Stability properties and performance of Douglas-fir and comparison with radiata pine

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Abstract: In this study, stability properties of Douglas fir and radiata pine were measured with small clear samples and stability performance of their timber of 100x50 mm were measured in a commercial sawmill. The samples were prepared from 31 Douglas logs and 31 radiata pine logs which were cut from 9 Douglas fir trees and 13 radiata pine trees, respectively. The small clear samples were prepared from disks cut from both ends of the log from which the full scale timber was sawn. For the small clear sample studies, variation of shrinkage within and between trees was studied for the three directions (radial, tangential and longitudinal), moisture related dimensional swelling rates were obtained at 20 °C under water bath condition. For the full timber studies, dimensions and weights of each board were measured both before and after drying and distortion in terms of bow, spring and twist was measured after drying.

The results confirmed that Douglas fir has lower longitudinal shrinkage in corewood and much less distortion than radiate pine although there is significant variability in the shrinkage for both of the Douglas fir and radiate pine. Douglas fir showed much better water repellency properties than radiata pine. The corewood was believed to be the main reason that caused the shrinkage variability, which is also consistent with excessive spring and bow with the full-sized timber where the corewood proportion is high. However, the influence of the tree height within a log is minimum. Variation between trees was also found to be significant for both of the species. This study shows that there was a necessity to sort the timber based on the corewood proportion before drying thus different drying schedules can be used.

Key word: Douglas fir timber, dimensional swelling, shape stability, corewood proportion, drying

1 Introduction

Douglas-fir is a highly regarded and preferred structural timber for its superior strength, durability and decay resistance. Douglas-fir is also claimed to have uniform properties and thus to be more stable compared to radiata pine. Spring, bow and twist are the basic modes of distortion for structural timber. Spring and bow are mainly influenced by variation in longitudinal shrinkage, spiral grain, curvature of growth ring, moisture content and drying process. Parameters that have effects on twist are distance from the pith, spiral grain angle, shrinkage and moisture content (MC).

Although Douglas fir has a great application opportunity in structure, its potential has not been realised due to an apparent lack of detailed data on the wood properties of the NZ grown Douglas-fir. A trial was undertaken by Turner (2007) to compare the relative stability of stud-length samples of 100x50 mm radiata pine and Douglas fir when subjected to a number of wetting and drying cycles. The trial confirmed the better stability of Douglas-fir in terms of moisture content changes and timber distortion. It also confirmed that radiata pine gains and loses moisture more rapidly during the humidity cycling and shows higher distortion compared to Douglas fir. Johansson (2002) reported that grain angle and annual ring curvature could explain 73% of the variation in the twist.

In order to obtain deeper understanding of the stability of Douglas fir and to compare with radiata pine, a project was initiated through the Douglas-fir Association and the Wood Technology Research Centre at the University of Canterbury, and sponsored by the Douglas fir Association and Technology New Zealand, which is also supported by Sutherland & Company. The purpose of this study was to evaluate the dimensional and shape stability of Douglas-fir timber after drying and compare with those of radiata pine timber. Small clear wood samples were used to evaluate the variation of shrinkage in this study and the results were then used to explain the stability of full-sized timbers.

2 Materials and Methods

2.1 Materials

Nine Douglas fir trees and thirteen radiata pine trees were cut from South Canterbury forests owned by Selwyn Plantation Board Ltd. Then, the stems were cut into 5.1m long logs with disks of about 200mm long removed between adjacent logs. The 200 mm dicks were then sent to the Wood Technology Lab at the University of Canterbury for small clear sample preparation and the 4.9 m long logs were transferred to Sutherland & Company for full size timber study. In the clear sample studies, only disks with centralised pith were used (7 disks for radiata pine and 3 for Douglas-fir).

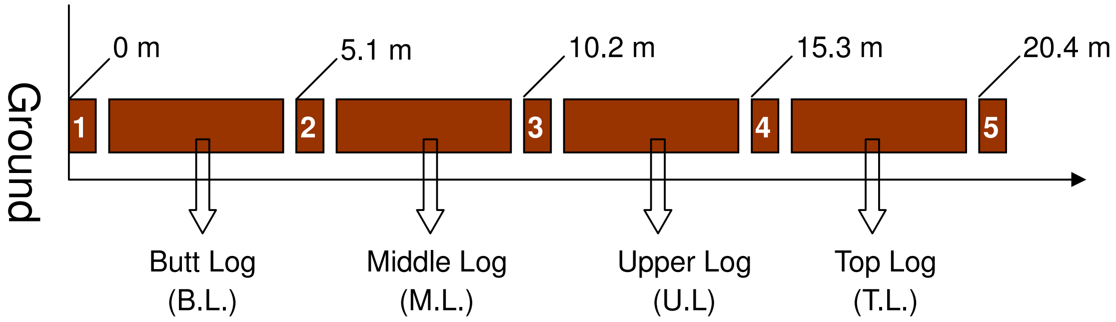


Fig.1 Vertical position of wood disc within tree

In the small sample preparation, four 50mm-wide strips were first cut out from each disc through the pith along the directions of North-South and East-West, respectively. After this cutting, the strips were cut into 515 samples of 120×30×20mm (longitudinal × tangential × radial) for measurement of wood stability properties including shrinkage and equilibrium moisture content.

In the full size timber studies, log ends were painted with different colours to identify the corewood (within 7th growth rings), outer wood (from 15th growth rings to the bark) and transition wood between these two categories as shown in Fig.2. The log's ID with information on its tree number and log height within the log were also recorded. After the colouring, the logs were cut using the commercial sawing practice to the timber with nominal dimensions of 100mm by 50mm with the sawing pattern showed in Fig.2. The timber was finally classified based on the corewood proportion (Table 1) for each timber which was used later for distortion analysis. CP (Corewood Proportion, %) is defined as the ratio of corewood area to the whole end cross-section area. All timbers were classified into four categories as shown in Table 1 and the results are given in Table 2.

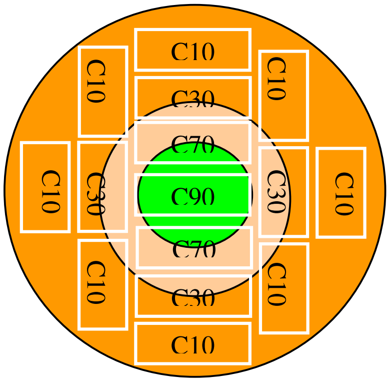


Fig.2 Sawing Pattern and colouring

Table 1. Classification of timber by CP

Group	CP / %
C90	>90%
C70	60%～90%
C30	30%～60%
C10	<30%

Table 2. Summary of timber classification for full size timber used in this study

Species	No. of stems	No. of logs	Number of timber of 4800mm*100mm*50mm (pieces)				
			C90	C70	C30	C10	Sum
Douglas-fir	9	31	22	53	75	52	202
Radiata Pine	13	31	31	56	59	12	158

2.2 Determination of shrinkage and distortion for full size timber studies

After sawing, dimensions of each green board (width, thickness and length) were measured at three points along the board length. Moisture content of Douglas fir was also measured using a capacitance type of moisture content meter. The green moisture content of radiata pine was unable to be measured as its values were out of the meter's measurement range. Then the timbers for this study were stacked in the bottom part of a full size stack to minimize the uneven constraint load between the stack top and the bottom. The timbers were dried in a commercial kiln with dry-bulb temperature of 75℃ and wet-bulb temperature of 61℃ for 20 h. In this period of drying, the Douglas fir timbers were dried from an average MC of 33.3% to an average MC of 18.4%. As the MC of radiata pine timber was higher and uneven, the radiata pine timbers were moved to dehumidification kiln and seasoned for another 2 more days. Then, all timbers of Douglas fir and radiata pine were equalized in a covered area for 7 days before the measurements were taken.

After the equalization, dimensions (width, thickness, length) and weight of each board were measured for shrinkage and moisture content. Board distortion of bow, spring and twist was also determined at the same time. Spring was measured with the board laying flat and the bow was measured with the board laying with the edges contacting the measuring table. In this way, the board weight had minimum effect. The timbers were graded according to distortion tolerances as shown in Table 3, which was designed based on others researches (Cai, 2007; Tarvainen, 2005; Pertorper, *et al.*, 2001; Haslett *et al.*, 1991). Timbers with Grade A have excellent shape stability while those with Grade D show the excessive distortion and should be rejected.

Table 3. Distortion tolerances (mm) and grading

Grade	A	B	C	D
Spring	≤5	5～15	15～30	>30
Bow	≤10	10～20	20～30	>30
Twist	≤5	5～10	10～20	>20

2.3 Determination of shrinkage and equilibrium moisture content for small clear sample studies

From the disks, 515 small samples were prepared. These samples were equalised in a conditioning chamber at a temperature of 30℃. The relative humidity (RH) was initially decreased from high to low in steps at 80%, 60%, 45% and 35%, respectively. Initially, the sample weights were checked every day and it was found the two weeks were sufficient for the samples to reach a stable weight thus in the following RH settings the equalization duration was controlled for two weeks. For each RH, dimensions and weight were measured to calculate the equilibrium moisture content (EMC) and shrinkage in longitudinal, tangential and radial directions. After the last step (lowest RH), the samples were dried at 103℃ for 24 hours to determine the oven-dried weight and dimensions.

2.4 Determination of water swelling rate for small clear sample studies

After completion of basic wood property experiment, an additional water resistant property experiment for both Douglas-fir and radiata pine was tested. 12 shrinkage samples (120×30×20mm) were selected from 5.1 meter high position of each species, representing corewood and outer wood. Water swelling rate was measured in longitudinal, tangential and radial directions, respectively. The samples were placed into three stainless steel frames and immersed under the water bath at controlled temperature of 20 ^{o}C. Dimensions (longitudinal, tangential and radial) were measured in each hour at first 2 hours period, then in every 6 hours during the following 12 hour period, and then in every 12 hours in the next 4 day period.

3 Results and Discussion

3.1 Shrinkage properties from small clear wood samples

The wood shrinkage from green values with moisture content to the values at oven dry is analysed and presented in this report. Variations of the shrinkage properties at oven dry within tree are illustrated in Fig.3 for Douglas-fir and in Fig.4 for radiata pine. For the two species, the longitudinal shrinkage decreased from pith to bark, while tangential and radial shrinkage increased from pith to bark. The longitudinal shrinkage of the bottom disc (termed as 0 m) was much larger than those of other positions although this difference for Douglas-fir was less than that for radiata pine. The difference of the tangential and radial shrinkage between the discs of different height locations was not consistent although the bottom discs tended to be lower than other discs in the outerwood and transition wood.

The longitudinal shrinkage variations along the cross section radius from pith to bark were largest near the pith or corewood area, where spiral grain angle and microfibril angle are high in radiata pine as reported by Cown et al. (1991) and Donaldson (1992, 1993). However, the lower variation in longitudinal shrinkage with the tree height is explained by the microfibril angle change as Cown *at al.* (1991) reported an increase of the spiral grain with the tree height reaching a maximum at 11 m above the ground.

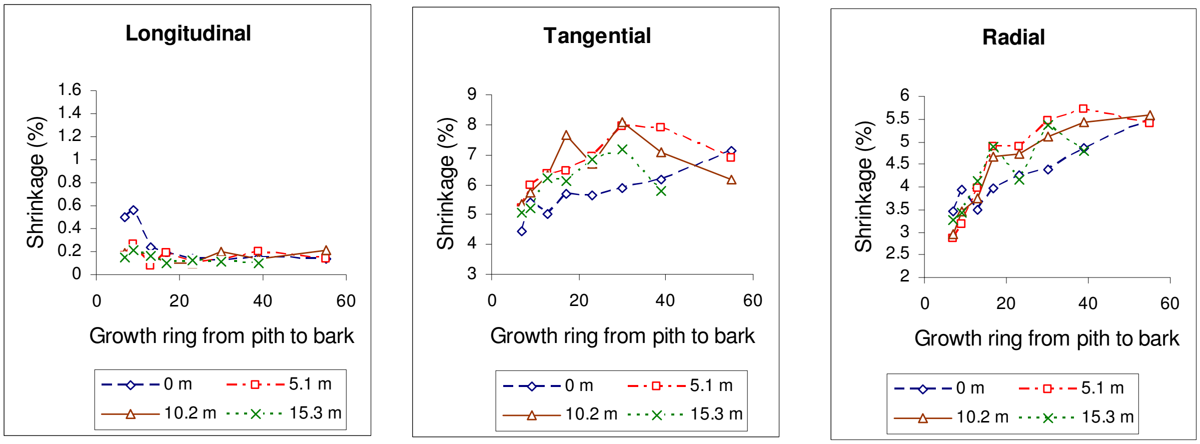


Fig.3 Variation of oven dry shrinkage rate for Douglas-Fir wood

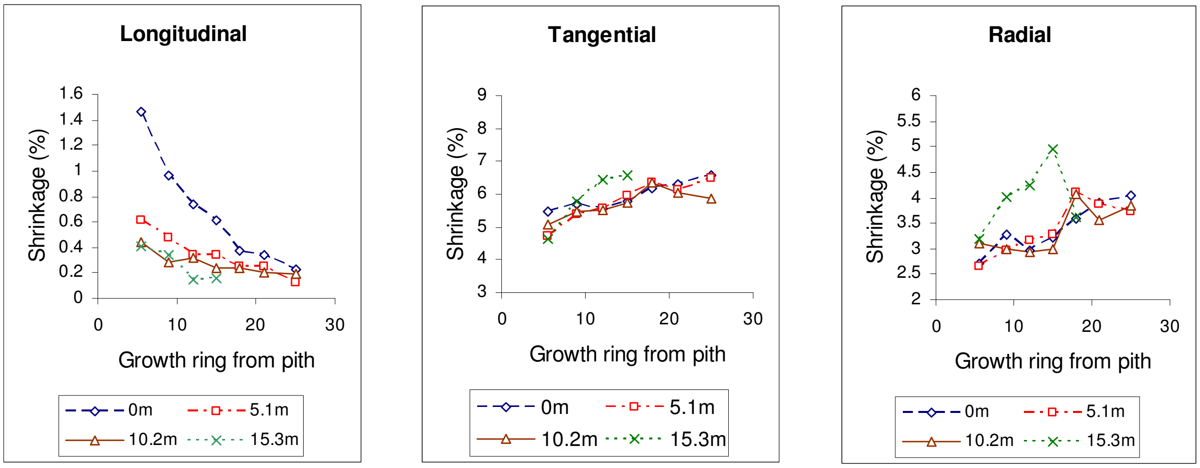


Fig.4 Variation of oven dry shrinkage rate for radiata pine wood

Two important points have been found from this study:

- The Douglas fir has much lower longitudinal shrinkage than radiata pine. Except for the bottom disc (D#1), the average longitudinal shrinkage for Douglas fir is less than 0.3% and 80% samples are between 0.1% and 0.2% whereas most of the radiata pine samples have the longitudinal shrinkage between 0.2% and 0.4%.
- The disc#1 has higher longitudinal shrinkage in the corewood and transition wood with values for Douglas fir from 0.4% to 1% and radiata pine from 0.8% to 1.9%.

In the experiment, it was observed that the width of each growth ring of the radiata pine was larger than that of Douglas-fir, thus the small clear samples of the radiata pine contained less growth rings than those of the Douglas-fir. In this way, the corewood samples in the Douglas fir may contain some transition wood thus the shrinkage variation is flattened to certain extent.

3.2 Swelling in water

The swelling rate of Douglas-fir and radiata pine wood in water bath condition was obtained in this study. Water repellency property was tested in a temperature controlled water bath for both Douglas-fir and radiata pine. It can be seen in Fig. 5 and Fig. 6 for the two species, the tangential and radial swelling rates increased rapidly in the first 2 hours, and then gradually reached their maximum swelling rates. The variation of longitudinal swelling rates for both species was not generally wide.

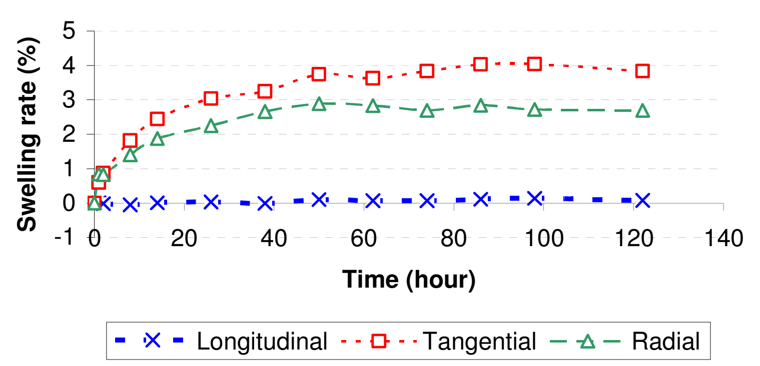


Fig. 5 Swelling profile of Douglas-fir samples in water bath, at 20°C

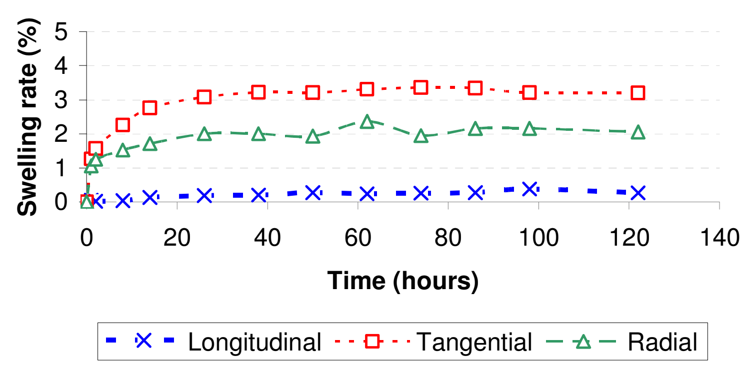


Fig. 6 Swelling profile of radiata pine samples in water bath, at 20°C

The demanding time for Douglas-fir samples to get to maximum swelling rate under water bath condition was over 48 hours, while it only took less than 24 hours for radiata pine samples to obtain the maximum value. This result was expected as Douglas-fir performed better water repellency property than radiata pine.

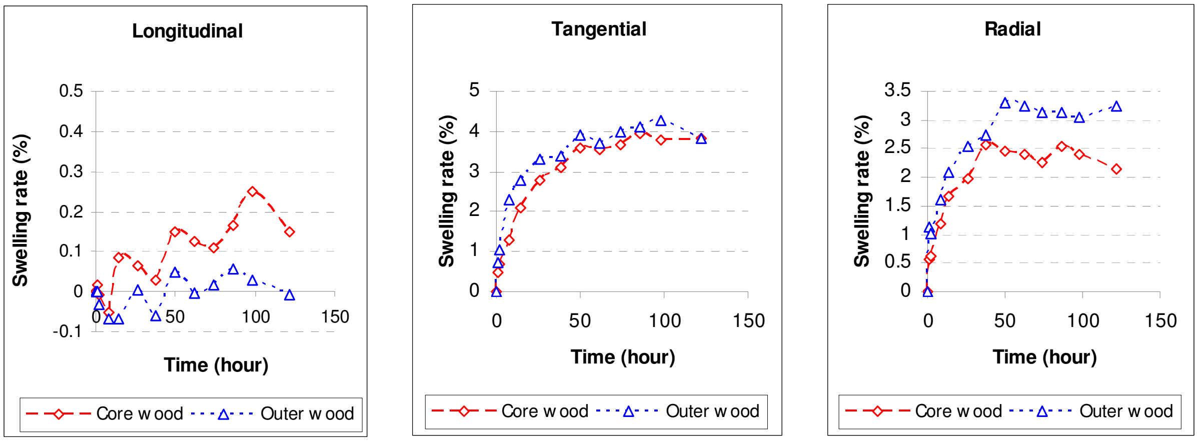


Fig.7 Water swelling rate for Douglas-fir

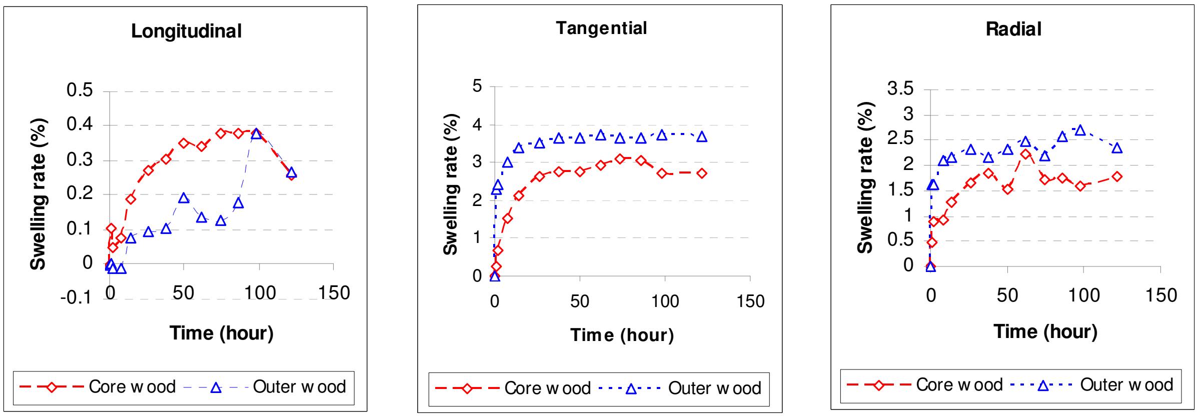


Fig.8 Water swelling rate for radiata pine

For two species (Fig. 7 and Fig.8), outer wood tended to swell more in tangential and radial directions, while it showed lower longitudinal swelling rate than core wood. The reason for this would be, similar as presented in previous shrinkage properties section, higher spiral grain and microfibril angle in corewood area. Longitudinal swelling was showing consistent raising trend within a narrow scope over a period of time, even when tangential and radial swelling had achieved maximum values. The maximum swelling rates in tangential and radial direction for Douglas-fir were around 4% and 3 %, respectively. These values were slightly higher than those for radiata pine (3.2% and 2.1%).

Important points to be considered in this study:

- Douglas-Fir absorbs less water than R-Pine in water immersion, although longer term swelling of Douglas-Fir was higher than Radiata pine in radial and tangential directions.
- Core wood has higher longitudinal swelling rate and lower tangential/radial swelling rate than outer wood.
- Longitudinal swelling of both Douglas-Fir and Radiata pine tends to keep increasing with elapsed time.

3.3 Dimensional stability of full-sized timber

Table 4 illustrates the tangential and radial shrinkage obtained from full-sized Douglas-fir and radiata pine timbers. The flatsawn and quarter sawn timbers were identified based on the ring orientation of most growth rings over the end sections. The tangential and radial shrinkage obtained from the flat-sawn timber both increased with the decrease of the corewood proportion which can be traced to the local shrinkage variation in radius direction. However, no clear trend was found with the quarter-sawn timber possibly due to the larger number of growth rings contained in the quarter sawn timber thus the variation in the radius direction was smoothed out.

Table 4. Shrinkage of Douglas-fir and radiata pine full-sized timber

Species	Group	Flat-sawn timber			Quarter-sawn timber		
		MC (%)	TS (%)*	RS (%)**	MC (%)	TS (%)*	RS (%)**
Douglas-fir	C90	14.4(0.89)	1.58(0.59)	1.60(0.58)	16.0(1.21)	1.78(0.73)	1.80(1.09)
	C70	15.1(0.97)	1.85(0.35)	1.80(0.30)	15.1(1.35)	1.31(0.26)	1.10(0.20)
	C30	15.0(1.32)	1.82(0.35)	1.70(0.35)	16.1(0.36)	1.44(0.41)	1.21(0.26)
	C10	16.2(1.31)	1.95(0.24)	1.71(0.27)	15.6(0.07)	1.78(0.32)	1.51(0.35)
Radiata pine	C90	10.8(0.74)	1.89(0.54)	1.76(0.40)	11.3(0.31)	2.01(0.71)	1.88(0.23)
	C70	11.1(0.70)	2.23(0.39)	2.17(0.39)	11.4(0.66)	1.84(0.23)	1.73(0.25)
	C30	11.5(1.09)	2.40(0.48)	2.22(0.42)	12.0(0.09)	1.90(0.54)	1.78(0.56)
	C10	11.1(0.66)	2.82(0.53)	2.35(0.56)	11.2(0.12)	2.20(0.27)	1.70(0.20)

**TS: Tangential shrinkage* ***RS: Radial shrinkage*

Note: Numbers in brackets are standard deviation.

3.4 Shape stability of full-sized timbers

3.4.1 Distribution of distortion

The distortion results are shown in Figs.9 to 11. In Figs. 9 and 10, the bow, spring and twists of all of the timbers as a function of moisture content are shown, while in Fig. 11, the proportion of each grade is illustrated. From these results, it is clearly shown that Douglas-fir timbers were straighter with lower levels of distortion than radiata pine timbers at similar final moisture content. Percentage of grade D was 2.4% for Douglas-fir, while the corresponding value for radiata pine was 49.5%. This difference can be related to the difference in the longitudinal shrinkage and the shrinkage variations between these two species. As mentioned in Section 3.1, the narrow growth ring in the Douglas fir also contributes to the better stability performance. Though the diameters of log were almost the same for logs of two species, the age of Douglas-fir tree was 60 years old whereas that of radiata tree was 27 years old thus there were more mature wood in the former than in the later.

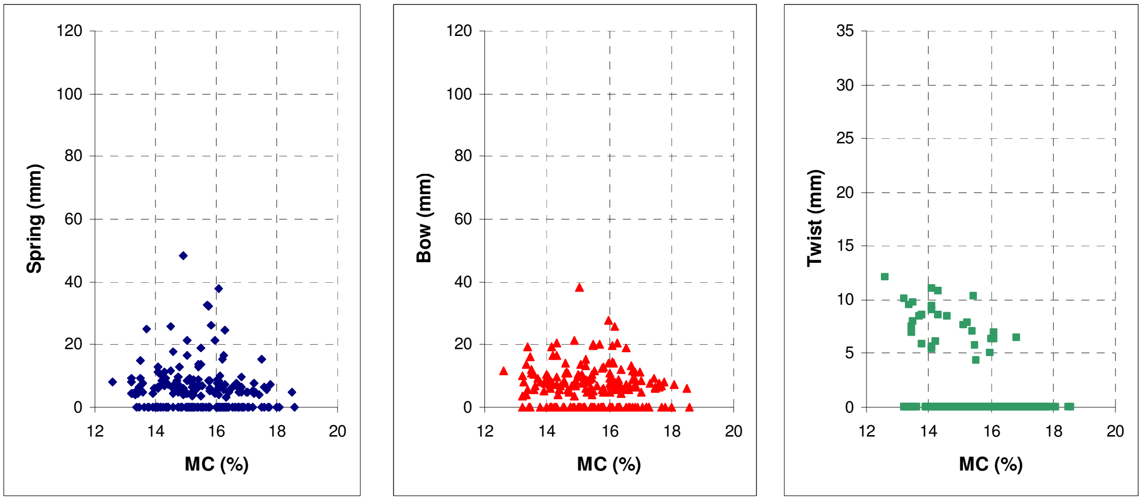


Fig.9 Spring/Bow/Twist of full-sized Douglas fir timber

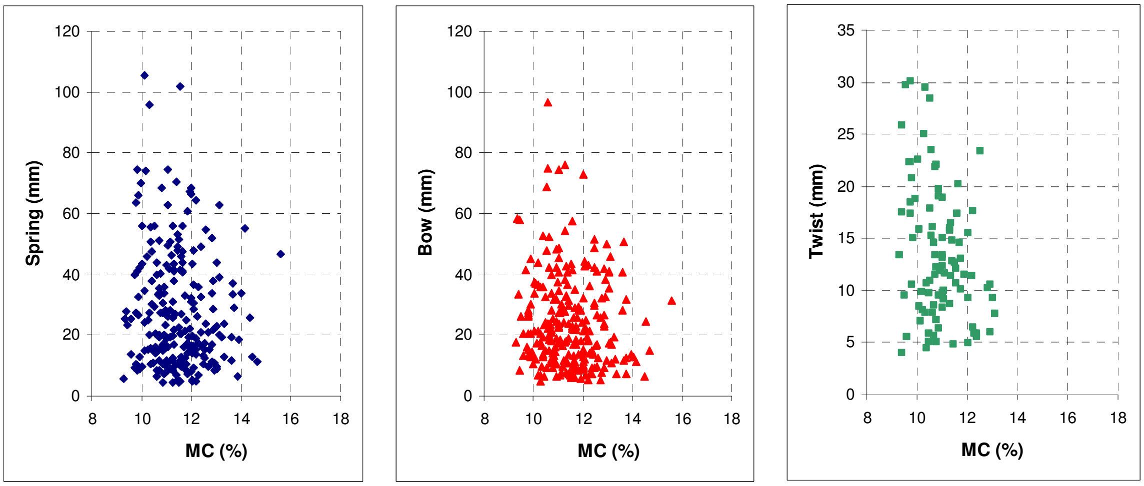


Fig.10 Spring/Bow/Twist of full-sized radiata pine timber

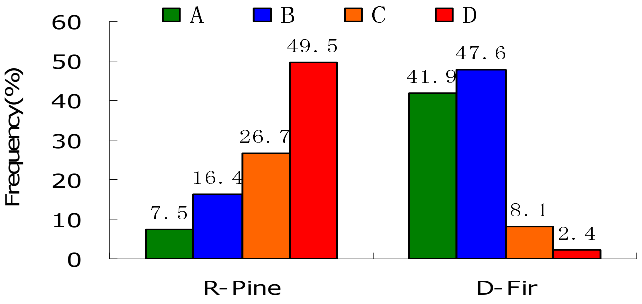


Fig.11. Grading of timber according to distortion tolerance

It is interesting to note from Fig.9 that the final MC for Douglas fir in the range of 13 – 18% did not have significant impact on the distortion although a trend was observed for radiata pine Fig 10 where MC in the range of 9 – 15% shows distortion increasing with decrease in the moisture content.

Further analysis of the timber distortion by individual categories (bow, spring, twist) is shown in Fig.12. The analysis results show that excessive spring and twist are the main reasons for the distortion rejection for radiata pine but the bow and spring are more significant for Douglas fir. The bow and spring distortion is closely related to the longitudinal shrinkage and its variability as shown in Fig.3 and Fig.4. The twist is more influenced by spiral grain angle which was not investigated in this study.

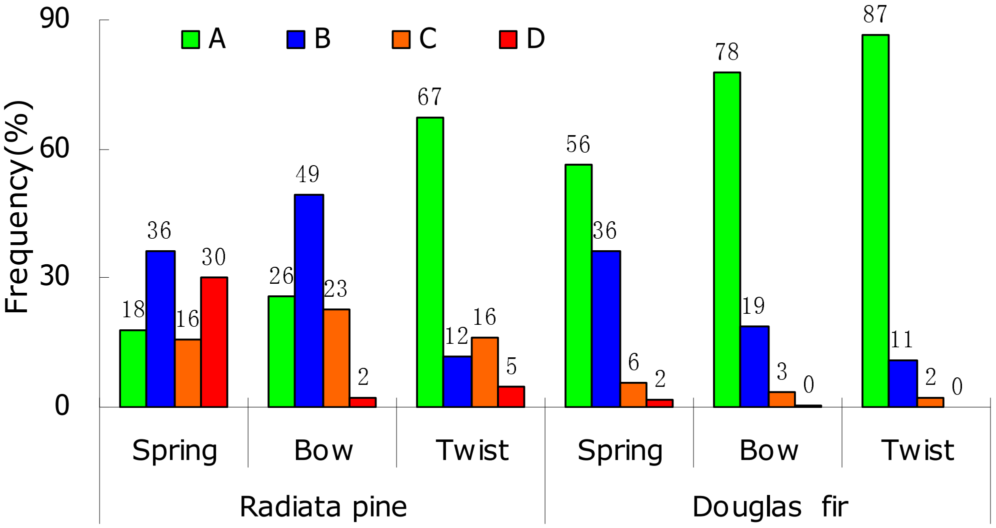


Fig.12. Distribution of different distortion parameters for radiata pine and Douglas-fir timber

Haslett (1991) reported that twist was the most serious distortion concern for 25-year-old radiata pine during high temperature drying. However, spring was the most significant factor in this study which may be due to the fact that the twist tolerance is set to be higher in this study than practical requirement by customers in the market. However, such information is not available in the public domain. Another possible reason for the lower twist distortion in this study is the position of the timbers in the stack (bottom) during drying. Oja (2006) reported that timbers in upper part of the stack had greater twist than those in lower part due to the difference in the constraint load.

3.4.2 Variation of distortion between trees

Results of shape stability performance of timbers from each tree were shown in Table 5 for Douglas-fir and in Table 6 for radiata pine. The proportion of various distortion parameters in each tree is shown in Fig.9. For the results, it is found that the distortion varies significantly between trees for both species. For Douglas-fir, timbers from trees S8 and S11 show excellent shape stability with all of the timber falling into Grade A (53%) and Grade B (47%) while timbers from tree S9 had excessive distortion with 44% of the timbers falling to Grade C (19%) and Grade D (25%). For radiata pine, timbers from tree L4 showed the good stability performance with the 21% Grade A, 45% Grade B and 34% Grade C. It is most noticeable that for radiata pine, most of the trees did not produce Grade A timber and small proportion of Grade B timber although trees L5, L12 and L10 were the worst with the Grade D timber proportion being 85%, 80% and 65%, respectively. The between-tree variation in the distortion is related to the variations of shrinkage characteristics as well as other properties such as spiral grain angle. Cown (1992) reported that the spiral grain angle varied greatly between trees for radiata pine.

Table 5. Number of each grade timber for different Douglas-fir trees

Douglas-fir tree IDs	S1	S3	S8	S9	S10	S11	S12	S13	S14	SUM
A	14	1	18	2	5	10	0	11	27	88
B	7	15	16	7	8	10	6	11	20	100
C	2	5	0	3	1	0	1	2	3	17
D	0	0	0	4	0	0	1	0	0	5
SUM	23	21	34	16	14	20	8	24	50	210

Table 6. Number of each grade timber for different radiata pine trees

Radiata pine tree IDs	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	SUM
A	2	1	1	6	0	0	0	0	0	0	0	0	1	11
B	2	2	0	13	0	1	1	1	4	0	2	0	2	28
C	3	3	4	10	1	7	2	2	1	2	6	3	4	48
D	11	5	2	0	7	10	8	3	10	4	6	11	14	91
SUM	18	11	7	29	8	18	11	6	15	6	14	14	21	178

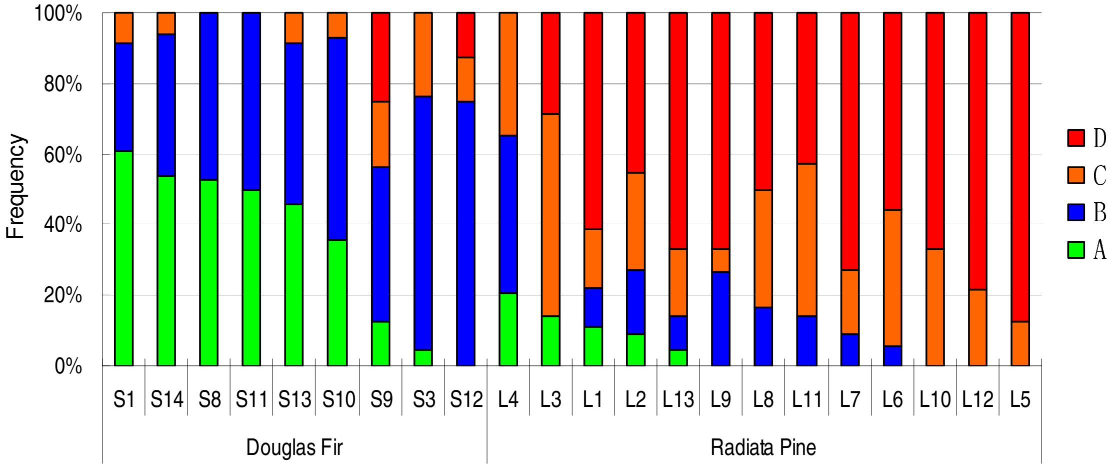
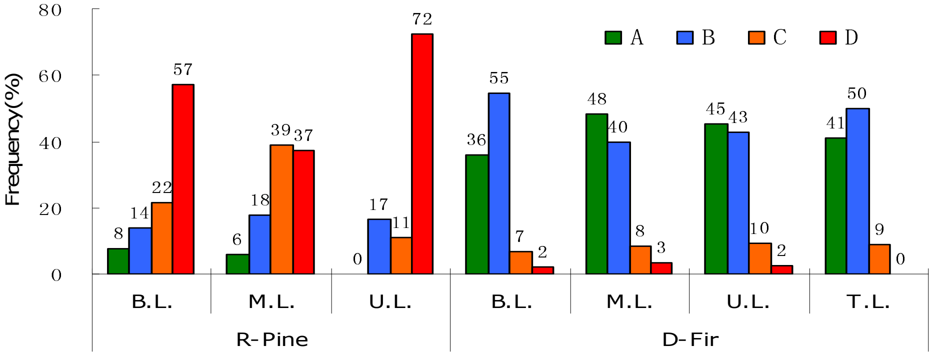


Fig.13 Grade distribution (frequency, %) of timber within a tree and between trees

3.4.3 Effect of vertical position within tree on timber distortion

From the shrinkage distribution within a log and variation with tree height as shown in Fig. 3 and Fig.4, it was expected that the timbers cut from butt log should have more serious distortion rejections, however, this trend is not significant as shown in Fig.14. For radiata pine, the combined Grades C and D timbers from butt logs are 79% compared to 76% for the medium height logs (second logs) and 72% for the upper logs. The corresponding values for Douglas-fir are 9% for the butt logs, 11% for the second logs, 12% for the third logs and 9% for the top logs. These trends do not have practical significance thus the tree height influence can be ignored.

In fact, the difference may be caused by variation between trees as described in Section 3.4.2. As shown in Table 7, Douglas-fir tree S14 shows a different trend in terms of tree height effect compared to other trees. From Table 7, the proportion of Grade A timbers were 63.2% for the butt logs, 54.6% for the second logs, 40% for the third logs and 50% for the top logs. However, other trees did not show such trend that the butt logs produced more Grade A timber. Some trees even showed the opposite trend with the butt logs having the lowest stability. Therefore, shrinkage alone is not sufficient to quantify the distortion trend. Shrinkage variation and spiral grain angle can play an important role in the timber distortion. Based on the current study results, tree height is not recommended as a criterion for log sorting.



Note: B.L. —Butt Log M.L. —Middle Log
U.L. —Upper Log T.L. —Top Log

Fig.14 Effect of log sites in tree on distortion

Tab.7 Effect of log sites on distortion in tree S14

Grade	Butt log	Middle log	Upper log	Top log	Sum
A	12(63.2)	6(54.6)	4(40.0)	5(50.0)	27
B	7(36.8)	5(45.6)	4(40.0)	4(40.0)	20
C	0(0.0)	0(0.0)	2(20.0)	1(10.0)	3
D	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0
Sum	19	11	10	10	50

3.4.4 Effect of corewood proportion on shape stability

The distribution of timber grades as a function of corewood proportion is shown in Fig.15 which confirmed a clear trend that high corewood proportion has negative impact on the timber stability. The timber quality degradation caused by the distortion worsened with the increase of the corewood proportion. This can be explained by combined effect of high longitudinal shrinkage, shrinkage variability and high spiral grain angle in the corewood. This result confirmed that the corewood proportion could be used as a criterion for timber sorting before drying to reduce the degradation caused by distortion. Special drying technology should be adopted for the timber with high corewood proportion.

Fig.16 illustrates the effects of corewood proportion on different modes of distortion. For Douglas fir, it seems that spring and bow correlated to the corewood proportion with high level of significance while twist does not show the obvious correlation. For radiata pine, bow and twist show significant correlation to the corewood proportion but the spring does not show such correlation.

Monge (2000) reported that twist was highly correlated to the distance from pith and the ratio of grain angle to pith was a good parameter for twist prediction. However, only radiata pine supports this argument whereas Douglas-fir does not show such correlation.

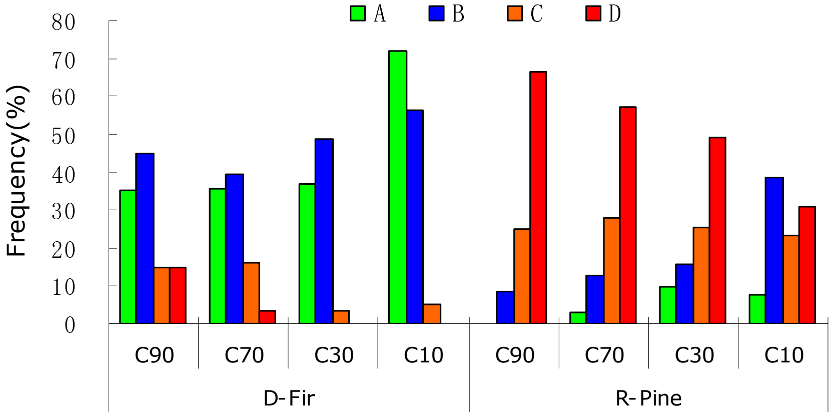


Fig15. Effect of CP on Distortion of Douglas-fir Timber and Radiata pine Timber

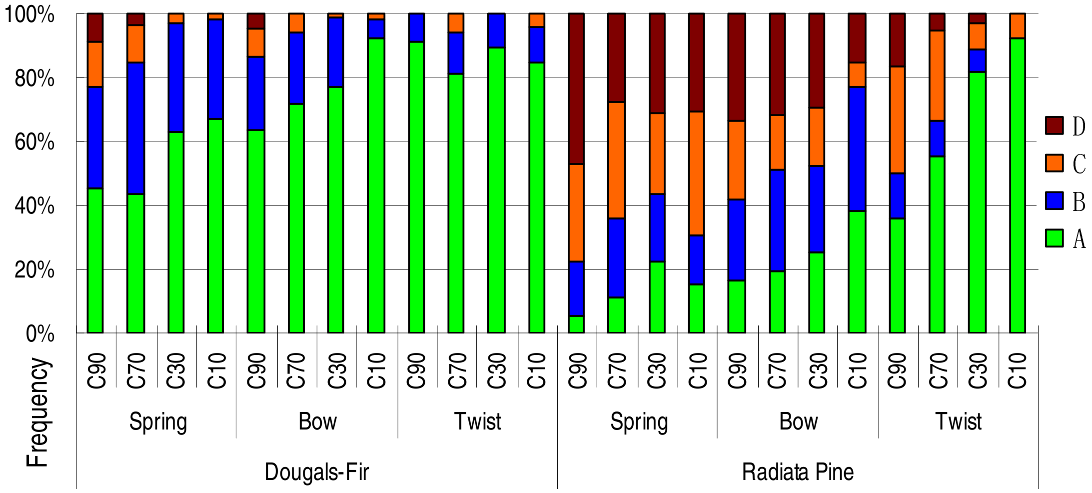


Fig.16. Effect of CP on spring/bow/twist

4 Conclusions

Dimensional shape stability of Douglas-fir wood were investigated and compared with radiata pine in this study for 100×50mm timber. The results show that Douglas fir has better shape stability than radiata pine, which is due to the difference in shrinkage properties obtained from small clear wood samples. Because of the various proportion of corewood wood, the shrinkage varied greatly in longitudinal and radial directions for the two species. This variation caused the difference of distortion between corewood, outerwood and transition wood, but the difference between butt log, middle log and top log is inconsistent. Therefore, it is recommended that the corewood proportion to be a criterion for the timber pre-sorting. Variation of stability performance between trees was also found to be significant for the two species, and methods needed to be developed for log sorting as well to reduce the timber distortion degradation.

5. Acknowledgements

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