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Correspondences between manually estimated compression wood in Norway spruce and the warp of the sawn timber

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Compression wood is regarded as a serious defect which affects the warp and machinability of sawn timber. To handle these problems, different regulations have been developed regarding grading of sawlogs and of sawn timber. This study is an attempt to clarify the relation between the amount of visible compression wood in Norway spruce (*Picea abies* L.) and the warping of the sawn timber in terms of bow, spring and twist as well as further deformation after ripping of the dried products. The amount of compression wood was defined and measured on logs according to the methods of the Swedish Timber Measurement Council (Regulations for measuring of round wood) and on the sawn timber according to the Nordic Timber. The impact of two different drying schedules was also investigated. The study shows that visible compression wood in both the butt end of the log and within the sawn timber was a rather poor indicator of the warp of the dried sawn timber. In no comparison did the correlation coefficient, *r*, exceed 0.3. In contrast to this, the correlation between the amount of compression wood and the warp of secondary products was fair, $r = 0.79$. This means that it should be possible to identify sawn timber less suitable for secondary processing by the amount of compression wood. The corresponding correlation between compression wood in the butt end of the log and the warp of the secondary products was $r = 0.46$. No significant differences could be shown in the degree of warp, as related to compression wood, between sawn timber or secondary products, dried at a wet-bulb temperature of 55 °C/117 h, LT-schedule, and a dry-bulb temperature of 110 °C/24 h, HT-schedule, respectively.

Zusammenhang zwischen visuell geschätztem Druckholzanteil und Verwerfung nach dem Trocknen von Fichtenholz

Druckholz wird als schwerwiegender Holzfehler angesehen, der das Trocknungsverhalten und die Bearbeitbarkeit beeinflußt. Deswegen sind verschiedene Klassifizierungsregeln für Rund- und Schnittholz entwickelt worden. In dieser Arbeit wird der Zusammenhang zwischen dem visuell geschätzten Druckholzanteil und der Verwerfung nach dem Trocknen von Fichtenholz untersucht, und zwar: Verbiegung, Krümmung, Verdrehung und andere Verformungen nach dem Aufschneiden der getrockneten Proben. Der Druckholzanteil wurde dabei gemäß den schwedischen Bestimmungen geschätzt. Weiterhin wurde der Einfluß zweier verschiedener Trocknungsbedingungen untersucht. Die Ergebnisse zeigen, daß der sichtbare Druckholzanteil im Rundholz (Stammende) oder im Schnittholz nur wenig über die Verwerfung aussagt. In keinem Fall lag der Korrelationskoeffizient über 0,3. Dagegen war die Korrelation zwischen Druckholzanteil und Verwerfung in sekundären Schnittwaren annehmbar ($r = 0{,}79$). Es sollte also möglich sein, weniger geeignete Schnittware anhand ihres Druckholzanteils auszusortieren. Die Korrelation zwischen Druckholzanteil am Stammende und der Verwerfung im Schnittholz betrug 0,46. Für das Ausmaß der Verformungen wurde kein signifikanter Unterschied zwischen den beiden Tocknungsbedingungen (55 °C/117 h und 110 °C/24 h) gefunden.

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1 Introduction

Compression wood in Norway spruce has been considered the cause of considerable problems during processing at the sawmill as well as in sawn timber. As a response to these problems, rules and regulations have been developed for sawn timber in the Scandinavian countries. By the definition of the Nordic Timber the compression wood is disregarded if it is less than one third of the width of the annual ring, and if the compression wood is judged not to affect the straightness of the sawn product. Overall, the amount of compression wood is divided into four tolerance levels, one for each of four grades. (Anon 1997a).

Corresponding rules have also been developed by the Swedish Timber Measurement Council (Regulations for measuring of round wood) to be used in quality grading of sawlogs. In this case, it is a matter of the allowable amount of visible dense compression wood in the butt end of the log. Compression wood is regarded as dense if it exceeds half the width of an annual ring and the assessment of each single log should result in a grade that corresponds to a specific area of use of the sawn timber (Anon 1997b).

The problems are mainly related to a greater longitudinal shrinkage than in normal wood. Schulz and Bellman (1982) have found that the longitudinal swelling of compression wood was up to 10 times greater than normal wood in Norway spruce. The amount of longitudinal shrinkage of compression wood has been shown to be positively correlated to changes in the thickness of the tracheid wall and microfibril angle within the S2 layer of the wall. In compression wood the microfibril angle is considerably higher than in normal wood, with the consequence that longitudinal shrinkage is greater as well (Wloch 1975; Boyd 1977; Harris 1977; Schulz and Bellman 1982; Schulz et al. 1984).

Beard et al. (1993) have shown that the fraction of compression wood in Southern Pine timber shows a low explained variation in warp. Pillow et al. (1937) and Du Toit (1963) have shown that the position of the compression wood within the sawn timber greatly affects the degree of warp.

Several studies have shown that the warp on the sawn timber can be related to the drying temperature and to applied top-load restraint. Morén and Sehlstedt-Persson (1990) have shown that the warp of sawn timber of Norway spruce can be reduced by applying a top-load restraint during high temperature drying. A study of the effect of kiln schedule on warp in Douglas fir shows that differences in drying temperature, 114 °C and 140 °C, do not affect the degree of warp if top-loaded during the drying process (Milota 1992). A study by Arganbright et al. (1978) showed that a top load reduces warp in Ponderosa pine when air dried, dried by conventional schedule at a wet-bulb temperature of 47–60 °C and by high temperature schedule at 100–110 °C. None of these studies were designed to study the relation between compression wood and the warp of the sawn timber or how the drying conditions affect the results.

Compression wood is a wood property which is hard to identify and estimate visually; it varies over a wide range from very mild to very dense, as well as in distribution from parts of one annual ring to many annual rings in a tree. Consequently, it becomes difficult to consider all these variations in practise under ordinary manual grading conditions. In addition, the effect of compression wood in terms of warp of the sawn timber might be affected by the drying process. To evaluate the accuracy of the visually based methods for grade sorting, according to amount of compression wood, this study had three objectives:

- To examine the correspondence between the manual estimation of compression wood on sawlogs and the manual estimation of compression wood on sawn timber.
- To investigate the relationships between the estimated amount of compression wood and the warp of the dried sawn timber and secondary products.
- To study whether the drying conditions affect the straightness of planks and secondary products containing varying amounts of compression wood.

2
Materials and methods

This study is based on Norway spruce (*Picea abies* L.) butt logs from four different locations in northern Sweden. A total of 200 butt logs were selected, 160 of them showing varying fractions of dense compression wood in the butt end and 40 logs were free from visible compression wood as well as showing good quality in other respects. The sawlogs were selected and examined according to the Swedish Timber Measurement Council's Regulations for measuring of round wood (Anon 1997b) by two of their inspectors.

These inspectors marked the areas of dense compression wood in the butt end of the logs. The butt ends of the logs were photographed and the amount of compression wood was then measured with the aid of image processing and expressed as a fraction of the butt end area, CW-log, (Fig. 1).

The selected saw logs were divided into to equal groups for the purpose of studying the influence of drying schedules on the degree of warp of the sawn timber.

All logs were cant-sawn, and the results based only on the two centre planks with the dimensions 50 × 125 mm. Half of the centre planks were dried by a conventional air drying schedule at a wet-bulb temperature of 55 °C, LT-schedule (Fig. 2). The other half were dried in a 3-step process. First the planks were preheated with saturated steam until a wet-bulb temperature of close to 100° was reached. Then the planks were dried at a dry-bulb temperature of 110°. Finally, when the planks had cooled to

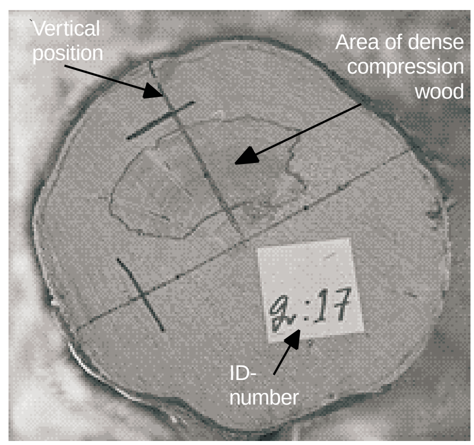

Fig. 1. A butt end of a log where the area of dense compression wood is marked and where the vertical positioning during block-sawing is shown
Bild 1. Stammende eines Rundholzes. Der Druckholzbereich ist markiert sowie die vertikale Position für den Einschnitt

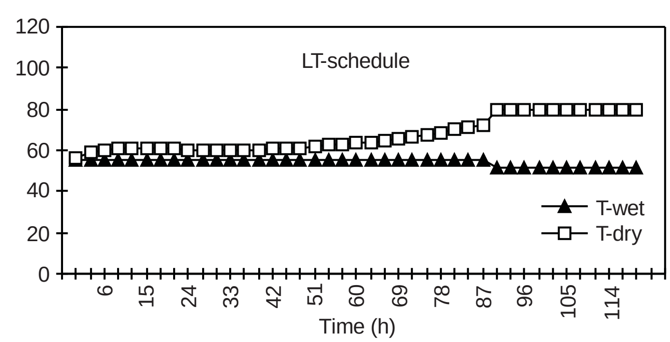

Fig. 2. The low temperature drying schedule. T-dry is the dry-bulb temperature and T-wet is the wet-bulb temperature
Bild 2. Fahrplan für die Niedrigtemperaturtrocknung mit Trockentemperatur (T-dry) und Feuchttemperatur (T-wet)

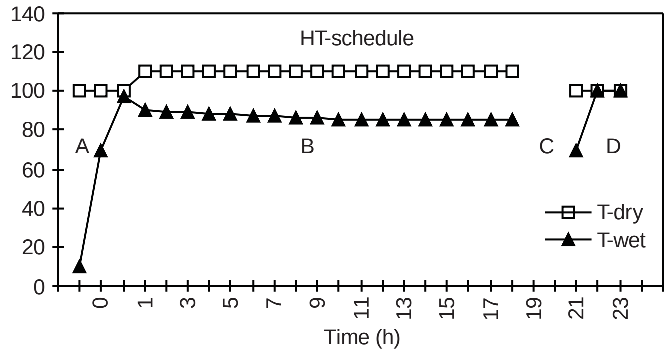

Fig. 3. The high temperature drying schedule. T-dry is the dry-bulb temperature and T-wet is the wet-bulb temperature. **A** is the pre-heating phase, **B** is the drying phase, **C** is the cooling phase of the timber and **D** is the conditioning phase
Bild 3. Fahrplan für die Hochtemperaturtrocknung mit Trockentemperatur (T-dry) und Feuchttemperatur (T-wet). **A** – Vorwärmphase; **B** – Trocknungsphase; **C** – Abkühlphase des Schnittholzes; **D** – Konditionierung

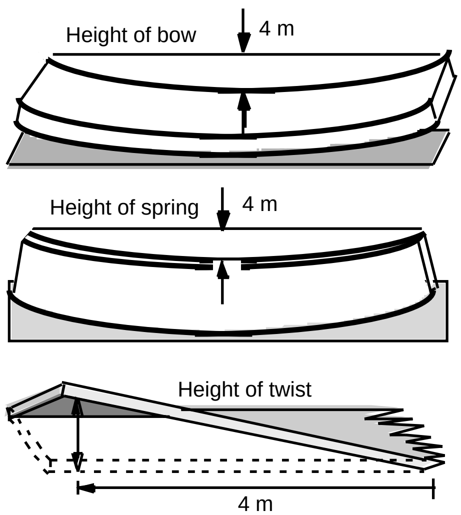

Fig. 4. Methods for measuring the warp of the sawn timber. Bow and spring in mm, twist expressed in percentage of the plank width
Bild 4. Bestimmen der Verwerfung im Schnittholz: Verbiegung und Krümmung in mm; Verdrehung in % der Brettbreite

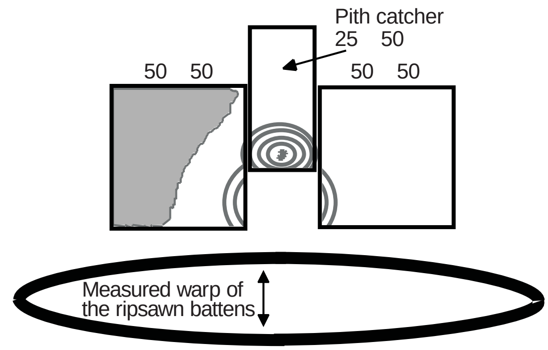

Fig. 5. The pattern of the ripsawn plank, and methods for measuring the warp of the battens
Bild 5. Einschnittmuster und Bestimmen der Verwerfung der Kanteln

approximately 70°, they were conditioned with saturated steam for 1.5 h (Fig. 3). All planks were dried to a moisture content of 12% and fixed in position during drying by a 230 kg/m^2 top-load restraint.

The measurement of warp (e.g. bow, spring and twist) was done shortly after drying in accordance with Nordic Timber (Anon 1997a). With one exception, the warp was measured over the full length of the planks, i.e. 4 m, instead of the stipulated worst 2 m (Fig. 4).

Due to the fact that the measuring of warp was done over a period of time, and to the way the logs were selected geographically, and to their being divided into different drying schedules, it becomes difficult to secure a total replicate of the conditions each time. To avoid differences in conditions affecting the level of the observed warp, each observation, X_i, is divided by a mean value of the batch, X_{ij}, (X_{ij}/X_j). There were a total of 8 batches of 50 planks each.

Two professional graders estimated the volume of an imagined box that encloses the compression wood in accordance to the definitions of the grading rules of Nordic Timber (1997a). They also estimated the percentage of compression wood of an imagined box within the plank.

The study of the relation between compression wood and the warp of secondary products was based on 152 centre planks, from 76 logs, stored outdoors under cover for 10 to 12 months. The 152 test planks were chosen to be a representative selection from each of the 4 geographical locations according to the amount of compression wood, warping of the planks and drying methods. Each plank was ripsawn into two battens of the dimensions 50 × 50 mm after removal of a 25 mm thick pith catcher. The warp arising during the ripsawing was defined as the largest measured span, in mm, between the two battens (Fig. 5).

All observations of compression wood in the planks were expressed as the sum of the compression wood in the two centre yield planks from the same log. This was done to simplify the comparison between the log parameter CW-log and the variables related to the centre planks. The relation between compression wood and the warp of the sawn products was evaluated by conventional statistical methods, such as linear regression analysis and unpaired significant tests at the 0.05 level by the Tukey-Kramer method for differences in group means (Box et al. 1978).

3
Results

In Table 1 the results from the linear regression analyses on the single log level are shown. The correspondence between the manual estimation of the amount of compression wood on the sawlogs, CW-log, and the estimation of compression wood in the planks, CW-plank, is rather weak: $r = 0.57$.

Table 1 also shows that the correlations between CW-log and CW-plank and the three different warp parameters, Twist, Spring and Bow, are generally very low.

If both CW-plank and PlankSpan are expressed as the sum of the two centre yield planks from each compared log, a correlation of 0.79 can be shown.

Table 1. Results from linear regression analyses where (n), is the number of observations, (r), is the shown correlation, CW-log, is the visible fraction of dense compression wood in the butt end of the log, CW-plank, is the fraction of CW within the plank. PlankSpan is the sum of the warp arising as a result of the rip-sawing of the dried plank. Twist, Bow, Spring and CW-plank are expressed as total sum of the two centre yield planks with the exception of PlankSpan*, which are based on each plank individually

Tabelle 1. Ergebnisse der linearen Regressionsanalyse; n = Anzahl der Beobachtungen; r = Korrelationskoeffizient; CW-log = sichtbarer Anteil des Druckholzes (CW) am Stammende; CW-plank = Druckholzanteil im Brett; die verschiedenen Holzfehler sind als Gesamtsumme von zwei Mittelbrettern zur Berechnung verwendet worden, außer bei PlankSpan* wobei die Werte der einzelnen Bretter ausgewertet wurden

Compared variables	r	N	Signif. prob. correlation
CW-log			
CW-plank	0.57	103	Yes
Bow	0.20	163	Yes
Twist	−0.06	160	No
Spring	0.18	161	Yes
PlankSpan	0.46	74	Yes
CW-plank			
Bow	0.33	99	Yes
Twist	0.04	97	No
Spring	0.21	97	Yes
PlankSpan	0.79	37	Yes
PlankSpan*	0.60	79	Yes

In a corresponding comparison based on the value CW-plank and PlankSpan of each single plank, the correlation decreases to $r = 0.60$.

This comparison and all other comparisons including those for the CW-plank were only based on planks dried at a wet-bulb temperature of 55 °C. The planks dried at the temperature of 110 °C were discoloured, darkened to such an extent that the difference in colour between normal and compression wood became so low that it was impossible to manually identify areas of compression wood.

In Table 2 the observations are divided into 4 groups according to the fraction of compression wood in the butt end of the logs (CW-log): group A: <5%, B: 5% to <20%, C: 20% to <35% and D: >35%. Table 2 shows that planks from logs in groups A and B have significantly lower volumes of compression wood than planks from groups C and D, with 95% confidence intervals for means.

Table 2 also shows that the amount of compression wood has no influence on the twist of the planks, while spring and bow are clearly affected only if the logs show a large amount of compression wood, CW-log ≥ 35%. This can be seen in the mean values of the groups and in the standard deviation of the groups, where only minor differences could be seen between groups A, B and C while group D is considerably larger.

The correlation, on a single-log level, between CW-log and the warp of the battens is poor: $r = 0.46$ (Table 1). While grouped at the 95% level, it is possible to show a significant difference in group mean value between logs with a high fraction of compression wood, CW-log ≥ 20%, and logs with CW-log ≤ 20% (Table 2).

Table 2. Comparisons based on observations grouped by the amount of CW-log, where the number of observations (n), Mean, Standard deviation, Median and possible Significant difference to the other groups are shown per group. In all comparisons, CW-log was grouped as A <5%, B 5–<20%, C 20–<35%, D >35% and CD*, ⩾20%. All variables, except CW-log, are expressed as the sum of the log's two centre planks

Tabelle 2. Vergleich verschiedener Gruppen anhand des Anteils an Druckholz (CW) mit n = Anzahl der Beobachtungen. Mittelwerte, Standardabweichung und mögliche signifikante Unterschiede zu den anderen Gruppen sind angegeben. Die CW-log-Gruppen sind: A <5%, B 5–<20%, C 20–<35%, D >35% and CD*, ⩾20%. Alle Variablen beruhen auf der Summe aus den zwei Mittelbrettern eines Stammabschnitts

	Group	n	Mean	Std. dev.	Median	Sign. diff.
Spring	A	45	0.84	0.58	0.63	–
	B	41	0.85	0.52	0.80	–
	C	49	0.79	0.74	0.58	D
	D	34	1.37	1.64	0.78	C
Bow	A	45	1.15	0.69	1.24	D
	B	43	1.15	0.46	1.10	D
	C	49	1.17	0.74	1.06	D
	D	34	1.90	2.19	1.06	ABC
Twist	A	45	1.49	1.30	1.04	–
	B	42	1.27	0.80	1.11	–
	C	49	1.65	1.05	1.29	–
	D	32	1.16	0.94	0.88	–
CW-plank	A	27	4	4.6	2	CD
	B	30	6	6.8	3	CD
	C	37	13	10.5	10	AB
	D	16	19	11.0	18	AB
PlankSpan	A	29	13.7	8.6	12	CD*
	B	21	21.5	22.3	13	CD*
	CD*	24	38.8	33.3	23	AB

No significant differences could be shown between the two drying schedules regarding either total warp of the dried planks or the warp of the battens. Comparisons were made with unpaired significant tests, 95% confidence intervals for means (Box et al. 1978).

4
Discussion

The results of this study show that compression wood expressed as CW-log is a rather poor indicator of the quality of the sawn products in terms of the degree of warp. Despite the significance of the correlation, the demonstrated correspondences between CW-log and the warp of the dried centre planks were not of such magnitude that a useful prediction of bow, twist or spring could be achieved. This agrees well with results found in other studies, (Forsberg 1997; Warensjö et al. 1998).

It is, however, possible to use the amount of CW-log as a rough indicator of both the risk of large amounts of warping of the secondary products (PlankSpan) and the risk of large amounts of compression wood within the plank (CW-plank). If logs with large amounts of compression wood, CW-log ≥ 20%, can be separated from those with moderate or no compression wood, fewer products will need to be rejected due to warp. The relation between warp and compression wood is more pronounced among secondary products than for dried sawn timber. However, to divide sawlogs into more than 2 grade classes according to the amount of compression wood cannot be justified due to the poor correlation shown between visible compression wood in the butt end of the log and the warp of the sawn products.

The results of this study show that the manually estimated fraction of compression wood on planks, CW-plank, is a poor indicator of the warp of the dried plank (Table 1). Consequently, it is not possible to use the fraction of compression wood, estimated on green sawn timber, in an attempt to predict the magnitude of the bow, spring or twist when dried. These results agree well with results found in other studies (Beard et al. 1993; Forsberg 1997).

Nevertheless, the amount of CW-plank clearly corresponds to the magnitude of the warp of the ripsawn battens (PlankSpan). The correspondence is fairly good, if the results of each log's whole centre yield is regarded, between the sum of compression wood and the sum of warp of the battens (CW-plank & PlankSpan in Table 1). While the corresponding correlation on single planks is considerably lower (CW-plank & PlankSpan* in Table 1). In spite of relatively few observations of the former case, the tendency is still such that it is better to base a prediction of the warp of the battens upon the amount of compression wood within the whole centre yield than on single green planks.

In Fig. 6, it is possible to study the accuracy of trying to estimate the warp of the battens, PlankSpan, by the fraction of compression wood of each single plank. Notable is that the spread of observed warp among planks free from compression wood is of the same magnitude as planks containing up to 30% compression wood. Nordic Timber stipulates 4 levels of tolerances, 0%, 10%, 20% and 50%

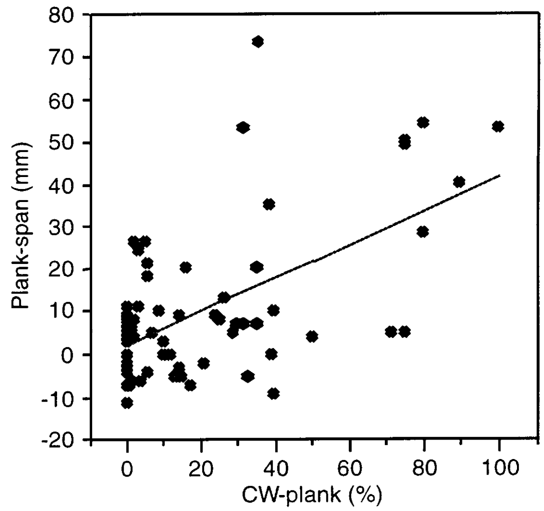

Fig. 6. Observed fraction of compression wood in planks, CW-plank, plotted against measured warp of the ripsawn battens in mm, Plank-Span

Bild 6. Beobachteter Druckholzanteil in den Brettern (CW-plank) im Vergleich mit dem gemessenen Anteil in den Kanteln (Plank-Span)

compression wood of the volume of the piece (Anon 1997a). If the intention of the compression wood tolerances is to agree with the warp of secondary products in general, it does not seem relevant, based on the information in Fig. 6, to use four levels of compression wood tolerance in the grading of sawn timber.

The shape of sawn timber is highly dependent on the magnitude and distribution of stresses acting within the same. High levels of stresses do not necessarily result in a large warp of the dried and sawn timber. For example, if the stresses are symmetrically distributed within the crosscut, no net stress (moment of force) arises and the plank will remain in shape. The origins of the stresses in wood are highly related to moisture content and the conditions during the drying process. Examples of properties that result in stresses are anisotropic shrinking properties in the tangential, radial and longitudinal direction of the annual ring of all types of wood. Furthermore, there are large differences in shrinking properties between different types of wood, e.g. juvenile, compression and normal wood. Finally, the stress levels and degree of warp are affected by preparation for and conditions during the drying process, such as how well the sawn timber is stacked and how restrained, by other planks in the stack or by external loads, each plank is from responding to stresses by warping.

A plausible explanation of why the amount of CW-plank alone fails to explain the magnitude of the warp of the dried sawn timber is that the location of the compression wood over the full length of a piece of wood must be taken into consideration before the degree and type of warp can be predicted, (Pillow et al. 1937; du Toit 1963). If the different types of wood are unevenly distributed within the crosscut of the sawn timber, the differences in shrinking properties give rise to a moment of force (torque) which will result in a warp of the plank. This torque is dependent on the amount, density and distribution within the plank of compression wood and on the moisture content. If the warp is a response to a torque, this explains why the amount of compression wood alone cannot indicate the warp of the dried sawn timber.

That the correlation between the fraction of compression wood within the plank (CW-plank) and the warp of the battens is considerably stronger than between CW-plank and the warp of the planks could plausibly be explained by the change in geometry and the release of internal stresses.

5
Conclusions and future work

There was no proof found in this study that an increase of the wet-bulb temperature from 55 to 100 °C affects the longitudinal internal stresses related to compression wood and thereby the magnitude of the warp of the sawn timber and secondary products of Norway spruce. It can therefore be concluded that the internal stresses, caused by differences in shrinking properties between normal and compression wood, do not respond to the differences in drying conditions (high-temperature short drying time versus low-temperature long drying time).

The visible dense compression wood in the butt end is generally a poor indicator of the warp of the dried planks ($r < 0.20$), of the warp of the ripsawn battens ($r = 0.46$) and of the amount of compression wood within the planks ($r = 0.57$). The use of the amount of compression wood in the butt end of the log might still be useful in some applications. If logs showing high amounts of compression wood (≥20%) can be separated from those with no or very little visible compression wood, then fewer products sawn from the latter category will need to be rejected due to warp, a relation which is more pronounced among secondary products than in sawn timber.

The manually estimated amount of compression wood within the sawn timber, CW-plank, must be regarded as a poor indicator of the warp of the dried sawn timber due to a rather poor correlation of $r = 0.33$. The possibility of using the estimated amount of compression wood within a single plank as an indicator of the warp of secondary products is limited due to a low correlation ($r = 0.60$). If the compression wood and the warp of the secondary products are expressed as the sum of the whole centre yield, the correlation increases to $r = 0.79$. Consequently, it seems more adequate to use the latter to indicate the dried sawn timber's suitability for refined secondary products.

Further studies are planned to investigate the relation between the warp of the sawn timber and the position of the compression wood on the four faces as well as within the sawn timber.

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