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SPIRAL GRAIN IN EUROPEAN ASPEN (*POPULUS TREMULA L.*): VARIATIONS WITHIN AND BETWEEN THE TREES

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Abstract:

The consequences of spiral grain are encountered in the form of twist in dry timber, distortion in veneer and plywood sheets, short-grained failure of timber under stress, and surfacing problems during machining. In this study grain angle measurements were made on wood disc samples from six 50 – 70 year old trees of European aspen (Populus tremula L.) from two different sites in southern Sweden. The grain angle was measured every 15mm pith to bark at three fixed heights using a disc "scribing method". The aim of the study was to examine variation in the spiral grain in vertical (bottom to top) and radial (pith to bark) direction within and between aspen trees.

The results proved that aspen tree belong to the group of "straight grained" trees. The highest values and deviations of grain angle were registered in the butt log and lowest in the middle. With regard to absolute values, the values of grain angle and deviations were highest in the top log and lowest in the middle.

Key words: *spiral grain; aspen; vertical and radial direction.*

INTRODUCTION

European aspen (*Populus tremula L.*), also called Native or Eurasian aspen belong to the group of hardwood. It is one of the most widely spread species in the world. Aspen is a fast-growing multi-purpose species. Its market include timber, veneer for matches, packaging material, and furniture, construction materials such as orientated strand board (OSB) and laminated veneer lumber (LVL), pulp and paper, biofuel. Aspen plays an important role in biodiversity. A very large number of organisms are dependent on aspen. In Sweden alone, there are 312 fungi, 15 bryophytes, around 350 beetles and 110 lichens, using aspen as their host. Fast growing broadleaves such aspen are considered to be economically viable plantations due to their high growth. New European approaches to silviculture call for maximum increase of biodiversity in forests through the creation of mixed forest stands.

Many technical problems arise when using roundwood, sawn timber, and veneers made from trees containing large spiral grain. Spiral grain is fundamentally simple concept in which wood grain, as for example can be seen on the outside the log, runs around spirally rather than parallel with the axis (Haris 1989). As grain angle (GA) increases, the strength and stiffness decreases (Kollmann and Côté 1968). Mechanical strength properties are affected negatively as the GA increases and deviate to a greater degree from the longitudinal direction of sawn timber (Kollmann & Côté 1968). Twist in sawn timber is a serious shape defect, which is dependent to the greatest degree on the moisture content of the wood, and on the spiral grain (Danborg 1994, Johansson *et al*. 1994). Twist can be explained to a great degree by the helical deviation of the grain angle in relation to the longitudinal direction of the log or the sawn board (Säll 2002). High deviation of grain angle can also have a serious effect on wood machining. In veneers, it contributes to splits or tears in the sheet. Twist in plywood usually arises due to differences in grain direction.

The technical disadvantages arising from spirally grained timber are certainly a major reason why so much interest has been expressed in the subject. Spiral grain is a very common defect, occurring both in softwood and hardwood. The grain angle, or inclinations of the fibre direction from the stem axis, vary from 0 degrees to approximately 30 degrees, but can reach 90 degrees in very rare cases.

There is great variation in the occurrence of grain pattern, both between and within trees species (Harris 1989). In some old trees, the cracks are visible under the bark. In softwood, the cracks lean mostly to the right which means that grain angle is right-handed. If the cracks lean in the opposite direction, then the grain angle is left handed. The left-handed angle is given a positive number and a right-handed angle is given a negative number. For most trees, the grain angle turns rom left-handed to right-handed in a linear fashion. A majority of coniferous trees seem to develop at first left-hand spirals, to change over to right hand after 10-30 years, maintaining right hand to the rest of their lifetime (Kubler 1991). Grain patterns in hardwoods are both less predictable and more complex than those in softwood. Based on summarized results (Ohkura 1958) for more than 140 species of hardwood leads to the pinion that the change in spiral grain direction is encountered less frequently in hardwoods than in softwoods. However, not all hardwood species have been studied equally. The formation of spiral grain is genetically controlled, but there are also environmental factors involved (Eklund and Säll 2000). All individual trees differ in appearance concerning spiral grain. Differences between species might be explained by the science of genetics, whilst differences between members of the same species can be explained by both inheritance and environment. Although aspen is considered fairly straight, trees in some stands can be very contorted (Perala and Carpenter 1985). An important observation (Skatter and Kucera 1998) is that spiral grain varies depending in degree from the pith to the bark. The authors of this paper are unaware of any research that has investigated variations of aspen spiral grain in the vertical and radial direction. Knowledge about characterization within and between tree variations in a spiral grain angle is urgently required for technological reasons. With regard to the influence of spiral grain on wood properties and thereby the quality of end products, detailed knowledge about variation of spiral grain enables removal of poor quality logs. Qualitative wood selection leads to a decrease in production costs and optimisation of raw materials.

OBJECTIVES

The objectives of the study are to (a) examine variation in spiral grain within and between aspen trees (b) draw conclusion and recommendations based on the results for wood processing industry, (c) give a brief overview of methods for spiral grain assessment from industry appliance perspective and recommendations for further research.

MATERIAL, METHOD, EQUIPMENT

Six aspen trees were cut from two different sites, Vimmerby and Askeramala (three trees from each sites) in southern Sweden. The stand age ranged between 50 and 70 years. Each tree is cross cut at 3m intervals and marked. Stem discs (10cm thick) were cut out from positions 1,2 and 3 (Fig. 1). In total 18 discs was marked and placed in plastic bags in a cold storage room, at a temperature of -15° C. The „scribing method" involved splitting of discs through the pith and measuring the deviation of the split surface every 15mm in radial direction (pith to bark). Many studies has been done using disc-scribing and splitting method (Cown et al. 1991, Danborg 1994, Sall 2000). This method have the advantage that the samples at equivalent positions on either side of the pith can be averaged to eliminate bias (hence giving ´absolute´ values referenced to the vertical axis of the stem) (Riddel et. al 2012). This process eliminates errors related to sample preparation, and leaning of the stem, and minimizes the effect of grain deviation around knots. Measurement started by marking up a line through the pith regardless of orientations. Care was taken to avoid knots and irregularities of the stem, which could affect the measurement.

Marks were made along the line at every 15mm from pith to bark. Diametrical strips, with a width of 4 cm to 5 cm and a thickness of 4 cm to 6 cm, were sawn from the stem discs in the direction of the line.

Measurement started at the outermost measurement point near the bark and proceeded towards pith. On the tangential surface, a sharp point was used to mark the direction of the grain.

The spiral grain angle was measured with a measurement frame (Fig. 2).

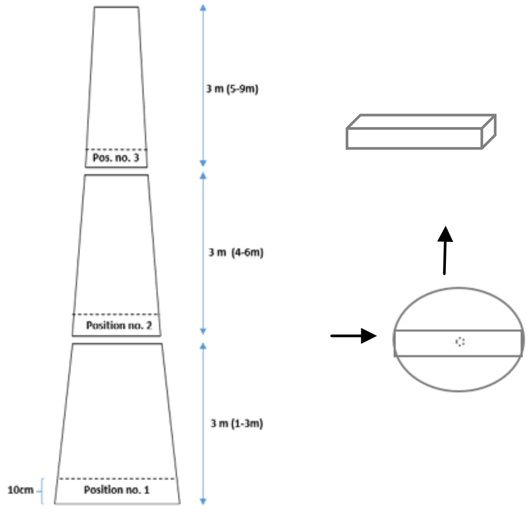

Fig. 1.
Extraction of wooden discs and strips.

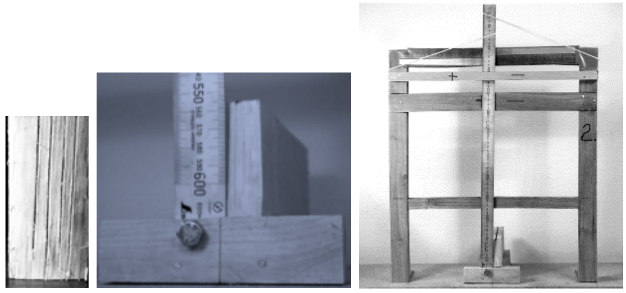

Fig. 2.
Marking and measurement with the tool.

The frame was made of a board, to which a flexible ruler was fixed with a screw. A millimetre-scale was fixed to the upper part of the frame, which was parallel to and at a distance of 500 mm from the board. Zero on the horizontal millimetre-scale corresponds to a vertical position for the ruler, and 0° spiral grain angle. The vertical line and the horizontal millimetre-scale form the smaller sides of a right-angled triangle. The smaller cathetus was read on the millimetre-scale and the longer cathetus was fixed at 500 mm. A positive value was assigned if the ruler leans to the left, and a negative value if the ruler leans to the right. Calculation of readings from millimetre-scale converted to degrees was made with the trigonometric function:

$$GA1 = \arctan(k1/500)$$

where: GA1 is the spiral grain angle;
k1 is the value read on the smaller cathetus.

RESULTS AND DISCUSSION

The results presented below are based on measurement of grain angle from 6 aspen trees and 18 wooden discs (six-disc samples from each of three positions). Data registration, generation of diagrams were made using Microsoft Excel software. Descriptive statistics are used to represent and describe results for variation of grain angle values.

Vertical (bottom to the top) variation of grain angle in aspen trees

The range of grain angle values recorded in position 1(here and after referred as the butt log) was between -4.7° to 2.5° with 50% of GA values between -1.7° and 0.4°. The mean value of aspen GA in the bottom log was -0.8° with 2° standard deviation.

The range of grain angle values recorded in position 2 (here and after referred as the middle log) was between -1.8° and 1.6° with 50% of values between -0.9° and 0.1°. The mean value was -0.4° and standard deviation of 1°.

The range of GA values recorded in position 3 (here and after referred as the top log) was between -2.7° and 1.7° with 50% of values between -0.9° and 0.4°. The mean value was -0.4° and standard deviation of 1.2°.

According to the results, there is no significant difference between the average values of the grain angle in a vertical direction. The differences between average GA in the butt, middle and top log appeared to be less than half of a degree. The results were as expected and in accordance with previous studies that concluded insignificant variation of GA in the vertical direction of most of the tree species.

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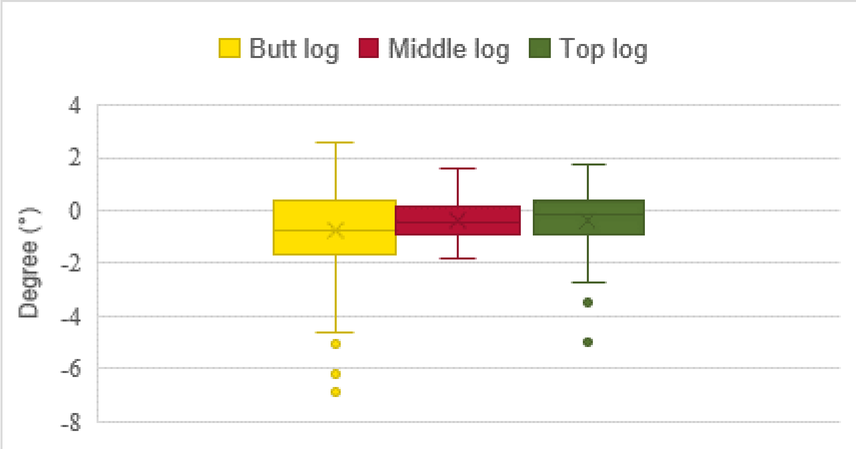
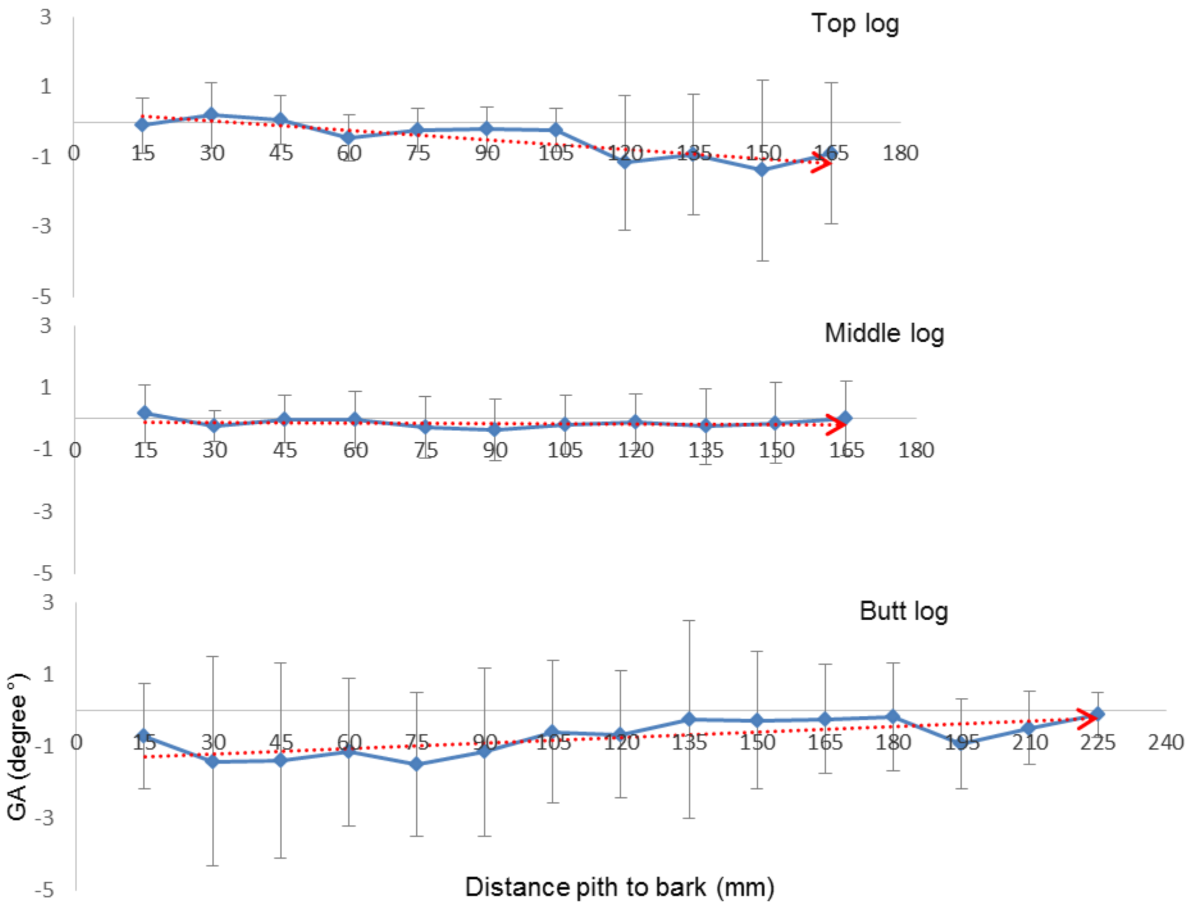


Fig. 3.
Vertical variation of GA.

Radial (pith to bark) variation of grain angle in aspen trees

The summarized values of grain angles in radial direction (pith to bark) from six aspen trees at three different positions are presented in Figure 4. The mean value of GA was not exceeding -2° at any of the measurement points (15mm intervals) regardless of the position in the tree. The values of GA registered in butt logs had a decreasing trend towards the bark. Opposite, the values of GA in top logs had an increasing trend towards the bark. The middle log had insignificant variation and deviation. An average values of all obtained measurements are presented with last graph in Figure 4, as typical pattern for aspen tree. The average values of GA at every measuring point (15mm distance) were less than -1° with almost constant trend line. This classifies aspen as "straight grained" tree.



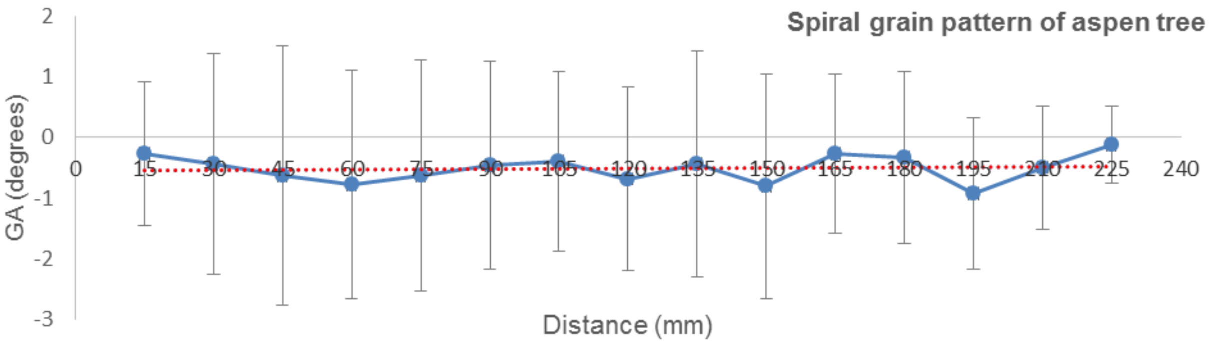


Fig. 4.
Radial variation of GA.

Radial variation of GA in absolute values

Due to the low thickness (usually less than 3mm), dispersion of grain angle from 0° regardless of positive or negative inclination is what influences the quality of veneer from a grain angle perspective. Therefore, for the purpose of GA variation from veneer perspective, the obtained results were converted in absolute values (Figure 5).

Thus, mean GA values recorded in the bottom logs were between 0.8° and 3.5° with 1.7° standard deviation. The top log had average values of GA between 1.5° and 4.1° with 1.9° standard deviation. The middle log had values between 1° and 2.3° with 0.9° standard deviation. According to these results, the highest values of mean GA and deviations appeared in top log. This might be explained with numbers of branches associated with this particular section in the tree.

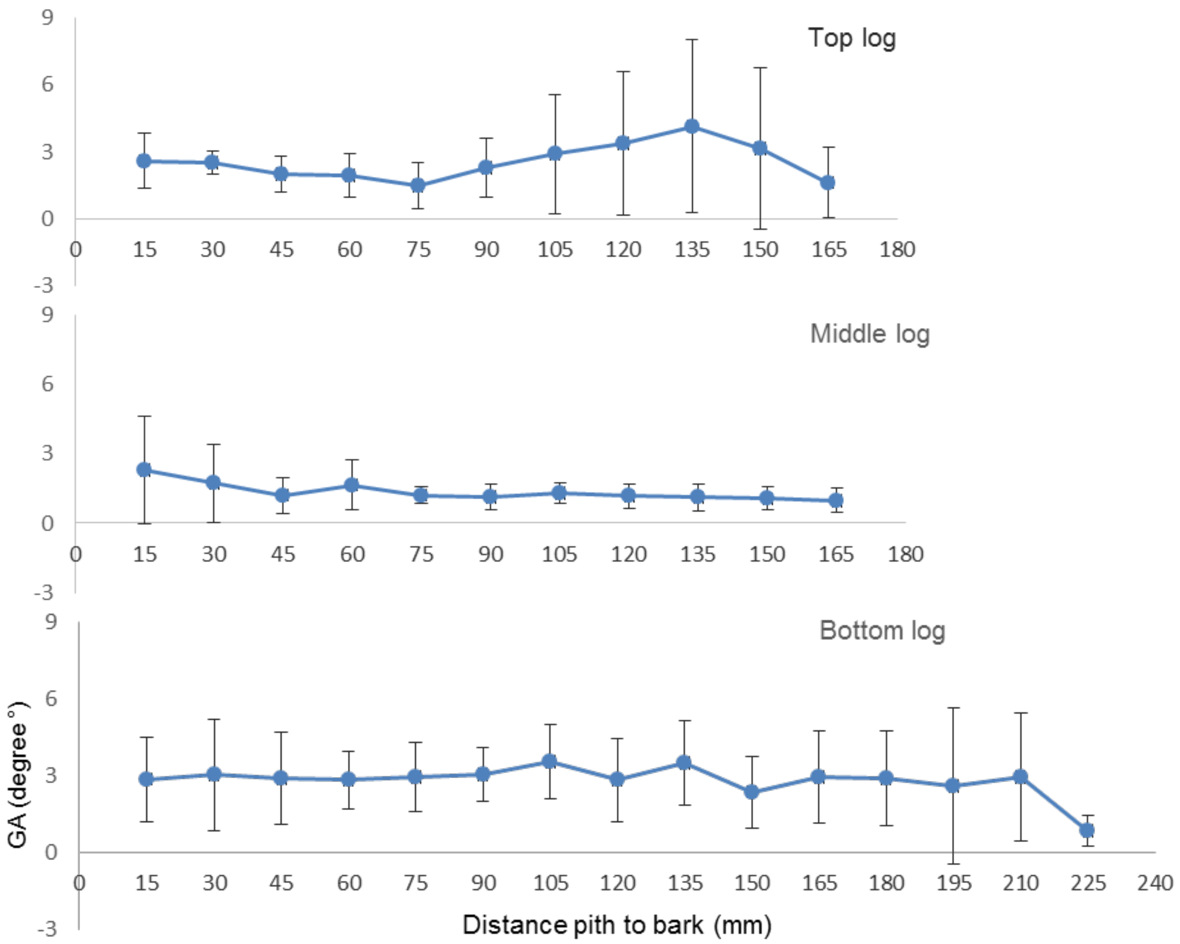


Fig. 5.
Radial variation of GA presented in absolute values.

The variation between the trees

Different values of mean and deviations of GA were observed for every tree (Table 1). Highest values were recorded in tree no. 3 from Askeramala site. In line with the above presented average values, this tree experienced high values and deviation in the butt and top log as presented in Figure 6. The pattern of GA in the top log (Figure 6) shows a change of almost 3° within 15mm (first 30 mm) and continuous low-high change of values every 15mm (pith to the bark). The GA values of the same tree in the top log position (Figure 6) reach 5° difference within a 60 mm distance (90-150 mm) in a radial direction. This might be connected with large knots registered at the samples. Vimmerby site appeared to have an advantage in term of GA values over the trees collected from Askeramala site.

Table 1.

Mean and deviation in absolute values of GA (in degrees °)

Site	*Askeramala*				*Vimmerby*			
Tree no.	*1*	*2*	*3*	*Mean*	*4*	*5*	*6*	*Mean*
Mean	1.8	2.1	3.9	2.6	1.3	2.8	1.7	1.9
Deviation	0.8	1	2.7	1.5	0.6	1.6	1	1

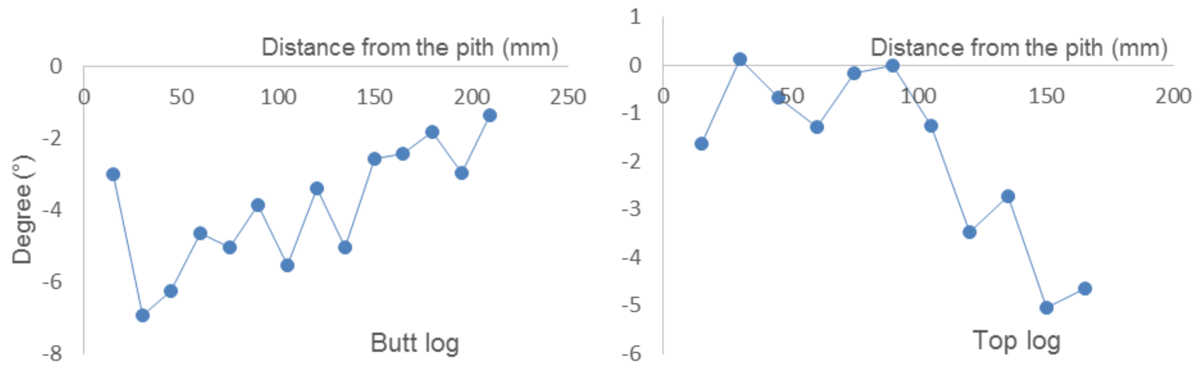


Fig. 6.
Tree no. 3 - variation of GA in radial direction.

CONCLUSION

This study was based on measurement on grain angle in six aspen trees at three vertical positions. The values obtained from measurement of 18 wooden discs (a six from each position) were collected and grain angles were calculated. The results confirmed that aspen belongs to species with straight-grained wood. In line with other species, aspen tree shows higher variation in radial than in vertical direction. In vertical direction (bottom to the top), the bottom log had highest values. The registered mean value of aspen GA in this position was -0.8° with 2° standard deviation. The middle log recorded lowest values. The average GA in this position was -0.4° and standard deviation 1°.

With regard to radial variation, the mean values of GA registered in butt logs had a decreasing trend towards the bark. The average value was not exceeding 2° of grain angle value and deviation at any of measuring points (15mm intervals) within three different positions. The values obtained from a concluded study on GA in aspen are highly desirable in sawmilling industry. From this perspective, aspen could be considered for higher utilization in this industry.

For the purpose of grain angle significance in veneer industry, the obtained results were presented in absolute values. According to these results, the highest values of mean GA and deviations appeared in the top log. This section recorded mean values of GA higher than 4° with nearly 4° deviation in the outer part of the log. With less than 2°, lowest values of grain angles and deviations are obtained in the middle log. As higher values and deviations are associated with the outer part of the top log, this part should be carefully evaluated before processing and converting into veneer. In both cases, it can be concluded that best quality of wood from the aspect of GA is to be extracted from the middle part of the aspen tree.

Nevertheless, as conducted on six trees, this study showed that individual trees might have much higher values as registered with tree no. 3. It would be of high importance for the wood processing industry to consider this aspect. Detection of spiral grain enables qualitative wood selection. This way raw material with unacceptable spiral grain can be excluded before processing or selected for other purpose. The same applies for detection of grain angle during processing according to different quality requirements of end products.

In overall, the acquired knowledge of aspen spiral grain can be considered as promising in the expansion and better utilization of this wood in the future.

Considering these aspects it will be of significant importance to expand the research by:
- More extensive study of GA variation in terms of larger number of aspen trees,
- Appliance of different testing methods for detection on GA in aspen (logs, timber, veneer),
- Testing significance of GA values for specific end products.

Brief overview of methods for spiral grain assessment from industry appliance perspective

In general, most published studies based on GA measurements are often averaged over a specific distance or group of growth rings. However, some recent studies (Nilsson *et al.* 2007, Cown *et al.* 2010) have indicated that there may be more variation present within a tree than has been previously reported. Although, while universally recognized as important for wood behaviour, as yet, there is no accepted of efficiently collecting data on within-tree grain angles (Riddel *et al.* 2012). There are several developed methods that were able to be automated. In 2002 Nystrom developed an automated method for measuring spiral grain on sawlogs and lumber utilizing so-called "tracheid effect". This created the possibility for measurement and segregation of softwood material according to surface grain angles in commercial situations. In addition, techniques based on X-rays and/or microwaves (Sepuveda *et al.* 2003, Ekevad 2004, Sjoden *et al.* 2005, Buksnowitz *et al.* 2008, Riddel *et al.* 2012) have been developed. Most of them require rather expensive equipment and mathematical modelling capability. They are applicable for certain types of wood, for instance, the tracheid effect in the softwood milling industry. As mentioned in the earlier text trend of increasing hardwood forest inspired many scientists towards more intensive research for extensive and efficient use of this wood source. In a recent study (Schlotzhauer *et al*. 2018) performed the study about the comparison of three systems for automatic grain angle determination on European hardwood for construction use. The tracheid effect, microwave measurement, and electrical field strength measurement were tested on six indigenous hardwoods (ash, basswood, beech, birch, maple, oak) and spruce as reference. Ash showed no correlation at all. The tracheid effect showed a high R^2 value for basswood (0.71), maple wood (0.81) and low value for birchwood (0.51). For beech wood, the electrical field strength measurement showed the highest correlation (0.66). For oak, the electrical field system and microwave measurement systems showed a high correlation (0.80 and 0.73). The microwave system showed a high correlation (0.88) for maple.

The other recent study (Viguier *et al.* 2018) presented an innovative method based on grain angle measurement to sort veneer and predict mechanical properties of beach laminated veneer lumber. This study proposed an innovative model based on local grain angle measurements to predict the modulus of elasticity of LVL made from beech. Local grain angle was obtained with two-dimensional scanners by projecting a line of laser spots on the surface of the veneer. Due to low computational time veneers, a sorting method was considered as industrially compatible. The model based only on local grain angle measurements has been proven more efficient than models taking into account the veneer density. The proposed method can be used to sort veneer during the peeling process and grade the production of LVL panels to optimize their mechanical properties even for a low-quality veneer.

Since considered as important wood attribute it is to expect more research connected to the spiral grain, particularly from in the area of detection methods for industry appliance.

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