CHARACTERIZING CHANGBAI LARCH THROUGH VENEERING. PART 2: EFFECT OF DIAMETER AT BREAST HEIGHT AND RADIAL GROWTH

Suyong Huang,[a] Brad Jianhe Wang,[b] Jianxiong Lu,[a,]* Yuancai Lei,[c] Chunping Dai,[b] and Xiaomei Sun [d]

This is the second part of a large research initiative aimed at characterizing Changbai larch (*Larix olgensis* Henry) for veneer and high-valued product potential. The objective of this work was to investigate the effect of the tree growth characteristics, particularly diameter at breast height (DBH) and radial growth from pith (or peeler core) to bark on clear wood and veneer properties. A population of 36 trees was chosen and classified into three DBH classes, namely 20, 25, and 30 cm, and crosscut into six segments each along the vertical stem. With the entire veneer ribbon peeled from the pith to bark for each segment, the effect of sapwood and heartwood on wood properties was revealed. The tree DBH and height were moderately and positively correlated. The tree DBH significantly affected properties of both clear wood and veneer in a similar pattern. For the larch veneer population, veneer mean ultrasonic propagation time (UPT) and density decreased but veneer mean dynamic modulus of elasticity (MOE) increased from the heartwood to sapwood or from the pith to bark. Among the three DBH classes, the 25 cm DBH yielded the highest mean veneer density and MOE, followed by the 20 cm DBH and 30 cm DBH. This was found to be caused by the radial evolution of veneer properties from the pith to bark in combination with the variation of veneer yield and stem position.

Keywords: Changbai larch; DBH; Tree height; Growth characteristics; Heartwood; Sapwood; Property; Clear wood; Veneer

*Contact information: a: State Key Laboratory of Tree Genetics and Breeding, Research Institute of Wood Industry of Chinese Academy of Forestry, Beijing, 100091 P. R. China; b: FPInnovations - Wood Products, 2665 East Mall, Vancouver, B.C. V6T 1W5, Canada; c: Research Institute of Forest Resource Information Techniques, CAF, Beijing, 100091 P. R. China; d: Research Institute of Forestry, CAF, Beijing, 100091 P. R. China; * Corresponding author: jianxiong@caf.ac.cn*

INTRODUCTION

It is well known that living trees grow simultaneously in both horizontal and vertical directions. The former is generally evaluated by diameter at breast height (DBH) whereas the latter is assessed by tree height. Specifically, the tree has to increase its DBH continuously to resist harsh environments such as strong winds, snow storms, *etc.* In general, the DBH has a good or moderately good correlation with branch diameter, tree taper, tree height, and crown size (or width) (Huang *et al*. 2012).

From a perspective of industrial use for commodity products, a faster growth rate generally means a higher recovery and yield. Over the past decades, the main focus of silvicultural management worldwide has been placed on tree growth rate and timber yield, with particular interest placed on the tree DBH, tree height, and volume recovery. Such practices of stand management, including thinning, pruning, and fertilizing are found to increase the tree growth rate. Additionally, genetic variations, climate, and site conditions also influence the tree growth rate (Mahmood *et al*. 2003; Nishizono *et al*. 2008; Crookston *et al*. 2010).

Ishiguri *et al.* (2011a) examined the tree growth of Sri Lanka pigeonpea (*Pericopsis mooniana*) using a stress wave method. The trees were classified into three categories based on tree DBH and height: fast, moderately fast, and slow. But no meaningful correlation was found between the tree growth rate and stress wave velocity. Similar results were obtained for Sumatran pine (*Pinus merkusii*) in this regard. For this species, the wood density and compression strength of slow-growing trees were significantly lower than those of fast-growing and moderately fast-growing trees (Ishiguri *et al.* 2011b).

Key wood properties including modulus of elasticity (MOE) and modulus of rupture (MOR) are greatly affected by wood density (Burdon *et al.* 2001). From both theoretical and practical standpoints, the microfibril angle (MFA) at the S2 layer has been widely identified as a critical factor affecting those properties (Cave and Walker 1994; Cown *et al.* 1999; Raymond 2002; Deresse *et al.* 2003). Booker and Sell (1998) found that for clear wood of radiata pine (*Pinus radiata* D.), a high correlation exists among the density, MOE, and MFA. From the perspective of cell wall micro-structure, the MFA is the only significant factor. Nakada *et al.* (2003) demonstrated that breeding and cloning seedlings with a smaller MFA can result in higher stiffness timber. To date, a number of studies have been conducted on the relationship between the MFA and tree growth rate. For example, Apiolaza *et al.* (2005) found that the DBH has a significant but negative correlation with the MFA. On the contrary, Baltunis *et al.* (2007) found no significant correlation between the growth rate and wood density, MFA, and MOE.

To date, tremendous work has been done regarding the effect of the tree growth rate on wood structure and physical and mechanical properties for various species targeted for solid wood and pulping. Nevertheless, the results have been inconsistent. A negative correlation was found by Koubaa *et al.* (1998) between the wood fiber length and growth rate; but little effect of the growth rate on the fiber length was found by others (Bendtsen and Senft 1986; DeBell *et al.* 1998). Secondly, the correlation between the wood properties and tree DBH was found to be negative from some investigations (Beaudoin *et al.* 1992; Kumar *et al.* 2008; Tong *et al.* 2009), but to be insignificant based on other studies (DeBell *et al.* 2002; Zhang *et al.* 2003; Fujimoto *et al.* 2006). It is therefore evident that the wood density alone cannot provide sufficient information for resource characterization to define attributes of end products (Knudson *et al.* 2006). Not only could those discrepancies result from the variation of species, site and growth conditions, and ages of selected stands, but also from the variation of research methods involved. The majority of the research done on the growth rate was only DBH-related (Fujimoto *et al*. 2006; Tong *et al.* 2009). The evolution of wood properties in the radial direction has seldom been examined.

For some species in the radial direction, heartwood and sapwood can be easily identified. To date, most studies related to the heartwood and sapwood have been focused on variation of their ratio (Gominho *et al.* 2001; Pinto *et al.* 2004; Miranda *et al.* 2009), their chemical composition, particularly extractive content (Bertaud and Holmbom 2004; Morais and Pereira 2011), and moisture content (Lee *et al.* 2004). Those differences between the heartwood and sapwood were found to influence wood drying schedules (Pang 2000; Carlsson and Tinnsten 2002) and quality of pulping and paper (Adamapoulos *et al.* 2005; Lourenço *et al.* 2008). Generally, the heartwood contains more extractives but less cellulose and holocellulose than the sapwood (Bertaud and Holmbom 2004). However, in practice, very little is known about the property difference of wood products made from the heartwood and sapwood, because they are often not differentiated in the production. Only through veneering, the difference in properties of wood products made from the sapwood and heartwood can be better revealed (Wang and Dai 2012).

At the front of veneer-based products such as laminated veneer lumber (LVL) and plywood, it seemed that only the properties of white spruce (*Picea glauca*) veneer and LVL have been studied from logs sampled from different stands (Knudson *et al.* 2006). Indeed, little research has been done on the performance of veneer-based products made from logs with various growth rates, particularly DBH.

As one of the most important commercial plantation species in the northern part of China, Changbai larch (*Larix olgensis* Henry) has been widely used for the manufacture of solid wood, as well as for pulping and paper. However, systematic research on resource characterization and utilization of this larch has been lacking. To maximize its value return, a national research program was recently initiated to characterize this resource through veneering with regard to stand density, growth rate, and stem position, in order to determine its suitability for plywood and LVL. The goal of work described in Part 1 of this series (Huang *et al.* 2012) was to examine the effect of stand density on properties of larch clear wood and veneer. The key objective of Part 2 (the present article) was to determine how the properties of clear wood and veneer of this larch are affected by the growth rate, particularly DBH, and heartwood and sapwood in the radial direction. The same sample sizes of larch trees from Part 1 of the study were used with three DBH classes: small (20 cm), medium (25 cm), and large (30 cm). Veneer was used as the target product, and its properties were compared to those of clear wood from the same trees in terms of density and MOE. Veneer population was from all 36 trees, which were crosscut into six segments each along the vertical stem (tree height). Further work pertaining to the effect of stem position on larch clear wood and veneer properties will be discussed in a subsequent paper (Part 3).

MATERIALS AND METHODS

Larch Tree Samples and DBH Classification

As described in Part 1 (Huang *et al*. 2012), 36 sample trees of Changbai larch were felled from four typical stands in Jiamusi, Heilongjiang province, China. Each tree was measured for DBH, tree height, branch height, crown width, tree taper, and mean diameter of the 5 biggest branches. There were three DBH classes for this larch: small (20 cm), medium (25 cm), and large (30 cm). Each DBH class contained 12 trees. This larch has a distinct boundary of the heartwood and sapwood.

Table 1 shows the distribution of the tree DBH and height for those 36 trees felled and sampled. The actual diameter and height of each tree were measured to yield a mean value and standard deviation.

Table 1. Distribution of Sample Trees by DBH Class

DBH Class (cm)	Actual Diameter (cm)	Range (cm)	Actual Height (m)	Range (m)	Number of Trees
30	30.6 (1.8)	28.4-34. 0	23.2 (0.9)	21.9-24.7	12
25	24.6 (1.7)	23.2-26.5	21.8 (1.2)	19.8-23.5	12
20	19.8 (1.2)	17.8-21.3	20.7 (0.8)	18.8-21.9	12
Total					36
Note: Data in brackets refer to standard deviation					

The correlation between the larch tree DBH and height for those 36 trees was positive and moderately good, with an R^2 of 0.61 (Huang *et al*. 2012). This indicates that trees with larger DBH were generally taller. In both the radial and height directions, the larch tree is likely growing at a concerted rate.

Larch Clear Wood and Veneer Properties

As described in Part 1 (Huang *et al*. 2012), each stem of 36 trees was systematically bucked into 6 segments from the butt to top (crown) to indicate its stem position. The first segment (1300 mm from the butt) was right at breast height for basic density measurement and veneer processing. Each of the other 5 consecutive segments (2500 mm long) was crosscut into 5 sections (A to E). Each section D (bolt D) from the segments 2 to 6 was used to test clear wood properties such as density, bending MOE, bending MOR, and compression MOR, whereas each section E (bolt E) from the segments 1 to 6 was used to peel veneers with a target thickness of 2.6 mm. Veneer ribbon from each peel was clipped into a sheet of 600 mm in width and then dried and nondestructively tested for veneer density, ultrasonic propagation time (UPT), and dynamic MOE. A total of 216 ribbons were generated. The entire ribbon length of each peel was calculated by adding the actual width of each sheet in a sequence from the pith (or peeler core) to bark. Based on the measurement of mean heartwood radius from each disk (section B), the length of the partial veneer ribbon from the heartwood can be estimated for each peel with the following equation,

$$L_{\text{heartwood}} = \pi\,(R^2_{\text{heartwood}} - r^2)\,/\,t \qquad (1)$$

where $R_{\text{heartwood}}$ is the mean radius of the heartwood, r is the core drop size (or peeler core radius), and t is the veneer thickness. The peeler core radius was about 38 mm. By knowing the accumulated length of the heartwood veneer, each ribbon was first subdivided into heartwood and sapwood groups. Then each veneer sheet was assigned to one of the two groups.

The properties of larch clear wood and veneer population were analyzed in relation to the tree DBH first and subsequently from the pith (or peeler core) to bark in the radial direction. In addition, the larch veneer properties were further categorized in terms of two large classes of stem positions: lower and upper. The class 1 (lower) included stem positions from 1 to 3, whereas the class 2 (upper) contained stem positions from 4 to 6. Veneer sheets were tallied for each bolt to help analyze the final results.

RESULTS AND DISCUSSION

Effect of Tree DBH on Larch Clear Wood Properties

Properties of larch clear wood in relation to tree DBH

Table 2 summarizes the properties of larch clear wood in relation to the tree DBH. Based on the mean value, 25 cm DBH yielded the highest wood properties. Except for the bending MOE, 20 cm DBH resulted in the lowest wood properties, including density, bending MOR, and compression MOR. Those results did not exactly follow what has been published (Beaudoin *et al.* 1992; DeBell *et al.* 2002; Zhang *et al.* 2003). For example, a negative correlation was found by Beaudoin *et al.* (1992) between the wood density and tree DBH; however, the results from DeBell *et al.* (2002) and Zhang *et al.* (2003) did not show a significant correlation between these two variables. Note that due to the difference in the tree DBH, for the same number of trees, 30 cm DBH generated about 20% and 35% more samples than 25 cm DBH and 20 cm DBH, respectively. Note also that the number of samples was different from one bolt to another along the stem. Based on the number of samples tallied, the mean number of clear wood samples per bolt was 4, 3, and 2.6 for density tests, 5.9, 4.6, and 3.5 for bending tests, and 7.7, 5.6, and 4.2 for compression MOR tests with regard to 30 cm, 25 cm, and 20 cm DBH classes.

Table 2. The Properties of Larch Clear Wood with regard to the Tree DBH

DBH Class (cm)	Bolt Tally	Density (g/cm^3)			Bending					Compression MOR (MPa)		
					Count	MOE(GPa)		MOR (MPa)				
		Count *	Mean	Std. Dev.		Mean	Std. Dev.	Mean	Std. Dev.	Count	Mean	Std. Dev.
30	60	245	0.584	0.08	352	15.2	3.4	107.8	26.6	461	57.3	10.7
25	60	182	0.587	0.08	275	16.4	3.5	116.3	24.7	335	58.2	11.1
20	60	154	0.557	0.08	210	15.4	3.6	106.0	24.6	250	54.0	11.3

*Specimen number. Bending MOE and MOR used the same specimen.

Figure 1 depicts the cumulative distribution function (CDF) of key larch clear wood properties including density, bending MOE, and MOR, as well as compression MOR, with regard to the DBH. For each DBH class, there was a big variation for each of the properties.

As far as wood density is concerned, the t-tests demonstrated that no significant difference exists between the 25 cm and 30 cm DBH classes, but their mean value is about 4.9% higher than the 20 cm DBH class ($p<0.05$). As far as the bending MOE and MOR are concerned, the 25 cm DBH class yielded the highest values, whereas the 20 cm and 30 cm DBH classes did not show a significant difference ($p>0.05$). The mean MOE and MOR values of the 25 cm DBH were about 6.8% and 8.8% greater than those of the

20 cm or 30 cm DBH, respectively. As for the compression MOR, the 20 cm DBH yielded the lowest values, whereas the 25 cm and 30 cm DBH classes did not show a significant difference ($p>0.05$). On average, the compression MOR of the 20 cm DBH was about 6.4% lower than that of the 25 cm DBH or 30 cm DBH.

Although there existed no significant difference in clear wood density and compression MOR between the 25 cm DBH and 30 cm DBH, the former had significantly higher bending MOE and MOR than the latter ($p<0.05$). Overall, by comparison, the 25 cm DBH yielded the highest wood properties. The reason was unclear based on the clear wood tests alone.

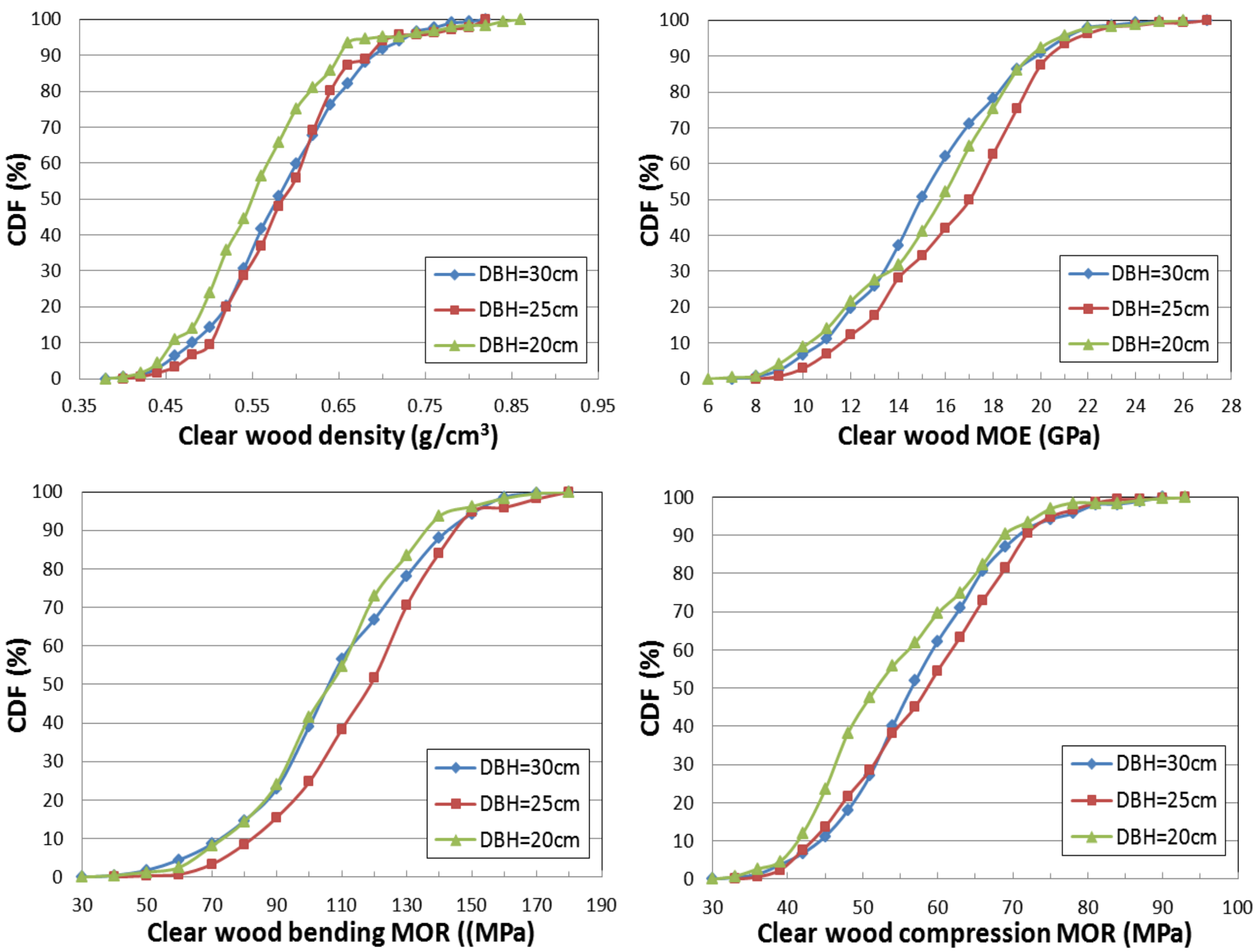

Fig. 1. CDF of clear wood properties compared by DBH

Properties of larch veneer in relation to tree DBH

Table 3 summarizes the properties of larch veneer in terms of the tree DBH classes. Veneer properties mainly include density, UPT, and dynamic MOE. Note that with the same number of trees per DBH class, the number of veneer sheets was dramatically different from the 30 cm DBH to 20 cm DBH, indicating a drastic impact of the DBH on veneer yield. By comparison, the 30 cm DBH would result in about 68.2% and 165.3% higher yield than the 25 cm DBH and 20 cm DBH, respectively.

Table 3. The Properties of Larch Veneer with regard to the Tree DBH

DBH Class (cm)	Bolt Tally	Sheet Tally	Density (g/cm^3)		UPT (µs)		MOE (GPa)	
			Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
30	72	1162	0.529	0.06	206.6	16.8	12.4	1.8
25	72	691	0.547	0.06	199.0	14.1	13.4	1.5
20	72	438	0.530	0.06	199.2	12.7	13.1	1.6

It is generally believed that larger DBH means faster growth and therefore lower wood density and MOE (Molteberg and Hib. 2006). However, based on the mean value (Table 3), the 25 cm DBH yielded the highest veneer density and dynamic MOE, followed by the 20 cm DBH and 30 cm DBH. This was consistent with observations from the clear wood tests. Nevertheless, the trend observed for the 25 cm DBH and 20 cm DBH was not in agreement with some earlier findings (Fujimoto *et al*. 2006; Kumar *et al.* 2008; Tong *et al.* 2009). For instance, no significant correlation was found for hybrid larch between the wood physical and mechanical properties and DBH (Fujimoto *et al.* 2006). But these wood properties were found to be inversely proportional to the DBH for radiata pine and black spruce (*Picea marina* (Mill.) B.S.P.) (Kumar *et al.* 2008; Tong *et al.* 2009).

Similarly, Fig. 2 shows CDF of larch veneer properties including UPT, density, and dynamic MOE, with regard to the DBH. For each DBH class, there was a big variation for each veneer property. As far as the veneer UPT is concerned, no significant difference was found between the 20 cm DBH class and 25 cm DBH class, but they were about 3.8% shorter than the 30 cm DBH class ($p<0.05$). As far as the veneer density is concerned, the t-tests demonstrated that no significant difference existed between the 20 cm class and 30 cm DBH class, but their mean value was about 2.9% lower than the 25 cm DBH class ($p<0.05$). With the combined effect of the veneer UPT and density, a significant difference was found in veneer MOE between any two of the DBH classes ($p<0.05$). The 25 cm DBH yielded the highest veneer MOE, followed by the 20 cm DBH and 30 cm DBH. Again, this trend was consistent with that obtained from the clear wood test, but was somewhat contrary to what was anticipated. By comparison, the 25 cm DBH was about 2.3% and 8.1% higher in veneer MOE than the 20 cm DBH and 30 cm DBH, respectively. It is generally believed that for most species the wood MOE will decrease with increasing DBH (Fujimoto *et al.* 2006; Tong *et al.* 2009). The reason why this discrepancy appeared is unknown by simply comparing veneer properties in relation to the tree DBH. Thus, an in-depth analysis of how veneer properties change from the pith (or peeler core) to bark in the radial direction seems necessary.

Effect of Tree Radial Growth

Property distribution of veneer population with regard to heartwood and sapwood

Figure 3 shows CDF of the properties of larch veneer population including UPT, density, and dynamic MOE, with regard to the heartwood and sapwood categories. For each category, there was a significant variation for each of the three veneer properties.

As far as the veneer UPT is concerned, a significant difference was found between the heartwood and sapwood, with the sapwood being substantially shorter ($p<0.05$). This is expected since the heartwood contains more juvenile wood with a larger MFA in S2 layer.

As far as the veneer density is concerned, a significant difference was also found between the heartwood and sapwood, with the heartwood being denser ($p<0.05$). This could be a unique characteristic for this larch, since the sapwood is generally denser than the heartwood for most softwood species (Bao and Jiang 1998). However, as expected, with the combined effect of the veneer UPT and density, a significant difference was found in the veneer MOE between the sapwood and heartwood with the former being greater ($p<0.05$).

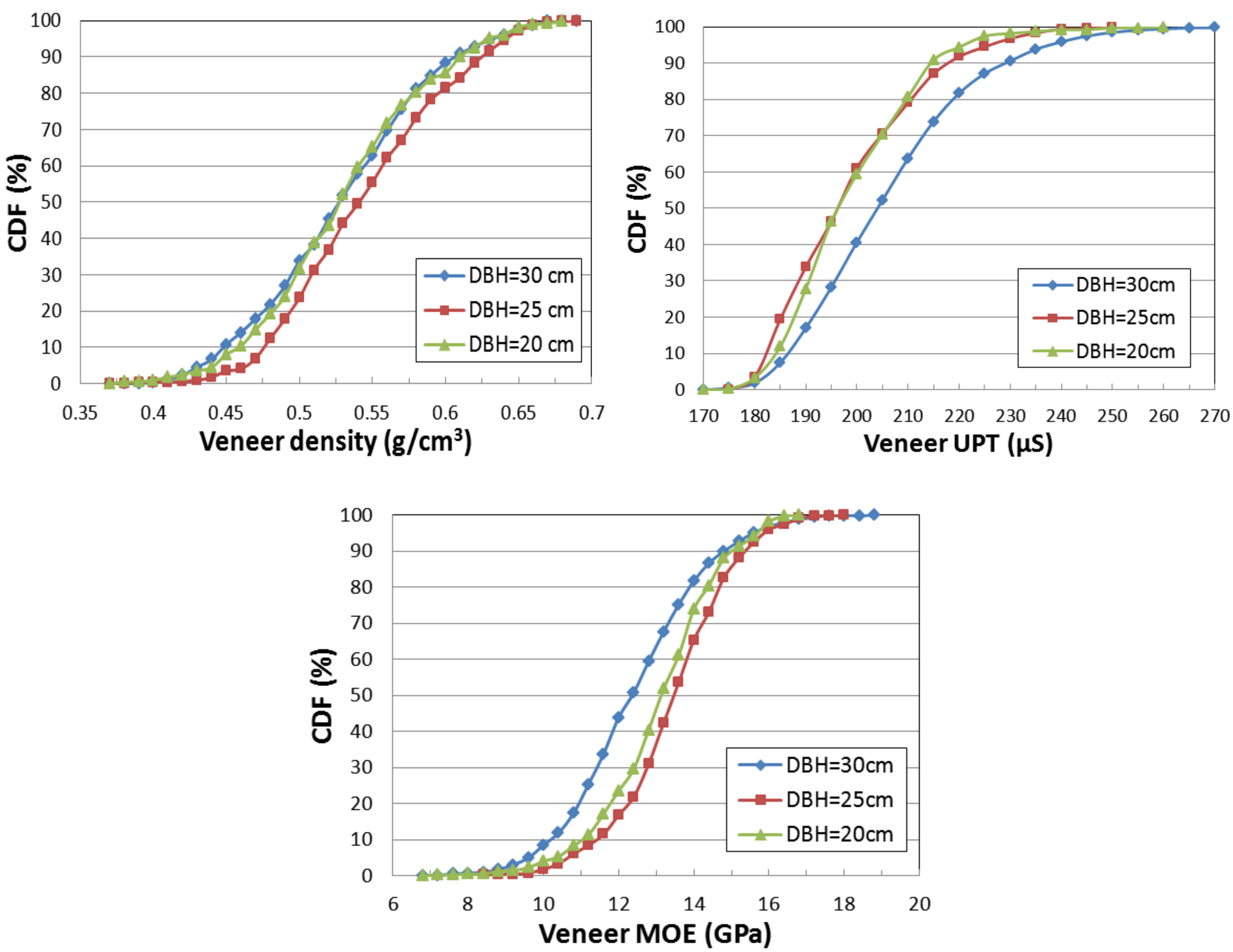

Fig. 2. CDF of Veneer Properties Compared by DBH

As indicated by the veneer UPT, the larch heartwood contained more juvenile wood than its sapwood counterpart. Note that juvenile wood has a larger MFA than mature wood. Based on the previous research, juvenile wood in Changbai larch is generally formed in the first 15 years of tree growth (Bao and Jiang 1998). But its proportion may change with growth rate for the same age of trees.

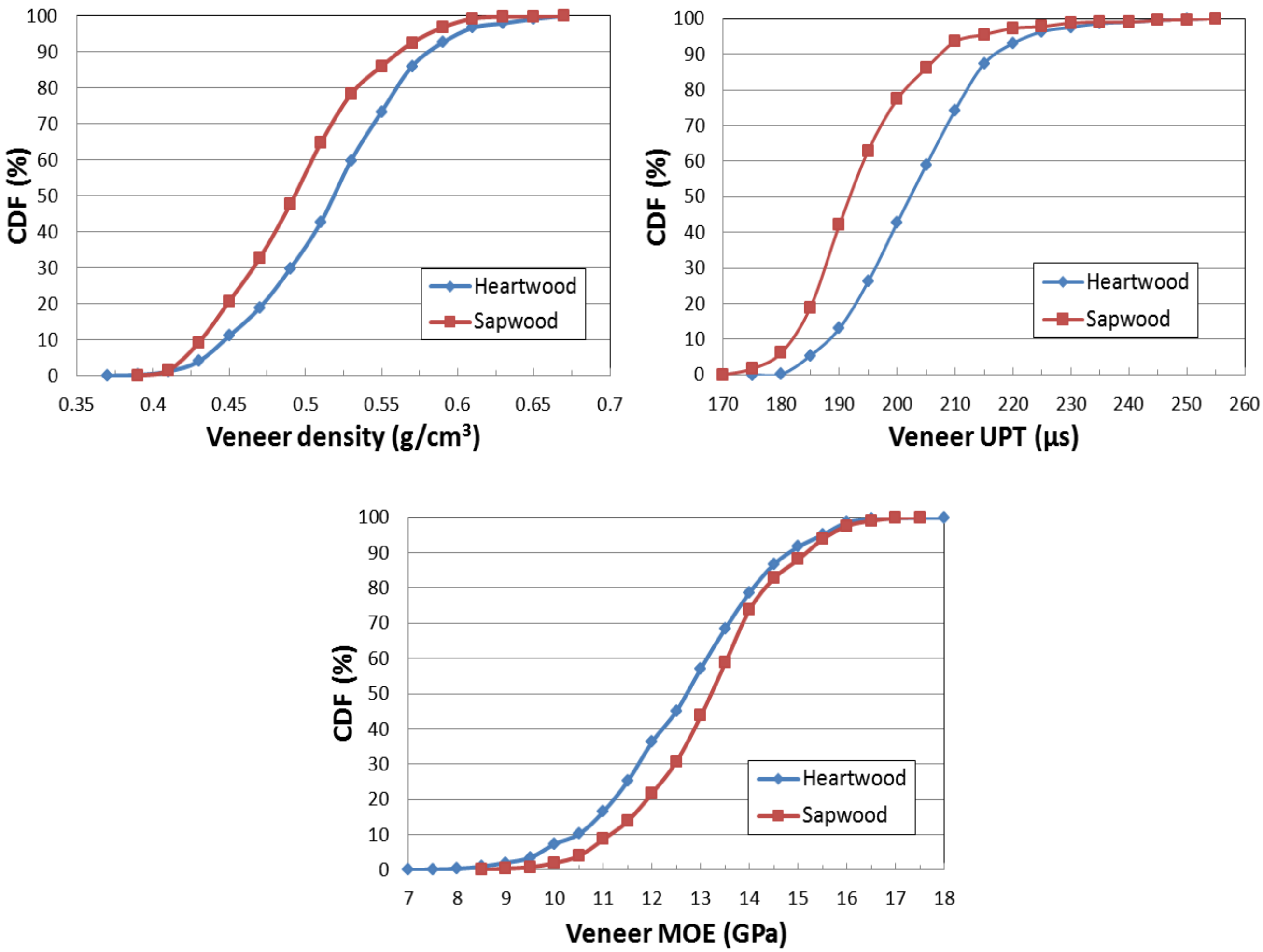

Fig. 3. CDF of veneer properties compared by sapwood and heartwood

Variation of mean properties of veneer population from pith to bark

With the entire veneer ribbon peeled from each bolt, changes of the mean veneer properties in the radial direction from the pith to bark can be characterized. Each DBH class involved 12 trees with six bolts, each numbering from 1 (butt) to 6 (top). Based on the number of sheets tallied (Table 3), it was determined that the average number of sheets per bolt is 16, 10, and 6 for the 30 cm DBH, 25 cm DBH, and 20 cm DBH, respectively. In general, the ratio of the heartwood veneer increases with increasing DBH. For this larch, the heartwood veneer ratio was about 40 to 45%, 50 to 55%, and 60 to 65% for the 20 cm, 25 cm, and 30 cm DBH classes, respectively.

Figure 4 shows the changes of the veneer mean UPT from the pith to bark with regard to the three DBH classes. Each data point represented a weighted average of the 72 measurements at the same ribbon position sequentially from the peeler core to bark. Due to the variation of the bolt diameter along the stem, the mean UPT value from the pith to bark reflects the combined effect of the heartwood and sapwood. Based on Fig. 4, for the veneer population, veneer mean UPT generally decreased from the pith to bark, or from the juvenile wood to mature wood. As the UPT was largely affected by the wood grain angle or MFA in the S2 layer, it was speculated that for this larch, the juvenile wood (or heartwood) has a larger MFA than the mature wood (or sapwood). As indicated by the UPT trend line, the 30 cm DBH had the longest UPT, followed by the 25 cm DBH and 20 cm DBH. However, as the mean value indicated (Table 3), the 25 cm DBH yielded a slightly shorter UPT than the 20 cm DBH. This result was unexpected and found to be caused by the difference in number of veneer sheets between the two DBH classes and its evolution pattern in the radial direction. As shown in Fig. 4, on average, the 25 DBH class generated four more sheets with relatively shorter UPT value than the 20 cm DBH class. When averaging out, the 25 DBH class resulted in an even slightly shorter UPT than the 20 cm DBH class.

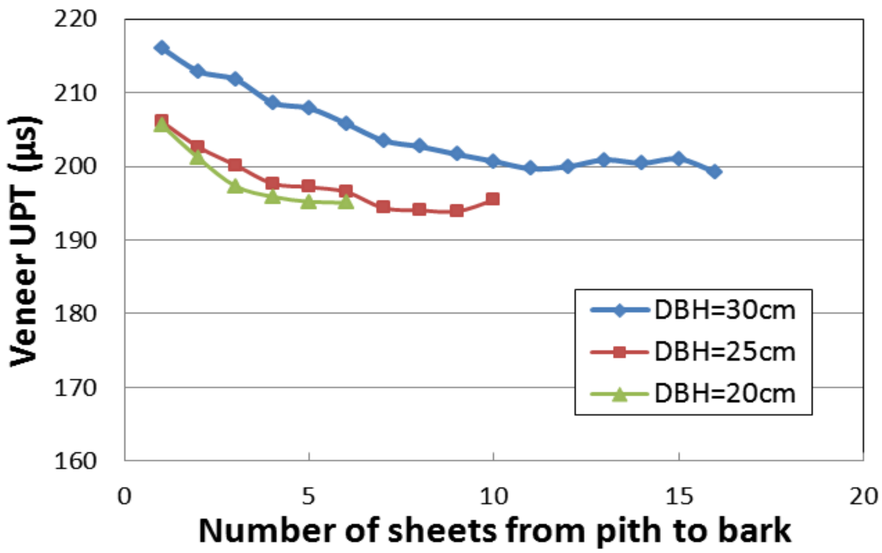

Fig. 4. Change of veneer mean UPT in relation to the DBH and sheet sequential number

Similarly for the veneer mean density (Fig. 5), due to the variation in the bolt diameter along the vertical stem, its value from the pith to bark generally reflects the combined effect of the sapwood and heartwood. As indicated by the trend line, the 30 cm DBH had the lowest density. But the trend lines of the 25 cm DBH and 20 cm DBH were overlapping starting from the peeler core. Due to its larger diameter, on average, the 25 cm DBH class generated four higher density sheets than the 20 cm DBH class. Thus, statistically, the 25 cm DBH class yielded a higher density than the 20 cm DBH class ($p<0.05$), which agrees with the result summarized in Table 3.

Veneer dynamic MOE is affected by both veneer UPT and density. The value of veneer mean MOE (Fig. 6) clearly increased from the pith to bark, or from the juvenile wood to mature wood. As indicated by the MOE trend line, the 30 cm DBH class had the lowest MOE. But the two trend lines for the 25 cm DBH and 20 cm DBH classes were somewhat overlapping, starting from the peeler core. On average, for the first six sheets starting from the peeler core, the 20 cm DBH class seemed to yield a slightly higher veneer MOE than the 25 cm DBH class. Nevertheless, the 25 cm DBH class yielded four more high-MOE sheets than the 20 cm DBH class. Thus, the former had a significantly higher MOE than the latter ($p<0.05$). Basically, this explains and confirms the MOE results summarized in Table 3.

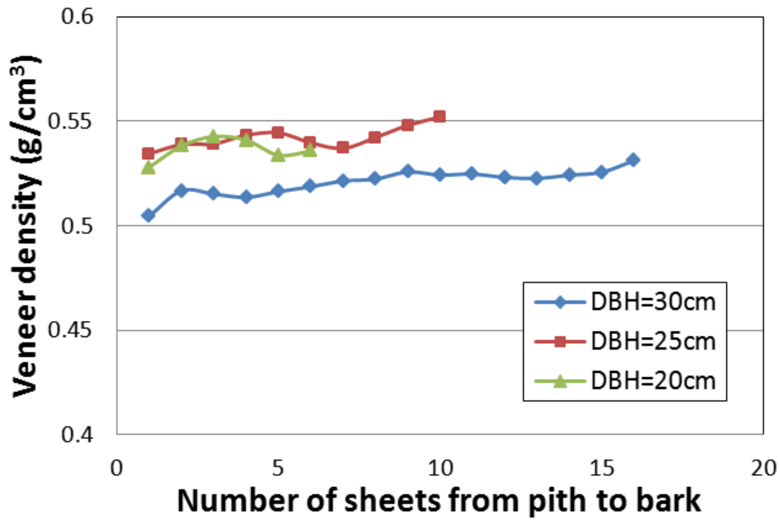

Fig. 5. Change of veneer mean density in relation to the DBH and sheet sequential number

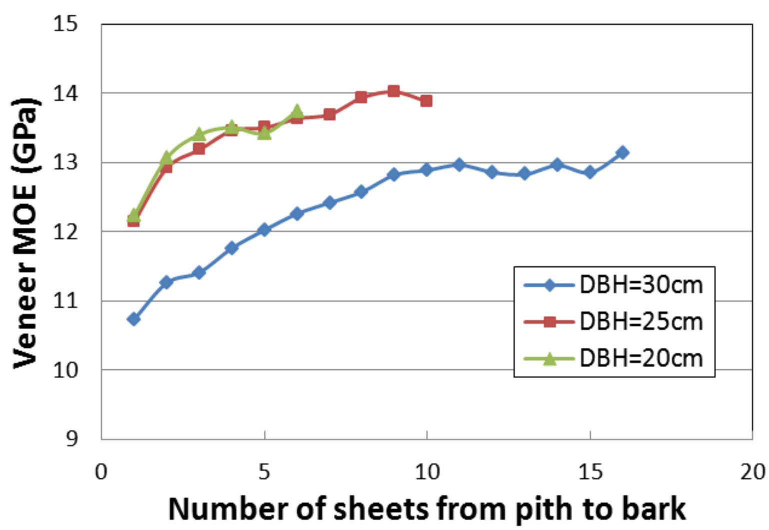

Fig. 6. Change of veneer mean MOE in relation to the DBH and sheet sequential number

In summary, the effect of the tree DBH on clear wood and veneer properties can be better characterized by analyzing their radial evolution from the pith to bark. The resulting number of veneer sheets or veneer yield plays an important role in comparing wood properties among the DBH classes. Compared with clear wood testing, veneering seems to be better suited for uncovering how wood properties are affected by the evolution of heartwood to sapwood in the radial direction for any given DBH class. A judgment on the effect of the tree DBH can only be made after examining the property evolution of an entire veneer ribbon from the pith to bark. Otherwise, the judgment could be biased, as some inconclusive studies have been reported regarding the effect of the DBH on wood properties (Kumar 2004; Fujimoto *et al.* 2006; Tong *et al.* 2009).

Variation of veneer properties from pith to bark in two stem positions

In general, the ratio of heartwood and sapwood not only changes with the tree DBH, but also changes with the stem position. For simplicity, the stem position can be classified into two categories: upper and lower. As described, the lower stem position incorporated the three bolts from the butt, namely, 1+2+3, whereas the upper stem position combined the remaining three bolts, namely, 4+5+6.

Figure 7 depicts the change of veneer mean UPT from the pith to bark with regard to the DBH, sheet sequential number, and stem position. In this case, each data point was derived by averaging out 36 measurements at the same ribbon position sequentially from the peeler core to bark. Based on Fig. 7, for both upper and lower stem positions, veneer UPT generally decreased from the pith to bark, or from the juvenile wood to mature wood. By comparison, the lower stem position yielded a longer UPT than the upper stem position. The veneer UPT is largely affected by the wood grain angle or MFA in the S2 layer, and it was evident that the lower stem has a larger MFA than the upper stem. As indicated by the UPT trend line, for the lower stem position, the 25 cm DBH yielded a slightly shorter mean UPT than the 20 cm DBH. This is mainly caused by their difference in the sheet tally. Compared with the 20 cm DBH, the 25 cm DBH generated more sheets from the ribbon with a shorter UPT. However, for the upper stem position, the 30 cm DBH had the longest UPT, followed by the 25 cm DBH and 20 cm DBH.

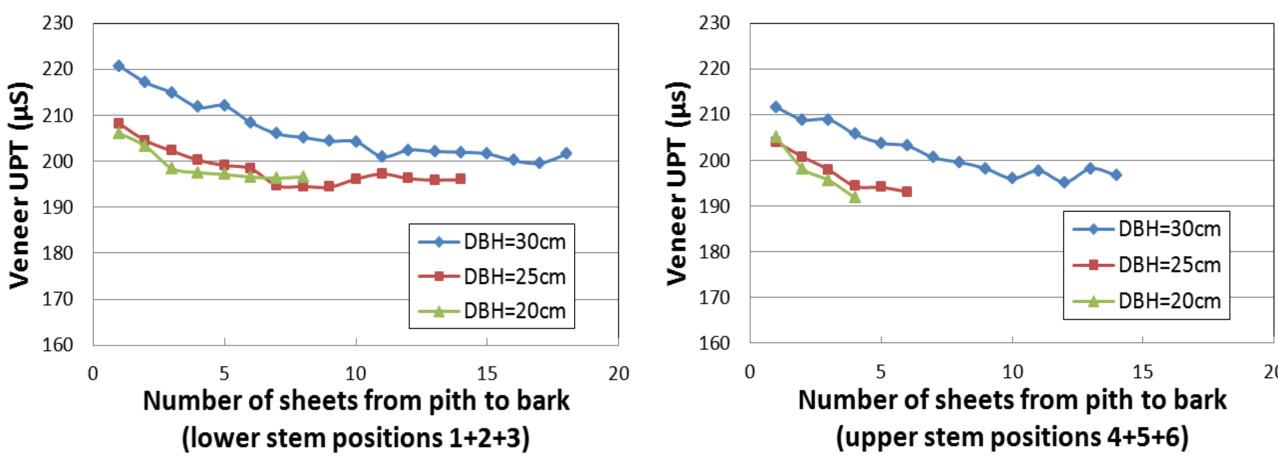

Fig. 7. Change of veneer UPT in relation to the DBH, sheet sequential number, and stem position

Similarly for the veneer density (Fig. 8), its evolution was rather complex with the two stem positions showing different patterns. For the upper stem position, the 30 cm DBH class had the lowest density, followed by the 25 cm DBH and 20 cm DBH classes. However, for the lower stem position, unexpectedly, the 25 cm DBH class had the highest density, followed by the 20 cm and 30 cm DBH classes. As far as the trend is concerned, veneer density from the pith to bark for the 30 cm DBH class exhibited an ascending trend for the lower stem position but a descending trend for the upper stem position. For the 25 cm DBH class, veneer density seemed to decrease from the pith to bark for the lower stem positions but uncertain for the upper stem position. For the 20 cm DBH class, the trend of veneer density was not clear for both stem positions. Those results demonstrate that the stem position has a significant effect on veneer density.

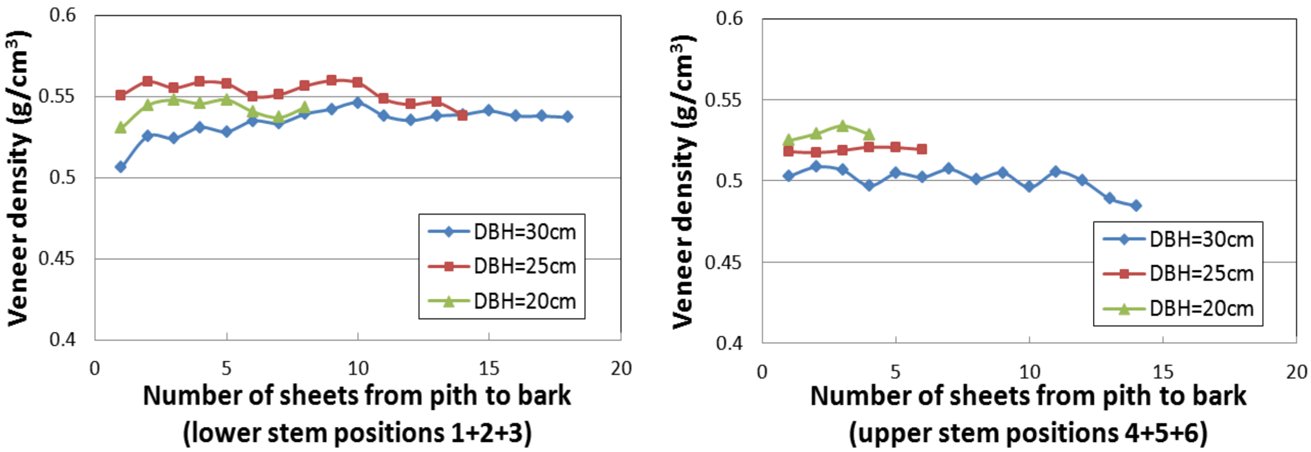

Fig. 8. Change of veneer density in relation to the DBH, sheet sequential number, and stem position

Unlike veneer density, veneer MOE (Fig. 9) generally increased from the pith to bark. However, the effect of the DBH on veneer MOE differed between the two stem positions. For the upper stem position, as expected from the effect of tree growth rate, veneer MOE increased from the 30 cm DBH to 25 cm DBH and to 20 cm DBH. However, for the lower stem position, veneer MOE between the 20 cm DBH and 25 cm DBH was rather close by comparing the same sheet sequential number from the peeler core. Since the 25 cm DBH class had more high-MOE sheets than the 20 cm DBH class, the former yielded significantly higher mean veneer MOE ($p<0.05$). Those results demonstrate that the stem position also has a significant effect on veneer MOE. Despite different patterns of veneer MOE with regard to the stem position, the lower stem position had a more significant effect in determining veneer properties due to its higher yield; therefore, for the veneer population, the 25 cm DBH class yielded a significant higher veneer MOE than the 20 cm DBH class.

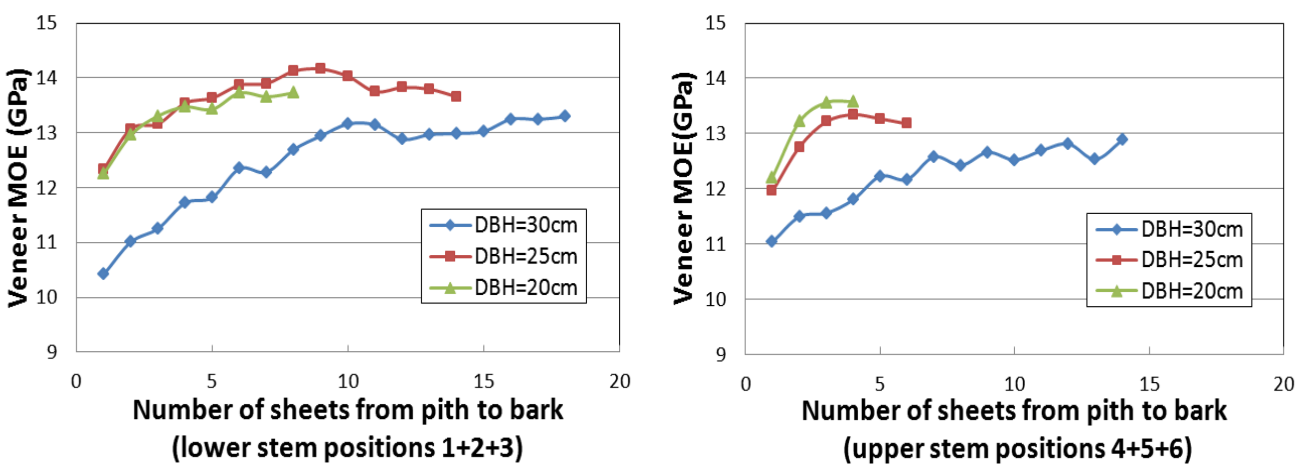

Fig. 9. Change of veneer MOE in relation to the DBH, sheet sequential number, and stem position

In summary, veneer properties not only change with the tree DBH, but also evolve from the pith to bark in the radial direction. As demonstrated, veneer properties are further affected by the stem position. For the same tree DBH, the stem position also significantly affects veneer yield. Further work is needed to characterize the effect of the stem position in the vertical direction for optimum product options.

CONCLUSIONS

For Changbai larch, growth rate is a key factor influencing the properties of clear wood and veneer. The tree DBH had a moderately good correlation with its height. The tree DBH significantly affected properties of both clear wood and veneer in a similar pattern. Among the three larch DBH classes, the 25 cm DBH yielded the highest clear wood density, bending MOE and MOR, and compression MOR. For mean veneer properties, the 25 cm DBH had the lowest veneer UPT but the highest veneer density and MOE, followed by the 20 cm DBH and 30 cm DBH. This was caused by the radial evolution of veneer properties from the pith (or peeler core) to bark, and the difference in veneer yield and stem position. This result reinforces the importance of a holistic resource characterization through veneering. By analyzing the entire veneer ribbon peeled from the pith to bark, the evolution of wood properties in the radial direction can be revealed; therefore, a conclusive decision regarding the effect of the tree DBH on wood properties can be made.

As far as the veneer yield is concerned, the 30 cm DBH class was 68.2% and 165.3% higher than the 25 cm DBH and 20 cm DBH classes, respectively. Thus, it is essential to consider both veneer yield and veneer properties for resource characterization and utilization.

For the larch veneer population, its heartwood yielded significantly higher UPT and density but substantially lower MOE than its sapwood counterpart. In the radial direction, the veneer mean UPT decreased but the mean MOE increased from the pith to bark.

A further study is deemed necessary to characterize the effect of the stem position on larch wood and veneer properties and find the optimum product potentials along the vertical stem.

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