Comparative study of stability between New Zealand grown Douglas-fir and radiata pine structural timber when subjected to moisture cycling

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Report No. 53, February 2007

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ABSTRACT

A trial was undertaken to compare the relative stability of stud-length samples of 4x2 radiata pine and Douglas fir when subjected to a number of wetting and drying cycles. Samples of Douglas-fir, both green and dry, and kiln-dried radiata pine, were obtained from one Central North Island and two South Island sources representing a typical mix of frame 1 grade for each resource.

Each stud sample was weighed and then scanned for any initial distortion using the Ensis ‘Warpmaster’. Samples were then positioned individually in a rack so they were free to move while equilibrating, and in the case of the green studs while air drying. When the green Douglas-fir samples reached approximately 15% MC, all samples were remeasured for weight and distortion. Samples were then given a 1 hour soak in water to simulate rain wetting and remeasured for weight and distortion. This sequence was repeated a second time after redrying the samples to approximately 15%. Distortion levels between samples for each measurement period were compared.

The trial confirmed the ‘refractory’ reputation of Douglas-fir, and the ‘absorbent’ reputation of radiata pine. During the wetting/drying cycles, the radiata pine absorbed 3 to 4 times more water than the Douglas-fir. The soaking period confirmed previous findings that at a practical level, Douglas-fir heartwood and sapwood can be regarded as equally impermeable, independent of where it is grown in New Zealand (Hedley et.al. 2004).

Increases in timber warp during the course of the trial were greater in green Douglas-fir than in either dried Douglas-fir or kiln-dried radiata pine. The increased warp for green Douglas-fir occurred during the initial two-month period of drying rather than in the subsequent wetting/drying cycles.

As a result of repeated wetting/drying cycles, the greater permeability and water uptake of radiata pine led to greater timber movement and warp when compared with Douglas-fir. However, the difference in level of movement between the two species induced by these cycles was small, being generally less than 1mm per stud length (1.5mm for bow).

INTRODUCTION

There is a perception in the building trade that Douglas-fir framing remains more stable (straighter) during construction both while drying to equilibrium moisture content (if erected green) or when erected dry, than kiln dried radiata pine.

Although both timbers differ little in water uptake to fibre saturation point (30% MC) if fully immersed for more than four days, there are significant differences in resistance to moisture uptake if both are exposed to the same wetting regimes, such as that represented by rainfall or short term soaking. It is well known that Douglas-fir is a refractory species and its timber is difficult to impregnate with water, even under pressure. Radiata pine sapwood, on the other hand, is much more permeable to liquid water while radiata pine heartwood has more variable permeability; sometimes being as permeable as sapwood, and other times as refractory as Douglas-fir. Being the more permeable, radiata pine attains a higher moisture content much more readily than Douglas-fir (Turner et.al 2005). It could be expected that this greater permeability of radiata pine to water could lead to greater swelling/shrinkage while exposed to weather, and hence to the likelihood of greater distortion.

Considerable information is available on the stability of radiata pine (e.g., Haslett et.al. 1993, Harding et. al. 1999, Turner 2000), but little information is available for New Zealand-grown Douglas-fir and only one direct comparative study was found, although this compared NZ radiata pine with North American Douglas-fir. The radiata was rated poor and the Douglas-fir fair based on anisotropic shrinkage, i.e. tangential, radial and longitudinal values. (Simpson 1994).

This report describes a study involving several cycles of wetting and re-drying, intended to simulate exposure of timber to heavy rainfall followed by drying, and measuring of resultant warp in framing timber of both species to confirm or disprove the perception that New Zealand grown-Douglas-fir is more stable than radiata pine.

MATERIALS AND METHODS

Three framing wood types were tested for stability: Green Douglas-fir, air-dry Douglas-fir and kiln-dried radiata pine. The original intention was to obtain all three wood types from each of four locations, one in the Central North Island (Rotorua), and three in the South Island (Canterbury, Nelson and Tapanui). However, all three wood types were only available from Nelson. No wood was available from the Canterbury source, no dry Douglas-fir was available from Rotorua, and no radiata pine from Tapanui. There were therefore seven batches of framing timber tested for stability in the trial. These consisted of kiln-dried radiata pine from two sources (Rotorua and Nelson), green Douglas-fir from three sources (Rotorua, Nelson and Tapanui), and dry Douglas-fir from two sources (Nelson and Tapanui). Each batch of timber comprised fifty pieces of 100x 50mm framing, 2.4m in length, representing a typical mix of frame 1 grade from each resource. Note that neither air-dried nor green radiata pine were included in the trial nor was kiln dried Douglas-fir. The objective of the study was not to compare the two species at common moisture levels, but rather to compare commonly used types of framing timber representative of the two species. Both 'green' and air-dried Douglas-fir are used for construction in New Zealand, but for radiata pine, only kiln-dried timber is generally used.

All wood samples of Douglas-fir and radiata pine were weighed immediately on arrival, and those that were dry were measured with a resistance type meter for moisture content. Samples were then scanned for initial warp on the Ensis "Warpmaster". This device uses lasers to create a three-dimensional model of the scanned sample and then compares it to a perfectly straight rectangular stud to determine distortion (bow, crook and twist, all measured in mm per 2.4 m length). The accuracy of the distortion measurements is to within 0.5mm. It took approximately 1 hour to weigh and scan 50 pieces.

Following this initial scan samples were placed in specially made racks, so that each sample was free to move without restriction, to equilibrate. Samples were re-measured for weight and scanned about two months after the initial scan. Following a further three months equilibration, all samples were re-weighed, soaked in water, weighed again, and then rescanned. The soaking process involved submerging each set of 50 samples in water for one hour and then leaving them to drain for 1 hour prior to scanning. Samples were then allowed to dry again in the racks, back to their pre-soak weight, (approx. two weeks) before weighing and re-scanning. The cycle was then repeated, with a weigh and scan a month later while dry, followed by soaking, weighing and scanning and a final weigh and scan after drying for an additional month.

Changes in weight were used to monitor moisture content. Moisture content was derived from an estimated oven-dry weight for each sample calculated from the initial moisture meter reading. In the case of green samples estimated oven-dry weights were derived from meter readings taken after air-drying.

The percentage of boards in each batch that did not meet N.Z. timber grading rules for a 100 x 50mm stud 2.4 m in lengths (NZS 3631, 1988), was calculated at each scan. The allowable limits used were 5mm for twist, 15mm for bow, and 10mm for crook.

Changes in bow, crook and twist were calculated for each board. Changes were calculated against the initial scan, and against each preceding scan. These differences were expressed as absolute values. Comparisons between mean changes in warp were then made between the seven batches of timber in the study using analysis of variance (ANOVA) and least significant difference (LSD) tests. Because these changes in warp measurements were highly skewed in distribution, they were log-transformed (after adding a small constant of 0.05mm to allow for zero values) prior to analysis, and the means were then back-transformed to the original mm scale. Effectively, this analysis tested for differences in the geometric mean change in warp measurements.

RESULTS & DISCUSSION

The mean initial moisture content (MC) of each batch is shown in Table 1. Mean MC at each assessment during the trial for each batch is shown in Fig. 1. The average percentage change in weight for each batch is shown in Table 2.

Moisture content in the green Douglas-fir reduced from initial levels of 52-60% to 14-15% after two months. Moisture content in the Nelson dry Douglas-fir reduced from 23% to 14% over the same period, while the Tapanui dry Douglas-fir was already near equilibrium at 18% at the start of the trial, and only reduced a further 2%. Moisture content of the kiln-dried radiata pine also reduced slightly during the initial two months. There was little change in MC of any batch during the next 3 months prior to the initial soak.

The 1-hour soaking in water elevated the MC substantially in the radiata pine by 12-16 percentage points, but only by 2-4 percentage points in the Douglas-fir, confirming the lower water permeability of the species. Corresponding reductions in MC in the weeks following soaking occurred, with much greater reductions for radiata pine than Douglas-fir.

The water soaking treatments were intended to simulate the effects of framing left out in heavy rain. To test this, samples of Douglas-fir and radiata pine, with their wide surface exposed uppermost, were left out for five hours in heavy rain. The Douglas-fir gained 2% in weight and the radiata 6%. From the % weight change figures for soaking shown in Table 2 it may be deduced that the soaking treatments represent the equivalent of more than five hours heavy rain.

Table 1. Mean Initial moisture contents of each batch of timber.

		Initial Moisture Content (%)		
Source	**Species and initial condition**	**Mean**	**Minimum**	**Maximum**
Tapanui	Douglas-fir green	Estimated 54	21	109
	Douglas-fir dried	18	14	23
Rotorua	Douglas-fir green	Estimated 60	27	143
	Radiata kiln-dried	15	9	18
Nelson (Waimea)	Douglas-fir green	Estimated 52	30	98
	Douglas-fir dried	23	18	33
	Radiata kiln-dried	17	11	24

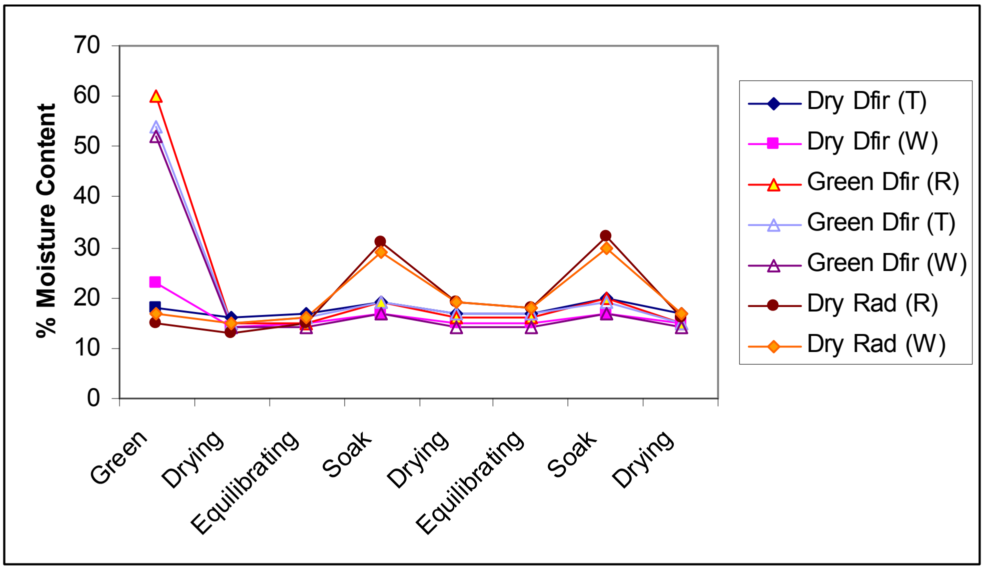

Fig. 1. Mean moisture content of each batch of timber at different stages during the trial.

Table 2. Average percentage weight change between successive measurements in each timber batch during the wetting/drying cycles.

Source	Species and initial condition	2 mths from start	5 mths from start	1st soak	2 wks after 1st soak	6 wks after 1st soak	2nd soak	10 days after 2nd soak
Tapanui	Douglas-fir green	-39%	1%	3%	-2%	0%	2%	-4%
	Douglas-fir dried	-2%	1%	2%	-2%	0%	3%	-3%
Rotorua	Douglas-fir green	-45%	0%	4%	-3%	0%	4%	-5%
	Radiata kiln-dried	-2%	2%	16%	-12%	-1%	14%	-16%
Nelson (Waimea)	Douglas-fir green	-38%	0%	3%	-3%	0%	3%	-3%
	Douglas-fir dried	-9%	1%	2%	-2%	0%	2%	-2%
	Radiata kiln-dried	-2%	1%	13%	-10%	-1%	12%	-13%

The graphical representation of MC (Fig. 1) indicates that there was little difference in wetting between batches for each wood type. After an initial drying period, all Douglas-fir batches behaved similarly, as did all radiata pine batches, during the wetting and drying cycles.

At the start of the trial, most boards were within New Zealand grading rules specification for distortion, with seven boards from the Rotorua radiata, four boards from the Tapanui dry Douglas-fir, two boards from the Nelson dry Douglas-fir, and one each from of the Nelson and Tapanui green Douglas-fir being outside the allowable limits (Fig. 2), in all cases due to excessive twist. At the end of the trial, the percentage of boards outside specification for the green Douglas-fir batches had risen substantially to 24-38% (Table 3), followed by the radiata pine (21-24%) and the dry Douglas-fir (10-12%). Statistically, the green Douglas-fir batches showed significantly more out-of-specification boards than the dry Douglas-fir batches, but the radiata pine batches did not differ significantly from either the dry or green Douglas-fir. For all wood types, most of the increased % out of specification occurred during the initial drying period rather than during the wetting/drying cycles (Fig. 2). As at the start of the trial, the principal reason for rejection at the end of the trial was excessive twist. Only one out-of-specification board did not have excessive twist, while three had excessive bow and only one had excessive crook.

The changes in twist, bow and crook from the start to end of the trial (geometric means), were significantly higher for green Douglas-fir than for other wood types, but no clear differences between the dry Douglas-fir and radiata pine batches were evident (Table 3). The greater warp in the green Douglas-fir compared with the other two treatments was most pronounced for twist and crook but less obvious for bow (Table 3, Figs. 3-5). Most of the increase in warp for all treatments occurred during the initial 2-months drying period rather than during the wetting/drying cycles (Figs. 3-5).

When changes in warp between successive measurements averaged across all measurements made during the two wetting/drying cycles were examined, it was found that statistically the radiata pine showed significantly greater warp change than either of the two Douglas-fir treatments (Table 4, Figs. 6-8,). However, these changes were small (note Y axis scale). Overall, warp induced by the wetting/drying cycles was minimal for all three treatments. For example, geometric mean change in twist ranged from 0.4-0.5 mm in Douglas-fir and 1.0-1.1 mm in radiata pine while the change in crook ranged from 0.2 to 0.3 mm in Douglas-fir and 0.6-0.8 mm in radiata pine.

Table 3. Mean rejection due to warp at the end of the trial, and change in twist, bow and crook from beginning to end of trial (geometric means) for each batch of timber. Values in a column followed by the same letter do not differ significantly (LSD test, α=0.05).

Source	**Species and initial condition**	**Reject (%)**	**Twist (mm)**	**Bow (mm)**	**Crook (mm)**
Tapanui	Douglas-fir green	33 ab	2.7 a	3.5 a	1.4 a
	Douglas-fir dried	12 c	0.8 c	1.1 cd	0.6 cd
Rotorua	Douglas-fir green	38 a	3.8 a	1.7 bc	1.2 ab
	Radiata kiln-dried	24 abc	1.0 bc	1.0 d	0.4 d
Nelson (Waimea)	Douglas-fir green	24 abc	2.7 a	1.4 cd	1.7 a
	Douglas-fir dried	10 c	1.0 bc	0.8 d	0.7 bc
	Radiata kiln-dried	21 bc	1.6 b	2.3 ab	0.8 bc

Table 4. Change in twist, bow and crook for each batch of timber during soaking/drying cycles (geometric means). Values in a column followed by the same letter do not differ significantly (LSD test, α=0.05).

Source	**Species and initial condition**	**Twist (mm)**	**Bow (mm)**	**Crook (mm)**
Tapanui	Douglas-fir green	0.5 b	0.4 b	0.3 b
	Douglas-fir dried	0.4 bc	0.3 d	0.2 b
Rotorua	Douglas-fir green	0.4 bc	0.4 bc	0.3 b
	Radiata kiln-dried	1.0 a	1.3 a	0.6 a
Nelson (Waimea)	Douglas-fir green	0.4 c	0.3 cd	0.2 b
	Douglas-fir dried	0.4 bc	0.3 d	0.2 b
	Radiata kiln-dried	1.1 a	1.8 a	0.8 a

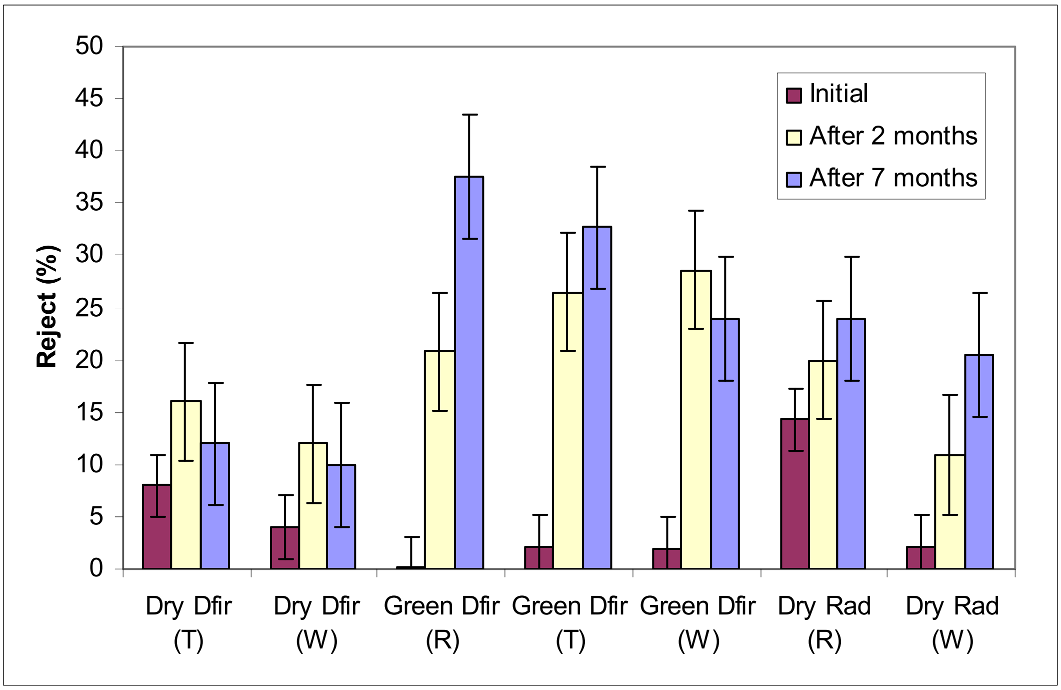

Fig. 2. Percent rejection due to excessive twist, bow or crook of each batch of timber initially, after 2 months, and at the end of the trial. Error bars show standard errors.

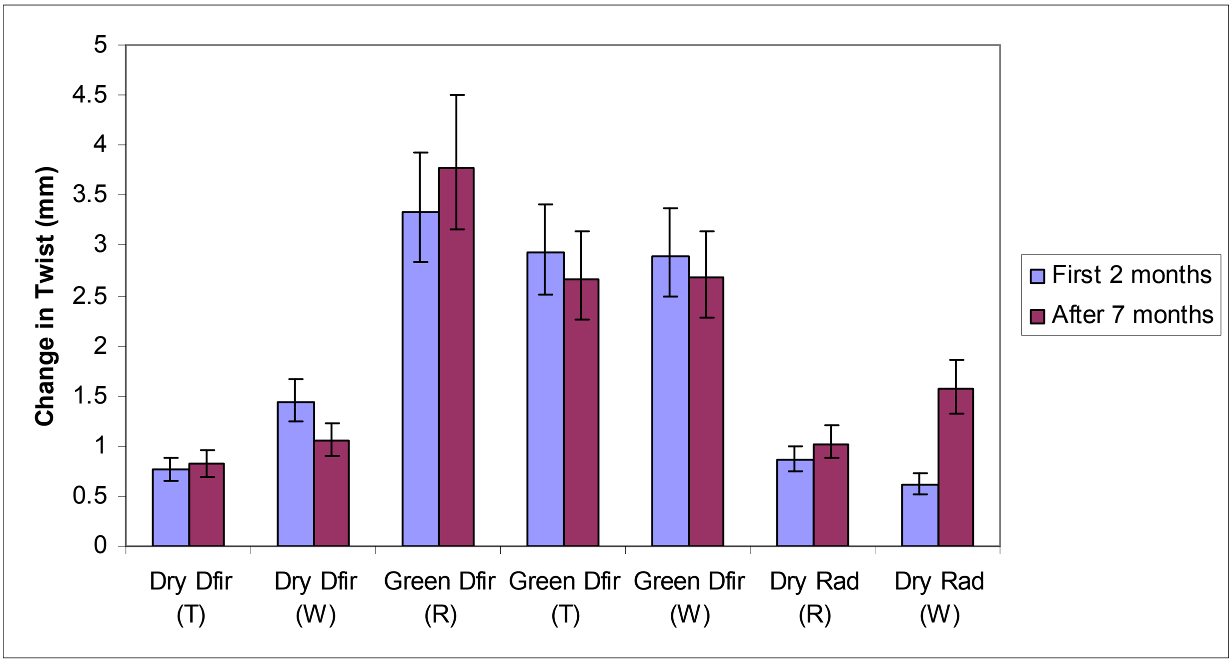

Fig. 3. Geometric mean change in Twist from the initial measurement for each batch after approximately 2 months, and after 7 months at the end of the trial. Error bars show standard errors.

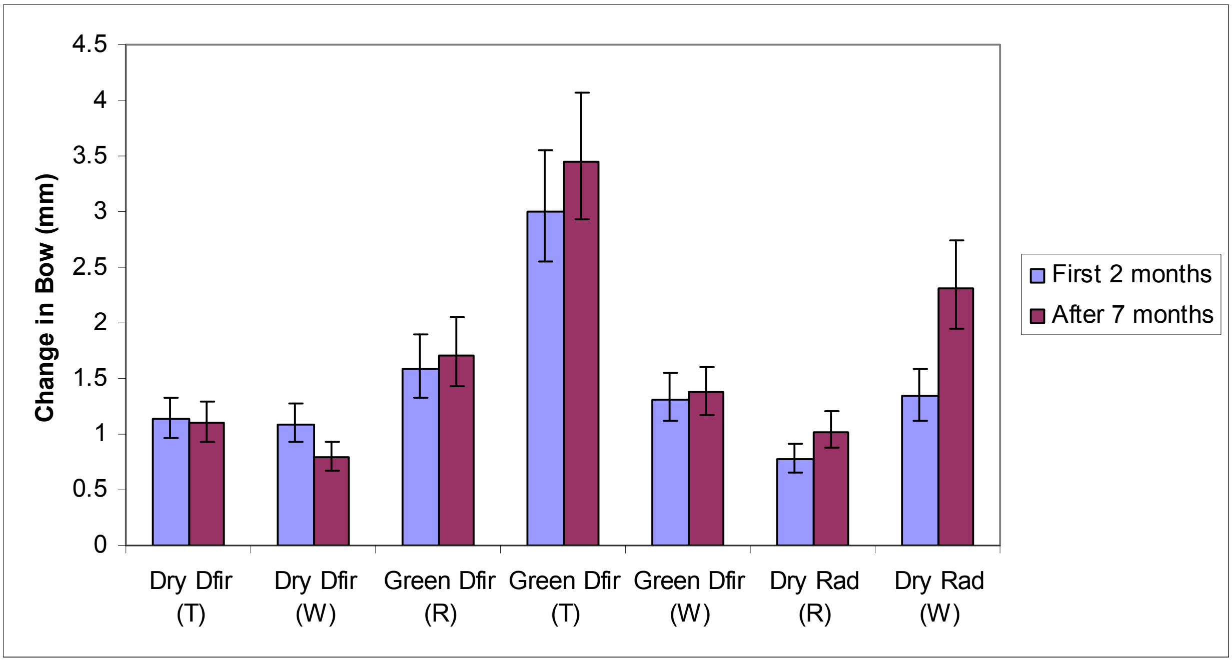

Fig. 4. Geometric mean change in Bow from the initial measurement for each batch after approximately 2 months, and after 7 months at the end of the trial. Error bars show standard errors.

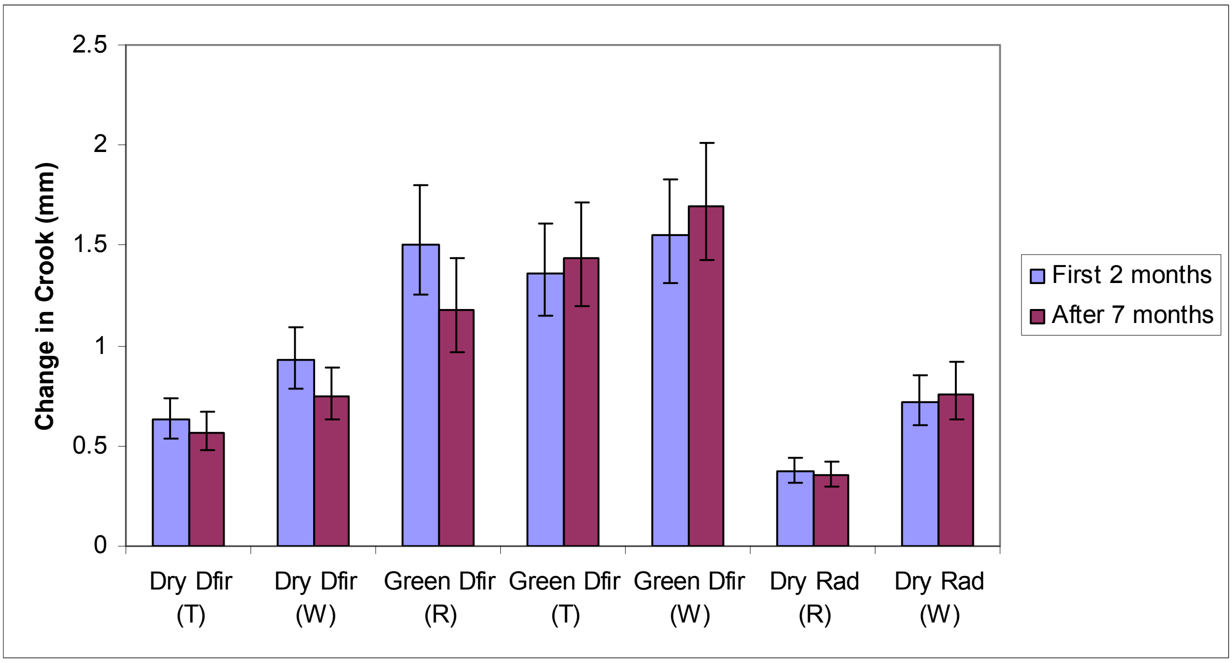

Fig. 5. Geometric mean change in Crook from the initial measurement for each batch after approximately 2 months, and after 7 months at the end of the trial. Error bars show standard errors.

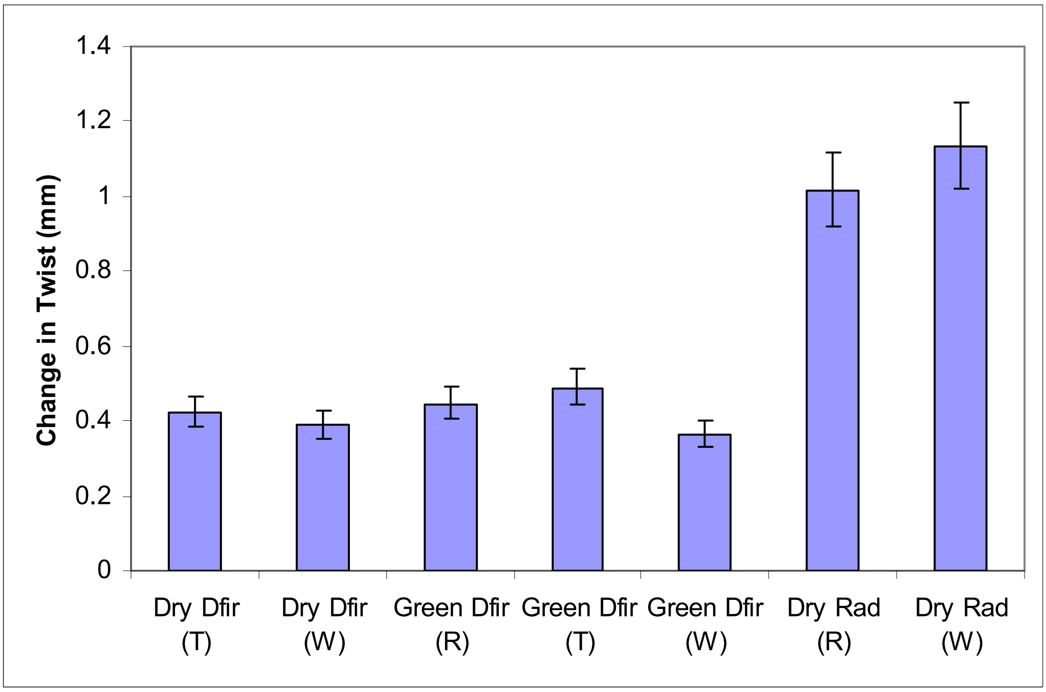

Fig. 6. Geometric mean change in Twist between pairs of measurements during soaking/drying cycles. Error bars show standard errors.

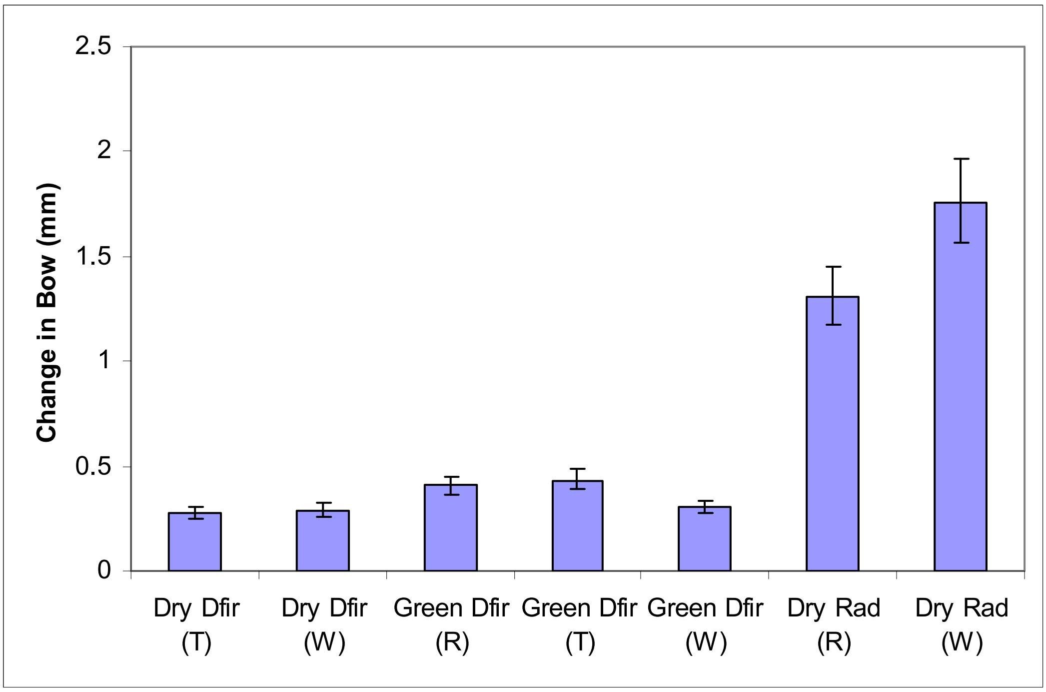

Fig. 7. Geometric mean change in Bow between pairs of measurements during soaking/drying cycles. Error bars show standard errors.

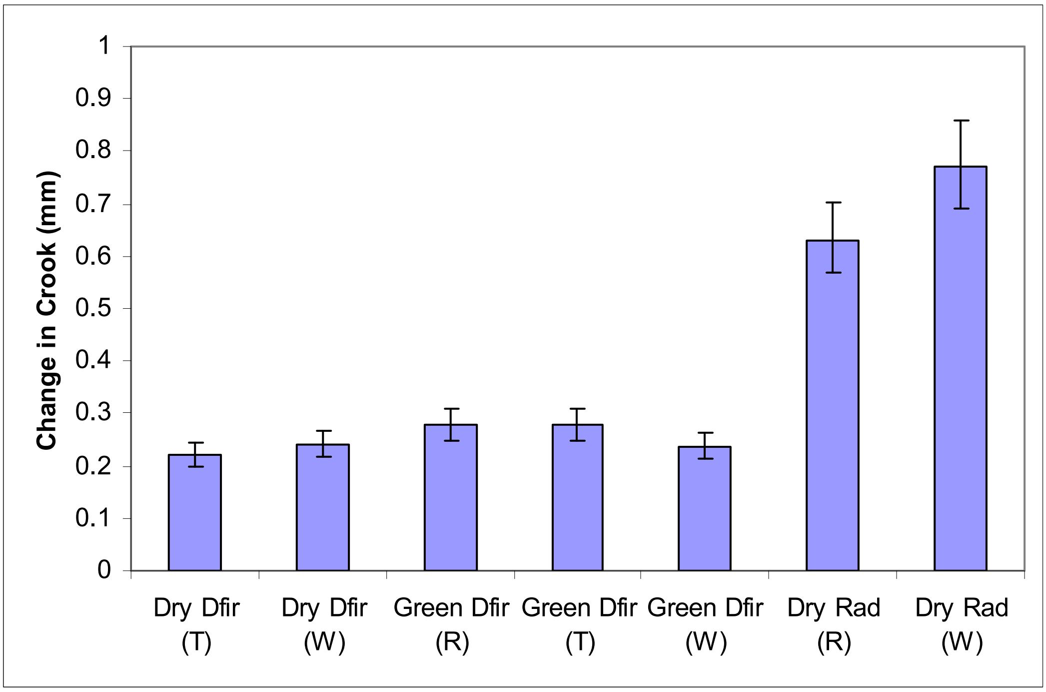

Fig. 8. Geometric mean change in Crook between pairs of measurements during soaking/drying cycles. Error bars show standard errors.

CONCLUSIONS

- Increases in timber warp during the course of the trial were greater in green Douglas-fir than in either dry Douglas-fir or kiln-dried radiata pine. The increased warp for green Douglas-fir occurred during the initial 2-month period of drying rather than in the subsequent wetting/drying cycles.

- This trial further confirms the 'refractory' reputation of Douglas-fir, and the 'absorbent' reputation of radiata pine. At a practical level, Douglas-fir heartwood and sapwood can be regarded as equally impermeable, independent of where it is grown in New Zealand.

- As a result of repeated wetting/drying cycles, the greater permeability and water uptake of radiata pine led to greater timber movement and warp when compared with Douglas-fir. However, the difference in level of movement between the two species induced by these cycles was small, being generally less than 1mm per stud length (1.5mm for bow).

REFERENCES

NZS 3631: 1988. New Zealand Timber Grading Rules. Standards New Zealand, Wellington.

Haslett, A. N; Turner, J. C. P; Miller, W. R. 1993. Stability of radiata pine timber for remanufacturing uses. NZFRI , What's New in Forest Research No. 230.

Simpson I. 1994. Dimensional stability of radiata pine compared to North American species. NZFRI project record No 3988. (unpublished).

Harding, O. V. Turner, J. Herbert, J. 1999. Performance of radiata pine as moulding raw material. Forest Products Journal Vol. 49 No 9.

Hedley, M. Durbin, G. Wichmann-Hansen, L. Knowles, L. 2004. Comparative moisture uptake of New Zealand grown Douglas-fir and radiata-pine structural timber when exposed to wetting. NZ Douglas-fir Cooperative. Report No 36 (unpublished).

Turner, J. 2000. Compression wood in radiata pine: effect on product stability. Proceedings of the 26th Forest Products Research Conference "Research Developments and Industrial Applications" and Wood Waste Forum, 19-21 June 2000. CSIRO Forestry and Forest Products, Clayton, Vic, Australia. Pp 57-58.

Turner, J; Riley, S; Haque, N; Cown, D. 2005: Comparison of the water absorbency of Douglas-fir and radiata pine framing timber. NZ Douglas-fir Cooperative. Report No 47 (unpublished).