SILVA FENNICA Silva Fennica 41(4) research articles
www.metla.fi/silvafennica · ISSN 0037-5330
The Finnish Society of Forest Science · The Finnish Forest Research Institute

The Effect of Annual Ring Orientation and Drying Method on Deformations, Casehardening and Colour of Silver Birch (*Betula pendula*) Boards

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Luostarinen, K. 2007. The effect of annual ring orientation and drying method on deformations, casehardening and colour of silver birch (*Betula pendula*) boards. Silva Fennica 41(4): 717–730.

Deformations of timber, caused mainly by anisotropic shrinkage, can be partially directed by controlling annual ring orientation through different sawing patterns. Ring orientation also affects the movement of water from within the board to its surface, with rapidity of drying having implications for the wood colour. Here sawn silver birch (*Betula pendula* Roth) timber was classed into two groups according to ring orientation. Two drying methods were used. The final moisture content was lower and the colour lighter in dried boards with radial than with tangential flats, but deformations were larger in radial than in tangential boards. Both drying and ring orientation affected the final moisture content and moisture gradient of the boards. Very small differences in board sizes or shape had an effect on both colour and deformations. The results support the need for accurate sawing and for classing silver birch timber sawn into parquet billets according to ring orientation in order to optimise the drying quality.

Keywords dimensional stability, distortion, drying schedules, kiln drying, L*a*b* coordinates, timber quality, wood
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Received 6 February 2007 **Revised** 19 July 2007 **Accepted** 3 October 2007
Available at http://www.metla.fi/silvafennica/full/sf41/sf414717.pdf

1 Introduction

Timber can warp immediately after sawing, when strains in the wood are partly relieved, but the main reason for deformations during the drying of timber is the anisotropic shrinkage of wood. Deformations cause problems in wood processing, the scale of problems depending on the species and the intended end-use. In addition to the drying temperature and method (Erickson et al. 1986, Milota 1992, 2000, Klaiber and Seeling 2004, Kliger et al. 2005), different sawing patterns have been tested to minimise deformations (Erickson et al. 1986, Beauregard et al. 1992, Paukkonen et al. 1999). With sawing patterns, the orientation of annual rings and the location of pith in sawn timber can be regulated. To produce timber with radial flats quarter sawing is used, and in addition to uniform appearance, this ring orientation is believed to cause fewer deformations and to direct deformations uniformly (Keinänen and Tahvanainen 1995, Luostarinen and Verkasalo 2000). However, the quarter sawing process is not used by the sawmill industry in Finland; instead, the classification of sawn silver birch timber according to ring orientation could be possible though also is not used there. Furthermore, deformations are poorly studied in silver birch (see Paukkonen et al. 1999, Luostarinen and Luostarinen 2001) although the crooked growth habits of birch is known to affect deformations through grain direction and its variation.

The orientation of annual rings in a piece of sawn timber may affect wood colour in addition to deformations, because cell walls of dense latewood, particularly, are a barrier for water movement (see e.g. Langrish and Walker 1993). In addition, it is well known among professionals in practical birch timber processing that the thickness of birch timber affects darkening of the inner parts of timber pieces, thick pieces darken more easily and more often than thin pieces. Instead, a surface layer of a few millimetres may remain light-coloured when sawn silver birch timber is dried (Luostarinen and Luostarinen 2001). A relationship between a light coloured surface layer and casehardening has been suggested, because the conditions for their formation are similar (Luostarinen 2006). Thus, casehardening and/or a light surface layer may be another barrier for water movement to the surface of the timber piece, in which case they would promote darkening of the inner parts of a timber piece.

The purposes of this study were to determine 1) the relationships between colour, both surface and inner colour, and casehardening, and 2) the effect of annual ring orientation and drying method on deformations, as well as their effect on colour and casehardening of birch boards. The approach was practical: a sawing method used in industry producing billets for parquet surface lamellae was used, and a sorting method possible to be applied in practice in the small companies commonly sawing the billets for parquet industry was tested. On the basis of this knowledge, the possibilities of sorting by annual ring orientation to improve the quality (colour, deformations, moisture content) of dried birch boards meant for the parquet industry can be determined.

2 Material and Methods

In this study, wood from 70–80-year-old silver birches (*Betula pendula* Roth), grown in Ilomantsi, North-Karelia, Finland, was used. A total of 60 trees were felled for the experiment, with an average diameter at breast height of 29.9 cm. Two logs of 2.5 m long (butt log and top log) were taken from each tree. The basic density of the wood material used was 503.5 ± 1.3 (SE) kg/m^3 (SE – standard error of the mean). The logs were sawn into 30 mm × 70 mm × 1200 mm (dry dimensions of common parquet billet boards) boards using a manual portable circular saw. The fresh volume of boards ranged from 2.995×10^{-3} m^3 to 3.706×10^{-3} m^3 due to sawing inaccuracy; the radial location from which boards were sawn did not affect the amount of inaccuracy. Sawing was carried out to get maximum yield from each log, but the discoloured wood around the pith was discarded (Fig. 1). This method was applied because it is used in practise when billets for parquet surface lamellae are sawn. Thus, depending on the size of the individual log, size of the discoloured wood around the pith and other logs defects, different amounts of boards were attained from each log and the amounts of radial boards were small. In addition, the discarding of

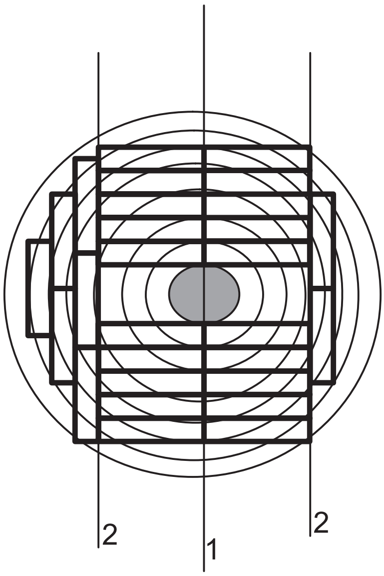

Fig. 1. Scheme about sawing the logs into boards. Sawing started by splitting the log (sawing line "1"). The cross section in the figure presents a large log: the side boards in the left and right from the cutting lines marked with "2" could not be sawn from each log. Among them, if they existed, there were boards with ring orientation nearer to radial than tangential in the flat. Radial boards were got also with the cuts near to the discoloured wood.

the dark wood around the pith resulted in there being only a small amount of juvenile wood in the boards. The direction of annual rings in the flats of the boards was determined according to the one which was closer to the two classifications: those with tangential flats (referred also to "tangential boards") and those with radial flats (referred also to "radial boards"). The boards that were intermediate between tangential and radial were excluded. The sorting by annual ring orientation is simple and can be done visually without extensive investments in new equipment. Both conventional and vacuum drying contained boards from each tree and log. Not all the sawn boards were taken for drying, instead, boards for drying were chosen so that boards near the pith, near the surface and from the middle, as well as at least one radial board from each log were included.

There were fifteen timber lots for both conventional (CD) and vacuum drying (VD) in laboratory size kilns (Brunner). The heating of both kilns was electric, and the adjustment of air humidity was performed by water spraying. Drying was controlled by wood moisture content (MC), measured from twelve points within the wood and based on changes in electrical conductivity caused by drying of the wood. To control the climate inside the kilns, both dry and wet temperature and equilibrium moisture content (EMC) were measured throughout the processes. The same drying schedule was programmed for each CD as well as for each VD lot (Table 1). The air flow direction was changed on three hourly intervals. The final MC was set to 5.0% and moisture gradient to 0.5% in both processes. Programmed schedules were not meant to produce timber of good quality, instead, drying defects, especially the darkening of the wood, was wanted to be emphasised so that the differences between the differently dried boards and between boards of different ring orientation would be large enough for measuring them from these boards with small dimensions. Thus weights were not used on the top of the load either.

Deformations, i.e. twist, bow/crook and cup were measured before and after dryings. They were measured in tangential and radial directions. The other end of a board, with both corners, was pressed against a straight surface so that the other end rose freely. Twist was measured as degrees with a digital Lucas angle instrument from the free end of the board. Bow and crook were measured from the free end of the board employing the method of Paukkonen et al. (1999) in which the lifting of the lower corner (mm) corresponds to the bow or crook (Fig. 2). Cup (mm) was measured with a digital Mitutoyo gauge for depth of holes from the outer flat side of the boards, and from another flat of the boards with exactly radial ring orientation in flats.

After drying, MC (g water / g absolutely dry wood) was determined from 20 boards of each drying lot with the oven-drying method (103 ± 2 °C). For that, a slice of 5 cm was taken from the middle of each board, and this slice was divided into 3 pieces in the direction of the flat, with each of pieces being measured separately (Fig. 3). Two of the pieces represented surface wood and one piece represented inner wood of the

Table 1. Programmed ($_p$) and measured ($_m$) values for conventional and vacuum drying schedule used here. T – dry temperature, Tw – wood temperature, Tt – wet temperature determined according to EMC table (Isomäki et al. 2002), DF – drying force (DF = MC / EMC), EMC – equilibrium moisture content, Time – time for each phase of the schedule, and P – air pressure. The drying phase was controlled by the intervals of wood moisture content.

Stage of process		Conventional drying								Vacuum drying								
		T_p (°C)	DF_p	EMC_p (%)	$Time_p$ (h)	$Time_m$ (h)	T_m (°C)	Tw_m (°C)	EMC_m (%)	T_p (ºC)	DF_p	EMC_p (%)	$Time_p$ (h)	$Time_m$ (h)	T_m (°C)	Tt (°C)	EMC_m (%)	P_m (mbar)
Pressure lowering										50		17		7	20	15	10	110
Heating		37		15	4	4	34	35	15	64		17	10	10	67	60	10	210
Drying	>70%	37	2.0			6	38	36	17	65	3			16	67	62	11	230
	60–70%	38	2.4			12	38	36	16	68	3			14	68	64	11	230
	50–60%	39	2.4			21	40	37	15	70	3.1			15	69	62	10	230
	40–50%	40	2.7			27	41	38	13	72	3.2			11	71	67	10	230
	30–40%	41	3.2			27	42	40	10	73	3.2			10	73	64	9	250
	25–30%	42	3.2			17	43	42	9	74	3.3			4	75	64	8	260
	20–25%	42	3.2			21	45	45	7	75	3.4			3	76	63	7	230
	15–20%	60	3.5			21	59	58	5	76	3.5			6	78	58	5	230
	10–15%	65	3.5			27	65	66	3	77	1.8			6	81	62	5	230
	<10%	65	3.5			105	66	67	2	82	1.4			14	81	57	4	210
Conditioning		70		3	12	6	70	72	3	73		3.7	12	19	74	54	5	160
Cooling		40		5	6	19	35	33	3	40		3.3	5	20	down to 40	22	4	up to 1000

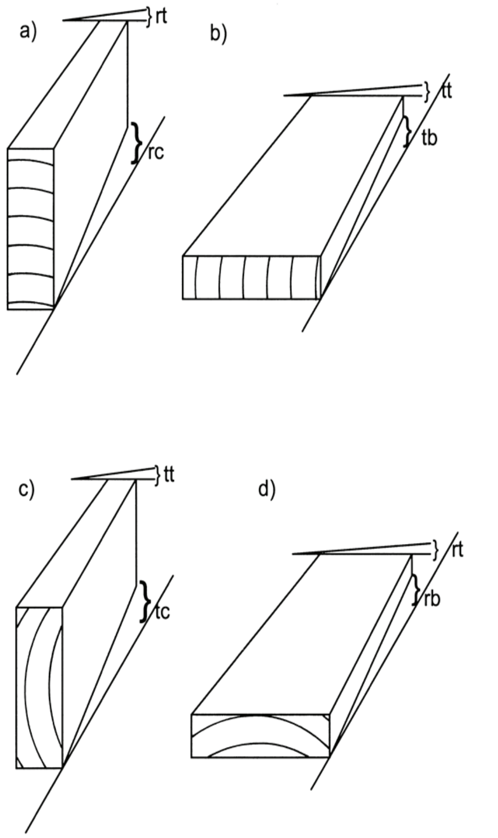

Fig. 2. Scheme about deformation measurements: a) and b) radial boards, c) and d) tangential boards. rt – radial twist, rc – radial crook, tt – tangential twist, tb – tangential bow, tc – tangential crook, rb – radial bow.

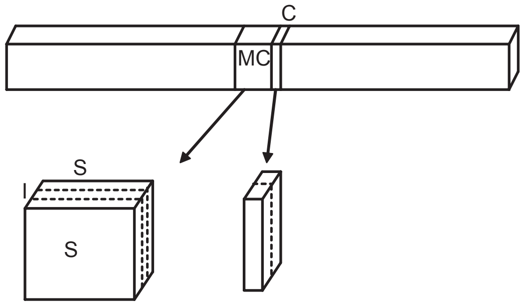

Fig. 3. Scheme about moisture content (MC) and casehardening (C) samples. MC was determined for surface wood (S) (two pieces) and inner wood (I) separately. A gap between the pieces (sawing line is shown as dash line) was measured from the C samples after rest of 24 hours.

board. Casehardening was determined by sawing a 1 cm slice from each board next to the MC slice and ripping it longitudinally in the direction of the flat (Fig. 3). After the ripped slices had rested for 24 h, the gap (mm) between the halves was measured with a Morhard feeler gauge. The samples were taken from sound wood (knots and other defects affecting MC and casehardening were discarded).

The reflectance spectra of surface wood were measured from thinly planed surfaces of the boards, and the boards were split to expose the inner wood in them to plane for spectral measurement. L*a*b* colour coordinates of CIE (Precise color… 1994), which were calculated from the measured spectra, were used to demonstrate the colour. With birch wood, the colour coordinates a* and b* are positive, i.e. they represent red and yellow tones, respectively. The coordinate L* represents lightness, ranging from 0 (black) to 100 (white).

The measured results were analysed with SPSS statistical software (Version 14.0 for Windows, SPSS Inc., 2005). As there were differences in the final MC and amount of deformation before drying, they were used as covariates to remove their effect from the results of General Linear Model (GLM). Deformations were compared with GLM univariate analysis. Differences in colour coordinates as well as in casehardening, deformations and MC between flat directions and drying methods were compared with GLM multivariate statistics. Pearson correlation procedures were used between colour coordinates, deformations, MC and casehardening and fresh volume as such, and partial correlation procedure to remove the effect of final MC and amount of deformation before drying.

3 Results

No significant differences were observed in deformations between boards of different ring orientations before drying (Table 2a) although the largest

Table 2. Statistically significant differences in deformations, casehardening and moisture content (MC) before and after drying by a) orientation of annual rings, and by b) drying method (CD – conventional drying, VD – vacuum drying). F value was calculated by GLM and χ^2 value (marked with *) by Kruskall-Wallis test. Capital letters: significant difference in deformation before drying between drying methods. Small letters: significant difference in deformation before and after drying within drying method or ring orientation. Shown F/χ^2 and p values are for comparisons of measurements made after drying for ring orientations and drying methods. Numbers are mean ± SE(N), SE – standard error of mean, N – number of samples.

a)

	Tangential flat		Radial flat			
Parameter	Before drying	After drying	Before drying	After drying	F after	p after
Radial twist, °	0.48 ± 0.04(430)	0.47 ± 0.23(430)	0.35 ± 0.07(99)a	2.26 ± 0.51(99)a	11.841	0.001
Radial bow/crook, mm	4.20 ± 0.15(430)a	6.35 ± 0.26(430)a	4.28 ± 0.29(99)a	7.95 ± 0.60(99)a	7.113	0.008
Tangential twist, °	0.31 ± 0.07(430)	0.02 ± 0.22(430)	0.53 ± 0.05(99)a	2.32 ± 0.45(99)a	19.859	<0.001
Tangential bow/crook, mm	9.22 ± 6.32(430)	6.40 ± 0.25(430)	2.21 ± 0.20(99)a	7.63 ± 0.74(99)a	5.026	0.025
Casehardening, mm		1.07 ± 0.03(428)		0.93 ± 0.06(99)	5.145	0.024
MC inner, %		6.20 ± 0.05(430)		5.84 ± 0.12(98)	8.222	0.004
MC surface, %		5.74 ± 0.05(430)		5.50 ± 0.11(98)	3.754	0.053
MC average, %		5.90 ± 0.05(430)		5.61 ± 0.10(98)	6.390	0.012

b)

	CD		VD			
Parameter	Before drying	After drying	Before drying	After drying	F/χ^2* after	p after
Radial twist, °	0.57 ± 0.05(259)A	0.73 ± 0.30(259)	0.34 ± 0.05(270)A	0.88 ± 0.30(270)	0.005	0.945
Radial bow/crook, mm	4.43 ± 0.20(259)a	6.98 ± 0.38(259)a	4.00 ± 0.18(270)a	6.31 ± 0.29(270)a	3.803	0.052
Tangential twist, °	0.48 ± 0.09(259)A	0.29 ± 0.28(259)	0.22 ± 0.06(270)A	0.61 ± 0.31(270)	<0.001	0.983
Tangential bow/crook, mm	13.19 ± 10.27(259)	9.17 ± 0.36(259)	2.26 ± 0.13(270)a	6.31 ± 0.33(270)a	1.395	0.238
Casehardening, mm		1.60 ± 0.02(258)		0.53 ± 0.03(269)	587.416	<0.001
MC inner, %		6.18 ± 0.07(259)		6.09 ± 0.07(270)	0.867	0.352
MC surface, %		5.24 ± 0.05(259)		6.14 ± 0.07(270)	82.702*	<0.001
MC average, %		5.55 ± 0.05(259)		6.10 ± 0.07(270)	32.214*	<0.001

Table 3. Statistically significant partial correlations between average final moisture content (MC) or fresh volume of boards and deformations by a) orientation of annual rings, and by b) drying method (CD – conventionally dried, VD – vacuum dried).

a)

			Tangential flat		Radial flat	
Correlated variables		Controlling for	r	p	r	p
Average MC	Radial bow/crook	Radial bow/crook before drying	–0.098	0.043		
Fresh volume	Radial twist	MC + radial twist before drying	–0.166	0.003	–0.307	0.006
Fresh volume	Radial bow/crook	MC + radial bow/crook before drying			0.238	0.036
Fresh volume	Tangential twist	MC + tangential twist before drying	–0.140	0.013	–0.308	0.006

b)

			CD		VD	
Correlated variables		Controlling for	r	p	r	p
Average MC	Radial twist	Radial twist before drying	0.166	0.008		
Average MC	Tangential twist	Tangential twist before drying	0.189	0.002		
Average MC	Cupping	Cupping before drying	–0.140	0.024	0.121	0.048
Fresh volume	Radial twist	MC + radial twist before drying	–0.149	0.039	–0.224	0.001
Fresh volume	Radial bow/crook	MC + radial bow/crook before drying	0.147	0.041		
Fresh volume	Tangential twist	MC + tangential twist before drying			–0.187	0.008
Fresh volume	Tangential bow/crook	MC + tangential bow/crook before drying			–0.213	0.002

Table 4. Significant interaction of the drying method and ring orientation was observed in cupping after drying (lower result row). Numbers are mean ± SE(N) mm; SE – standard error of mean, N – number of samples.

	Tangential flat		Radial flat			
Cupping, mm	CD	VD	CD	VD	F	p
Before drying	0.05 ± 0.005(212)	0.06 ± 0.005(219)	0.05 ± 0.009(47)	0.06 ± 0.009(52)		
After drying	0.60 ± 0.028(212)	0.68 ± 0.018(219)	0.46 ± 0.037(47)	0.46 ± 0.030(52)	6.650	0.01

Table 5. Statistically significant Pearson correlations between casehardening and final moisture content (MC) of boards by a) orientation of annual rings, and by b) drying method (CD – conventionally dried, VD – vacuum dried).

a)

		Tangential flat		Radial flat	
Correlated variables		r	p	r	p
Inner MC	Casehardening	0.288	<0.001		
Surface MC	Casehardening	–0.220	<0.001	–0.255	0.011

b)

		CD		VD	
Correlated variables		r	p	r	p
Inner MC	Casehardening	0.454	<0.001	0.351	<0.001
Surface MC	Casehardening	0.226	<0.001	0.128	0.036
Average MC	Casehardening	0.346	<0.001	0.231	<0.001

deformation was different in tangential than in radial boards. The tangential bow/crook was large in boards with tangential flats and radial bow/crook in boards with radial flats. Both radial and tangential twists of those boards to be conventionally dried were slightly different to those boards that were to be vacuum dried (Table 2b).

The deformations in the radial boards grew during drying, while in tangential boards only the radial bow/crook grew. After drying, both twists and bows/crooks were larger in radial than tangential boards (Table 2a). During both dryings radial bow/crook, and during VD also tangential bow/crook, grew. However, the amount of twists and bows/crooks were similar after CD and VD (Table 2b). Deformations did not correlate with casehardening, and only radial bow/crook correlated negatively with MC when the material was grouped by ring orientation (Table 3a). Instead, there were differences in correlations between final MC and deformations, when CD and VD are compared: twists in CD were bigger the higher the MC, furthermore the higher the MC, the smaller and the larger the cup in CD and VD, respectively (Table 3b).

After drying, cupping was the only parameter examined in which interaction between the orientation of annual rings and the drying method was observed (Table 4). Boards with tangential flats cupped more than boards with radial flats; and among tangential boards, VD boards cupped more than CD boards.

Casehardening differed between boards of different annual ring orientation, being smaller in boards with radial than with tangential flats (Table 2a). In addition, it was smaller after VD than after CD (Table 2b). The final MC of boards correlated with casehardening when boards were classed according to ring orientation (Table 5a) or drying method (Table 5b). In both ring orienta-

Table 6. GLM results of differences in colour coordinates between a) boards with different orientation of annual rings, and b) boards dried differently (CD – conventionally dried, VD – vacuum dried). Numbers are mean ± SE(N); SE – standard error of mean, N – number of samples.

a)

Parameter	Tangential flat	Radial flat	F	p
L* inner wood	79.2 ± 0.08(423)	79.9 ± 0.19(95)	32.173	0.001
a* inner wood	5.1 ± 0.04(423)	5.1 ± 0.10(95)	0.230	0.632
b* inner wood	19.1 ± 0.06(423)	18.9 ± 0.14(95)	1.640	0.201
L* surface	80.0 ± 0.20(423)	80.9 ± 0.42(95)	1.973	0.161
a* surface	4.5 ± 0.07(423)	4.3 ± 0.16(95)	0.148	0.700
b* surface	18.6 ± 0.10(423)	18.4 ± 0.22(95)	0.388	0.534

b)

Parameter	CD	VD	F	p
L* inner wood	79.5 ± 0.10(249)	79.2 ± 0.11(269)	5.367	0.021
a* inner wood	4.7 ± 0.04(249)	5.5 ± 0.06(269)	122.677	<0.001
b* inner wood	18.8 ± 0.06(249)	19.3 ± 0.08(269)	20.368	<0.001
L* surface	83.9 ± 0.15(249)	76.8 ± 0.13(269)	1014.323	<0.001
a* surface	3.2 ± 0.06(249)	5.6 ± 0.06(269)	623.860	<0.001
b* surface	17.3 ± 0.12(249)	19.7 ± 0.08(269)	220.530	<0.001

Table 7. Statistically significant Pearson correlations between final MC and colour coordinates by a) orientation of annual rings, and by b) drying method (CD – conventionally dried, VD – vacuum dried).

a)

Correlated variables		Tangential flat r	Tangential flat p	Radial flat r	Radial flat p
Surface MC	L* surface	–0.391	<0.001	–0.476	<0.001
Surface MC	a* surface	0.315	<0.001	0.454	<0.001
Surface MC	b* surface	0.307	<0.001	0.510	<0.001

b)

Correlated variables		CD r	CD p	VD r	VD p
Surface MC	L* inner wood	–0.221	<0.001		
Inner MC	a* inner wood			0.188	0.002
Surface MC	b* inner wood	0.134	0.035		
Surface MC	L* surface	–0.243	<0.001		
Surface MC	a* surface	0.214	0.001		
Surface MC	b* surface	0.299	<0.001		

Table 8. Statistically significant partial correlations between casehardening or fresh volume of boards, and colour coordinates by a) orientation of annual rings, and by b) drying method (CD – conventionally dried, VD – vacuum dried).

a)

Correlated variables		Controlling for	Tangential flat		Radial flat	
			r	p	r	p
Casehardening	L* inner wood	Inner MC	0.165	0.004		
Casehardening	a* inner wood	Inner MC	–0.363	<0.001		
Casehardening	b* inner wood	Inner MC	–0.192	0.001		
Casehardening	L* surface	Surface MC	0.675	<0.001	0.645	<0.001
Casehardening	a* surface	Surface MC	–0.594	<0.001	–0.569	<0.001
Casehardening	b* surface	Surface MC	–0.506	<0.001	–0.461	<0.001
Fresh volume	L* inner wood	Inner MC	–0.144	0.011	–0.364	0.001
Fresh volume	a* inner wood	Inner MC	0.124	0.030	0.303	0.008
Fresh volume	b* inner wood	Inner MC			0.235	0.042
Fresh volume	L* surface	Surface MC			–0.276	0.016

b)

Correlated variables		Controlling for	CD		VD	
			r	p	r	p
Casehardening	a* inner wood	Inner MC			0.142	0.044
Casehardening	L* surface	Surface MC			–0.200	0.004
Casehardening	a* surface	Surface MC			0.270	<0.001
Casehardening	b* surface	Surface MC			0.192	0.006
Fresh volume	L* inner wood	Inner MC			–0.244	<0.001
Fresh volume	a* inner wood	Inner MC			0.214	0.002
Fresh volume	b* inner wood	Inner MC			0.196	0.005
Fresh volume	L* surface	Surface MC			–0.231	0.001

tions, the higher the MC was in board surfaces, the smaller the casehardening, but in boards with tangential flats large casehardening corresponded with a high inner MC. In both drying methods, the larger the casehardening, the higher both inner and surface MC were.

The inner wood of radial boards was slightly lighter than the inner wood of tangential boards (Table 6a). VD wood was darker, redder and more yellow than CD wood (Table 6b). MC affected wood colour: the lower the MC in the boards with both ring orientations and CD, the lighter and less yellow and red the surface wood was (Table 7a, b). MC of board surfaces correlated negatively also with lightness of the inner wood of CD boards.

Surface colour of boards correlated with casehardening. In both ring orientations, if the board surface got lighter, the casehardening increased, and in boards with tangential flats a similar correlation between casehardening and inner colour of wood was observed (Table 8a). However, in VD, the larger the casehardening, the darker the surface layer was (Table 8b). According to visual observations, width of the light surface layer varied markedly in one piece of timber and it could not be measured because the exact border was impossible to determine.

Even small differences in the fresh volume of boards affected the final colour of boards, larger boards darkening more during drying (Table 8). Some correlations were also observed between deformations and fresh volume of boards (Table 3). In most cases with significant correlation, the larger the fresh volume was, the smaller the deformation was, the correlation with bow/crook being opposite.

4 Discussion

In this study a practical point of view was chosen by using a sawing method used in the parquet billet industry, and a sorting basis, i.e. annual ring orientation, which can be applied without large investment, was tested. Another wood characteristic, in addition to ring orientation, that strongly affects deformations and wood drying rate would be density. Density, for its part, is affected by many factors: cambial age of wood, growth rate, earlywood/latewood, location of wood in the trunk, reaction wood, defects in grain direction and knots (see e.g. Zobel and van Buijtenen 1989). Thus it may vary within a timber piece and its influence on different parts of the timber piece is different. In birch the density may be affected by all of these. Knots also cause defects in grain direction which emphasises their effect on deformations. Grain angle varies in each yearly growth in sympodial species like birches, which may result in the variation of grain direction within a timber piece and as a consequence of this deformations may be large and varying. The cambial age of wood affects the curvature of the annual rings in addition to density; the curvature has been observed to affect deformations (Ormarsson et al. 2000). Reaction wood is usually common in birches and its existence strongly affects deformations. In this study, the trunks of harvested birches were as straight as possible which minimises the amount of reaction wood. Though this research did not explicitly focus on reaction wood, it was noted that it was not observed. Reaction wood was also not found in the anatomical samples made from the boards of this study for another part of this research. This study did not cover either cambial age of wood, density and knots, because considering them would be very difficult, probably impossible, for sawmills producing birch parquet billets.

It was expected that differences would have occurred in deformations before drying between boards with different ring orientation because of strains relieved in sawing, but no significant differences were observed. This may be due to the smaller number of radial boards than tangential ones; with more material some of the differences might have been significant. The differences in deformations between boards meant for different dryings were most probably random.

The cup observed in the birch boards was small in this study. The amount of cupping did not weaken the class of the dried timber: according to the amount of cup the timber belonged to class I of Norwegian classification for sawn birch timber (see Verkasalo and Paukkonen 1999) and to class A of sorting recommendations of Nordic Timber (NT) (Pohjoismainen sahatavara… 1994). Here the observed cup in radial boards is mainly due to the fact that all the flats of the boards were not precisely radial, which is the situation in practice. Earlier studies have found that the level of cupping in birch boards is dependent on the drying schedule used: drying in room conditions caused the smallest cupping (Paukkonen et al. 1999) and the most aggressive conventional schedule caused the largest cupping (Luostarinen and Luostarinen 2001). Although the aggressiveness of the schedules used in this study corresponded to that of the aggressive schedule in the study of Luostarinen and Luostarinen (2001), in this study the amount of cupping corresponded to cupping of birch timber dried with mild and intermediate schedules in the study of Luostarinen and Luostarinen (2001). Pine timber with exactly radial flats has been observed to cup only if the boards were sawn from large butt logs with buttness, which caused varying orientation of annual rings (Sandberg 1997). In addition to orientation of annual rings, the cup depends on the distance of wood from the pith, being largest near the pith (Ormarsson et al. 2000).

In this study the amounts of bow and crook in dried timber were large. Amounts of bow and crook in Norwegian classification for birch boards of classes I and II are 5 and 3 mm / 1 m, respectively (see Verkasalo and Paukkonen 1999); thus the boards of this study did not meet these requirements. The boards here did not meet the requirements of class A of NT (Pohjoismainen sahatavara… 1994) for bow and crook either. Instead, the amount of twists here were small (class I in Norwegian classification, see Verkasalo and Paukkonen 1999; class A1 in NT, see Pohjoismainen sahatavara… 1994). However, the justification for applying the bow, crook and twist rules of NT, created for softwoods, for birch timber can be questioned because of the differences in growing habits of the species (sympodial in birches, monopodial in conifers). Because the bow and crook here were large, the suitability of saw-dry-rip –method (sawing logs into flitches, drying them, and ripping the flitches into studs; in the case of parquet billet boards further sawing after ripping the flitches is needed) could be tested for silver birch timber in which deformations should be kept as small as possible: saw-dry-rip -method has produced sawn and dried paper birch (*Betula papyrifera*) (Erickson et al. 1986) and aspen (*Populus tremuloides*) (Beauregard et al. 1992) timber with minor deformations.

After drying, both twists and bows/crooks were larger in birch timber with radial than tangential flats, but no differences in the amounts of deformations were observed between drying methods. With birch, no difference between tangential and radial bow/crook have been earlier observed when classification according to ring orientation in flat was not performed (Paukkonen et al. 1999, Luostarinen and Luostarinen 2001). However, in spruce (*Picea abies*) deformations have been observed to be larger when the flat was tangential (Sandberg 1997), but annual ring orientation did not affect the twist (Ormarsson et al. 2000). For short rotation hybrid poplar (*Populus deltoides* × *Populus trichocarpa*) timber, an aggressive drying schedule has been recommended because it apparently caused fewer deformations (Kang et al. 2007). However, for birch boards different conventional schedules caused no differences in terms of deformations (Luostarinen and Luostarinen 2001). Instead, drying slowly in room conditions seemed to decrease the tangential, but not radial, twist in birch boards (Paukkonen et al. 1999). Also in spruce, twist has been observed to be smaller after air than conventional drying (Klaiber and Seeling 2004) and warp, generally, smaller after high temperature than conventional drying (Kliger et al. 2005). Both spiral grain (Ormarsson et al. 2000, Kliger 2001) and pith location (Ormarsson et al. 2000) affect twist. In this study, with only slightly twisted silver birch timber, pith was not included and the amount of juvenile wood was small (discarded discoloured wood around the pith), but the sympodial growth habit of birches causes varying grain angles. Spiral grain is not included in any Finnish classification of sawn birch timber of different saw mills, but in Norwegian classification grain angle is included (max 1:10 in the class I) (see Verkasalo and Paukkonen 1999). The allowed grain angle in the class A for softwoods is the same in NT (Pohjoismainen sahatavara… 1994).

Although the final amounts of deformations were similar for the drying methods, correlations of deformations with MC were different. This is probably due to different ways and speeds for the water to move to the surface of the timber piece in the drying methods and schedules used. The main way of water movements are different between the drying methods regardless of the schedule (see Chen and Lamb 2004) but modifying schedules inside a method may cause a different response of the wood material to the drying conditions. However, similar to this study, Erickson et al. (1986) found no differences in the amount of deformations between differently dried paper birch (*Betula papyrifera*) timbers, and Milota concluded that the amount of bow, crook and twist in hemlock (*Tsuga heterophylla*) and fir (*Abies* spp.) (Milota 2000) and Douglas fir (*Pseudotsuga menziesii*) (Milota 1992) planks depend on final MC rather than on the drying method even though two very different drying methods, conventional and high temperature, were compared (Milota 2000).

The casehardening in tangential boards in this study fulfil the recommendation of class Q, quality dried, while the radial boards belonged to the best class E (exclusive) of European Drying Group (EDG) (see Sipi 2002). Even larger differences in casehardening was observed between boards dried differently than between boards with different ring orientations, but EDG classification would still be similar: casehardening in VD boards corresponded to class E and in CD boards to class Q of EDG. The results of casehardening in this study are similar to the results of birch drying tests of Jørgensen et al. (1995).

As ring orientation affects the direction of the shrinkage and also the amount of shrinkage in birch boards (Paukkonen et al. 1999), shrinkage affects the deformations in relation to board flat and edge, and in this study, it may have had an impact on measured casehardening between ring orientations. Differences in casehardening between ring orientations may also be connected to the drying rate: it is different between boards of different ring orientations. Thicker walls of latewood cells slow down the movement of water out of the inner parts of timber pieces particularly in tangential boards (see e.g. Langrish and Walker 1993), and a dry hardened surface layer develops easier in tangential than in radial boards. Thus particularly the inner wood of radial boards dried faster than that of tangential boards, which caused a smaller MC gradient for radial boards, as expected. High MC in the inner parts of the boards causes large shrinkage of these parts when the MC gradient evens out, resulting in bending of the test pieces. The lack of clear transverse MC gradient in VD boards is the most probable reason for the small casehardening in them. The lack of transverse MC gradient in VD wood has been explained by the way in which water moves to the surface of a sawn timber piece through open fibres and pores in longitudinal direction as steam when air pressure is reduced strongly (Chen and Lamb 2004). In the study of Luostarinen and Luostarinen (2001) in which three conventional schedules were compared, casehardening differed between them, with it being smallest, 1.2 mm, after the most aggressive schedule; the amount of casehardening was similar to that in this study. The largest casehardening was achieved when timber was dried with intermediate temperature (Luostarinen and Luostarinen 2001)

The negative correlation between casehardening and lightness of surface colour in VD was opposite to the correlation observed in tangential and radial boards. In VD the darkness of surface colour may correspond to its fast drying (see next paragraph) but more commonly a quickly dried surface layer both casehardens and remains light coloured. However, in the tangential boards the observed positive correlation between casehardening and lightness of inner wood was unexpected. According to the hypothesis of Paukkonen et al. (1999) a faster dried, both casehardened and light coloured surface layer slows down the drying of the inner parts of boards. Furthermore, according to the observations of Stenudd (2002) and Sundqvist (2002), the length of drying time in raised temperatures is important for the inner colour of birch boards: the faster birch wood dries, the lighter it remains. Thus the result that the inner wood of radial boards was slightly lighter than the inner wood of tangential boards was expected. The measured difference of 0.7 units in L* coordinate is, however, hardly visible. Instead, the colour difference between CD and VD wood was emphasised by the differences in a* and b* coordinates and was thus clearly visible. In addition, the difference in colours between inner wood and surface layer of boards was clearly visible and thus of commercial importance. However, no rules for classifying dried birch timber according to colour or colour differences among and between timber pieces exist.

The lower the MC was in boards with both ring orientations and in CD, the lighter and less yellow and red the surface wood was. This suggested that small colour differences in the surface of dried silver birch boards are caused by different amounts of water in the cell walls. In the inner parts of the boards, which darken commonly, there may be more complicated reasons for colour darkening. Proanthocyanidins have been observed to decrease, i.e. polymerise or oxidise, which correlates with the coordinate a*, red, in silver birch wood (Luostarinen 2006). On the basis of the observation of Chen and Lamb (2004), that in VD water moves mainly longitudinally within a timber piece, a lighter or a darker surface layer can not be expected in VD. However, raised amounts of carbohydrates in the surface of VD timber pieces, a possible reason for the observed dark surface layer, has been measured (Piispanen and Saranpää 2001) and it may be caused by the lower boiling temperature than wood temperature in the surface layer of timber piece (Chen and Lamb 2001). Fast vaporisation of water in this layer may have had an impact on the wood compounds and caused the darkening.

It was not expected that the very small differences in thickness observed in the boards used in this study would affect colour, although the phenomenon is well known in practice with birch timber with large differences in thickness and has been observed in laboratory tests (see Stenudd 2002, Sundqvist 2002). Differences in colour between boards of different sizes is not due to the fact that inner sapwood contains slightly more phenolics and carbohydrates than the surface wood of trunks (Mononen et al. 2004) because the inaccuracy of sawing was the same in all locations of logs. No earlier information about the effects of the volume of sawn timber on deformations caused by drying was found, but Stöhr (1988) observed that the wider the tangentially sawn boards are the less they shrink during drying. This is important because anisotropic shrinkage is the main reason for deformations. The main result from fresh volume analysis of this study was that the smallest deformations occurred in the largest boards which is in accordance with Stöhr's (1988) observation. Instead, when dried with different conventional schedules, tangential and radial shrinkage of birch boards did not differ from each other (Luostarinen and Luostarinen 2001) but shrinkage was larger in the birch boards dried in room conditions than conventionally (Paukkonen et al. 1999). Instead, in red oak (*Quercus rubra* L.) timber drying at high temperatures had significantly larger shrinkage than at low temperatures (McMillen 1955). Here the differences in volume were small and unintentional, due to movements of logs during sawing. Thus the effects that were calculated with fresh volume may also be due to the slightly irregular shape causing differences in relations of dimensions of radial and tangential surfaces. However, in this study, unexpectedly small volume/shape differences had an influence.

5 Conclusions

The differences in final MC between timber pieces of the same drying lot in this study corresponded with the situation in practice. The differences in final MC affected the colour of dried birch wood. The lower the MC, the lighter the colour was. The radial orientation of annual rings in board flats speeded up the drying of the boards and kept the MC gradient small, which helped to keep the boards light coloured. This orientation of rings, however, caused larger deformations than tangential orientation. Thus these results support the classing of sawn silver birch parquet billet timber roughly into two groups according to annual ring orientation for drying with different schedules to minimise deformations and darkening.

Acknowledgements

The author thanks those colleagues who helped with tree felling, sawing, drying and sampling. Particularly Timo Aavakallio, B.Eng., is thanked for performing the vacuum dryings at Mikkeli Polytechnic. Birches were donated by Stora Enso Oyj, and the project was funded by the Academy of Finland (project no. 43153).

References

Beauregard, R., Beaudoin, M., Fortin, Y. & Samson, M. 1992. Evaluating warp from three sawing processes including saw-dry-rip to produce aspen structural lumber. Forest Products Journal 42(6): 61–64.

Chen, Z. & Lamb, F.M. 2001. Investigation of boiling front during vacuum drying of wood. Wood and Fiber Science 33: 639–647.

— & Lamb, F.M. 2004. A vacuum drying system for green hardwood parts. Drying Technology 22: 577–595.

Erickson, R.W., Petersen, H.D., Larson, T.D. & Maeglin, R. 1986. Producing studs from paper birch by saw-dry-rip. USDA Forest Service, Forest Products Laboratory, Research Paper FPL-RP-480.

Isomäki, O., Koponen, H., Nummela, A. & Suomi-Lindberg, L. 2002. Puutuoteteollisuus 2. Raaka-aineet ja aihiot. Opetushallitus, Helsinki. 154 p. ISBN 952-13-1448-6.

Jørgensen, P.F., Tronstad, S. & Tengs, A. 1995. Tørking av bjørk. Resultater fra 9 tørkesforsøk. Norsk Treteknisk Institutt, Rapport 29. 46 p. + 10 app. ISSN 0333-2020.

Kang, K.-Y., Bradic, S., Avramidis, S. & Mansfield, S.D. 2007. Kiln-drying lumber quality of hybrid poplar clones. Holzforschung 61: 65–73.

Keinänen, E. & Tahvanainen, V. 1995. Pohjolan jalot puut. Erikoispuiden mitta-, laatu- ja käsittelyopas. Kuopion käsi- ja taideteollisuusakatemia. 160 p. ISBN 952-5018-04-0.

Klaiber, V. & Seeling, U. 2004. The influence of drying method on the warp behavior of Norway spruce (Picea abies (L.) Karst.) sawn timber. Forest Products Journal 54(4): 79–87.

Kliger, I.R. 2001. Spiral grain on logs under bark reveals twist-prone raw material. Forest Products Journal 51(6): 67–73.

— , Bengtsson, C. & Johansson, M. 2005. Comparison between HT-dried and LT-dried spruce timber in terms of shape and dimensional stability. Holzforschung 59: 647–653.

Langrish, T.A.G. & Walker, J.C.F. 1993. Transport processes in wood. In: Walker, J.C.F. (ed.). Primary wood processing. Principles and practices. Chapman & Hall, London, p. 121–152.

Luostarinen, K. 2006. Effects of environmental and internal factors of trees and timber treatment on colour of dried birch (Betula pendula) wood. Dissertationes Forestales 19. Available at: http://www.metla.fi/dissertationes. [Cited 5 Feb 2007].

— & Luostarinen, J. 2001. Discolouration and deformations of birch parquet boards during conventional drying. Wood Science and Technology 35: 517–528.

— & Verkasalo, E. 2000. Birch as sawn timber and in mechanical processing in Finland. A literature study. Silva Fennica Monographs 1.

McMillen, J.M. 1955. Drying stresses in red oak: effect of temperature. Forest Products Journal, August: 230–241.

Milota, M. 1992. Effect of kiln schedule on warp in Douglas-fir lumber. Forest Products Journal 42(2): 57–60.

— 2000. Warp and shrinkage of hem-fir stud lumber dried at conventional and high temperatures. Forest Products Journal 50(11/12): 79–84.

Mononen, K., Alvila, L. & Pakkanen, T. T. 2004. Effect of growth site type, felling season, storage time and kiln drying on contents and distributions of phenolic extractives and low molecular mass carbohydrates in secondary xylem of silver birch Betula pendula. Holzforschung 58: 53–65.

Ormarsson, S., Dahlblom, O. & Petersson, H. 2000. A numerical study of the shape stability of sawn timber subjected to moisture variation. 3. Influence of annual ring orientation. Wood Science and Technology 34: 207–219.

Paukkonen, K., Luostarinen, J., Asp, J. & Asikainen, A. 1999. Koivusahatavaran muodon- ja värinmuutokset kuivauksessa. Metsätieteen Aikakauskirja no. 2: 227–238.

Piispanen, R. & Saranpää, P. 2001. Rauduskoivun varastoravintoaineet ja puuaineksen värinmuutos kuivauksessa. In: Luostarinen, K., Möttönen, V., Asikainen, A., Pakkanen, T., Saranpää, P. & Tolonen, Y. (eds.). Koivun puuaineksen kemia ja värinmuutokset kuivauksessa. Konsortion loppuraportti. [Chemistry and discolouration of birch wood. Final report.]. University of Joensuu, Faculty of Forestry, Research Notes 134. p. 7–21. ISBN 952-458-066-7.

Pohjoismainen sahatavara. Lajitteluohjeet. 1994. Suomen sahateollisuusmiesten yhdistys. Helsinki. 64 p. + 16 app. ISBN 852-90-5750-4.

Precise color communication. Color control from feeling to instrumentation. 1994. Minolta Co., Osaka, Japan. 49 p.

Sandberg, D. 1997. Radially sawn timber. The influence of annual rings on crack formation and deformation in water soaked pine (Pinus silvestris L.) and spruce (Picea abies Karst.) timber. Holz als Roh- und Werkstoff 55: 175–182.

Sipi, M. 2002. Sahatavaratuotanto. Opetushallitus, Helsinki. 213 p. ISBN 952-13-1309-9.

Stenudd, S. 2002. On colour changes during kiln drying of hardwood with special reference to beech and birch. Linköping Studies in Science and Technology, Thesis 997. Linköping University, Sweden. 37 p. ISBN 91-7373-578-7.

Stöhr, H.-P. 1988. Shrinkage differential as a measure for drying stress determination. Wood Science and Technology 22: 121–128.

Sundqvist, B. 2002. Color response of Scots pine (Pinus sylvestris), Norway spruce (Picea abies) and birch (Betula pubescens) subjected to heat treatment in capillary phase. Holz als Roh- und Werkstoff 60: 106–114.

Verkasalo, E. & Paukkonen, K. 1999. Koivun ominaisuudet ja käyttömahdollisuudet sahauksessa ja jatkojalostuksessa Suomessa. Metsäntutkimuslaitoksen tiedonantoja 751. 91 p. ISBN 951-40-1706-4.

Zobel, B.J. & van Buijtenen, J.P. 1989. Wood variation. Its causes and control. Springer-Verlag. Berlin. 363 p. ISBN 3-540-50298-X.

Total of 31 references