factor of 1.15, which was determined by considering all test series and all measurements. Within the moisture content of 30 % and 180 %, the calculated mean values vary between 1.13 and 1.17. Compared to that, it is clearly shown that the ratios of the $MoE_{dyn,US}$, calculated from the ultrasonic runtime measurement, are decreasing with increasing moisture content. Within the moisture content of 30 % and 180 % the calculated average values decrease from 1.15 to 1.02, combined with less spread of the ratios. The determined global factor of 1.078 does not represent the trend of the ratios very well above fiber saturation.

DISCUSSION

As described in the paragraphs before, the modulus of elasticity, calculated from the eigenfrequency measurement, is more qualified for a pre-grading in green condition because of the independence from the wood moisture above the fiber saturation. The reliability of the defined equation of a dynamic MoE for dry condition, based on green condition, has to be proved in practice. For this purpose the static properties were required for classifying the test specimens in quality classes.

For the examined pre-grading, the requirement concerning the numbers of grading classes was the separation by the static modulus of elasticity into two quality classes, a low-grade and a high-grade timber quality class. For this purpose the mean value of the static MoE (global MoE in tension, local MoE in bending) was fixed with 9,000 N/mm² for the quality separation.

A total of 154 boards were tested in tension. 32 boards (20.8 %) matched the lower quality class concerning the global modulus of elasticity in tension. After calculation of the dynamic MoE with the given linear function the same ranking of the boards was attempted. The class limit from the dynamic MoE could be found with 10,000 N/mm². 37 boards (24 %) had to be arranged in the lower quality class; this represented a failure classing of 4.6 %.

155 boards were tested in bending according to EN 408; 34 boards (21.9 %) had to be classified in the lower quality class concerning the local modulus of elasticity in bending. After calculation of the dynamic MoE with the given linear function, the same ranking of the boards was attempted. The class limit of the dynamic MoE could be found with 10,600 N/mm², whereas 45 boards (29.7 %) had to be arranged in the lower quality class. This represents a incorrect classing of 14 %.

The classing with the dynamic MoE for the bending series did not deliver such reliable results as for the tension series. One of the reasons is the weaker correlation of the dynamic and static bending modulus of elasticity in comparison to the strong relations of dynamic MoE and modulus of global elasticity in tension (Figure 4).

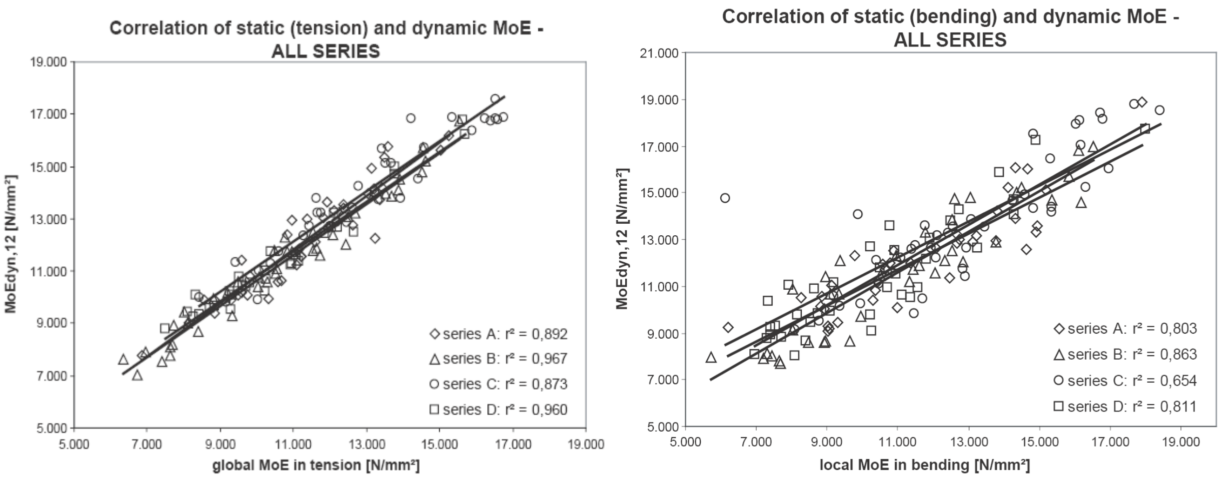

Figure 4. Relations of static and dynamic MoE for tension (le) and bending (ri)

It is clearly shown that the correlations of the MoE in tension and dynamic MoE are strong for each series ($0.87 < r^2 < 0.97$). The reference length for calculating the global modulus of elasticity is given with 2,943 mm, which nearly covers the entire board length (3,500 mm). Both MoE, the global MoE in tension and the dynamic MoE display the whole board with its characteristics; thereof the correlation of the two properties is stronger than that for the MoE in bending. For the bending series a wider spread of the test values is displayed, especially for series C (sideboards). For this series a coefficient of determination r^2 of 0.65 could be reached. The local bending MoE with the reference length of $5 \cdot b$ does not display the entire board with its characteristics.

CONCLUSIONS

The investigation showed that a pre-grading of boards in green condition is possible. After analysis, the technique of eigenfrequency measurement could be more suitable for the pre-grading purpose because of the independence of the dynamic modulus of elasticity from the moisture content above fiber saturation. The input parameters density and eigenfrequency compensate their moisture influences by reason of their contrary behavior. With a simple linear function it is possible to calculate a ‘dry’ dynamic modulus of elasticity, based on green condition, without knowledge of the existing wood moisture content. The strong correlation between the green and dry dynamic MoE is displayed by a coefficient of determination of $r^2 = 0.96$. For comparison, the measurements of the ultrasonic runtime deliver modulus of elasticity, which do not show such a good correlation in green and dry condition ($r^2 = 0.88$). The effects of moisture on density and ultrasonic runtime do not compensate each other in the same way as the input parameters of the MoE, determined from the eigenfrequency measurement. The relative changes of the dynamic MoE are influenced by the existing moisture content in the wood. Thus, a reliable pre-grading will be hindered. Another point to prefer the technique of eigenfrequency measurement was observed during the investigation. Faulty measurements of the ultrasonic runtime were observed, when a special industrial noise was present during the measurement. The measurement had to be repeated.

After the determination of the static properties in tension and bending, the pre-grading with the calculated dynamic MoE could be carried out. For this purpose the four series were divided into a lower and a higher quality class, whereas the limit value of the static MoE was defined with 9,000 N/mm^2. The separation of the boards was tried to reproduce with consideration of the dynamic MoE from the green condition, which was adjusted with the given linear function to a wood moisture of 12 %. From a total of 309 spruce boards 10 % were classified wrong. Thereof, 5 % of the boards showed very low stiffness properties, but were classified in the higher quality class.

The aim of the current investigation was a pre-grading of sawn timber in green condition and not a substitute of the grading process in dry condition. Most important for industrial use is the definition of the desired grading or quality classes. With the investigated stiffness-pre-grading, it is possible to separate low quality boards from boards with high (strength) stiffness properties. For definition of several grading classes, the pre-grading with the stiffness properties only is possibly not sufficient for prediction of strength properties. Additional grading techniques have to be accomplished. Further investigations should deal with that task.

REFERENCES

1. Blaß H.J., Frese M., (2004): Sortierverfahren für die kombinierte maschinelle und visuelle Festigkeitssortierung. Forschungsbericht, Lehrstuhl für Ingenieurholzbau und Baukonstruktionen, Universität Karlsruhe (in German)
2. Hanhijärvi A., Ranta-Maunus A., Turk G., (2005): Potential of strength grading of timber with combined measurement techniques. Report of the Combigrade-project-phase 1, VTT Publications 568, Espoo
3. Steiger R., (1996): Mechanische Eigenschaften von Schweizer Fichten-Bauholz bei Biege-, Zug-, Druck- und kombinierter M/N Beanspruchung. IBK Bericht Nr. 221, Institut für Baustatik und Konstruktionen, ETH Zürich (in German)
4. Unterwieser H., Fritz S., (2006): Steifigkeitssortierung von Schnittholz im Frischzustand. Arbeitsbericht der Vorversuche, holz.bau forschungs gmbh (in German)