Effect of Spiral Grain Occurrence on Strength Properties of *Pinus Patula* Grown in Kenya

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Abstract

Spiral grain occurrence in timber is an important wood quality characteristic. High spirality in timber beyond permissible limits reduces wood strength and causes distortion. It is also time consuming during straightening and fastening the material. Spiral grain occurrence should therefore be minimized in wood to allowable specifications. It is for these reasons that this study was undertaken to determine allowable spiral grain in Pinus patula logs, its relationship to slope of grain in sawnwood and the effect of the grain angles on strength properties. Spiral grain angles were taken on standing trees from Muguga plantations in Central Kenya at Diameter at Breast Height (DBH) using a hammer, hollow metal tube, pencil and protractor. The trees were then felled and grain angles taken along their merchantable length. Using a grain detector the corresponding slopes of grain were determined after the logs were converted into sawnwood. Results showed that spiral grain angles are directly proportional to slope of grain of sawnwood. Special Structural (SS), General Structural (GS) and Reject grade of sawn timber corresponded with grain angles not exceeding 2.5^o, between 2.5 – 5^o and not less than 5^o respectively. There were also significant variations in spiral grain angles between and within trees. Trees with grain angles between 0^o and 5^o were categorized as good seed sources. Spiral grain seemed to reduce bending strength and stiffness of construction timber. Bending strength was reduced by almost 40% at 1:10 (SS grade) and 32% at 1:6 (GS grade) spirality. The reduction factor due to spiral grain on strength is highest between SS grade and Reject grade. It is recommended that selection of seed sources should consider low occurrence of spiral grain to ensure compliance to timber specifications for construction purposes.

Keywords: *Pinus patula,* Spiral grain, Slope of grain, Strength properties

1.0 Introduction and Background

Wood quality refers to the cumulative effects of various wood properties on specified products. The definition is based on wood quality characteristics such as wood density, fibre length and diameter, fibril angle, cell wall thickness, cellulose content and extractive content. Stem characteristics such as sapwood and heartwood percent, kino number and frequency, decay and discoloration and knot size and frequency are also considered.

Wood quality is defined depending on the end use of a specific product (Kollman and Cote, 1968). Spiral grain occurrence in wood is particularly an important wood quality characteristic. Depending on its severity, spirality influences the strength of timber at work. High proportion of spiral grain beyond permissible limits also causes distortion and is time consuming (Brazier, 1965).

In Kenya, *Cuppressus lusitanica* and *Pinus patula* are currently the major plantation species for timber for the construction industry. *Pinus patula*, known as Mexican Weeping Pine in English and is native to Mexico, belongs to the Pinaceae family. The species grows well in high potential areas with not less than 1000 mm annual rainfall. It grows to over 35 m in height in Western, Central and Rift Valley provinces of Kenya. *Cuppressus lusitanica* is native to Mexico and Guatamala and is widely planted in all high potential areas of Kenya especially Western, Rift Valley and Central highlands (Omondi, *et al*, 2004).

Cuppressus lusitanica is preferred to *P. patula* as a construction material because it is perceived to have better timber quality. However, studies on mechanical properties of the two species based on small clear testing and structural size members have shown that *P. patula* timber is superior in strength than *C. lusitanica*. Permissible and characteristic strength values based on testing visually graded structural size members of pine timber were found to be higher than for cypress. However, due to lack of machine grading techniques of structural timber in Kenya which could increase grade yield upto 75 % for pine through reduction of distortion (minimizing spiral grain in pine), about 30 % of *P. patula* and only 2 % of *C. lusitanica* timber is classified as "Reject grade" due to spiral grain alone (Keith, 1983, Fewell, 2000).

Chikamai, *et al* (2001) have categorized *P. patula* as a relatively strong timber (S2) timber in strength grouping of Kenya's commercial species based on wood properties generated from data on small clear specimens. Timbers in this strength group are most suitable and efficiently used for structural purposes. However, it is expected to be in the higher category with recent permissible values determined using full-size structural members.

To efficiently and economically utilize *P. patula* as a construction material in Kenya, there is need to assess the effects of spiral grain occurrence on strength properties through analysis of the relationship between spiral grain on sawnwood and standing logs and timber grades classification based on spiral grain. Results of such a study would lead to selection of spiral grain in tree improvement programmes which would subsequently save on the quantities of the material used in construction. The objectives of this study was to determine the allowable fiber grain spiral condition in trees and the relationship between the slope of grain in sawnwood and standing tree. The effect of spiral grain on the strength properties of *P. patula* was also tested. The generated data is expected to guide in future selection on wood quality attributes.

2.0 Materials and Methods

2.1 Allowable spirality in logs and its relationship to slope of grain in sawnwood

Sample trees were systematically selected along rows and columns from mature provenance, progeny and clonal plantations 109, 106 and 116 in Muguga in Central Kenya respectively. From each plot 19, 6 and 4 stems respectively were selected, marked and pre-assessed for spiral grain at Diameter at Breast Height (DBH). A hammer and a hollow circular metal rod were used to remove the stem bark completely from each of the stems. Then a sharp pencil and protractor were used to measure the deviation of the fibres from the vertical axis which were recorded as grain angles of the stem in degrees at four compass directions, i.e. North, East, South and West (Plate 1).

After pre-assessment of spiral grain, 8 trees with a range of grain angles ($0 – 1^o$, $1 – 3^o$, $3 – 5^o$ and more than 5^o) were selected and felled. Each of the trees was again assessed for spiral grain at various points along the length of the stem and four compass directions. Assessment of spiral grain along the log was important to avoid localized grain angles and allow reasonable average values. The trees were then cross-cut into 3 m logs and transported to KEFRI- Forest Products Research Centre where they were converted into sawnwood. Sawing of the logs was systematically done along the compass directions, i.e. North – South or East – West and marked. The sawn wood was then assessed for slope of grain using a grain detector at various points along the timber and along the compass directions and recorded (Plate 2).

Microsoft Word 2000 statistical package was used to compute measures of centrality (arithmetic mean, standard deviation, minimum and maximum values) for spiral grain angles and slope of grain. MS Excel 2000 was also used to give empirical categories of allowable grain angles in the stems that represent permissible limits of slope of grain in sawnwood; as well as a graphical representation of the relationship between spiral grain and slope of grain.

2.1 The effect of spiral grain on strength

Thirty (30), 100mm x 50mm pieces of sawnwood were graded using KS02: 771 (1989) grading rules into Special Structural (SS), General Structural (GS) and Reject grades on the basis of spiral grain. These grades correspond to 1:10, 1:6 and above 1:6 grade ratios respectively. The grading was on the basis of spiral grain alone without the influence of other timber defects particularly knot area ratio. Each piece was then marked for the corresponding grade and tested for bending and stiffness strength using a Universal Strength Testing Machine (USTM) (Plate 3).

Measures of central tendency (arithmetic mean, standard deviation, maximum and minimum values) were determined using MS Excel 2000 for various grades against the strength property. The relationship between different grades, which are strong indices of the proportion of spirality, and strength were represented by linear graphs.

3.0 Results and Discussion

3.1. Allowable spirality in logs and its relationship to slope of grain in sawnwood

Table 1 gives various measures of central tendency for the three plots (109, 106 and 116) that were assessed for spiral grain at DBH and at different points along the stems. At DBH, trees from Plot 109 had an average of 2.6^o degrees of grain angle with a maximum angle of 5.8^o, while trees from plot 106 and 116 had average grain angles of 2.5^o (with maximum of 4.0^o) and 1.6^o (with maximum of 3.2^o) respectively. The deviation of these values from those found at various points along the stems was minimal. This showed that there is insignificant variation of grain angle along the stems of individual trees.

However, there was significant variation in grain angle between trees within the same plots. This was reflected in minimum and maximum values within the same experimental plots; the range between maximum and minimum values was 5^o, 3^o and 2.5^o for trees from experimental plots 109, 106 and 116 respectively, which was significantly high.

Variation in grain angles between trees from the same plantation/plot was genetic because these were provenance and progeny trials. Provenance trials are from seed of unselected trees while progeny trials are from seeds of selected trees. Clonal banks are grafts from selected trees. This was why the grain angles reduces from Plot 109 to Plot 106 and Plot 116 Genetic factors which are inherited from mother or parent trees to their progenies include sapwood and heartwood, basic density and slope of grain while environmental and physiological factors are wood defects such as knots, kino veins, decay and discoloration rather than (For. Prod. Lab., 1987).

Table 2 also gives average spiral grain angles in logs from the three plots with their corresponding sawnwood grain angles and grade types. The grain angles that were obtained from the logs ranged from a minimum of 1.4^o and 3.2^o to a maximum of about 5^o which corresponds with Special Structural (SS) and General Structural (GS) grades respectively (KS02-771, 1989).

The grain angle in stems that qualify for SS grade timber did not exceed 2.5^o, while for the GS grade timber, the grain angle ranged between 2.5^o to 4.5^o. Trees with grain angles exceeding 5^o produced Reject grade sawn timber for structural purposes. SS grade and GS grade should have slope of grain not exceeding 1 in 10 and 1 in 6 respectively according to KS02-771 (1989) grading rules. Average slope of grain values for 7EP109 and 21EP106 sawnwood corresponded to the Reject grade (RJ) of between 1:1.3 and 1:1.5 respectively although their corresponding grain angles of logs were not exceeding 5^o . This deviation from the expected could be due to the number of logs used and therefore there is need for further research to establish reasons for it.

Fig. 1 indicates that there is direct proportionality between spiral angle in logs and slope of grain in the respective sawnwood; slope of grain in sawn timber increases with increasing spiral angle.

Generally, slope of grain obtained from sawnwood using grain detector were higher than the spiral grain obtained in the field using a protractor and a hammer. This could be because spiral grain is only one of the factors that determine slope of grain, whereas slope of grain is determined by taking the square root of the sum of the squares of spiral grain on flat-grain surface and the diagonal slope (For. Prod. Lab, 1987). Grain angles from logs certainly explain the severity of the slope of grain of the sawnwood. Grain angles in sawnwood are almost twice as high as those in logs.

Figure 1 shows the relationship between slope of grain and cross grain in sawnwood. Slope of grain is mostly a genetic phenomenon in timber which is highly heritable from mother trees to progenies. Sometimes it is induced by other natural defects such as knots. Slope of grain relates to the fibre direction to the edges of a piece of timber. It is a measure of a condition called “cross grain”, which is in two important forms namely spiral grain and diagonal grain. Other forms of cross grain are wavy, dipped, interlocked and curly grain (For. Prod. Lab., 1987).

Spiral grain in a tree is caused by fibres growing in a winding or spiral course about a bole of a tree instead of vertically. In sawn products, spiral grain is defined as fibres lying in tangential plane of the growth rings, not parallel to the longitudinal axis of the product. The presence of spiral grain is determined using non-destructive method by the alignment of pores, rays and resin ducts on the flat-sawn face. Drying checks on a flat-sawn surface follow fibres and indicate the slope of the fibres. A combination of spiral and diagonal grain can produce a complex cross grain. To determine net cross grain fibre slopes on continuous surfaces of a piece are measured and combined. The combined slope of grain is determined by taking the square root of the sum of the squares of the two slopes, e.g. assuming spiral grain slope on flat-grain surface is 1 in 12 and diagonal-grain slope is 1 in 18. The combined slope is computed as;

$$\sqrt{(1/18)^2 + (1/12)^2} = 1/10 \text{ or slope of 1 in 10}$$

3.1 Effect of spiral grain on strength properties

Table 3 shows average measures of central tendency for SS, GS and Reject grades which correspond to maximum slope of grain of 1:10, 1:6 and above 1:6 respectively. These are average values for modulus of rupture (bending strength) and modulus of elasticity (stiffness strength) of timber members. The average MOR for SS, GS and Reject grade was 44.89 KN/mm^2, 35.36 KN/mm^2 and 26.74 KN/mm^2 respectively. The strength difference between the maximum slope of grain of 1:10 or 2.5^o grain angle for SS and that above 1:6 or greater than 5^o was almost 50%. The same trend was observed for MOE for different levels of spirality.

Figure 2 shows linear graphs representing the relationship between various grades and strength of pieces of sawn timber. Bending strength was generally significantly reduced with increasing slope of grain. The higher the slope of grain the lower the bending strength. This was more pronounced in MOR than in MOE. In both cases, SS grade with a maximum slope of grain of 1:10 was superior in strength than GS whose maximum slope of grain was 1:6. Reject grade had the minimum bending and stiffness strength compared to those for SS and GS grades. However, the difference in strength between SS and GS grades was not as high as in Reject grade. This is in conformity with findings by Forest Products Laboratory (1987). Spiral grain in timber is known to reduce strength and cause distortion which leads to difficulties in machining and nailing. However, spirality varies from one species to another, e.g. in *P. longifolia*, there is no significant reduction in strength due to spirality upto 5.0^0 grain angle. According to Banks (1953) and Brazier (1965), straight-grained material with 0^0 spirality has strength ratio of 100%. In most cases, 7^0 spirality is accepted as maximum spirality permissible in logs used as structural timber, 12^0 is suitable for box timber logs. Generally, 2^0 spirality corresponds to about 6% strength loss.

4. Conclusions

- Selection against spiral grain in the breeding programme would be worthwhile as evidenced from the progressive reduction of spiral grain angle from provenance trials, through progeny trials to clonal banks
- Spiral grain angles in logs are intimately related to slope of grain in sawnwood. The SS, GS and RJ grades in sawnwood are equivalent to grain angles not exceeding 2.5^o, between $2.5^o – 5^o$ and not less than 5^o respectively

- Bending strength (MOR) and stiffness strength (MOE) were significantly reduced with increasing slope of grain. There was a difference of almost 50% between maximum slope of grain of 1:10 and 1:6 (SS and GS grades respectively) against Reject grade

4.1 Recommendations

- It is recommended that a national assessment of seed sources of *p. patula* be carried out to establish those seed stands that comply to allowable or permissible spiral grain angles and physical characteristics for structural purposes. Plantations that would be found to meet the criteria as seed sources should be preserved for seed collection. Additional plus trees with good straight grains should be selected to build the breeding populations of pines
- Genetic manipulation of potential seed sources should be initiated to reduce spirality in logs to acceptable limits hence improve on wood quality using germplasm which are already selected for and adapted to local conditions

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Appendix 1. List of Tables, Figures and Plates

Table 1. Average grain angles in logs at DBH and along their length

		Grain angle (degrees)	
Plantation	**Measure of centrality**	**At DBH**	**Along stem**
Provenance plot109	• Arithmetic mean	2.6	2.6
	• Standard deviation	1.21	1.26
	• Minimum	0.9	0.5
	• Maximum	5.8	5.8
Progeny plot106	• Arithmetic mean	2.5	2.3
	• Standard deviation	1.33	1.32
	• Minimum	1.0	0.8
	• Maximum	4.0	4.0
Clonal plot116	• Arithmetic mean	1.6	1.5
	• Standard deviation	0.97	1.09
	• Minimum	0.8	0.5
	• Maximum	3.3	3.0

Table 2. Average spiral grain angles of logs and their corresponding slope of grain

Log/Sawnwood code	Grain angle (degrees)	Slope of grain (1:n)	Grade type
9EP109	1.4	12.1	SS
24EP116	1.4	11.7	SS
19EP106	1.6	10.7	SS
25EP116	2.1	10.1	SS
5EP109	3.2	9.2	GS
3EP109	3.7	6.7	GS
7EP109	4.3	1.5	RJ
21EP106	4.7	1.3	RJ
Summary	**0 – 2.5°**	**1 in 10**	**SS**
	2.5° – 5.0°	**1 in 6**	**GS**
	Exceeding 5.0°	**Exceeding 1:6**	**RJ**

Table 3. Average values of modulus of rupture and elasticity based on spiral grain

Measures of Centrality	Modulus of rupture, N/mm^2			Modulus of elasticity, N/mm^2		
	SS	GS	Reject	SS	GS	Reject
Arithmetic mean	44.981	35.35765	26.7414	12.0296	8.9143	6.1583
Standard deviation	12.924	9.354245	7.225692	3.301056	1.770707	1.052259
Maximum value	69.190	56.2600	39.3900	18.0047	11.8847	8.0765
Minimum value	23.850	18.1800	11.7200	7.1943	6.3667	3.9027

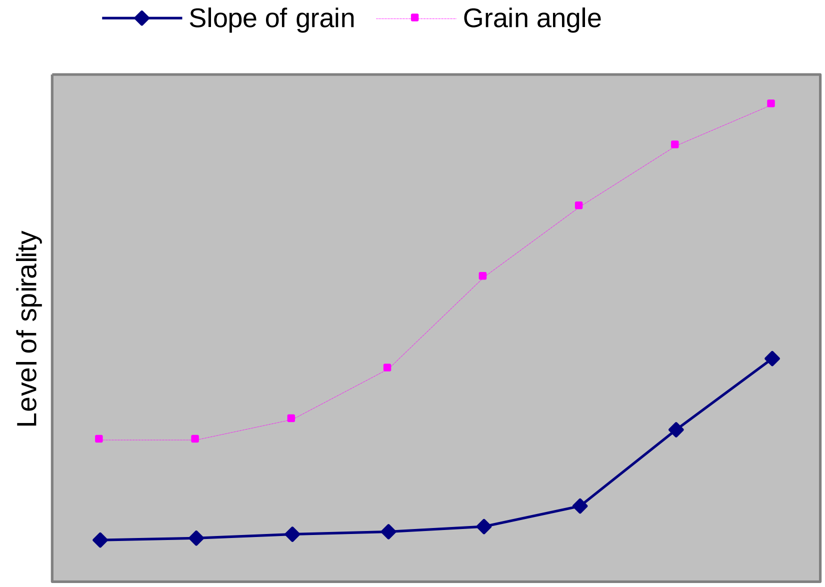

Fig. 1. Relationship between slope of grain and grain angle

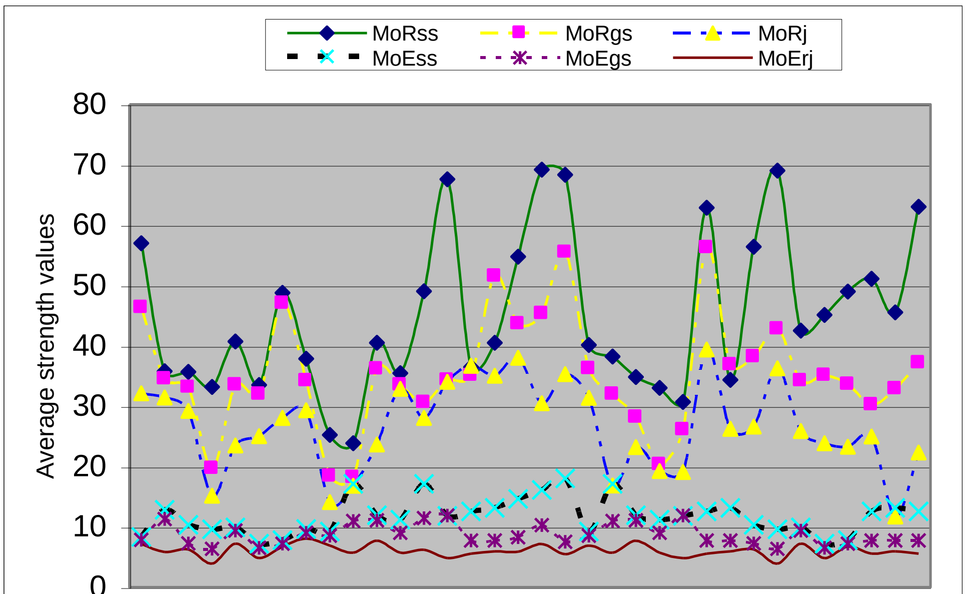

Fig.2. Effect of spiral grain on strength

Note: MOR_{ss}, MOR_{gs} and MOR_{rj} – Modulus of rupture for SS, GS and Reject grade respectively
MOE_{ss}, MOE_{gs} and MOE_{rj} - Modulus of elasticity for SS, GS and Reject grade respectively

Figure 1. Determination of spiral grain angle on standing tree in Muguga

Figure 2. Grading sawn timber into SS, GS and Reject grades

Figure 3. Testing of various grades of sawn timber using USTM