Development of twist on boards of Norway spruce during kiln drying

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ABSTRACT

Development of twist of Norway spruce boards (Picea abies Karst.) during normal temperature kiln drying was researched. Oriented tangential boards (18 × 80 × 800 mm) were sawed from diametrical radial planks, with known axial shrinking, density, growth dynamics and spiral grain angle (SGA). Unrestrained boards were later on kiln dried at normal temperature, to determine moisture content (MC) and twist development and in 2 days drying interval. Twist was induced in most cases around fibre saturation point, and raised proportionally with decrease of MC towards to the highest values at the end of the process. Radial position of boards had the strongest influence on twist. End values of twist amounted from 10 and 20 °/m close to the pith, and decreased to less than 4 °/m at 70 mm from the centre of logs. SGA, generally decreasing in radial direction, significantly influenced the twist, especially at low MC, bellow 16%. Tangential shrinkage had also pronounced impact on twist variation, especially at MC above 20%, which is ascribed to the likely presence of tangible MC gradient as a consequence of drying procedure.

INTRODUCTION

Warp, mainly twist, crook and bow, of sawn wood of Norway spruce (*Picea abies* Karst.) frequently cause serious problems in wood construction industry. Twist often causes the most severe problems (Perstorper et al. 1995, Forsberg 1997).

The two parameters most commonly associated with twist are distance from pith to the centre of the cross-section of the board, which is an indirect expression of the annual-ring curvature, and spiral grain angle (SGA). Significancy of these parameters was studied by some analytical models (Stevens et al. 1960, Booker 2005, Bäckström et al. 2006), statistical surveys on data from stationary conditioning experiments (Johansson et al. 2001, Warensjo et al. 2004) and at numerical modelling (Ormarsson et al. 1998). In most cases ring curvature was the best predicting variable or had the strongest impact on twist variation, followed by SGA. Recently, additional explanation of twist of sawn wood was achieved by including of SGA gradient (Forsberg et al. 2001).

A lot of research was done to prevent twist of sawn wood during experimental and industrial drying. Therefore different drying schedules were studied at normal temperature, varying drying time, temperature and climatic conditions (Milota 2000). Improved shape stability of dried sawn wood was achieved using additional steaming of boards, varying climatic conditions during drying or with increasing of top loads on kiln stacks (Mackay 1973, Arganbright et al. 1978, Kliger et al. 2005, Frühwald 2006). The impact of green moisture content variation and especially moisture content gradient at dried boards is less investigated. Some research in this field was done by finite elements modelling or with experimentation by static conditioning (Bäckström et al. 2006).

This research was designed to follow the development of twist in sawn wood of Norway spruce (*Picea abies* Karst.) during unrestrained normal temperature kiln drying. The aim of the study is to determine some material characteristics as growth rate, density, axial shrinking and spiral grain, to asses their variation and to analyze the applicability of material data in twist modelling during drying process.

MATERIALS AND METHODS

Ten Norway spruce trees (*Picea abies* Karst.), 50 to 70 years old, were cut down for the survey purposes. Afterwards, two succesive logs, 0.4 and 0.8 m in length, were sawed off from breast height of individual tree. Material characterization was carried out on shortest logs, wherefrom samples for density determination, growth dynamic, axial shrinkages ($\square_L$, $\square_R$, $\square_T$) and spiral grain angle (SGA) were prepared in radial direction of logs. Material data was determined using standard test procedures (DIN 52182; DIN 52184), whereas SGA was determined by hand breaking of, 3 mm thick, oriented and radially positioned lamellas, in longitudinal-tangential plane.

Diametrical radial planks, 60 mm thick, were sawed from 0.8 m long logs. Planks were ripped through the pith and radially sawed into 18 mm thick, tangentially oriented lamellas, with known radial position and material characteristics (Fig. 1). 170 lamellas were later on kiln dried, without restrain, using common normal temperature drying schedule, with step raised temperature (from 67 to 80 °C) and increasing drying gradient (from 3 to 4.3). During the drying, moisture content (MC) and twist development were successively determined in 2 days interval, using 2 h breaks of the drying process. We measured MC gravimetrically, by weighting of individual lamellas (EN 13183-1). Twist on lamellas was measured by aluminium wedge, with 0.5 mm precision.

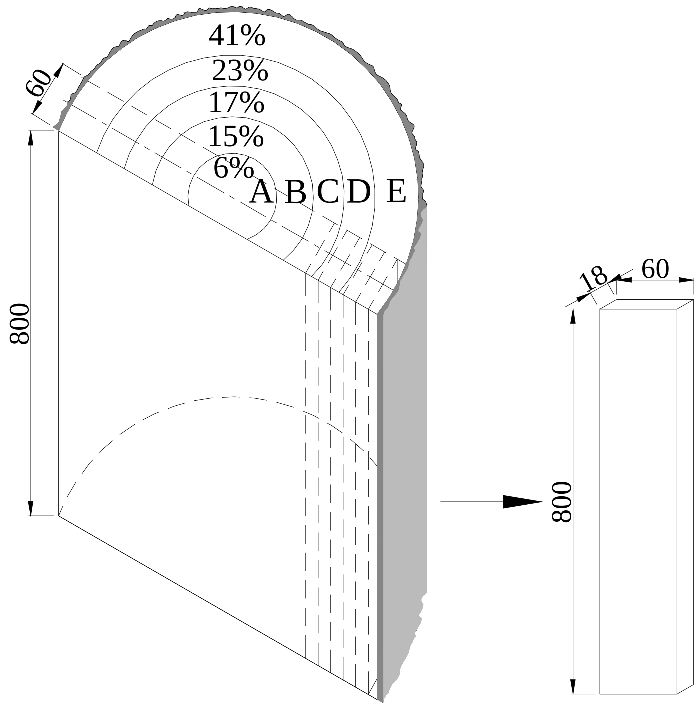

Figure 1 Saving of sawn lamellas from a long log (A to E – growth ring decades with volume share)

RESULTS AND DISCUSSION

Material data

In general, longitudinally aligned wood tissue significantly deviated from the tree axis. In all examined trees the helix was left-handed in juvenile region with the maximum angle, from 2 to 6°, close to the pith (Figure 2). As a rule, reduction of SGA with distance from the pith was present in all examined trees, where three typical radial patterns were observed: a - grain direction may stay left handed, b - grain direction tend to become almost straight or c - grain can change direction to right hand. Determined SGA patterns caused great variability at the outer part of different stems. These observations coincide well with results from other studies of Norway spruce (Danborg 1994, Forsberg et al. 2001, Perstoper et al. 2001, Sepulveda 2001).

Total tangential shrinkage of this material is similar to what is reported in the literature. The overall mean value is 8.97% (CV = 0.145), with significantly lower value, namely 8.54 (CV = 0.107), close to the pith ($p = 0.05$) (Figure 3). One of the reasons for this difference is most probably the influence of growth ring curvature on the measurements close to the pith, since measurement length is 20 mm. However, small increase of tangential shrinkage is also noted in similar studies (Cown et al. 1983, Perstoper et al. 2001).

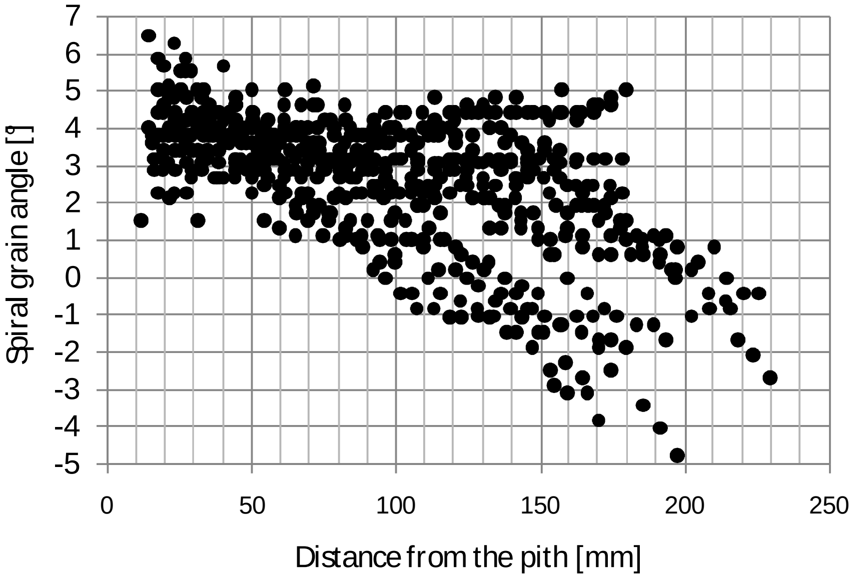

Figure 2 Spiral grain angle variation of Norway spruce wood with distance from the pith.

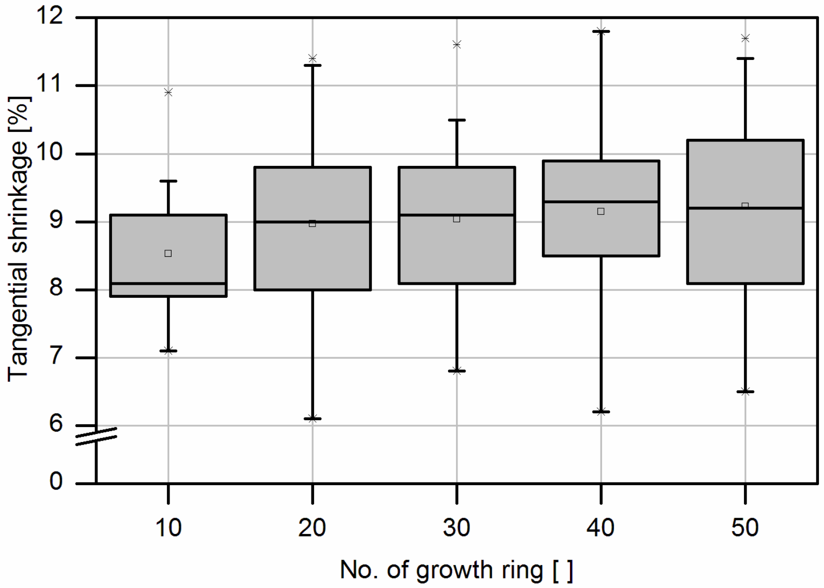

Figure 3 Variability of tangential shrinkage in radial direction of Norway spruce wood.

Drying kinetics

Position of lamellas in cross section of trees significantly influenced their green moisture content and its variation, as well as their drying progress. Generally, low MC values, from 40 to 80% were determined in central part of logs. Contrary, lamellas from the circumference of logs had much higher green MC, always above 100% (

Figure 4). The green state has strong impact on drying kinetics in followed procedure. During the drying, central and intermediate lamellas reached fibre saturation point already in first 2 days of the process, whereas at least doubled time was needed to reach a similar

MC at peripheral lamellas (Figure 5). Additionally, because of high MC at the beginning, higher MC gradient at cross section of peripheral lamellas is expected during the whole drying process.

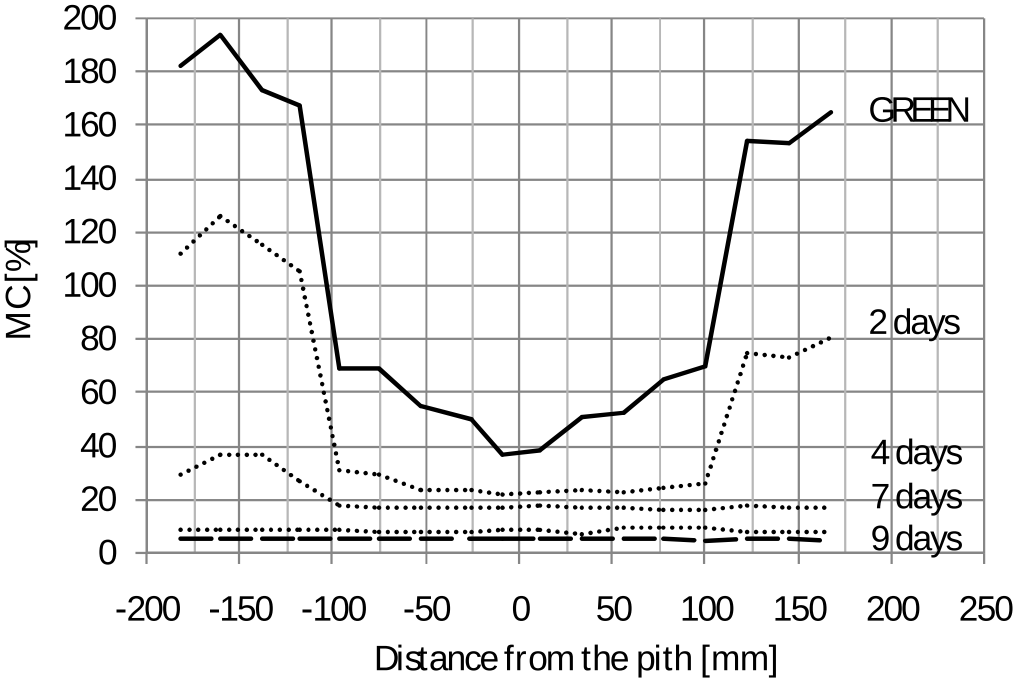

Figure 4 MC distribution with distance from the pith in green (—), partly dried (···) and in kiln dried state (- --) of Norway spruce boards (Log #1).

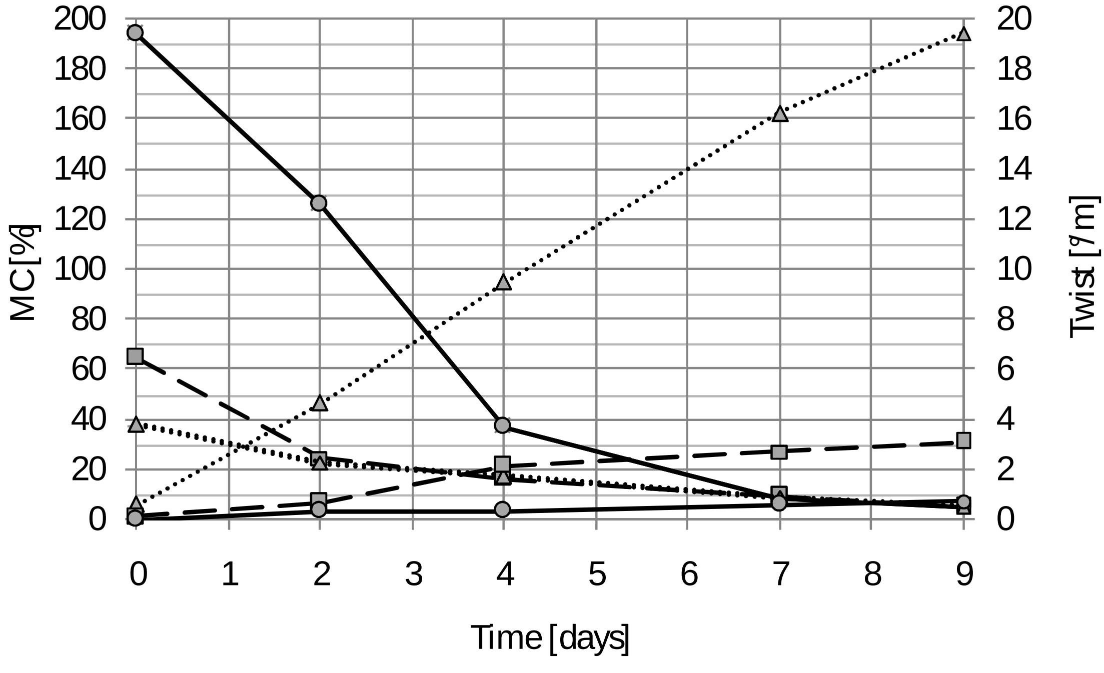

Figure 5 Typical drying curves and twist development at kiln dried boards of Norway spruce from sapwood (—), intermediate wood (- - -) and heartwood (···).

Twist development

Twisting of lamellas, irrespective of their radial position in log, generally started at reaching of MC around fibre saturation point. According to expectations, more pronounced twisting was developed on lamellas positioned near the centre of logs, especially in radius of approx. 60 mm. Succesive sampling in hygroscopic range confirmed almost straight-line warping of lamellas with decreasing of their moisture content (Figure 1). Linear dependency of twist with decrease of MC was confirmed in similar drying experiments (Mackay 1973), or during static climatic conditioning (Johansson et al. 2001).

The largest distortions were present at the lowest MC, at the end of the procedure, where lamellas close to the pith reached mean twist angle of 17 °/m. Fast reduction of maximum twist angle with distance from the pith was confirmed, where at location of 70 mm from the centre reached constant mean value, between 1 and 3 °/m (Figure 6). Similar values of twist, and radial tendency has also been shown for conifer species in some experimental studies (Balodis 1972, Shelly et al. 1979, Johansson et al. 2001).

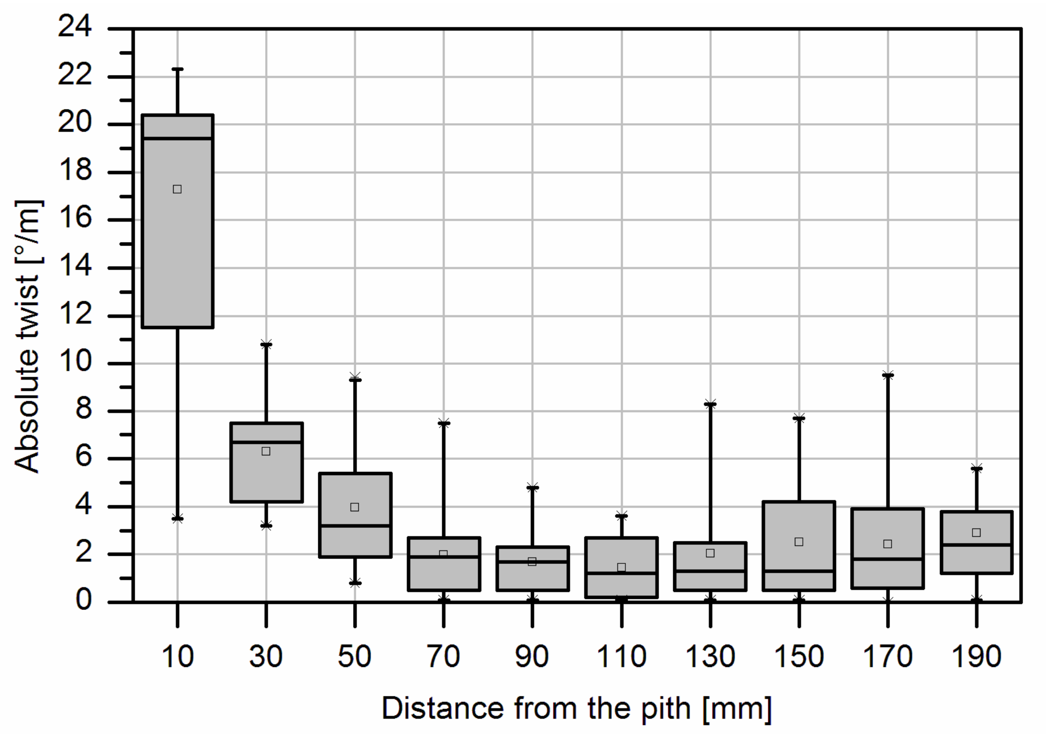

Figure 6 Twist distibution on boards of Norway spruce in radial direction at the end of drying process (MC = 5.0%, CV% = 6.2%).

Modelling twist and regression analysis

Stepwise regression analysis, using determined material data, was made in order to investigate to what extent different parameters influenced the magnitude of twist. The stepwise regression analysis is a good tool since collinearity between parameters is taken into account. Using this method, 60% of the variation in twist in whole MC range could be explained in resulting governing equation of step 3 (constant is excluded from the model):

$$Twist = 0.057\frac{1}{r} + 0.313 \cdot \varepsilon_T + 0.104 \cdot \theta$$

Denotation:
r = distance from the pith [mm],
ε_T = realized tangential shrinkage [%] (FSP = 30%) and
θ = spiral grain angle in the middle of lamella [°].

To better understand the twist development the same analysis was repeated at successive MC interval (ΔMC = 2%) in the narrower hygroscopic range, where the twist was induced. Values of variable estimates with explanation of experimental data variation in the stepwise regression model are presented in Table 1. The ring curvature was confirmed as the most important variable in the whole

MC range, and explained more than 80% of twist variation at low values (MC < 8%). Some variability of twist, namely 1.8 to 4.5%, explains also tangential shrinkage, but only at MC above 18%. At lower MC, below 16%, gave SGA also low contribution to the multiple regression model ($R^2 \leq 2\%$) (Figure 7).

Table 1 Stepwise regression analysis of twist variation in hygroscopic range of Norway spruce wood.

Variable / MC	< 6	< 8	< 10	< 12	< 14	< 16	< 18	< 20	< 22	< 24	< 26	< 28	< 30
1/r	0.122	0.113	0.112	0.112	0.112	0.099	0.099	0.084	0.08	0.075	0.075	0.075	0.072
St.error	0.006	0.004	0.005	0.005	0.005	0.004	0.003	0.003	0.003	0.003	0.003	0.003	0.003
%model	*83.1*	*82.3*	*79.9*	*79.9*	*79.9*	*77.5*	*77.2*	*67.7*	*65.4*	*62.8*	*62.8*	*62.8*	*61.0*
ε_T							0.125	0.169	0.179	0.195	0.195	0.195	0.207
St.error							0.02	0.022	0.022	0.022	0.022	0.022	0.022
%model							*1.8*	*3.3*	*3.7*	*4.5*	*4.5*	*4.5*	*5.1*
θ	0.289	0.264	0.281	0.281	0.281	0.244							
St.error	0.066	0.048	0.048	0.048	0.048	0.039							
%model	*1.7*	*1.8*	*2.0*	*2.0*	*2.0*	*1.8*							
N	153	269	308	308	308	430	457	515	552	566	568	572	581
R^2	84.8	84.1	82.0	81.9	81.9	79.3	79.0	71.0	69.1	67.2	67.2	67.2	66.1
St.err.of est.	2.196	2.127	2.236	2.236	2.236	2.184	2.148	2.415	2.427	2.473	2.469	2.46	2.485

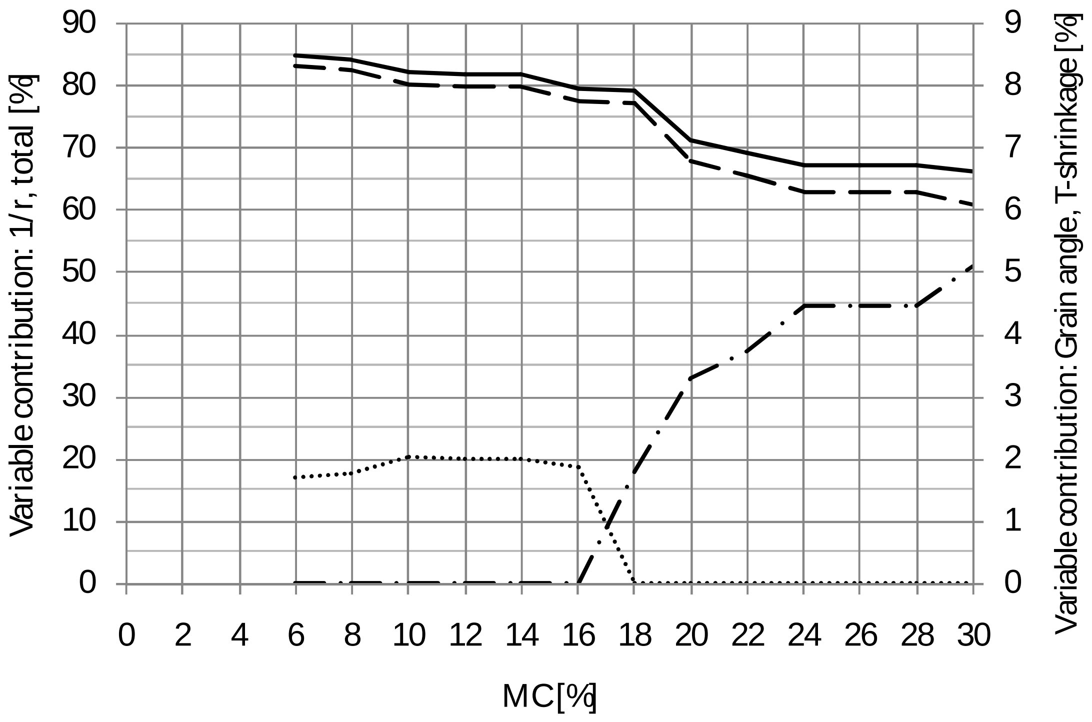

Figure 7 Explanatory values of variables in stepwise regression model of twist variation in the hygroscopic range of Norway spruce wood (— total; - - - ring curvature; ··· spiral grain angle; - · - tangential shrinkage).

These results confirmed the best stepwise regression modelling at MC bellow 18%, where ring curvature and SGA explained more than 80% of experimentally determined twist variation. Many studies on twist, using statistical modelling, brought forward similar findings (Forsberg et al. 2001, Johansson et al. 2001). Regression modelling at MC above 20% was less succesful, even with significant explanatory value of tangential shrinkage. Most likely, significant impact on this finding can be assigned to presumably presence of tangible MC gradient and induced drying stresses.

Measuring of MC gradient, especially determing MC of board's circumference, would certainly improve predicting of twist at high MC, as was confirmed for instance in experimental drying studies (Mackay 1973) and in FEM models of twist (Ormarsson et al. 1999). The improvement of twist prediction at high MC would also be possible with determining of drying stresses and analysis of possible relaxation, as a consequence of drying time, temperature, present MC and reological properties of wood (Mackay 1973, Price et al. 1980, Pang et al. 2004).

CONCLUSSIONS

The research confirmed significant influence of some material properties, like ring curvature, variying spiral grain angle with distance from the pith and tangential shrinkage on development and magnitude of twist in sawn wood of Norway spruce. Proportionaly increasing twist with moisture content decrease was the most pronuonced closed to the pith at the end of the drying, with lower, almost constant values at least 70 mm from centre of logs. Stepwise regresion analysis of twist with drying time confirmed varying impact of determined material properties on experimentaly determined twist at specific moisture content of sawn wood of Norway spruce.

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