Variables affecting the performance of British grown Sitka spruce

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ABSTRACT

This paper details the findings of a study into the relationships between tree, log and board variables to the mechanical properties and distortion of British grown Sitka spruce. The influence of knots, compression wood, slope of grain, log shape, density and other parameters is discussed, together with the effect of using these variables as sorting criteria or the basis of log or sawn timber scanning equipment. The database amassed by BRE in collaboration with Forest Research can also be used to develop predictive silvicultural models.

INTRODUCTION

Timber is an immensely useful but naturally variable material. Inherent in its structure, both in log and sawn form, are features which affect qualities of dimensional stability, stiffness and strength. These include knots, compression wood and spiral grain. Physical characteristics such as log shape, density, rate of growth, presence of juvenile wood and microfibril angle also affect these qualities and, in turn, utilisation. British-grown Sitka spruce trees reach maturity relatively quickly; as a consequence the timber differs significantly from slower grown softwoods imported from northern America and northern Europe. British-grown Sitka spruce tends to meet a lower structural grade than imported softwoods, which can exclude it from certain markets. For example, none at present is used for trussed rafters. Some UK timber frame manufacturers prefer imported timber because they consider the level of distortion and knots in British-grown material to be too high. Ply web beams and other glued laminated elements require timber which is not prone to distortion on drying, as does timber supplied to other markets such as the DIY trade where boards are often stacked unrestrained in heated buildings. Sorting of timber in the future is likely to be aided by automatic scanning equipment, but the effects of segregating the better quality from the lower, particularly on strength grading, need to be considered. With better information on the material being processed, optimised sorting can be performed. For example, material likely to distort excessively or be rejected at machine grader stage can be segregated prior to kiln drying. Relatively simple laser/camera setups can be used to measure grain angle and knot content on boards. Three dimensional log shape scanners are already used to optimise volumetric yield, and also have the potential to be used to determine timber quality. By investigating the relationships between timber variables the potential worth of these techniques can be indicated.

MATERIALS AND METHODS

The overall methodology used was to obtain sample batches of timber and relate the predictor variables of the logs and boards to the criterion variables of the end product. By additionally studying the behaviour of small scale samples, free of defects such a knots, the effect of variables such as density and compression wood content could be evaluated. Practical difficulties in the characterisation and measurement of timber variables, and their adequacy, were also investigated. The main bulk of the practical work comprised the testing and assessment of around 500 battens of Sitka spruce obtained from two localities in Scotland. Ninety logs of 3m length were manually assessed, then scanned by a 3D laser scanner. The timber was “curve sawn” into three nominal sizes 200 x 47mm, 150 x 47mm, 100 x 47mm which are commonly used in construction. Aside from the obviously required site, tree, log and batten number identification numbers and sawn timber dimensions, the following variables were determined: Tree height and diameter at breast height (dbh), tree taper (height/dbh), log diameter (top, middle, bottom),log taper (ratio of bottom diameter to top diameter), log maximum and overall curvature, number of whorls per log, whorl spacing (maximum, minimum and mean spacings), log spiral grain angle, log ovality, log pith eccentricity, log compression wood content, batten density, batten slope of grain on outer and inner faces and edges, compression wood content on outer and inner batten faces, knot content (number and area of knots on batten edges and sides, and maximum concentration of knots in any 300mm span), knot area ratios (MKAR, TKAR etc as defined by BS 4978), average ring width, percentage of juvenile wood, and distance from pith to centre of the batten.

The battens were machine strength graded using a Cook Bollinder grader to obtain detailed Indicating Parameter (IP) values along the board lengths. Since all of the battens were of the same nominal thickness a value of IP normalised for batten width could be determined. $E_{\text{(Cook Bollinder)}}$ was also calculated. Since the position of every batten was known, stiffness profiles both axially and radially within the trees could be established. MOE and MOR from bending tests to EN 408 were also obtained. Distortion measurements of bow, spring twist and cup where obtained following drying.

Other sets of timber were also used for purposes of validation, comparison and further study included sets of battens obtained from sawmills which were rejected at machine grading and because of excessive distortion. An extensive dataset of earlier test work on Sitka spruce was also analysed.

SPIRAL GRAIN AND TWIST

Spiral grain has long been known to influence distortion in the form of twist (Stevens 1961). Balodis (1972) noted that twist increased with increasing angle of spiral grain and decreased with increasing distance of the board from the pith. His analysis showed that twist was proportional to the ratio of grain angle: distance from pith; and that the constant of proportionality is a function of the tangential shrinkage component of the wood. Figure 1 shows the observed relation between twist and slope of grain recorded on the inner and outer faces of the boards for a subset of 100 x 47mm battens.

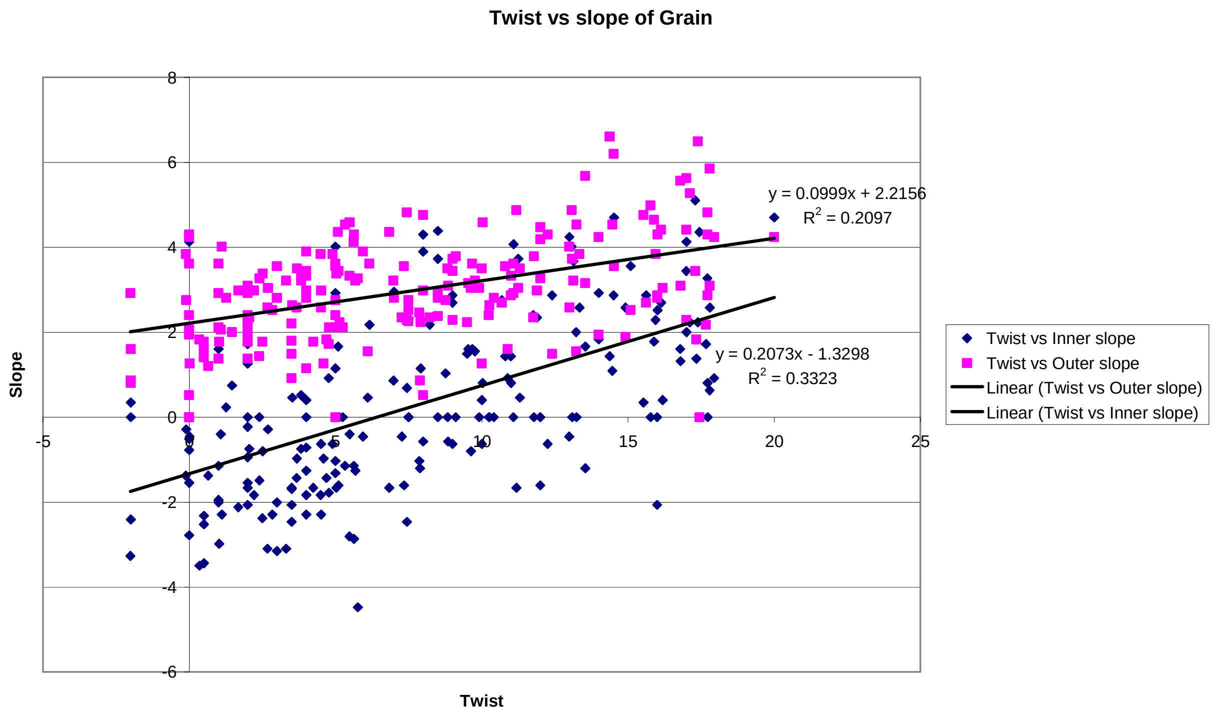

Figure 1. Twist (mm) plotted against slope of grain (deg)

A reasonable relationship between slope of grain measured on the faces and twist is evident. However the relationships between slope of grain on the outer face and inner face are different, most significantly on the intercept with the y axis. From the above graph (together with detailed inspection of the boards), the following could be deduced. Only a few boards with high values of slope of grain which are prone to twisting can be identified and possibly removed. There are very few boards which twist in the opposite direction to the bulk. Outer face slope of grain is almost always positive (relative to the observer, given the provisos of the measurement protocol). Twist appears to increase as inner face slope of grain ranges from negative values to positive. Large negative values of spiral grain are, apparently, associated with low twist. Battens with inner face spiral grain angles which are positive tend not to contain pith. A feature also observable in the dataset, since the orientation of the battens wrt height in the tree is known, is that the majority of battens have come from trees (or sections of trees) that have remained left hand spiral grained. It is also clear from the above graph that sorting on the basis of the magnitude of spiral grain angle alone will be ineffective. For predictions of twist, measurements of spiral grain angle must always be made on a tangential face. The influence of a variable relating to proximity to pith was also noted, with boards containing pith being particularly prone to twisting.

COMPRESSION WOOD

Compression wood is a type of reaction wood that tends to form in conifers that have been partially blown over, in trees on the windward side of exposed plantations, in the lower part of trees growing on a slope, and below heavy branches (Desch and Dinwoodie, 1996). The greater longitudinal shrinkage of compression wood causes bow and spring on drying. Compression wood in logs may be indicated by their shape and form, as shown in other work on Scots pine and Norway spruce (Warensjo, 2003). Industrial 3D laser scanners are used in many sawmills to optimise yield, and also have the potential to be used automatically for log sorting on the basis of propensity to distort.

In this study no clear systematic relations were observed between the log shape (ie ovality, pith eccentricity, arc), batten compression wood content, and distortion in the form of bow and spring. Although several logs with abrupt changes in curvature were noted to yield battens which bowed or sprung considerably (Figure 2), some relatively straight round logs contained high levels of compression wood, or yielded timber which distorted on drying. The high distortion of timber coming from these straight logs was attributed to the consistent imbalance of compression wood that could occur from one face or side of the board along its entire length (Figure 3).

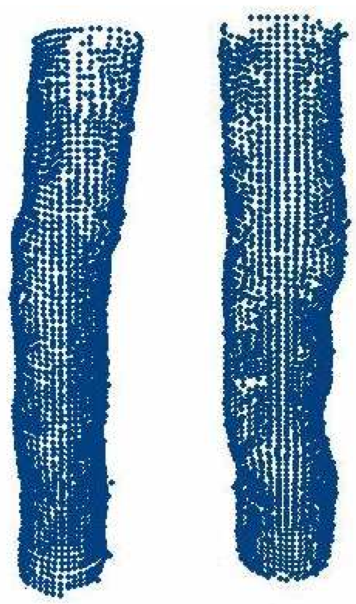

Figure 2. Scanned image of logs with abrupt changes in curvature which yielded distorted timber

As expected, severe compression wood was found to be associated with stem correction, particularly leader loss. Compression wood is denser than normal wood, and it was found that its presence undermined the quite good relation observed between stiffness and density for normal wood.

Figure 3. Distorted batten, originating from relatively straight log. (compression wood shown marked)

EFFECT OF KNOTS AND DENSITY ON STIFFNESS

A key feature of British grown Sitka spruce often noted is the presence low stiffness material near to the base of the tree. In this study, since the orientation of the battens was known, and kept constant during machine grading, stiffness profiles for each tree could be established (Figure 4). This feature was noted to be highly variable both between trees and stands. The effect is not attributed to any outwardly measurable feature on boards (such as knots, low density, slope of grain etc), but to high microfibrill angle. The feature is grade determining for many battens, and this has a profound effect on the efficacy of any potential sorting system.

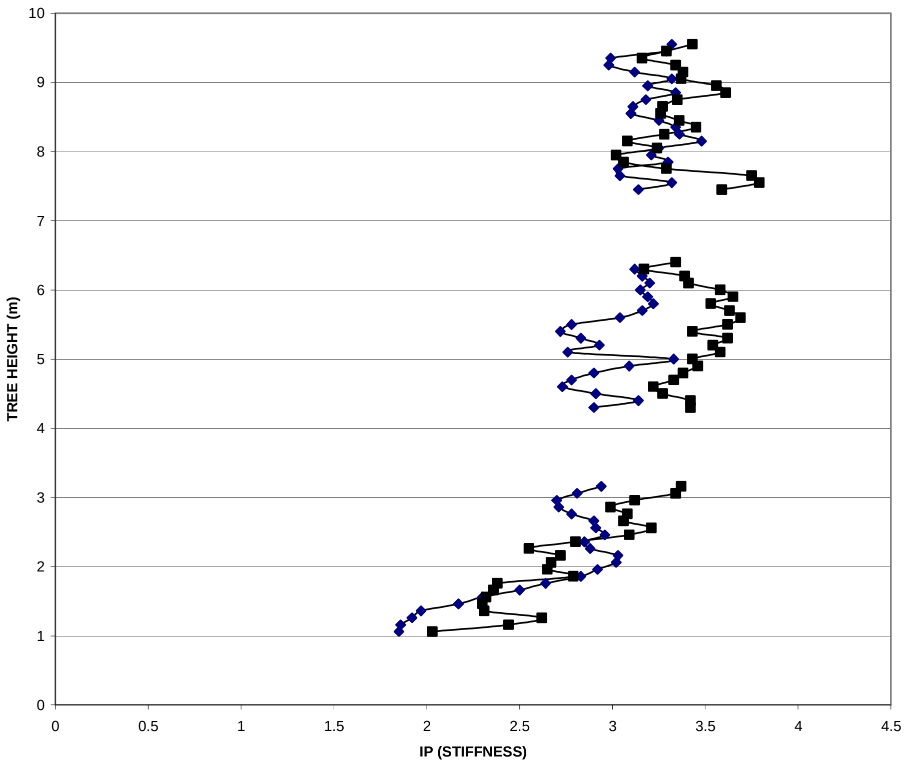

Figure 4. Batten stiffness profiles showing low stiffness at the base of trees.

As expected from the batten stiffness profiles, log variables associated with batten height (eg taper) were found significant. Figure 5 (below) shows that there is a reasonable relationship between density and stiffness for upper logs, but that this relation is apparently not present at all for the butt logs. For both small clear samples of normal wood and battens from upper logs, stiffness is was found to be directly proportional to density. Spiral grain angle was not found to be a significant variable.

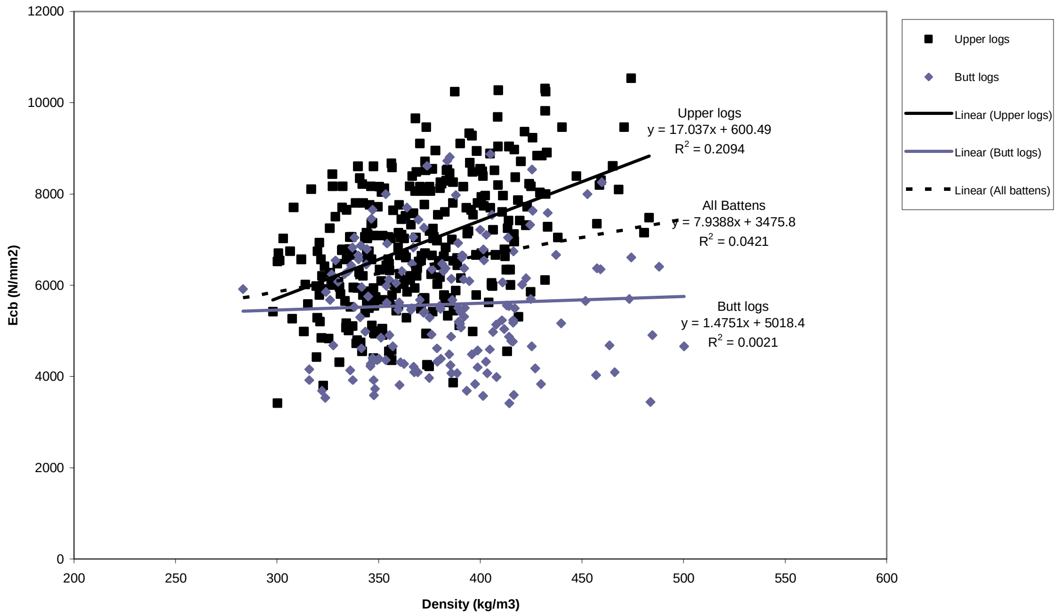

Figure 5. Stiffness plotted against density for subgroups of butt logs and upper logs.

Figure 6 below shows the observed non-linear relation between KAR and stiffness for a set of 97 x 45mm timber.

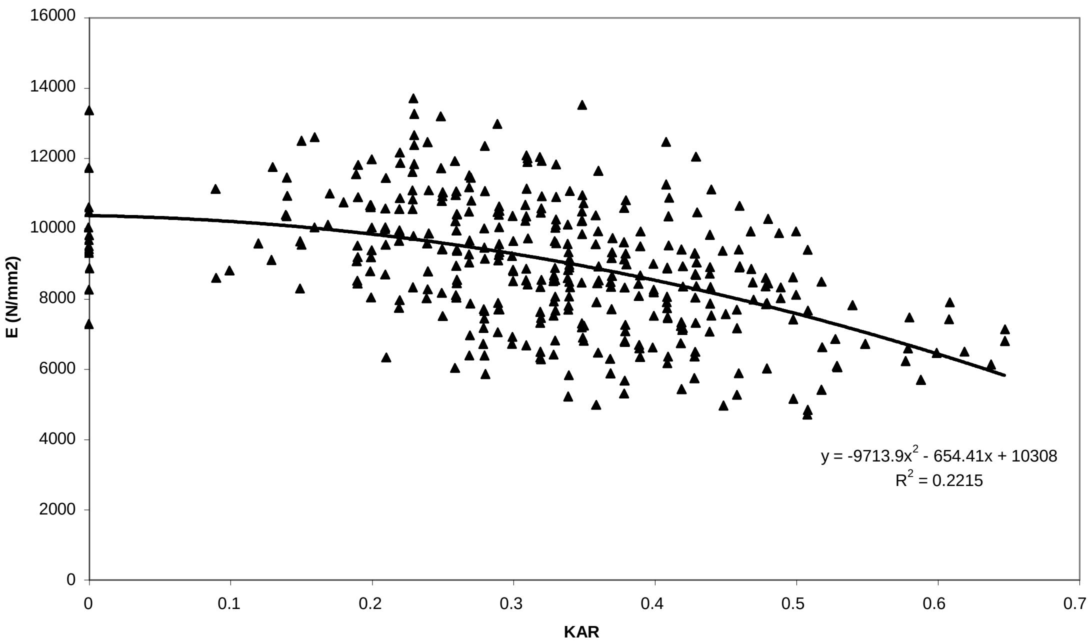

Figure 6. Relation observed between KAR and stiffness.

DISCUSSION

Good knowledge has been gained of the numerical relations between the variables affecting the performance of British grown Sitka spruce. The presence of low stiffness material near to the base of the trees was noted to be highly variable both between trees and stands, and the feature grade determining for many battens. This effect can occlude relations observed between other variables. Clearly extremes of knot content, slope of grain and log shape can be used as sorting criteria to improve quality. For segregation of timber into different quality groups, knowledge of the effect of combined variables is required. The necessary strictures of the grading system can also make certain forms of sorting un-worthwhile, or counter-productive. By selecting out better quality logs or battens the average quality of the remainder may fall. The database amassed by BRE in collaboration with Forest Research can also be used to develop predictive silvicultural models. From the study of machine grader rejects, severe cross grain associated with either large knot groups (Figure 7) or log curvature was noted to be highly significant. However determining descriptive variables for this feature is problematic.

Figure 7. Machine grader rejects with severe cross grain.

CONCLUSIONS

It was found that the presence of low stiffness clear wood at the base of the trees studied, together with the natural variability between individual trees and stands, has a profound effect on the ability to sort timber on the basis of industrially measurable variables such as density or knot content. Practical difficulties with the use of slope of grain measurements to determine batten twist were also noted. Relatively straight, round logs were observed to contain compression wood and hence yield timber which distorted on drying.

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REFERENCES

1. Balodis V(1972): Influence of grain angle on twist. Wood Science vol 5 no.1 p44–50
2. Desch H. E. and Dinwoodie J.M. (1996): Timber – structure, properties, conversion and use. MacMillan Press, London
3. Stevens W.C. (1961): Drying with and without restraint. Forest Products Journal Aug p348-356
4. Warensjo M. (2003): Compression wood in Scots pine and Norway spruce – Distribution in relation to external geometry and the impact on dimensional stability in sawn wood. Doctoral thesis Swedish University of Agricultural Sciences. Umea.