Improving the stability of structural timber

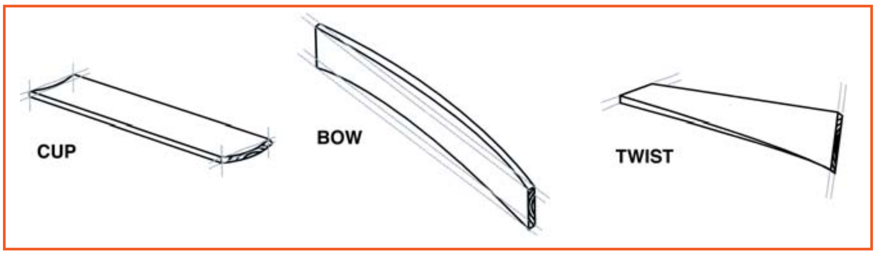
Michael Bourke[1]

- *Twist is the dominant form of distortion in fast-grown Sitka spruce. In excess of 35% of material may be downgraded on drying from 20% m.c. to 12% m.c. due to warp.*
- *Significant variation was observed with respect to radial location. There is a strong negative correlation between distance from pith and twist (R value up to – 0.8)*
- *Modified sawing patterns could greatly improve the predictability of performance of timber in service.*
- *The use of larger logs may be advisable for stable stud timber.*
- *Diverting core timber before further costly processing could yield significant benefits.*
- *Timber should be supplied at moisture content closer to actual operating conditions.*

A considerable effort has been made in Ireland over the last few decades to improve the quality of output of the sawmilling sector. Substantial investments were made in handling equipment, machining and especially kilns to produce timber capable of competing with imported material. In addition, operators were trained in quality assurance methods and licensed strength graders now operate under the authority of the National Standards Authority of Ireland (NSAI). Some of the larger mills have installed strength grading machines.

A significant proportion of the timber required for construction in Ireland is produced by a number of medium to large sawmills, sawn to standard dimensions and kiln-dried as specified in the relevant standard (IS 127). This standard sets a target mean of 20% moisture content (m.c.), with no piece to exceed 24%. Boards are either visually graded, in a process which takes into account known strength reducing characteristics such as knots, slope of grain, annual ring width and fissures, or mechanically strength graded. Permissible limits for the amount of warp are specified under a number of headings in the standard.

As houses are increasingly being heated to higher levels and thermally insulated, wood in many areas of the building will eventually equilibrate to less than 12% m.c. These changes cause timber shrinkage and are commonly manifested in gaps between timber floors and skirting boards, cracks in the plaster around door frames, between ceilings and walls, and unacceptable gaps



▲ Forms of distortion found in timber boards include:
Cup - a curvature across the width or face of a timber board;
Bow - a curvature along the length of a timber board;
Twist: a warp resulting from the turning of the ends of a timber board in the opposite direction (Woodspec 2001).

COFORD
Arena House
Arena Road
Sandyford
Dublin 18
Ireland
Telephone: +353 1 2130725
Email: info@coford.ie
http://www.coford.ie

[1] *Michael Bourke, Wood Technology Centre, Department of Materials Science, University of Limerick. Email: Michael.Bourke@ul.ie*

between floorboards. The most serious problems occur where the wood both shrinks and deviates from its original shape, that is significant warp occurs *in situ*.

This note reports the preliminary results from a study on Irish-grown Sitka spruce (*Picea sitchensis* (Bong.) Carr.), kiln-dried to 20% m.c., then conditioned to 12% m.c. The study is intended to describe and quantify the principal warp modes, assess the most important issues and propose strategies to improve efficiency in the production and application of the material.

Sitka spruce is the principal species grown in Ireland, covering in excess of 60% of planted land controlled by the semi-state company, Coillte (Anon. 1999), and a significant proportion of the newly emerging private forest plantations. The study is set in the context of expanding output, year on year, from the Irish forest resource. In order to ensure both economic and silvicultural efficiency, trees are removed from the forests at different stages of development, thus providing a range of log sizes suited to a variety of end uses. Recent figures indicate that pulpwood output will rise by 80%, from 835,000 m^3 to 1,508,000 m^3 by the year 2015 (Gallagher and O'Carroll 2001). The pulpwood increase will be of use to the wood-based panels sector, principally particleboard and MDF. Small sawlog shows the least dramatic increase, rising from 1,262,000 m^3 to 1,393,000 m^3. The large sawlog fraction is expected to increase by almost 40%, from 1,495,000 m^3 to 2,091,000 m^3 and this will have to be processed by the sawmills.

In order to maintain a financially viable forest products industry, it is necessary that each market for the various outputs is managed efficiently. Pulpwood prices are at the bottom end of the scale, while small sawlog typically sells as standing timber for considerably more. The highest prices are obtained for large sawlog and it is this sector which shows the greatest opportunity for development. However, producers of commercial timber are also subject to considerable challenges due to the inherent properties of fast-grown Sitka spruce and have to sell in direct competition with large scale, established Scandinavian companies.

The current standard for construction timber allows a 20% m.c., which is suitable for timber in contact with the external environment, but not for timber which equilibrates to interior conditions of temperature and relative humidity. At the 20% to 24% m.c. level little distortion is normally apparent. However, as moisture content drops with rising temperatures, distortion may occur.

The challenge for the future is to produce softwood timber at lower moisture contents, which will perform predictably in service, without significant distortion and at a competitive price.

Experimental Methods

In designing this part of the study, reference was made to work carried out for the Irish Forestry and Wildlife Service at the IIRS Forest Products Department (Picardo 1987). It was decided to obtain material from commercial sawmills, in dimensions which are typically used in the construction industry, dried to around 20% m.c. and stress graded to IS/EN standards. The intention was to get a substantial number of pieces, in batches of approximately 85 boards, from a typical forestry region. The timber sought was to represent three common yield classes (as near to Yield Class 16, 20 and 24 as was possible).

This batch size allows for a reasonable spread of characteristic properties, given the wide diversity observed in numerous studies and at 2 m^3 was capable of being dried in the experimental kiln at the University of Limerick as a single charge. Boards varying in length from 2.7 m to 3.6 m and of section size 150 mm x 44 mm were obtained.

Distortion measurements were made at the incoming moisture content and later after conditioning to 12%. A resistance-based meter was used to check moisture content initially.

A jig was designed to facilitate consistent evaluation of the various modes of distortion in the boards. This consisted of a table mounted on two steel I beams of substantial section size to give a level base (Figure 1). Datum points were determined by reference to blocks fixed to the table surface. One end of each board was clamped to the table, allowing the rest of the board to settle according to its shape. Individual measurements were made using a height gauge and a vernier calliper. Data regarding the x, y, z co-ordinates of each corner and of mid points was recorded. As specified in the standard (IS 127), measurements of the principal modes of distortion, bow, crook and twist were determined with respect to the worst 2 m portion of each board.

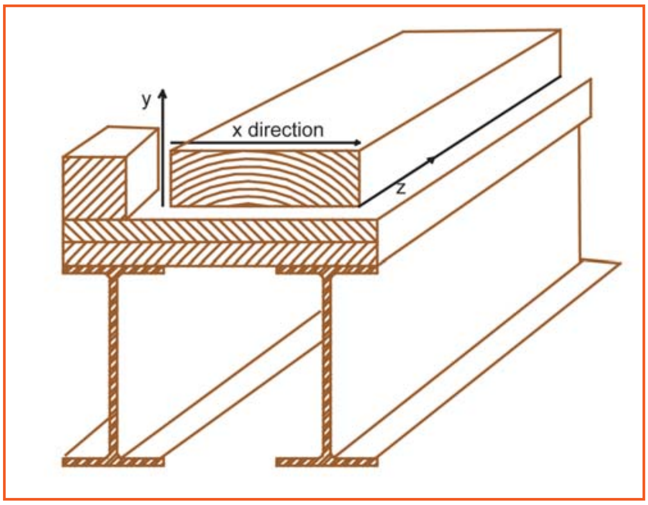


FIGURE 1: Jig to assess distortion.

Material conditioning

A mild schedule was used in order to minimise the influence of kiln drying defects on the timber, thus allowing any natural tendency towards distortion to develop. Over a number of days, the timber was brought to 12% m.c. After conditioning to this level, a second set of measurements was made on the same test jig and the corresponding data were compared.

Additional experimental data

To facilitate the acquisition of relevant additional data on features present, such as ring width, late-wood proportion, position relative to pith and compression wood presence, thin sections were sawn from each end of the boards, after drying to 12% m.c. These cross-section specimens were cut to 4 mm thickness and stored separately for further analysis. The incidence and extent of spiral grain present in fast-grown Sitka spruce requires more indepth study. This feature was not examined in great detail on these boards.

Stress testing

It was decided that stress testing to determine the stiffness (expressed as the modulus of elasticity (MOE)) of the boards would yield a greater understanding of the timber. A test rig was arranged according to EN 408 to perform these tests. Loading was applied in a four point bending arrangement.

Location with respect to pith

In order to estimate the position of each board with respect to its original location in the tree, a transparent template consisting of a semi-circle with concentric rings spaced 10 mm apart was used (Milota 2000). The 4 mm thick cross-section specimens were placed under the template and aligned with one of the concentric rings near the centre of the piece. The radius of curvature of this ring was used as the distance from the pith in the log. This facilitated the evaluation of material typically supplied from industrial sawmilling facilities.

The ring angle was estimated by keeping the wide face of the specimen parallel to the bottom edge of the template. The angle between the 0 degree line and a line from the origin through the centre of the sample was read. A reading of 0^0 indicates a flat sawn board, while at 90^0 the orientation is radial or quarter sawn.

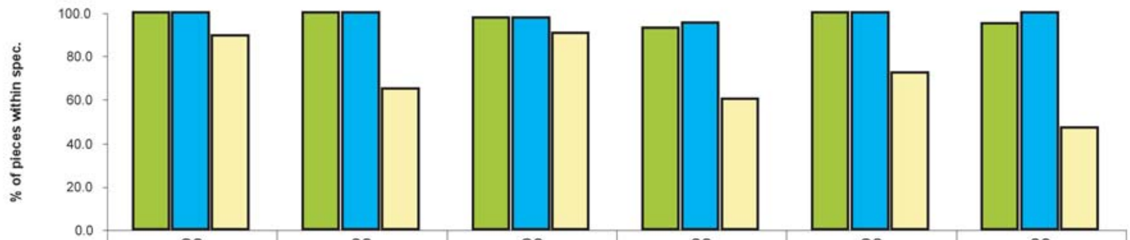
Results and Discussion

The standard IS 127 specifies limits for defects in structural timber, including the limits for distortion, listed in Table 1.

For the section size used in this study, the maximum permissible deviation due to twist is 12 mm for general structural (GS) and 6 mm for special structural (SS) material. The results in Figure 2 for all three batches, A, B and C clearly illustrate that the dominant mode of distortion is twist.

TABLE 1: Maximum permissible distortion over 2 m of length.

Type of Distortion	Grade GS (C18 and below)	Grade SS (above C18)
Bow	<= 20 mm	<= 10 mm
Spring (Crook)	<= 12 mm	<= 8 mm
Twist	<= 2 mm per 25 mm width	<= 1 mm per 25 mm width
Cup	No Restrictions	No Restrictions



	A		B		C	
	GS	SS	GS	SS	GS	SS
Bow	100.0	100.0	97.6	92.9	100.0	95.0
Crook	100.0	100.0	97.6	95.3	100.0	100.0
Twist	89.4	64.7	90.6	60.0	72.0	47.0

FIGURE 2: Grading to IS 127 regarding distortion characteristics at 12% m.c.

It was determined that almost all the boards were within specification for both bow and crook, even at the more stringent limits for SS. However, between 10% and 28% fell outside the GS limit and up to 53% failed to meet the SS grade as a result of their excessive twist. A useful indicator for likely behaviour under changing moisture content was found by examining the relationship between twist at 20% m.c. and at 12% m.c. Figure 3 gives the spread of data with least squares regression lines fitted for each series. The limits for warp allowed under the GS classification are quite high and it may be advisable for the processing industry to move to the more restrictive rules applied to SS timber for all timber intended for use in the interiors of buildings.

An examination was made, using the template described previously, to locate the position in the log of each board. The distance from pith to the centre of the specimens, from both ends of the boards was determined and an average value was computed. Figure 4 illustrates the concentration of defective boards around the core zone (hatched area of 75 mm diameter representing ~ 15 years growth) in batch A, while those sawn at a greater distance (in the right hand diagram) showed a much lower degree of twist.

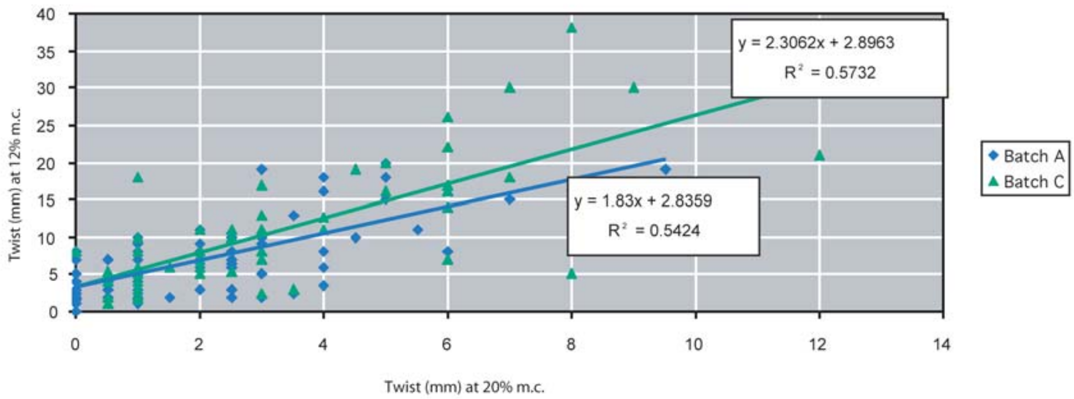


FIGURE 3: Distortion characteristics at 20% versus 12% m.c.

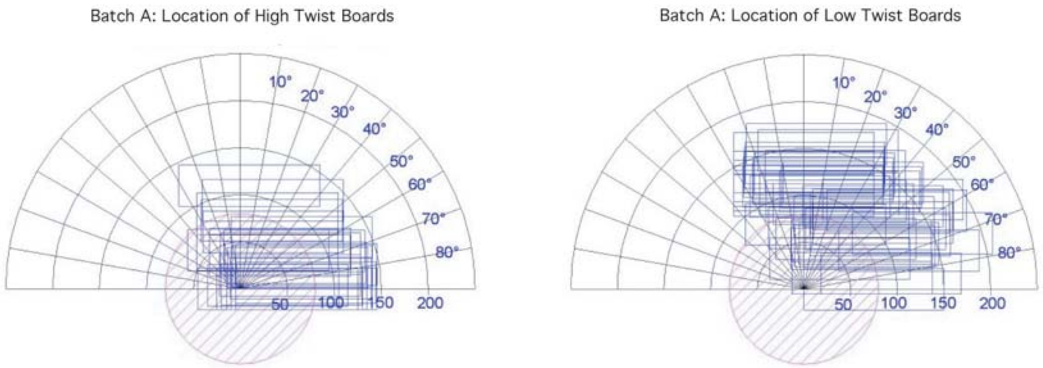


FIGURE 4: Location of boards relative to core.

The results in Figure 5 show a strong negative correlation between distance from pith and measured twist. The correlation coefficient (R value) for batch C is highest at -0.8, batch B is -0.72, while batch A is -0.68. This indicates that boards sawn at greater distance from the pith are considerably less prone to twist distortion. The relationship is in broad agreement with that suggested in a study of young British-grown Sitka spruce (Stevens and Johnston 1960).

The data in Figure 5 also point to the similarity between batches A and B, which is confirmed by reference to the mean diameter at breast height (DBH) data supplied by the forestry company. Batch C is a low yield class material, having taken 47 years to produce a 31 cm mean DBH stand, with an average annual ring width of 3.29 mm. The others produced larger diameter logs in a shorter time, giving an average annual ring width of approximately 4.8 mm.

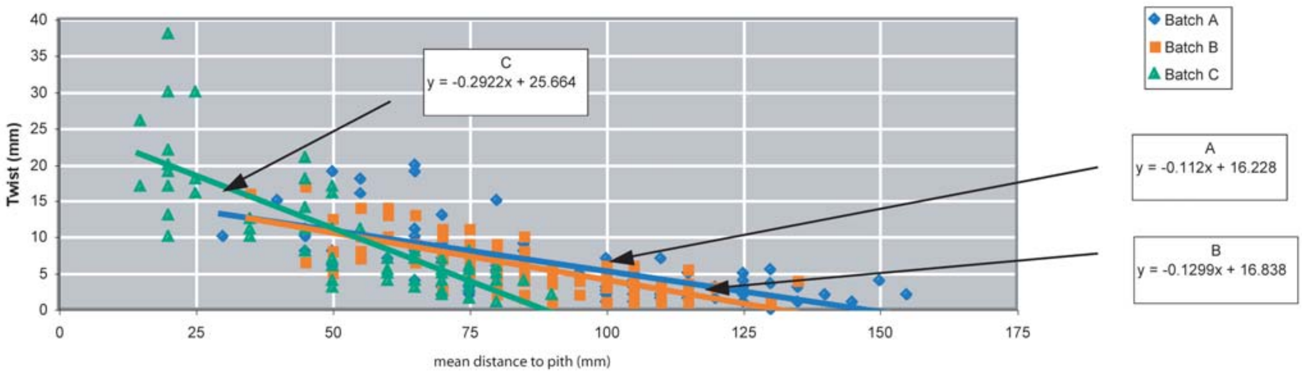


FIGURE 5: Relationship between twist and location in log.

Selection Model

By applying a filter to the data with a limitation on the distance from pith, it was possible to model the accuracy of this sawing pattern as a means of producing stable material. Table 2 lists the results, along with the corresponding values for MOE. It is evident that the boards showing greater stability also have higher stiffness properties, enhancing the value of this selection process.

It can be seen that the above model identifies between 80% and 90% of the material that will grade within the SS limitations. In the case of pieces incorrectly selected, none is beyond specification by more than one or two millimetres. Having selected this higher quality material, less processing time and energy could be applied to the fraction that would eventually perform badly. Lower quality boards could be diverted to uses where the need for geometric stability is not as great.

Conclusions

The work carried out to date, on distortion in timber from fast-grown Sitka spruce, dried to 12% m.c., points to twist as being the feature responsible for the highest level of degrade. It has been shown that the percentage still meeting the warp limits of the General Structural requirements drops to between 72% and 90% on drying to 12% m.c., due to twist distortion. For the more stringent Special Structural grade, or classes higher than C18, the percentage was between 47% and 65%. In relation to bow and crook, less than 10% of boards were downgraded. The loss was greatest in timber cut from smaller diameter logs from a low yield site.

An analysis of the location in the logs from which each board was sawn shows significant variation with respect to radial position. A strong negative correlation (R value as high as -0.8) was demonstrated between distance from the pith and the degree of twist that developed on further

TABLE 2: Using distance from pith to predict stable material.

	Batch		
	A	B	C
Total number of pieces	85	85	64
Mean twist (mm)	5.8	6	9.8
Number ‘in spec’ (SS)	55	52	30
Sort by this distance from pith (mm)	80	80	65
Number selected	53	54	29
Mean twist (mm)	3.5	4.2	4.5
Number ‘in spec’ (SS)	48	47	24
% correct	87	90	80
Mean MOE (MPa) full batch	9367	7475	9036
Mean MOE (MPa) ‘in spec’ (SS) pieces	9709	7672	9605
Mean MOE (MPa) ‘out of spec’ (SS) pieces	8859	7222	8319

drying. By restricting the area from which boards are cut with respect to pith, it would be possible to predict accurately between 80% and 90% of the material likely to remain stable. The influence of spiral grain on twist needs to be evaluated and will be part of the next stage of the study.

The use of larger logs may be appropriate to produce particular sizes of boards intended for use in timber frame and stud wall construction. The difficulties caused at the sawmill where logs are randomised by sorting simply on the basis of diameter and cut to produce the maximum rectangular section, mean that potentially useful knowledge regarding the most cost effective cutting patterns is lost. Further costly processing of material, which will subsequently fail to meet expectations, is a poor use of resources.

The importance of producing timber closer to the actual operating conditions was highlighted and it may be advisable to move to a specification of lower moisture content, in the 12% to 15% range, for timber intended for use in indoor conditions. The limits for warp applied to SS grade timber should be applied to such material.

Necessity for further development

Based on the findings of the work to date, a number of issues need to be addressed and the scope of the study should be extended. These include:

Models to improve stability based on sawing patterns

- The trends that were identified regarding warp development relative to the location in a log, and the prediction models suggested, will be validated on a larger sample of timber.
- Further refinement of the models will allow the development of revised sawing patterns for producing boards to industry standard dimensions.
- Producing timber at a distance from the pith will lead to an 'exclusion zone' of core timber and in practice, a square 'boxed' section will result. Models will be developed to determine an optimum size for this section, for a range of logs, with a spread of age classes, taking account of the economic implications.

Optimising core material

The issue identified above, as a key task requiring further research then becomes: how to deal with the core material. A number of strategies will be investigated. The main options centre around:

- grading out this timber for lower value applications;
- re-engineering the core wood to allow its use in higher value areas.

Spiral grain

The incidence and extent of spiral grain present in fast-grown Sitka spruce requires more indepth study. This feature was not examined in great detail on the boards sourced from commercial sawmills. Consideration will be given to getting access to full trees or logs from known sources, which can be assessed for spiral grain under bark, prior to sawing. The sawmilling industry has no formal mechanisms in place to identify and reject logs showing moderate spiral grain, prior to processing.

The goal of the extended study is to produce an integrated suite of strategies to enable the production of solid timber components for building construction, which will remain geometrically stable at low moisture content.

Acknowledgements

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