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TIMBER GRADE ORIENTED ANALYSIS OF *ABIES GRANDIS* TREES' OVENDRY DENSITY WITH DIFFERENT GROWTH RATES
PART I.: EXPERIMENTAL DESIGN

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ABSTRACT

The variability of ovendry density on 12 giant fir (*Abies grandis*) logs was investigated. Statistical analysis also was made. The wood was checked for compression wood, "coloured heartwood", knots and annual ring width. However, giant fir has usually no coloured heartwood in some investigated logs discolouration of the heartwood was detectable. The mean ovendry density (at MC of 0 %) of all specimens was 0.357 g.cm^{-3}. The statistical analysis showed significant differences between ovendry density of the sapwood (mean= 0.417 g.cm^{-3}) and those of visible (mean = 0.335 g.cm^{-3}) and non-visible (mean= 0.336 g.cm^{-3}) heartwood ovendry densities. The ovendry density was higher in compression wood than in normal wood in case of heartwood and sapwood as well. The ovendry density at 1.5 m height the highest was, and decreased constantly with increasing tree heights at 7.0, 14.0 and 20 m.

KEYWORDS: Giant fir, ovendry density, compression wood, heartwood discolouration.

INTRODUCTION

Recently, several factors induce a middle-term increase of demands for wood products in Germany, which can cause supply problems on the wood market in terms of softwood assortments. These factors are primarily insufficient timber supply in the future from the small private forestry sector and the increasing wood utilization in industrial and in energetic sector (Spellmann et al. 2011). Reduction or displacements of production capacity of wood industry especially to East Europe intensify this trend additionally.

The wide location amplitude and the high competitiveness of giant fir (*Abies grandis*) as well as the possibility of cultivation as a mixed species especially in beech stands make utilization of this wood species sustainable also considering the point of view of the climate change (Hof et al. 2008a). Furthermore the growth potential is similar to the Douglas fir, or depending on the habitat it might be superior to it. Besides the enormous growth capacity the wood quality also calls for cultivation of giant fir in Germany (Hapla 2011).

Wood density is the most important physical parameter of wood, which is also an indicator for other wood parameters, thus it is possible to draw conclusions regarding the possible utilization of the material. For example density is influencing the harvesting and transport costs, strength properties of wood, the yield in paper and fibre industry. However, the establishing of a representative wood density value for a specific wood species is not possible, because wood density is considerable between and within tree variation.

For the industrial processing the homogeneity of used raw material is of great importance. The more homogeneous the raw material is the easier is the processing and the control. Also the costs of processing are lower and the quality is higher in case of homogeneous material. It is also valid for the wood industries, like fibreboard or chipboard production and sawmills industry. Whereas wood is a natural growing raw material, the possibility to influence the homogeneity of wood material is very limited. However, there are some possibilities in silvicultural operations and the selection of the wood species. This study is dealing with the variability of wood density in radial stem direction as well as in longitudinal stem direction, accomplished with a comparative statistical analysis.

For the deeper description of the variability in density, the compression wood was also investigated. The deviation from the mean compression wood density and the other wood parts without compression wood was calculated. Reaction wood is a supporting structure in wood. While softwoods are forming lignin-rich compression wood, hardwoods forming cellulose-rich tensile wood. Compression wood develops when a bending load is permanently repeated or it lasts constantly, for example wind- or snow loads (Glos and Richter 2002). Contrary to normal wood, compression wood has increased lignin content. Consequently hardness of compression wood is higher as well as the shrinking and swelling values along the fibres (Timell 1986; Wagenführ 1999). Compression wood is often more brittle than normal wood, therefore its elastic reaction to external forces is worse. The enormous growth dynamic of fast growing tree species like giant fir procures an eccentric secondary thickness growing by softwoods and it often leads to the formation of compression wood (Riebel 1994).

An important aspect relates to the moisture dispersion in sap- and heartwood of giant fir, which can cause wet heartwood at well-defined places. Heartwood is often dark after harvesting and without a preservative treatment it is not durable. Analysis of wood extractives showed that the formation of wet heartwood is not necessarily associated with a microbial decomposition of reserve nutriments in parenchymatic cells and it is not associated with a change of lignification in the certain cell wall layers. Other investigations showed that the presence of wet heartwood not necessarily decreases the wood quality of giant fir (Hof et al. 2008b). The wet heartwood is formed because some aphid infestation (e.g. *Adelges piceae*). Some authors found reduced permeability of the giant fir as a result of aphid infestation, which was caused by some structural alterations in xylem. These alterations could explain the wetwood formation in heartwood (Puritch and Petty 1971).

MATERIAL AND METHODS

Material

12 logs were investigated, which were harvested from three different forest stands. The stands were located in the forest of the town Meschede in Sauerland. The giant fir was the governing species in all three stands mixed with douglas fir.

The marking of 12 logs were made with Latin numbers from I-XII. The logs were cut into 4 parts, which were marked with Arabic numbers (1-4). These 4 parts were cut into three sections, with the signs u (under), m (middle) and r (rest). The sections marked with u and m were 2.35 m long and the section marked with r was 1.3 m long (Fig. 1). The logs were cut in such a way that the middle board enclosed the pith in its full length. Furthermore the middle boards were edged and checked for compression wood, "coloured heartwood", knots and annual ring width.

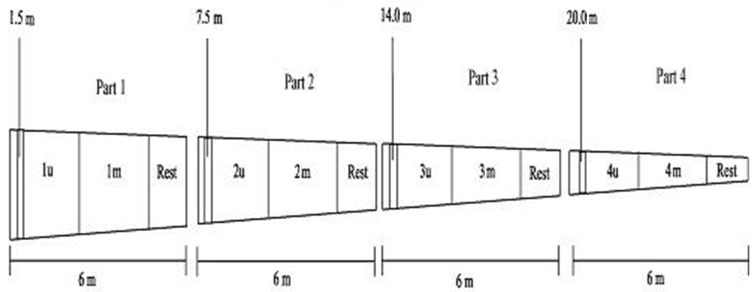

Fig. 1: Cutting and marking of the investigated logs. Places of sampling.

Sampling and number of samples

Samples were made of middle boards to ensure an entire radial profile of wood from the pith to the sapwood. The boards were edged parallel to the pith, therefore some pieces and with that some data of the sapwoods density got lost. All samples were made from middle boards of the sections marked with u. The sampling heights were 1.5 m (height 1), 7.5 m (height 2), 14.0 m (height 3) and 20.0 m (height 4). Fig. 2 shows the sampling method and marking of samples in a middle board. The dimensions of the samples were 20×20×20 mm. The marking of the samples contained the log number, the block number and the section number as well. Furthermore, the samples were differenced by radial position as well. The estimated heartwood was marked with "H", the estimated sapwood was marked with "S". The samples containing pith were marked with "M" (middle). The presence of compression wood was marked with "C".

The total number of the samples was 575 pieces. The samples of logs I, III and IV from the section 4u were missed, because of the small diameter of these sections.

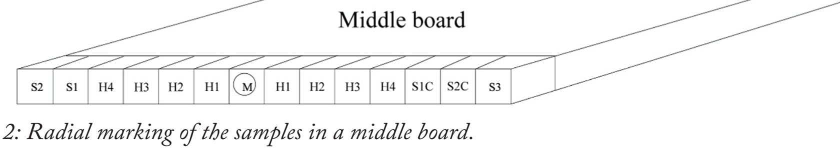

Fig. 2: Radial marking of the samples in a middle board.

Separation of heartwood and sapwood

Giant fir has no coloured heartwood, thus in normal case the heartwood and sapwood cannot be distinguished visually. However, in some investigated logs the heartwood discoloration was detectable (Fig. 3). In the field of forestry and wood industry it is called "wetwood". One of the goals of this study was to show whether this discolouration has any effect on the ovendry density.

Fig. 3: Logs with heartwood discolouration.

Fig. 4: Strong compression wood formation in an investigated board.

On the basis of the visible heartwood on the logs, two collectives were differentiated. In the first group the logs with visible heartwood (VH) and in the other group the logs with no visible heartwood (NVH) were sorted. The heartwood rate of the group with visible heartwood was determined with the number of annual rings. At all sampling heights and separated according to the tree age and social classes (according to the Kraft classes) was the mean of annual rings determined (Tab. 1). Based on these results, the calculated width of the heartwood was transmitted on the logs without coloured heartwood (NVH). Four trees were 50 years old and eight trees 64 years old. Six of the 12 trees had heartwood discolouration, but by six trees no discolouration could be observed. The effect of compression wood was determined as well (Fig. 4).

Tab. 1: Number of annual rings in coloured heartwood, in relation with the height and tree age (N=12 logs).

Section	1u	2u	3u	4u
KC1				
50 year	27	22	16	14
64 year	35	28	21	18
KC3				
50 year	21	17	11	10
64 year	26	22	14	11

Determination of the ovendry density

Preparation of the samples was made according to the standard DIN 52 180 (1977) dried for 48 hours at 103 ± 2°C in a drying chamber to reach ovendry state. Ovendry density was determined according to the equation:

$$\rho_0{}' = m_0 / V_0 \qquad (g.cm^{-3})$$

where: ρ_0 - ovendry density ($g.cm^{-3}$),
m_0 - ovendry mass (g),
V_0 - ovendry volume (cm^3).

Henceforth the word density is used for ovendry density.

Statistical analysis

The statistical analysis was carried out with the t-test, when possible. The requirement for the applicability of the t-test is a normal distribution of the investigated variables and the similarity of the variances, which was verified with the Levene-test. The Lilliefors test was used for the verification of the normal distribution. The pooled t-test was made if the variances were not similar. The U-test was made if the distribution was not normal. The requirement for the use of the U-test is the similarity of the investigated variables' distribution, which was verified with the K-S-test for two independent variables. The median test was used if this requirement was not fulfilled. The analysis was made with the software Statistica 6.0.

RESULTS AND DISCUSSION

General values

Altogether 575 pieces of samples were investigated. The general statistical values are shown in Tab. 2. The mean density of all specimens was 0.357 $g.cm^{-3}$. The median was 0.347 $g.cm^{-3}$. The minimum was 0.245 $g.cm^{-3}$ and the maximum 0.566 $g.cm^{-3}$. The distribution is not normal, according to the Lilliefors-test (p=0.01). The confidence interval shows that the real mean of the density is with 95 % probability between 0.352 $g.cm^{-3}$ and 0.361 $g.cm^{-3}$.

Tab. 2: General statistical values of the ovendry density ($g.cm^{-3}$), containing the data of all samples (al logs and heights).

Variable	N	$\bar{x}$	Median	s	X_{min}	X_{max}
Dry density	575	0.357	0.347	0.055	0.245	0.566

Comparison of the heartwood and sapwood

Altogether 373 samples from heartwood and 140 samples from sapwood were investigated. The general statistical values are shown in Tab. 3. The mean density of heartwood was 0.336 $g.cm^{-3}$. The minimum was 0.245 $g.cm^{-3}$ and the maximum 0.506 $g.cm^{-3}$. The mean dry densities of the visible (VH) and non-visible heartwood (NVH) were very close to each other (0.335 and 0.336 $g.cm^{-3}$). According to these results the discolouration of the heartwood results in no significant difference in the heartwood density.

Statistical analysis showed that density of the sapwood (mean = 0.417 $g.cm^{-3}$) significantly differs from both the visible (mean = 0.335 $g.cm^{-3}$) and non-visible (mean = 0.336 $g.cm^{-3}$) heartwoods densities (Tab. 3). The density of sapwood is clearly higher than density of heartwood. The difference of 0.080 $g.cm^{-3}$ between the mean of the two wooden parts has industrial importance, in case of the sorting of lumber in quality classes. The reason for the significant difference between sapwood and heartwood can be explained by the influencing effect of juvenility. As juvenile wood has lower cell wall / lumen ratio (Zobel and van Buijtenen 1989) the high juvenile wood content could decrease the density of the heartwood. High reliability of the presented results is guaranteed by the number of investigated logs (12), the high number of specimen and the moderate standard deviations.

Tab. 3: Basic statistical values of the ovendry density (g.cm^{-3}), containing the data of sapwood, visible (VH) and non-visible (NVH) heartwood.

Variable	N	$\bar{x}$	s	X_{min}	X_{max}
VH	252	0.335	0.036	0.245	0.475
NVH	121	0.336	0.042	0.265	0.506
„Heartwood“	373	0.336	0.038	0.245	0.506
Sapwood	140	0.417	0.053	0.306	0.566

The effect of compression wood

It is important to clear the effect of compression wood on the variability of density in sapwood and heartwood. Altogether 173 samples containing compression wood were investigated. Other 401 samples did not show the presence of compression wood (normal wood). The results are shown in Tab. 4.

Tab. 4: Basic statistical values of the ovendry density (g.cm^{-3}), containing the data of the compression wood and normal wood.

Variable	N	Median	s	X_{min}	X_{max}
Compression wood	173	0.388	0.058	0.281	0.566
Normal wood	401	0.334	0.044	0.245	0.524

The median of the compression wood and normal wood was 0.388 and 0.334 g.cm^{-3} respectively. The statistical analysis showed that the density of the compression wood and normal wood is significant different. The detailed analysis showed that the density of compression wood containing heartwood (0.363 g.cm^{-3}) is higher than the density of normal heartwood (0.327 g.cm^{-3}). The difference between the compression wood containing sapwood and normal sapwood was similar to the heartwood. Also in case of sapwood, the density was higher in the compression wood (0.423 compared to 0.397 g.cm^{-3}).

Variability of the ovendry density in longitudinal direction

The highest density value of 0.380 g.cm^{-3} was measured at the height of 1.5 m. At the height of 7.5 m was the density significantly lower (0.346 g.cm^{-3}). In longitudinal direction at 14.0 and 20 and 0.347 g.cm^{-3} respectively. Thus, the density at the stump of the trees was the highest (1.5 m), and decreased with height up to 7.5 m and reached a constant value (Tab. 5). The density is normally decreasing with the height by softwoods but there are some species (e.g. *Picea abies*, *Picea mariana*) where density is constant in vertical direction (Stern 1963; Olesen 1973; Risi and Zeller 1960). It is uncommon when the density decreases to the middle height and remains constant in the upper part of the stem and only possible by a few species (Hilmi 1960).

Tab. 5: Basic statistical values of the ovendry density (g.cm^{-3}) at different tree heights ovendry density (g.cm^{-3}).

Ovendry density (g.cm^{-3})	N	$\bar{x}$
20.0 m	83	0.347
14.0 m	159	0.344
7.5 m	195	0.346
1.5 m	250	0.380

CONCLUSIONS

The ovendry density of giant fir (*Abies grandis*) was investigated. The mean ovendry density concerning all samples was 0.357 g.cm^{-3} (N=12 logs, n=575 samples). The mean ovendry densities of the visible (VH) and non-visible heartwood (NVH) were very close to each other (0.335 and 0.336 g.cm^{-3}). According to the results the discoloured heartwood showes no significant difference in the ovendry density compared to the heartwood zone without discolouration. The ovendry density of compression wood was in both heartwood and sapwood higher than the ovendry density of normal heart- and sapwood. The ovendry density was the highest (1.5 m) at the bottom part of the trees, and decreased up to the tree height of 7.5 m and futher reached constant value.

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