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TIMBER GRADE ORIENTED ANALYSIS OF *ABIES GRANDIS* TREES' OVENDRY DENSITY WITH DIFFERENT GROWTH RATES
PART II.: EFFECT OF THE TREES' SOCIAL POSITION IN THE FOREST ON THE VARIABILITY OF OVENDRY DENSITY

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ABSTRACT

The variability of ovendry density on 12 giant fir logs (*Abies grandis*) was investigated. Statistical analysis was made also. The variation of the ovendry density was determined regarding to the different Kraft classes, heights and radial wood zones (sapwood, heartwood and compression wood). The difference between the ovendry density of the trees from the Kraft class 1 and 3 is not significant. According to the determined radial gradients the highest ovendry density was always measured in the outermost parts (next to the cambium) while the lowest ovendry density was measured in the innermost part of the heartwood (juvenile wood). In longitudinal direction the ovendry density showed at 1.5 m tree height the highest and at 7.5 and 14.0 m the lowest values. The density of the heartwood was lower than the density of the sapwood and compression wood at all investigated tree heights. The ovendry density of the compression wood reached values between the heartwoods and the sapwoods density, at all investigated tree heights. The test results provide a solid and practical basis for the timber grading of the giant fir logs.

KEYWORDS: Giant fir, ovendry density, compression wood, juvenile wood, Kraft classes.

INTRODUCTION

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 the utilization of this wood species sustainable, nevertheless considering the climate change in Europe (Hof et al. 2008). Furthermore the growth potential is similar to the Douglas fir, or depending on the habitat it may greater (Mitze 2010). Beside of the enormous growth capacity the favourable wood quality also justify the cultivation of giant fir in Europe (Hapla 2011; Vos and Kharazipour 2010).

Wood density is the most important physical parameter of wood, which is an indicator for other wood parameters, thus the utilization of the wood can be modelled based on density values (Bosshard 1974; Niemz 1993; Lukášek et al. 2012). For example density is influencing the harvesting and transport costs, strength properties, the yield in paper and fiber industry.

However, the establishing of a representative and exact wood density value for a specific wood species is not possible, because wood density has a large variation between the stand individuals as well as within one trunk – as it was already showed in Part I. The variability is depending on several factors. Important factors are the growth and habitat conditions. Also the social position and the tree age play an important role. The available sunlight, water and nutrients are influenced by the space available for the tree in the stand and effect a competition between the individual trees. These and further biotic and abiotic factors are influencing the growing dynamic and the annual ring width of giant fir as well.

In the industrial processing the homogeneity of the raw material is of great advantage. Whereas wood is a raw material grown by nature, the possibility to influence the homogeneity of wood material is very limited. However, there are some possibilities by applying proper silvicultural management and the selection of the wood species. This study is dealing with the variability of the wood density depending on the silvicultural management. The effect of two different social classes was investigated according to the Kraft classes. The variation of ovendry density was studied in radial and longitudinal directions as well. According to the position of the crown of a tree, the trees can be classified into one of four categories: dominant, codominant, intermediate, and suppressed. In the presented study samples were taken from trees with dominant crown position (Kraft class 1 – KC1) and from trees with intermediate crown position in the forest (Kraft class 3 – KC3), accomplished with a comparative statistical analysis.

The compression wood was investigated as well, to allow a better understanding of ovendry density's variability between and within the trees. The object of investigation was the middle deviation of the compression wood's and normal wood's ovendry density. The amount and the mean value of the compression wood's ovendry density in the KC1 and KC3 were compared as well. The enormous growth dynamic of fast growing species, like giant fir, often causes an eccentric secondary thickening, which can lead to the formation of compression wood (Riebel 1994). It occurs mainly in case of the trees in Kraft Class 1. The trees in the Kraft Class 1 are subjected to more intensive wind load, which also facilitates the formation of compression wood. Henceforth the word density is used for ovendry density.

MATERIAL AND METHODS

Altogether 12 logs from three different forest stands were investigated. The stands are located in the forest of the town Meschede in Sauerland (Germany). The giant fir was the main species in all three investigated stands, mixed with douglas fir. 4 logs were harvested from each stands. 2 of the 4 logs from each stand were harvested from the Kraft class 1 (KC1) and 2 from the Kraft class 3 (KC3). The trees from the KC1 are representing the growing conditions with a wide free space between the trees. Whereas the trees from KC3 were grown close to each other, and only moderate thinning was carried out (Böckenhoff 2003). The trees from KC1 are the most vital and the most competitive in a stand, whereas the trees in KC3 have only a moderate vitality. The higher vitality of the trees in KC1 results in a more intensive growth in height, in radial direction and in crown. They are also called as "dominant". Trees from the KC3 are called "intermediate" and have only lower growth capacity. The concept of the methods is extensively detailed in Part I.

RESULTS AND DISCUSSION

Variation of the ovendry density between the logs originating from different Kraft classes

The data of the significance test concerning the mean density between the collectives KC1 and KC3 are shown in Tab. 1. 6 logs of each the collectives KC1 and KC3 were involved into the investigations. The median was 0.343 and 0.355 g.cm^{-3} for the collectives KC1 and KC3 respectively. According to these results the mean density of the investigated collectives (all samples taken into consideration) does not differ from each other. However, the mean density of the logs from the KC3 collective showed slightly higher values. This shows the importance of the stratification according to the growth zones in radial direction.

Tab. 1: General statistical values of the ovendry density (g.cm^{-3}), containing the data of the different Kraft classes (KC1 and KC3).

Variable	N	$\overline{x}$	Median	s	x_{min}	x_{max}	Spread	Variation coefficient C_v (%)
KC1	367	0.351	0.343	0.052	0.245	0.566	0.321	14.8
KC3	208	0.366	0.355	0.058	0.251	0.528	0.277	15.8

The effect of the tree's social position in the forest is mainly in the sapwoods density clear (Figs. 1 and 2). Only in radial direction was significant difference between heartwood and sapwood. Tab. 1 shows the variability of the density within the collective KC1 and KC3 based on the spread. The spread of the measured density values within the KC1 collective is higher than within the KC3 collective. The spread of the density in the KC1 collective is 0.321 g.cm^{-3}, while the spread of the density in the KC3 collective is only 0.277 g.cm^{-3}. However, the number of samples is higher too, which may result in a higher scattering of the density values. But the standard deviation is smaller concerning the density of KC1. The variation coefficients show as well that the standard deviation is in relation to the mean density smaller by KC1 than by KC3 (14.8 against 15.8 %).

Variation of the ovendry density in radial direction at different heights

Mean density of heartwood, compression wood and sapwood of the collectives KC1 and KC3 at different heights are shown in Tabs. 2 and 3. The highest density was measured at 1.5 m tree height considering all the investigated wood zones. The mean density was in the heartwood and compression wood the lowest at the middle tree height (7.5 and 14 m), while the sapwood showed at 20 m tree height the minimum density. According to these results the density of the heartwood is lower than that of the compression wood and sapwood. However, the compression wood's density is always between heartwood and sapwood at all investigated heights. Sapwood has constantly the highest density at all heights.

The radial gradients of the density at different heights are shown in Fig. 1 (KC1, mean value of 6 logs) and Fig. 2 (KC3 mean value of 6 logs). The density of the heartwood decreases continuously from the sapwood to the pith (10-1 h), and then in the pith (m) a slight increase could be observed. The density has its minimum value next to the pith, but increases continuously until the outer part of the sapwood (next to the bark). The highest density was measured at every height in the outer part of the sapwood. Accordingly, giant fir has the lowest density next to the pith, and the highest next to the bark independent from the sampling height.

By the collective KC3 a continuous increasing density could be observed from the pith to the sapwood. In spite of that, the radial gradient of the density by the collective KC1 is slightly inconsistent. At certain locations are wood zones with density above average compared to the ambient wood (e.g. Fig. 1 at 1.5 m height, section "s4").

Tab. 2: Mean values of the ovendry density (g.cm^{-3}) in the heartwood, compression wood and sapwood at different heights, regarding the collective KC1.

Ovendry density (g.cm^{-3})	**KC1**					
Wood zone	***Heartwood***		***Compression wood***		***Sapwood***	
	N	$\bar{x}$	**N**	$\bar{x}$	**N**	$\bar{x}$
20.0 m	42	0.333	9	0.371	9	0.383
14.0 m	60	0.321	26	0.368	20	0.388
7.5 m	72	0.321	33	0.387	22	0.411
1.5 m	85	0.353	61	0.396	27	0.442

Tab. 3: Mean values of the ovendry density (g.cm^{-3}) in the heartwood, compression wood and sapwood at different heights, regarding the collective KC3.

Ovendry density (g.cm^{3})	**KC3**					
Wood zone	***Heartwood***		***Compression wood***		***Sapwood***	
	N	$\bar{x}$	**N**	$\bar{x}$	**N**	$\bar{x}$
20.0 m	13	0.335	0	-	10	0.398
14.0 m	23	0.329	12	0.386	18	0.394
7.5 m	40	0.336	15	0.398	13	0.425
1.5 m	38	0.354	17	0.449	22	0.457

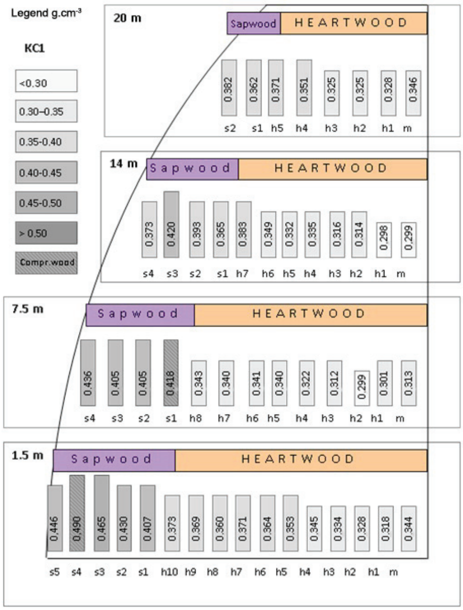

Fig. 1: Radial gradient of the ovendry density (g.cm^{-3}) at the four investigated sampling heights, regarding the collective KC1 (N=6 logs).

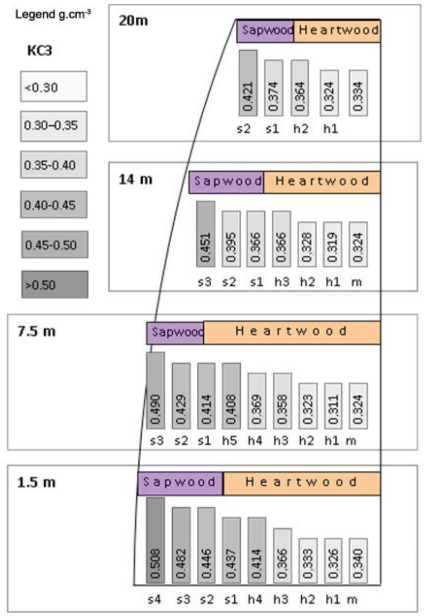

Fig. 2: Radial gradient of the dry density (g.cm^{-3}) at the four investigated sampling heights, regarding the collective KC3 (N=6 logs).

Heartwood

The gradients of the density at different heights are similar to each other in case of KC1 (Fig. 1). The innermost zone – the pith – has higher density than the ambient wood. The density decreases in the juvenile zone next to the pith. The density is in this internal heartwood zone the lowest, because of the wide cell lumens of the tracheids in the juvenile wood (Mombächer 2003). One exception in the radial gradient of the density is at 14.0 m height by the collective KC1. There is the density of the pith and the juvenile wood next to it at the same value. The juvenile wood is generally included in the samples h 1 and h 2. This corresponds to the fact that the first 10 to 20 annual rings are meant as the juvenile wood. The density is increasing continuously to the outer parts. Another exception could be identified in the heartwood zone by the collective KC1 at 7.5 m height. This part is located at the transition between heartwood and sapwood and the density is constant. This zone is in the Fig. 1 at 7.5 m height between the samples h 5 to h 8. At 14.0 m height an increased density compared to the ambient parts could be observed by the collective KC1 (Fig. 1, sample h 7), however no compression wood was present. The highest density in the heartwood was measured in the outer heartwood zone, next to the sapwood. This is the transition zone between the heartwood and sapwood.

The density showed similar radial gradients in the heartwood of the trees from the Kraft class 3 (Fig. 2) at the investigated heights than in the Kraft class 1. Only fewer samples could be investigated because of the smaller dimensions by the trees of the Kraft class 3. The pith-zone (m) has higher density than the ambient wood. The density is in the juvenile zone the lowest considering the whole radial gradient of the density. The juvenile wood is generally included in the samples h 1 and h 2. After the juvenile part the density is increasing continuously to the outer heartwood parts (transition zone between the heartwood and sapwood), which zone is described as mature wood. The zone with approximately equal density – as it was seen in the heartwood of the trees from the Kraft class 1 – is by the trees from the Kraft class 3 not strong pronounced and it is shifted to the transition zone between heartwood and sapwood (Fig. 2, at the heights 7.5 m, 14.0 m and 20 m) or completely to the sapwood (Fig. 2, at the height 1.5 m).

Mean density of heartwood, compression wood and sapwood of the collectives KC1 and KC3 at different heights are shown in Tabs. 2 and 3. The mean density was in the heartwood the lowest at all investigated heights compared to the sapwood and compression wood. Within the heartwood decreased the density from 1.5 m to 7.5 m height and remained constant until 14.0 m, but increased at 20.0 m height again. This is valid for both of the trees in the Kraft class 1 and 3, however the differences in the density are lower by the collective KC3. The highest density in the heartwood of the collective KC1 and KC3 was measured at 1.5 m height as well, and it was 0.353 and 0.354 $g.cm^{-3}$ respectively. The lowest density in the heartwood of the collective KC1 at 7.5 and 14.0 m heights with 0.321 $g.cm^{-3}$. The same could be observed by the collective KC3 is at 14.0 m height with 0.329 $g.cm^{-3}$.

Sapwood

The zones of juvenile and adolescent wood are followed by the adult wood zone with higher latewood ratio and density. It is located mostly in the sapwood zone. The density of the Kraft class 1 (Fig. 1) increases from the transition zone between heartwood and sapwood to the cambium. Opposite to the heartwood an increasing tendency of the density was found in the sapwood, which resulted in a significant difference between the spreads of the heartwood and sapwood. However, at 1.5 and 14.0 m heights a decrease in the density was observed in the outermost part (next to the cambium). By the collective KC1 at 1.5 m height was the density in the part s4 the highest. There was a frequent occurrence of compression wood, which explains the higher density. By the collective KC1 at 14.0 m height was the density in the part s3 the highest. There was no frequent occurrence of compression wood compared to the ambient wood. Another inconstancy was observed at 7.5 m height in the part s1. But there was a frequent occurrence of compression wood. The highest density was measured here in the part s4, which is the part next to the cambium. At 20.0 m height the highest density was measured in the part next to the cambium as well.

The sapwood of the Kraft class 3 did not show such irregularities in the radial density gradients. Between heartwood to sapwood a zone with constant density could be observed. This zone was partly extended to the sapwood by the trees of KC3 as well (e.g. at 14.0 m height in the parts h3 and s1). It is followed by a zone, where the density is increasing until the cambium. The highest density was observed next to the cambium.

Tabs. 2 and 3 show the mean values of the densities at different heights regarding the heartwood, sapwood and compression wood. The results of the collective KC1 showed a continuous decrease of the density from 1.5 to 20.0 m height with 0.442 and 0.383 $g.cm^{-3}$ respectively. However, the lowest density in the sapwood of the collective KC3 was measured at 14.0 m height. The mean dry density was there 0.394 $g.cm^{-3}$. The highest density was observed at 1.5 m height (0.457 $g.cm^{-3}$) similarly to the collective KC1. It is the altogether highest density regarding the investigated collectives, wood zones and heights as well. The density of the sapwood is at all the investigated heights higher than the density of the compression wood or heartwood.

Compression wood

According to the Tabs. 2 and 3 the mean value of the compression wood's density is always between the mean of the sapwood and the heartwood at all investigated heights. This result shows that the presence of compression wood does not result in extreme changes in the density and fits in the radial gradient well. However, the statistical analysis showed significant differences between the compression wood and the normal wood altogether as well as between compression wood and sapwood or heartwood. Though, the practical relevance of these significant differences is diminished by the fact that only at two locations was increased density observed due to the frequent occurrence of compression wood (Fig. 1 at 1.5 m height in the part s4 and at 7.5 m height in the part s1). Compression wood was only in the fast grown collective KC1 present.

About the vertical distribution of the compression woods density was stated that the lowest value in the collective KC1 is at 14.0 m height and the highest at 1.5 m height with 0.368 and 0.396 $g.cm^{-3}$ respectively. On the other hand by the trees of the collective KC3 the lowest density was detected at a height of 14.0 m with 0.386 $g.cm^{-3}$ and the highest density was found at a height of 1.5 m with 0.449 $g.cm^{-3}$. By the Kraft class 3 the density of the compression wood could not be determined at 20.0 m height because there was no compression wood present.

CONCLUSIONS

The radial ovendry density gradients of the trees from the Kraft classes 1 and 3 were investigated at four different heights. Results showed that the ovendry density of the trees from the collective KC1 is slightly lower than the ovendry density of the trees from the collective KC3, however the statistical analysis did not showed significant difference. Also the variability within the tree is not necessarily higher in the collective KC1. According to the determined radial gradients the highest ovendry density was always measured in the outermost parts (next to the cambium) while the lowest ovendry density was measured in the innermost part of the heartwood (juvenile wood). In longitudinal direction was the ovendry density at 1.5 m height the highest and at 7.5 and 14.0 m the lowest.

Another result is that the heartwood zone is dominated by the juvenile and adolescent wood. The samples containing the pith had almost at all investigated heights higher ovendry density than the ambient wood. The juvenile wood was followed by the adolescent wood, where the ovendry density was increasing continuously. In the transition zone between the heartwood and sapwood in almost all radial gradients a section with only very low increasing or stagnating ovendry density was found.

The sapwood is dominated by adult wood. The ovendry density is increasing in the sapwood towards the barkat all investigated heights. In the collective KC1 at several locations increased ovendry density was observed compared to the ambient wood parts without frequent occurrence of compression wood. In the ovendry density of the trees from the Kraft class 3 such discrepancies were not found. By this collective the radial gradients are increasing continuously until the cambium, where the highest densities were measured.

The ovendry density of the heartwood was lower than the ovendry density of the sapwood and compression wood at all investigated heights. The highest values were measured in the outermost part of the sapwood at 1.5 m height by both of the collective KC1 and KC3. The lowest ovendry density in the sapwood was measured at 20.0 and 14.0 m for the collectives KC1 and KC3 respectively.

Ovendry density of the compression wood was at all investigated heights between the heartwood's and the sapwood's ovendry density. This result shows that compression wood fits in the radial ovendry density gradients and only has a slight effect on the increased variability of the ovendry density. The highest ovendry density in the compression wood was measured at 1.5 m height and the lowest at 14.0 m by both investigated collectives.

The distribution of the ovendry density within the investigated giant fir logs (N=12) is similar to the distributions of other softwood species in both the radial and longitudinal directions. However, the giant fir reacts very sensitive on the silvicultural operations and as a result of that on the available space in the stand.

The test results provide a solid and practical basis for the timber oriented sorting of the giant fir logs. The bottom parts of the logs are suitable for the lumber producing because of the significant higher ovendry density which usually result in higher strength as well. From the height of about 14.0 m the industrial wood is recommended as assortment for the panel and paper industry (paper, chipboard, fibreboard, etc.).

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