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Theses of the Doctoral Dissertation

Comparing the Relationship Between the Most Important Physical Parameters of Lowland and Mountain Scots Pine Using Multivariate Regression

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I. RESEARCH TOPIC AND GOALS

Ever increasing wood utilisation, declining forest area and slow wood growth causes wood producers to want to learn as much of the raw material as possible. There is a need to provide a comparison of physical and mechanical properties within the same species, so that less favourable material may be used according to its value. Since about one third of the Hungary's coniferous forests was planted on lowlands, where they are not indigenous, and grow under adverse conditions, and the other two thirds are at mountain sites, there is a need to provide a reliable comparison of their physical and mechanical parameters. Thus, the task is to contrast lowland and mountain Scots pine in terms of their most important physical and mechanical characteristics. The fact that, so far, mechanical properties had been analysed as linear or sometimes as simple nonlinear functions of density, shows the significance of the chosen topic.

Accordingly, the dissertation has two main goals:

a.) creating a new mathematical model, and applying it to comparative wood material evaluation, and

b.) revealing the anatomical and physical characteristics of lowland and mountain Scots pine, and the differences thereof.

To do this, a test that differs from traditional statistical tests (sample analysis), is needed, that enables one to compare the materials from the two different sources. Density, as a major physical parameter and general material property, earlywood/latewood proportion, as an attribute of the annual ring structure and compression strength were chosen as bases for comparison. The goal was to reveal the differences between the two materials based on these three variables. This requires fitting a physically meaningful multivariate function, using density and ew/lw proportion as independent variables, and compression strength as the dependent variable. Multivariate function fitting had been preceded by a small-scale experiment using a novel, nonlinear characterisation of the relationship between density and compression strength. The goal of the pre-trial was to characterise the differences between the major anatomical parts using the aforementioned nonlinear regression.

II. EXPERIMENTAL MATERIALS, METHODS AND REQUIREMENTS

Materials used in the tests came from the Sopron and Bugac Forestry Companies. Pre-trials included small samples averaging 12 specimens each from the heartwood, sapwood and juvenile wood. Major tests involved large samples of 200 specimens both from the heartwood of lowland and that of mountain Scots pine. Each specimen was tested according to the relevant standards. Measured data provided a basis for analysing the density-compression strength and density-ew/lw proportion-compression strength relationships.

After the data was collected, the regression model needed for the pre-trial was chosen. The model was supposed to accurately follow the data points, stay within physically reasonable limits, be asymptotic and bounded, and possess a characteristic point that may be used as so-called "special averages" for comparing various curves.

In the main test, a physically reasonable function with two independent variables is used, that fulfils the following requirements:

- The function should provide a special average set of ρ (density), K (ew/lw proportion) and σ (compression strength) values for both types of material.
- The function should provide the change in σ for a unit increment of ρ (degree of increase) for both types of material.
- The function should provide the change in σ for a unit increment of K (degree of decrease) for both types of material.
- The function should provide the technologically viable lowest and highest values of σ, as well as its range for both types of materials.
- Using the derivatives of the function, one should be able to determine the limit values of ρ ($\rho_{\min}$; $\rho_{\max}$) belonging to the degree of increase (the technically viable interval of ρ.)
- Using the derivatives of the function, one should be able to determine the limit values of K (K_{min} ; K_{max}) belonging to the degree of increase (the technically viable interval of K.)
- The coefficients of the function should have physical and technological interpretations and physical dimensions.
- As many of the function coefficients should vary between the two types of material as possible.

- Good correlation in itself is insufficient. The model should also fulfil all eight of the above conditions.

III. TEST RESULTS

Based on the available data and the requirements above, a detailed analysis of the applicable functions took place.

1.) In the case of the small-scale study, the hyperbolic tangent function $\sigma = a \cdot \tanh\left(d\left(\rho - b\right)\right) + c$ was chosen. The function fulfils all the prescribed requirements: it is bouded, asymptotic, has an inflection point that is a good basis for comparison, and provides a good correlation between density and compression strength. In other words, not only does it describe and follow data points well, but its inflection point facilitates the comparison of different anatomical regions, too. The analysis showed that although sapwood and juvenile wood had higher σ values, the high variation shows them to be less reliable than heartwood is. Differences are evident, while the function type is more descriptive than linear or simpler nonlinear functions. Because of the uncertainty inherent to small samples, data were pooled into a larger sample. The function was fitted to all three anatomical parts, with results consistent with the findings for small samples.

2.) In the larger-scale main test, an expanded form of the model, used successfully for the pre-trial, was chosen. The new model is a multivariate function composed of two separate hyperbolic tangent functions with two independent variables:

$$\sigma = a_1 \tanh\left(a_2 \left(\rho - a_3\right)\right) + a_4 \tanh\left(a_5 \left(K - a_6\right)\right) + a_7 .$$

Detailed geometric analysis of the surface showed that the model is adequate, because it fulfils the requirements. Correlation data and statistic tests show that the model fits experimental data well (the *R* value is higher than 0.84.) Other, simplified models are physically inadequate.

In terms of the earlier criteria:

2.1 The function provides an average set of ρ, K and σ values for both materials.

The values provided by the regression analysis are affected by several parameters. The calculated planar point coordinates are conservative estimates of the sample averages. The difference from the arithmatic average is not significant for mountain Scots pine, but is somewhat larger for the lowland material. In terms of *K*, the difference is small compared to the average of *K* over the large sample in lowland materials, but the *K* value provided by the function for mountain Scots pine is clearly too high. The disparity may be explained by the less dominant role of *K* in the bivariate function. The significant difference between the planar point coordinates of the two materials, however, correctly indicates their different annual ring structures.

2.2 The function provides the change in σ for a unit increment of ρ (degree of increase) at the average set of data points, for both types of material. This facilitates the nondestructive estimation of compression strength at various density values.

The value calculated for mountain Scots pine, in agreement with the correlation coefficient, indicates that the structure of the material is more homogeneous, more consistent in terms of its strength, than lowland Scots pine is.

2.3 The function provides the change in σ for a unit increment of K (degree of decrease) for both types of material.

There is a significant difference in the change in σ for a unit increment of K between the two materials.

2.4 The function provides the lowest and highest acceptable values of σ and its range. These are partly acceptable technologically.

Mountain Scots pine interval limits agree with those specified for Scots pine in the literature (Molnar 1999)[1]. The upper limit for lowland Scots pine is almost the same as that of the mountain material, but the lower limit of σ is significantly displaced.

2.5 Using the derivatives of the function, the limit values of ρ that belong to the degree

[1] Molnar S. (1999) Faanyagismerettan. Mezőgazdasági Szaktudás Kiadó, Budapest. (*In Hungarian.*)

of increase (ρ_{min}, ρ_{max}) may be specified (thus the range of ρ is also calculable).

The calculated limit density values are technically meaningful.

2.6 Using the derivatives of the function, the limit values of K that belong to the degree of decrease (K_{min}, K_{max}) may be specified (thus the range of K is also calculable).

Lowland pine data apparently match real average data; the range covers measured and calculated K values. However, calculated values are too high in the case of mountain pine.

2.7 The function's coefficients are physically and technologically meaningful and have physical dimensions.

2.8 There are five coefficients in the fitted functions (a_1, a_3, a_5, a_6, a_7) that assume different values for the two types of materials.

2.9 The model fulfils all the prescribed requirements, in addition to showing good correlation to experimental data.

In summary, fitted functions fulfilled the requirements. Results confirm that mountain Scots pine differs significantly from that grown on lowland sites. In terms of strength, mountain material is preferable, as evidenced by its annual ring structure, despite the fact that, under optimal geographical site conditions, lowland Scots pine may also reach maximum density compression strength.

IV. RESULTS IN A THESIS FORMAT

1.) I have established that the hyperbolic functions that I chose were adequate for both the small and large sample tests, provided high correlations, and described the relationship of the examined physical and mechanical parameters reliably.

2.) Through the utilised models I managed to provide novel special average values of the examined parameters, in the case of both the univariate and bivariate functions, as well as presenting the change rate of the physical parameters at the characteristic point. This is new information for the user.

3.) Based on the small sample test I established that juvenile wood and sapwood physical parameters show higher variation than those of the heartwood. This variability could not to be omitted during the tests.

4.) By fitting functions to two materials from different site types I concluded that the two kinds of material show significant differences, as evidenced by the variation of the model's coefficients.

5.) Also from curve fitting results I established that ew/lw proportion plays an important role in the case of the lowland material, while it is less dominant in mountain Scots pine. From this I concluded that, for the sake of comparison, ew/lw proportion, as an independent variable is not to be eliminated from the model.

6.) Calculated regression models allowed me to provide intervals of density, compression strength and ew/lw proportion. This is a novel concept that takes the relationship of the variables into consideration. Interval limits are helpful in further research, with the exception of mountain Scots pine, in which case they need some refining.

V. POSSIBLE APPLICATIONS AND IMPROVEMENT

Research results demonstrate that, when comparing physical parameters, the utilised regression models are more versatile. The analysis based on the inflection and planar points of the uni- and multivariate functions provides more information about the species to be examined (see requirements.) Thus, they are preferable to traditional linear models.

Further examination of ew/lw proportion is a focal point of improvement. Possibilities include eliminating outlying values or repeating the large-scale study to include all major anatomical parts.

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