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KILN DRYING OF POPLAR WOOD AT LOW TEMPERATURE: BEAM DISTORTIONS IN RELATION TO WOOD DENSITY, TENSION WOOD OCCURRENCE AND MOISTURE DISTRIBUTION

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ABSTRACT

This study is aimed at comparing the final moisture distribution (mean MC and variability) and drying distortions of six Euramerican poplar clones (*Populus deltoides* x *nigra*) originating from a multiclonal stand using traditional kiln-drying at low temperature. The selected poplar clones yielded a different final MC after drying, implying the drying schedule needs adaptation per clone or clonal groups. An additional homogenization period of two weeks under ambient outdoor condition lowered the average final MC significantly with 2-3 %. The occurrence of wet pockets is a major concern in drying poplar lumber of which clonal differences have been demonstrated. Density and tension wood proportions are influencing factors to drying deformations (bow and crook). All clones display acceptable values for twist, while none of the clones comply to the demands concerning crook as requested for structural applications. The limitations for bow are only met by the poplar clones "Ghoy" and "Gaver".

KEYWORDS: Drying deformations, low temperature drying, moisture distribution, poplar wood.

INTRODUCTION

Poplar is an important tree species in the Flemish region (Belgium) delivering in relatively short rotations of approximately 20 year a substantial amount of 380.000 m^3 round wood harvested each year. The production system uses wide planting distances (8x8 m) and rotation periods ranging from 15 to 25 years. Management practices such as pruning aim at the production of quality logs. Shifts in ecological perception, changing legislation and rust disease spreading (*Melampsora* sp) have put pressure on the current monoclonal production system (Steenackers et al. 1996, 1997). These criticisms can lead to the use of a wider range of selected poplar and willow clones for plantation purposes (multiclonal plantations).

Nowadays poplar wood is used in a wide variety of semimanufactured and final products (packaging materials, veneer based products, sawn timber and board materials to pulp and paper) as a result of a broad spectrum of wood qualities (Balatinecz et al. 2001).

Due to the low density and favourable mechanical properties, poplar wood is comparable to softwoods, especially when envisaged to be applied in light constructions. However, limitations in this regard may be the lower dimensional stability and less auspicious mechano-sorptive behaviour.

Also the drying processing step must be carefully evaluated and adapted to the end-use in mind. (final moisture content and uniform moisture distribution). All parts of a living tree contain water. Water is a critical component in the process of photosynthesis leading to the formation of new tree cells and subsequently growth. The water or moisture content (MC) of wood is expressed as a percentage. The weight of water present in the wood is expressed proportional to the weight of dry wood-matter. Green (freshly cut) poplar wood yields a MC ranging from 120 to 240 %, varying considerably between trees and among boards cut from the same tree. Drying improves the resistance to biological attack, the volume to weight ratio, strength and stiffness, gluing and finishing properties as well as machining features.

As the lumber is dried it becomes progressively stronger. This allows dried structural components to have smaller dimensions and lighter weight, advantages in furniture and constructions. Because water can also be molecularly bonded to wood and, thus interfere with cross-linking of glue and wood finishes when applied to wet wood. Using such wet wood will produce dimensionally unstable products, exhibiting glue-line failures, warping or misalignment, which will contribute to several failures in products in service (Keey et al. 2000, Siau 1984, Skaar 1988, Wendell 1956).

In addition, tension wood and wet pocket occurrence in poplar sawn timber have a direct or indirect influence on the drying process (Balatinecz et al. 2010, Aléon et al. 1989, Gu et al. 2004, Vansteenkiste et al. 1997, Ward 1984, 1986).

The aim of this paper is to evaluate the variability in end moisture content in dried beams for several selected Euramerican poplar clones from a multiclonal stand as well as to establish relations between wood density, tension wood and false coloured heart wood occurrence with the induced deformations in drying.

MATERIAL AND METHODS

The studied clones were obtained from a polyclonal stand situated in Grimminge (Belgium). Six euramerican clones ('Ghoy', 'Primo', 'Gaver', 'Gibecq', 'Tardif de champagne' and 'Robusta') were selected for this research. The name of the poplar hybrid 'Tardif de Champagne' is the the further parts of this document abbreviated to 'Tardif'. For each clone, three trees were selected according to the variability in diameter at breast height and total tree height. A mixed sample of 12 logs (four logs of 2 meter per tree) was used for each selected clone. An optimal saw pattern at the sawmill was used in order to produce as many 2000x50x95 mm beams as possible.

In this study a traditional kiln drying process was applied. The beams stayed in the dryer for three weeks at a moderate temperature of 40 °C. No top-loading was applied. The well-known drying process allowed evaluating if several poplar clones can be processed by the same drying schedule aiming at minimal drying deformations. As such, the impact of processing multiclonal stands as one source of raw material was evaluated. The schedule was set to dry to final moisture content between 15 and 18 %.

The moisture content was measured at every 25 cm using a pinless type moisture meter based on capacity measurement, immediately after kiln drying and again after a two week period of acclimatisation under ambient outdoor conditions. Based on these MC measurements, wet pocket occurrence was assessed for each beam using the definition given by Balatinecz et al. (2010). A wet pocket is defined as a local point within a poplar beam displaying a MC that is at least 5 % higher in absolute MC compared to the non-parametric 25 % percentile value of the MC distribution within that respective beam.

At two, four and six meter a stem disc was taken to determine average density by the oven dry method (heartwood, transition wood and sapwood) as well as to evaluate the amounts of false coloured heartwood. To calculate the amount of false coloured heartwood in the whole commercial stem, data were volume weighted by extrapolation of the surface measures. Tension wood proportions were also assessed at the beam level after drying. A wooliness surface was used as an indication of tension wood occurrence. As estimation of the amount of tension wood as a percentage of the total beam surface was made in classes of 25 %.

Further, all beams were evaluated on drying deformations (bow, crook, twist and cup). The deformations were measured using a precision distance meter with an accuracy of 0.01 mm. The evaluation and calculation of the deformation values took into account the different types of warp configurations described by Milota (1991). Bow, crook and twist were expressed in mm. per meter, while cup was expressed as a percentage of the width of the beam.

In the result and discussion parts, the significance of statistical analysis are indicated by a number of asterisks (* p=0.05, ** p=0.01, *** p=0.001).

RESULTS

Final moisture content and incidence of wet pockets

First the final moisture content, directly after drying and after two weeks of homogenizing, has been evaluated. The drying process was continued until 10 reference beams (constantly monitored) reached an average MC of 16 %. Tab. 1 shows the average final MC immediately after and two weeks after kiln drying as well as the standard deviation, based on an assumed normal distribution.

The general overview of the results already proves that this drying process did not meet the requirements set in terms of final MC for all clones. 'Ghoy', 'Primo' and 'Gaver' (group 1) reach the same final MC of approximately 15-18 %, while the other clones still have MC levels over 20 % (group 2). Most of the clones show a lowering in average moisture content after a conditioning period of two weeks under ambient conditions. Only for the clones 'Gibecq' and 'Tardif' no changes in average moisture content could be observed (Tab. 1).

For each clone, timing (immediately after drying and two weeks later) and position (distance to the beam ends) two-parameter Weibull distributions for MC were fitted. Coefficients of determination (R^2) of these fits ranged from 0.80* to 0.95*. Fig. 1 shows a graphical representation for the clone 'Primo'. Conclusions are similar for all clones.

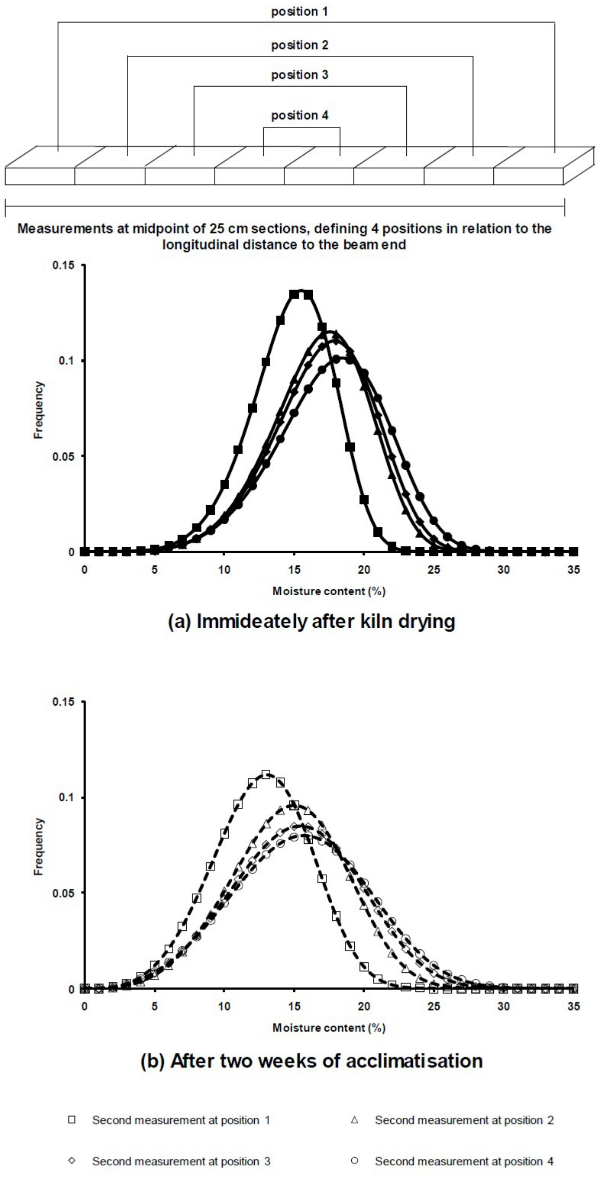

Fig. 1: Fitted two-parameter Weibull distributions for the moisture content (%) per position within the beams for the clone 'Primo'.

This lowering in mean MC is shown by a downward shifting of the MC distributions at each position. It is assumed that, during the two week homogenisation period, moisture diffusion both across cell cavities and through cell walls occurs, which results in a general reduction of the final MC. The lowering effect is the same at every position within the beams. Only for the clone 'Gaver' the MC lowered more significantly at the outer parts of the beam in comparison to the inner positions. Overall, the shape of MC distributions did not change significantly after two weeks of homogenisation.

Tab. 1: Average values with standard deviations (between brackets) of the final MC (%) and the number of wet pockets immediately after drying and after a two week during conditioning phase as well as the mean MC values per midpoint measurements of sections of 25 cm from end cut.

Clone	Timing	Number of wet pockets(%)	Final moisture content (%)	Final MC (%)			
				End of beam	⟷		Middle of the beam
				Position 1	Position 2	Position 3	Position 4
Ghoy	0 weeks	28	17.4 (4.3)	15.8 (4.4)	17.8 (5.2)	17.9 (5.5)	18.0 (5.5)
	2 weeks	29	14.3 (3.8)	12.7 (4.1)	14.5 (5.0)	15.1 (5.2)	14.9 (5.1)
Primo	0 weeks	30	16.6 (2.7)	14.8 (3.1)	16.8 (3.7)	17.1 (3.9)	17.7 (4.3)
	2 weeks	32	14.5 (3.7)	12.7 (4.1)	14.6 (4.6)	15.2 (5.2)	15.5 (5.5)
Gaver	0 weeks	25	18.5 (3.9)	17.1 (4.0)	19.0 (5.1)	18.9 (4.7)	19.0 (5.2)
	2 weeks	25	17.5 (4.5)	15.8 (4.4)	18.0 (5.2)	18.0 (5.6)	18.4 (6.0)
Robusta	0 weeks	53	23.3 (5.1)	19.2 (5.3)	23.3 (6.7)	24.2 (7.1)	26.4 (7.6)
	2 weeks	39	19.5 (3.3)	17.7 (4.1)	19.5 (4.1)	19.8 (4.6)	20.9 (4.5)
Gibecq	0 weeks	35	21.8 (5.4)	17.9 (4.1)	22.5 (5.8)	22.7 (7.5)	24.1 (7.1)
	2 weeks	30	21.4 (4.4)	19.0 (4.5)	21.6 (5.4)	22.3 (6.0)	22.9 (6.0)
Tardif	0 weeks	40	21.1 (4.5)	18.3 (5.5)	21.5 (5.8)	22.0 (6.0)	22.7 (6.2)
	2 weeks	36	21.3 (3.8)	18.1 (4.5)	21.9 (5.1)	22.2 (5.2)	22.8 (6.1)

The number of beams containing wet pockets is given in Tab. 1. Group 1 ('Gaver', 'Ghoy' and 'Primo') displays a lower degree of wet pocket occurrence (around 30 %) while the clones in group 2 ('Gibecq', 'Robusta' and 'Tardif') yield higher values around 40 %. However, no significant correlation was determined between the final moisture content and wet pocket occurrence.

Density values and heartwood proportions

Average density values per clone as well as the average density values for heartwood, transition wood and sapwood at three different heights and the proportions of false coloured heartwood are presented in Tab. 2.

Density is increasing significantly (p=0.05) from pith to bark for every clone at every height level. Density increases generally with height, although no significant differences could be pointed out by statistics. Average density values differ between clones. 'Ghoy', 'Primo' and 'Tardif' have lower density values (approximately 430 $kg.m^{-3}$), while 'Gibecq' shows significantly higher values (approximately 480 $kg.m^{-3}$). 'Robusta' and 'Gaver' show intermediate figures (Tab. 2).

As the false coloured heartwood proportion is concerned, only the clone 'Gaver' shows significantly lower amounts (±40 % in comparison to ±50 %).

Deformation parameters bow, crook, twist and cup.

Tab. 3 lists the average values for the different deformation parameters (bow, crook, twist and cup) as well as the total warp for each clone.

Tab. 2: Average density values per clone as well as the average density values for heartwood, transition wood and sapwood at three different heights and the proportions of heartwood.

			Density (kg.m^{-3})				Heartwood proportion (%)
			Heartwood	Transition zone	Sapwood	$\dot{x}$	
Group 1 (Final MC <20%)	Ghoy	2m	392	412	431	422	59
		4m	418	427	448	438	52
		6m	400	454	481	468	44
		$\dot{x}$	403	431	453	429	52
	Primo	2m	400	422	456	426	57
		4m	415	420	475	437	47
		6m	426	434	460	440	42
		$\dot{x}$	414	425	464	434	49
	Gaver	2m	409	430	450	440	49
		4m	425	450	470	460	41
		6m	435	465	501	483	35
		$\dot{x}$	423	448	474	448	42
Group 2 (Final MC >20%)	Robusta	2m	409	424	447	436	56
		4m	424	432	464	448	44
		6m	437	441	475	458	37
		$\dot{x}$	423	432	462	439	46
	Gibecq	2m	436	455	488	471	59
		4m	453	474	512	493	46
		6m	474	495	551	523	40
		$\dot{x}$	454	474	517	482	48
	Tardif	2m	365	395	440	418	53
		4m	391	425	458	442	47
		6m	388	431	498	465	41
		$\dot{x}$	381	417	465	421	47

Tab. 3: Average values for the different deformation parameters (bow, crook, twist and cup) as well as the total warp (sum of twist, bow and crook) and the Duncan multiple range post-hoc statistic (letter code).

	Clone	(%)		Twist (cm.m^{-1})		Bow (cm.m^{-1})		Crook (cm.m^{-1})		Total warp (cm.m^{-1})	
Group 1	Ghoy	0.79	a	0.96	a	1.98	a	1.96	a	4.9	a
	Primo	0.90	b	1.36	b	2.02	a	2.33	a	5.7	b
	Gaver	0.74	a	0.92	a	1.61	b	1.40	b	3.9	c
Group 2	Robusta	1.17	b	0.71	a	2.11	a	2.70	c	5.5	b
	Gibecq	0.30	a	0.76	a	2.64	c	2.41	a	5.8	b
	Tardif	0.66	a	0.97	a	2.17	a	2.15	a	5.3	a

Differences exist between clones. The clones are grouped differently for every deformation parameter. As twist is concerned, only the clone ‘Primo’ shows a significantly higher value (±1.40 compared to ±1.00 cm.m^{-1}). Values for cup are the lowest for ‘Gibecq’ and ‘Tardif’. As crook and bow is concerned, the clone ‘Gaver’ shows the lowest degree of deformation. ‘Gibecq’ has the highest value for bow, while for crook the clone ‘Robusta’ shows less favourable values (almost twice the deformation of ‘Gaver’). The total warp (sum of crook, bow and twist) allows distinguishing three groups of clones. ‘Gaver’ has the lowest overall warp of all clones. ‘Primo’ ‘Gibecq’ and ‘Robusta’ have the highest values for total warp (sum of twist, bow and crook) (±5.6 cm.m^{-1}).

DISCUSSION

Accuracy of moisture content and distortion values

Even with very careful execution of the measurements, some degree of uncertainty exists. The only reliable method for determining the moisture content is the oven dry method. However, the oven dry method is a destructive method. Therefore, it could not be applied on the battens to be assessed for distortion. Because of this the electrical capacitance type method was used to determine the moisture content along the battens. But this method also has some limiting conditions. The accuracy of this type of meter varies between 1-3 percent in moisture content and 5-8 percent when MC is above the fibre saturation point (> 30 % MC). Capacitance meters are sensitive to surface moisture and are also dependent on material density. Wet regions can only be detected upon 1.3 cm below the surface (Milota 1994, Wengert and Bois 1997, Breiner 1987).

All drying induced distortions are related to moisture content due to the linear relationship between MC and shrinkage. Errors in the determination of the MC will have some effect on the interpretation of the degree of distortion. For measuring twist one of the ends of a batten must be used as the reference. This was achieved by pressing down one end of the batten onto a flat plane. Depending on the amount of cupping and depending on which face of the batten was pressed on the flat plane, different results were obtained. Also the amount of pressure used is an influencing factor. In case of different results, the worst distortion value was retained for the further evaluation. For the interpretation of twist, moisture content and grain angle are the most important influencing factors (Kretschmann et al. 1999, Keey et al. 2000). The latter factor was not determined in this study, implying caution when interpreting the results on twist.

When determining bow and crook, the amount of twist is a disturbing factor. The measurement of bow and crook also implies the need of a reference plane. The batten has to be aligned with this plane and a twisted end complicates the measurement and its interpretation.

Density and moisture content as predictor of total warp

Dense wood will show more resistance to drying stresses that are responsible for collapse and honeycombing development than lower density wood. On the other hand increased density is linked to increasing shrinkage values which can negatively influence drying distortions as crook, bow and twist (Keey et al. 2000, Vansteenkiste et al. 1997). The occurrence of tension wood also increases local density, while it shows increased longitudinal shrinkage leading to a more excessive crook and bow. Tab. 2 shows for every clone a clear and significant trend of increasing density when going from pith to bark. The found variability in density of poplar wood in this study is confirmed by earlier reported data (Beaudoin et al. 1992, Debell et al. 2002, Klasnja et al. 2003, Pezlen 1998, De Boever et al. 2007). Therefore, the beams were subdivided into three density classes corresponding with their radial position within the stem. The relation with the deformation parameters (crook, bow, twist and cup) for the selected clones as well as the final MC are shown in Fig. 2.

No overall relation between wood density and drying deformation could be established. This could be due to the fact that not all clones did reach the set final moisture content of 15-18 % after kiln drying (Group 1 versus Group 2).

For the clones 'Ghoy' and 'Gaver' deformation parameters do not vary significantly with density related to radial stem position. Their total warp (Tab. 3) is also significantly lower than that of the other clones. The clone 'Primo' , also showing lower density wood, yielded on the other hand a significantly higher amount of distorted beams.All the latter clones (Group 1) did reach the foreseen final moisture content.

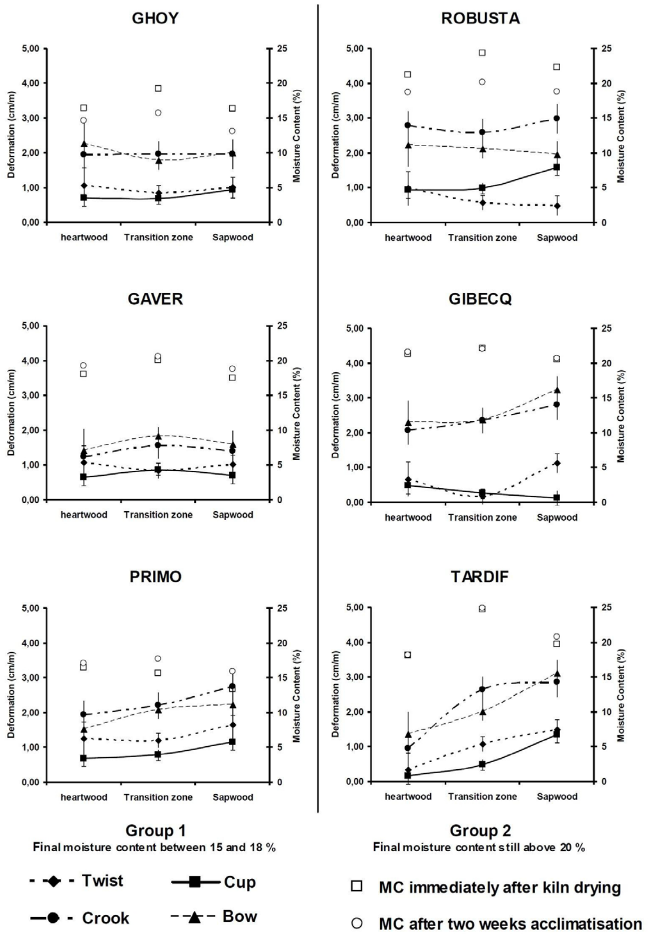

Fig. 2: Relation between radial position within the stem and the deformation parameters (bow, crook, cup and twist) for two groups of selected clones.

Further deformations upon drying are not to be anticipated. A hypothesis for the distinct behaviour for the clones 'Ghoy' and 'Gaver' compared to 'Primo' lies in lower absolute shrinkage values or smaller grain angle (not determined in this study). Literature reports on positive correlations between density and both radial and tangential shrinkage values (Koubaa et al. 1998, Pliura et al. 2005). This could explain the lower deformation values for 'Ghoy' and 'Gaver' but is contradictory for 'Primo'. Although absolute shrinkage values can be higher, the shape factor (tangential shrinkage divided by radial shrinkage) could still be more favourable for the clones 'Ghoy' and 'Gaver'. The latter factor will display an increasing influence when at the same time the grain angle is elevated.

The clones 'Gibecq' and 'Tardif' (Group 2) display similarly to the clone 'Primo' (Group 1) increasing deformations when moving form pith to bark, following increasing density. These clear trends could be explained by the hypothesis of increased shrinkage values with increasing density.

'Primo' did reach the foreseen final MC, while 'Gibecq' and 'Tardif' still show high MC. This implies that upon further drying deformations are likely to increase. The clone 'Robusta' deviates in behaviour compared to the other clones in Group 2. Drying deformations are considerably high for the clone 'Robusta' but no radial trend with increasing density could be retrieved. It is not clear weather this trend will be maintained upon drying.

Allowable values of bow (1.30-1.90 $cm.m^{-1}$), crook (0.60-0.90 $cm.m^{-1}$) and twist (0.90-1.30 $cm.m^{-1}$) for structural graded timber could be retrieved from literature (Kretschmann et al. 1999, Faust 1990, Simpson et al. 1998).

Overall, all clones have acceptable values for twist, while none of the clones comply with the demands concerning crook. The limitations for bow are only met by 'Ghoy' and 'Gaver'. Karki (2002) reported much higher values of bow (3.5-5.0) and twist (1.5-2.5) for European aspen wood. Slight adaptations of the drying process (top loading) could reduce bow and crook significantly. This opens the potential of producing structural graded timber (as drying is concerned) for the investigated poplar clones. Caution is needed for the clones not yet reaching final moisture content.

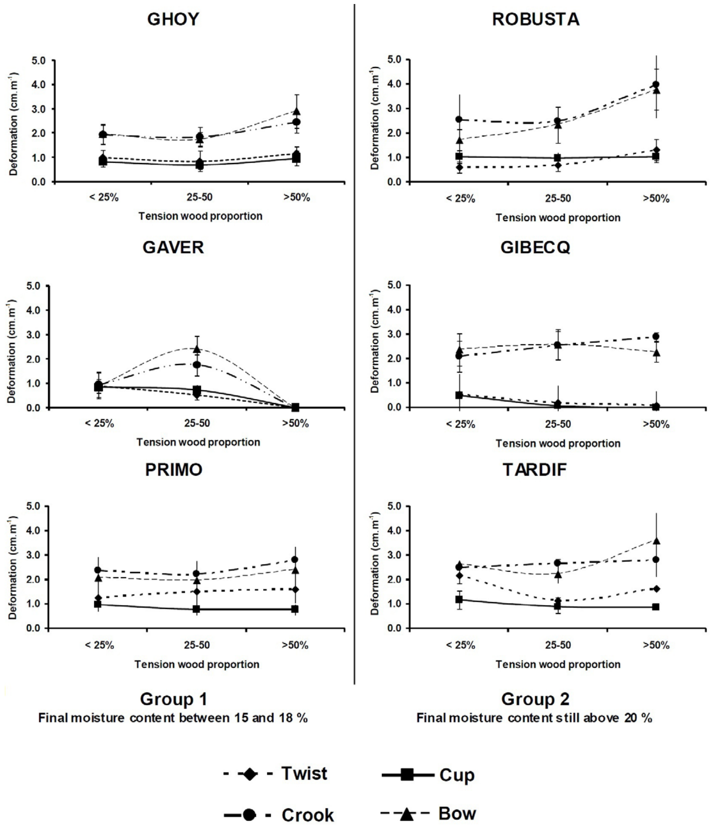

Fig. 3: Relation between the tension wood proportions (Surface based estimate) for the individual battens and the corresponding deformation parameters (bow, crook, cup and twist) for the two groups of selected clones.

Tension wood influence on deformation parameters

The formation of tension wood is induced by a gravitational stimulus. This was experimentally proven by Jourez et al. (2003) for *P. euramericana* cv 'Ghoy'. Badia et al. (2006) and Castera et al. (1994) reported different clonal patterns of tension wood distribution. For a more direct link between tension wood occurrence and deformation parameters an estimation was made of the tension wood occurrence for each beam. The wooliness of the surface was used as an indication and this surface measure was estimated in classes of 25 % on both faces of the beam. The highest value was retained in the evaluation. The relation between tension wood proportions (Surface based estimate) for the individual battens and the corresponding deformation parameters (bow, crook, cup and twist) for the selected clones are given in Fig. 3.

Tension wood shows higher longitudinal shrinkage values. If tension wood is clumped in occurrence this could lead to differential longitudinal shrinkage, increasing distortions as crook and bow. The latter is shown for all clones in Fig. 3. Cup and twist are not significantly influenced by tension wood occurrence.

CONCLUSIONS

To obtain satisfactory performance in the applications as light construction materials, poplar lumber needs to be dried. Due to the clonal character of populiculture, research is needed with regard to clonal differences in wood quality and the necessity to develop adapted drying schedules.

Using a traditional kiln-drying schedule at low temperature, the results presented in this study, show that not all clones reached satisfying final MC. In fact, several clones have final moisture levels still remaining above 20 %. This is a first indication that drying time and temperature need to be adapted for each clone or group of clones. This has a direct impact on the logistics of companies who would use such schedules for drying poplar lumber. It was shown that a homogenization period of two weeks under ambient outdoor conditions lowered the mean MC with approximately 2-3 %. The MC reduction is evenly distributed within the beams.

Apart from the natural variability in final MC induced by position in the tree, position in the kiln, knots, chemical composition… poplar has an additional MC variation induced by the formation of wet pockets.

As drying deformations are concerned, all poplar clones range acceptable values for twist, while none of the clones comply with the demands concerning crook. The limitations for bow are only met by 'Ghoy' and 'Gaver'. Slight adaptations of the drying process (top loading) could reduce bow and crook significantly. Cup and twist are not significantly influenced by tension wood occurrence.

This opens the potential of producing structural graded timber (as drying is concerned) for the investigated poplar clones. Pre-sorting lumber could furthermore offer a solution towards more uniform end MC distributions.

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