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NOTE

Evaluation of the strength of shaved steamed *Pinus radiata* poles

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Abstract

Bending strength of *Pinus radiata* (D.Don) poles is critical in a range of structural applications, such as retaining-walls. *Pinus radiata* poles in a wet, shaved and steamed condition were obtained from five suppliers located across the central North Island of New Zealand. This sample of poles met the stiffness (Modulus of Elasticity) value expected of normal-density poles according to New Zealand Standard3603, but their characteristic bending and compression stresses were 40% and 39%, respectively, lower than expected. Applying a maximum allowable knot size restriction (measured as the knot diameter ratio) made little difference to the results. Applying a minimum stress-wave velocity (measured using a HM-200 device) also had little effect on the derived characteristic values until the value was raised to 3.2 km/s, which would eliminate about 20% of the sample. A minimum stress-wave velocity reading of 2.8 km/s is recommended. At this level, some poles from two of the five suppliers would have to be rejected. These results indicate that pole selection based on the basic density of outer-zone wood is less effective than that using stress-wave velocity measured using a HM-200 device. It is recommended that New Zealand Standard3603 should be amended in the light of these findings.

Keywords: poles; strength; *Pinus radiata*; grading.

Introduction

In the 1993 edition of the timber design code, NZS3603: 1993 (New Zealand Standards, 1993), characteristic stresses were published for two grades of softwood poles; "high" and "normal" density. These values were based on an analysis by Walford (1994) of work by Hellawell (1965). In order to qualify poles as belonging in the high density category, producers were required to verify either that the basic wood density of the outer part of poles had a value of at least 450 kg/m^3, or that the poles had the expected strength by means of proof testing. Characteristic stresses assigned to green, unshaved poles and steamed, shaved poles of normal density in NZS3603 are given in Table 1.

Poles are generally obtained from small-diameter trees of high density, from largely unmanaged stands. Modern management regimes, however, involve intensive pruning and thinning, which eliminate most of these trees. Nevertheless, some regions in New Zealand, such as Northland, still produce poles with the required high outer-zone density.

Design engineers generally are not aware of these changes to silvicultural practices and continue to specify high density poles because this yields the smallest diameter, and, presumably, cheapest poles. The specification of density is a problem for producers, however, because of its lack of efficiency as an indicator of pole strength. Often a producer can prove by appropriate testing that a pole is strong enough for

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TABLE 1: Characteristic stresses assigned in NZS3603 to normal-density poles in the green, unshaved and steamed, shaved conditions (New Zealand Standards, 1993)

Pole Type	**Category**	**Minimum outer-zone basic density, (kg/m³)**	**Characteristic stress***					
			Fb (MPa)	**Ft (MPa)**	**Fc (MPa)**	**Fs (MPa)**	**Fp (MPa)**	**Ek (GPa)**
Green, unshaved	High	450	52	31	25	3.5	7.7	12.1
	Normal	350	38	23	16	3.1	6.4	8.7
Steamed, shaved	High	450	37.6	22.4	22.5	3.2	6.9	10.9
	Normal	350	27.5	16.6	14.4	2.8	5.8	7.9

*Fb = bending stress, Ft = tension stress, Fc = compression stress parallel to the grain, Fs = shear stress, Fp = compression stress perpendicular to the grain, Ek = static modulus of elasticity

use but not that its density is high enough. Producers usually check that poles have been sourced from sites known to produce high-density poles but individual poles are rarely checked for density because it is simply too time-consuming to be cost-effective. If questioned as to whether or not the poles are of high density, the producer often replies that "they meet the standard". This does not actually answer the question because the producer might be referring to a different standard, NZS3605 (New Zealand Standards, 2001), which defines knot limits and straightness (but not density), while the specifier is referring to NZS3603. It is therefore possible that high-density poles are actually required for many structures and have been specified in the designs but structures are actually built with normal-density poles. One would expect, therefore, that there would be a noticeable rate of failures in pole structures, such as retaining walls (which are the most common pole structure). However, as failures have not occurred, or at least have not been reported, this begs the following questions:

1. are the poles stronger than we realise?
2. is the structural model used in retaining wall design too conservative? and
3. is it necessary to change the published design stresses for poles?

In this paper we determine the characteristic strength values for samples of radiata pine (*Pinus radiata* (D.Don)) poles obtained from five different suppliers and also investigate different potential methods for strength grading these poles to avoid the use of density grading.

Materials and Methods

Five pole producers (labelled A – E) supplied between 8 and 12 pole specimens each, taken from their normal production. Poles were specified as being 2.4 m long, between 200 and 300 mm in diameter, shaved and steamed. A total of 52 pole specimens was obtained, all of which were in a virtually 'wet' condition. Measurements were taken of the length, small- and large-end diameters, weight, and stress-wave velocity of each pole. This last measurement was taken using a portable resonance device (HM-200, Fibre-gen Ltd., Auckland). The HM-200 device was held against the end of each pole, which was then struck with a hammer. This device detects the resonant vibrations produced and from the frequency of these vibrations and the length of the pole, calculates the velocity (v) of the stress wave. Test density (ρ) of each pole was calculated from its actual weight and dimensions. A dynamic modulus of elasticity (MOE_d) was calculated using the formula:

$$MOE_d = \rho v^2 \quad [1]$$

The diameter of every knot in the worst knot whorl was measured regardless of its position in the pole because, in terms of NZS3605, the knot diameter ratio (sum of knot diameters/circumference) of the worst knot whorl in the pole governs its acceptability. Most of the poles were loaded to failure in four-point bending over a span of 2.2 m in a universal testing machine (Figure 1). The poles from supplier A were only 2.2 m long so they were tested over a span of 2 m. In every test, the load points were positioned at one-third of the span from the supports. The load at failure was recorded and the maximum bending stress (MOR) calculated based on the measured pole diameter and the consequent section modulus (Z). One sample, (300-mm long spanning the full cross-section) was cut from an undamaged portion of each pole and conveyed to Auckland University for testing in compression parallel to the grain. These compression specimens were deliberately cut so as to contain a knot whorl, wherever possible. From these tests, the maximum compression strength parallel to the grain (MCS) was determined. Characteristic values were calculated according to AS/NZS4063 (Standards Australia, 2009), which assumes a lognormal distribution and bases characteristic static modulus of elasticity (Ek) on the

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FIGURE 1: A pole under test in bending

sample mean value and the characteristic bending and compression strength values (Fb and Fc, respectively) on the sample 5th percentile values. Outer-wood basic density, defined as the oven-dry weight per green volume of the wood in the outer 20% of the stem radius, was determined for each pole.

Results and Discussion

A summary of results for the whole batch of 52 specimens is presented in Table 2. The test density values presented in this table are based on the wet weight of the pole so cannot be compared to the basic density values in Table 1, which are based on oven-dry weight and green volume. In NZS3603, the characteristic values for radiata pine poles are for the un-shaved, non-steamed, and "wet" condition, while the poles in this study were in a shaved, steamed and "virtually wet" condition. Comparing the experimentally determined characteristic stress and stiffness values in Table 2 with the standard values assigned to normal-density poles in Table 1, it can be seen that the stiffness (dynamic MOE_d or static Ek) is 107%, the bending stress (Fb) is 60% and the compression stress (Fc) is 61%. However, experimentally determined dynamic MOE_d will be higher than the value obtained from a static bending test because the latter includes the effect of shear deformation. The difference is about 10% if the standard bending test is conducted on rectangular posts, but is less if round poles are tested, as is the case here. Therefore, the difference of 7% observed here is in the expected range. The high rate of loading in a dynamic test and is also believed to affect the result slightly.

HM-200 threshold value

If a HM-200 (or other similar device) is to be used as a means to grade poles then it is desirable that stress-wave velocity should be a good predictor of pole properties. In this study, moderate to strong relationships (R^2 = 0.608, 0.429 and 0.471, respectively) were found between stress wave velocity and MOE_d, MOR and MCS (Figure 2). The strength of the relationship between stress wave velocity and MOE_d is artificially high, however, because stress-wave velocity has been used in the calculation of MOE_d.

Imposing a threshold stress-wave velocity reading above the minimum observed has the effect of raising design property values at the cost of reduced recovery (Figure 3). Raising the velocity threshold above 2.5 km/s has little effect on the characteristic value until a velocity of 3.2 km/s is reached at which point the loss in recovery is about 20%. If a minimum velocity of 2.8 km/s was used it would raise the characteristic value by between 2 and 4%, at a cost of rejecting 6% of the poles overall, or 12% from supplier A and 25% from supplier E. This is shown in Figure 4 where the stress-wave velocity values from supplier E are significantly below the rest. If a minimum velocity of, for example, 3.2 km/s were required, then many poles from supplier E and some from suppliers A and B would be rejected. However, target velocity values for the purpose of segregating poles will depend on the moisture condition of the poles, i.e. whether they are freshly felled and completely saturated or are partially dry as in the specimens tested. This is a matter for further research.

TABLE 2: Summary of results from tests of shaved, steamed and"virtually wet" poles in this study.

Parameter	Test density (kg/m^3)	Stress-wave velocity (km/s)	Dynamic modulus of elasticity (MOE_d)	Bending stress (MPa)	Compression stress (MPa)
Number of poles tested	52	52	52	52	49
Mean	739	3.44	8.76	27.56	13.53
CV%	13.5	10.1	29.6	23.7	20.5
Minimum	519	2.55	5.03	12.79	8.53
Maximum	917	4.22	13.05	41.53	20.54
Characteristic	-	-	8.49	16.5	8.74

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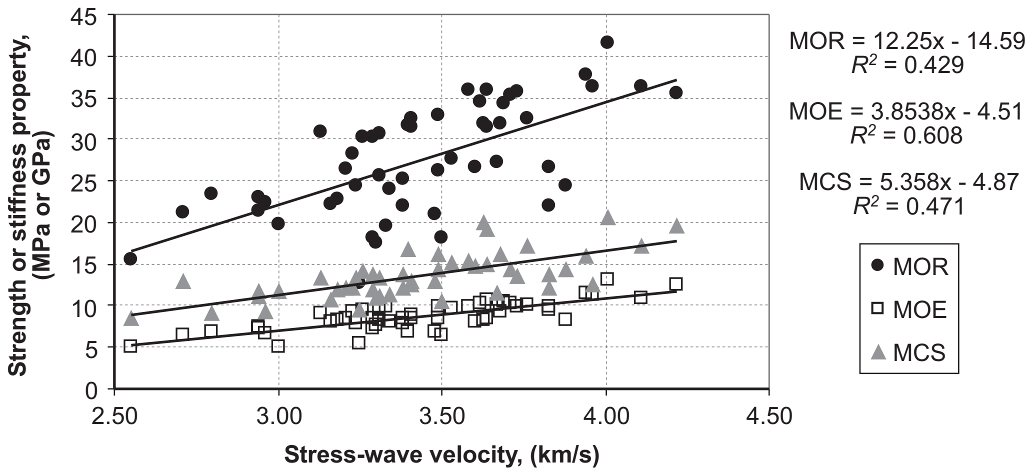

FIGURE 2: Correlation between HM-200 velocity reading and strength or stiffness property (MOE, MOR, MCS) for tested poles

Knot size

Knot size is normally a major feature of pole specification, for example NZS3605:2001 (New Zealand Standards, 2001). However, the effect of knot diameter ratio on the strength and stiffness of poles (MOE, MOR and MCS) was not found to be significant, as shown in Figure 5. As may be expected from this poor correlation, the imposition of a maximum knot size limit, at least up to a knot diameter ratio of 36%, had almost no effect on characteristic values (Figure 6). Part of the reason for the poor correlation of knot diameter ratio and MOR is that the worst knot whorl, on which the knot diameter ratio was calculated, was not always involved in the fracture. This was because it was not always possible to locate worst knot whorl in the region of maximum stress which occurs between the loading points in a four-point bending test.

Density

Weak to moderate linear relationships (R^2 = 0.24 – 0.34) were found between strength properties and outer-zone wood density (Figure 7). Here outer-zone basic density was used rather than whole-pole density because it is independent of moisture content. Standard NZS3603 refers to outer-zone density and it has a better correlation with strength properties

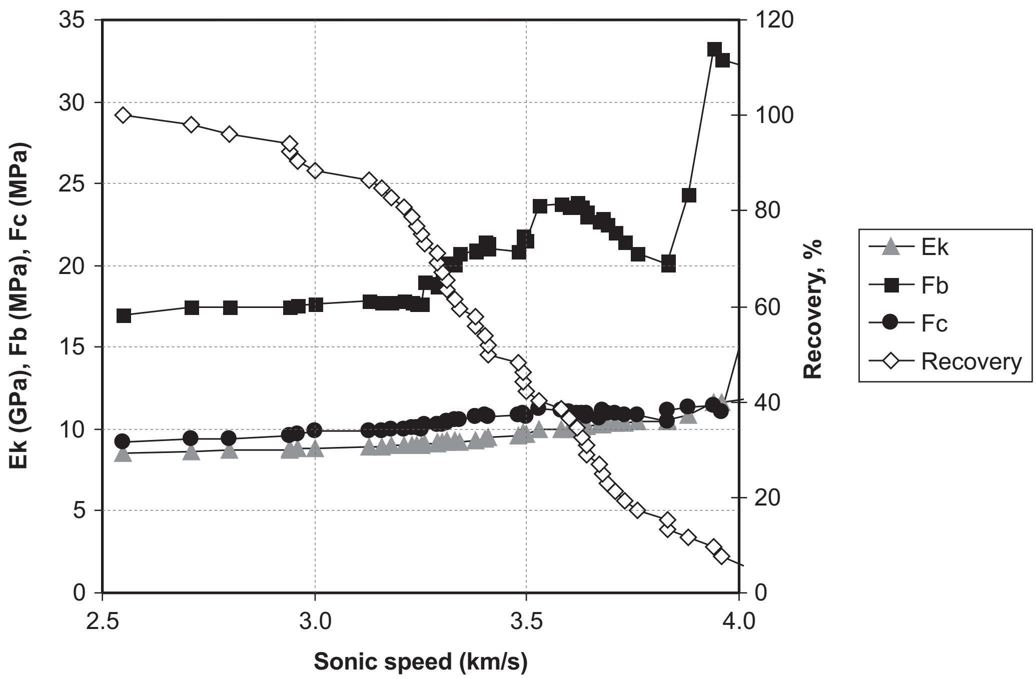

FIGURE 3: Effect of a minimum HM-200 velocity reading on Ek, Fb, Fc and recovery

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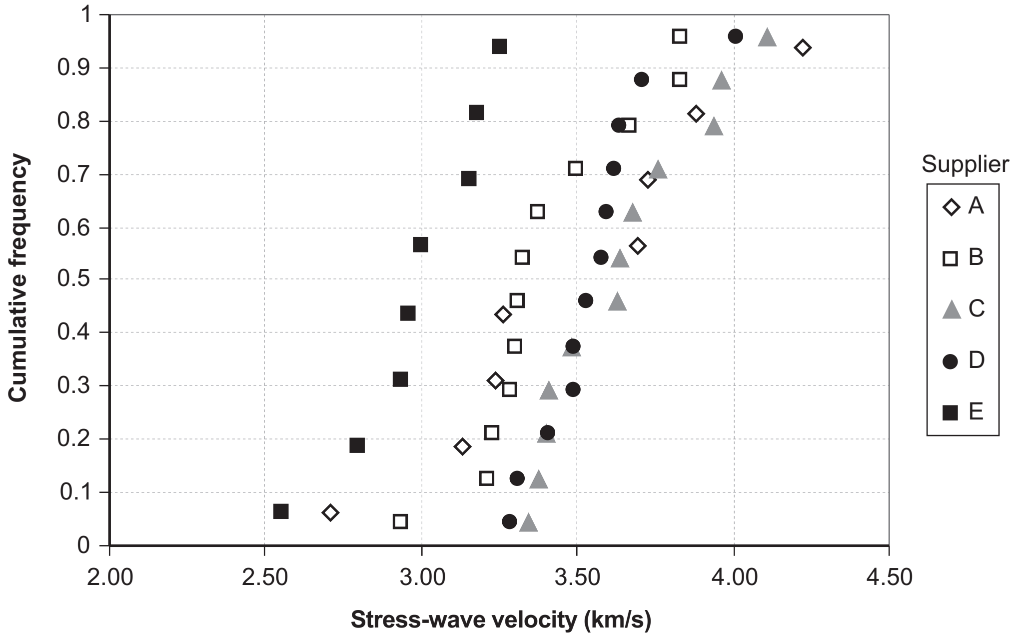

FIGURE 4: Comparison of HM-200 velocity readings for tested poles between suppliers

than does average density as shown by Walford (1994). A comparison of these relationships with those presented in Figure 2 show that stress-wave velocity is a better predictor of pole properties than outer-zone density, accounting for 78% more of the variation in MOE_d, 25% more for MOR and 96% more for MCS.

The effect of imposing a minimum density limitation is shown in Figure 8 where it is seen that there is an effect, albeit a small one. The present minimum density limit is 350 kg/m³ for normal-density category poles. Four of the 52 poles fell below this limit. Imposing a limit of 350 kg/m³ would raise Ek by 2.5%, Fb by 4.5% and Fc by 4.8%. Even raising the limit to 400 kg/m³ raises Ek by 6.9%, Fb by 11% and Fc by 10% but this is hardly worth the loss in recovery incurred.

Implications and recommendations

In retaining walls, MOE and compression strength usually are not critical, but bending strength is. The revelation that the normal density poles tested here have only 60% of their expected bending stress and only 44% of the bending stress assigned to high density poles means that there must be pole retaining walls in existence that are substantially under strength, at least in theory. The fact that there have been no reported failures must mean that those structures have not experienced their design loads or that the structural model of soil behaviour is very conservative. Those matters will not be debated here but the central issue remains that a structural product should have the properties expected and, presumably, claimed

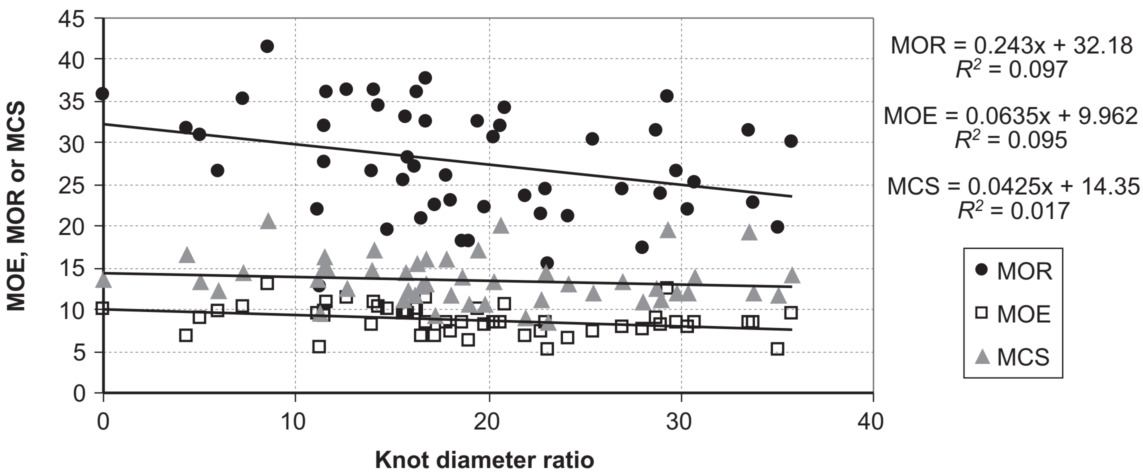

FIGURE 5: Relationship between knot diameter ratio and strength or stiffness property (MOE, MOR, MCS) for tested poles.

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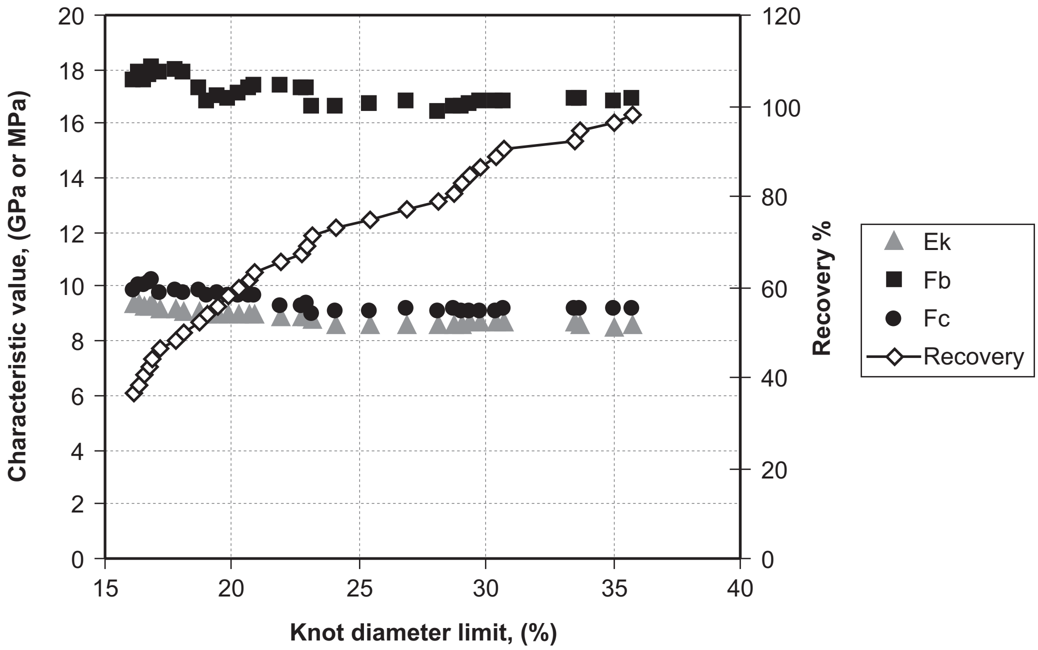

FIGURE 6: Effect of applying a knot diameter limitation on characteristic strength values and recovery.

for it. Therefore, a situation has to be reached where a grade (or grades) of poles is established that can be reliably achieved by producers. At the same time, design models should not be too conservative.

One problem with strength properties of timber and probably all materials is that they cannot be experimentally determined without damaging or destroying that material. Instead, we rely on non-destructive means to predict strength. In the case of round timber, measuring stress-wave velocity (using for example the HM-200) has become established as a convenient means to determine which logs should be processed for structural products, and which should not. Applying this technology to poles means that they can be sorted into grades more reliably and quicker than can be achieved using basic wood-density.

One problem with using the HM-200 device (and similar devices) is that the stress-wave velocity that is measured depends on both the density and the MOE of the wood, and density is further dependent on moisture content. In the "freshly- felled" condition, the density of radiata pine logs is approximately

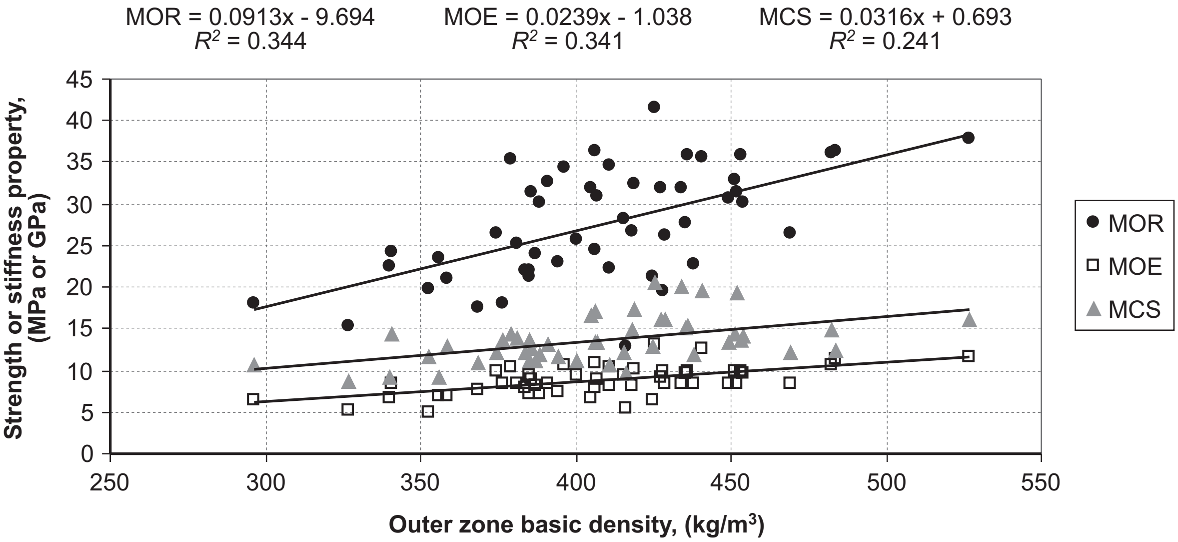

FIGURE 7: Relationship between outer zone density and strength or stiffness property (MOE, MOR, MCS) for tested poles.

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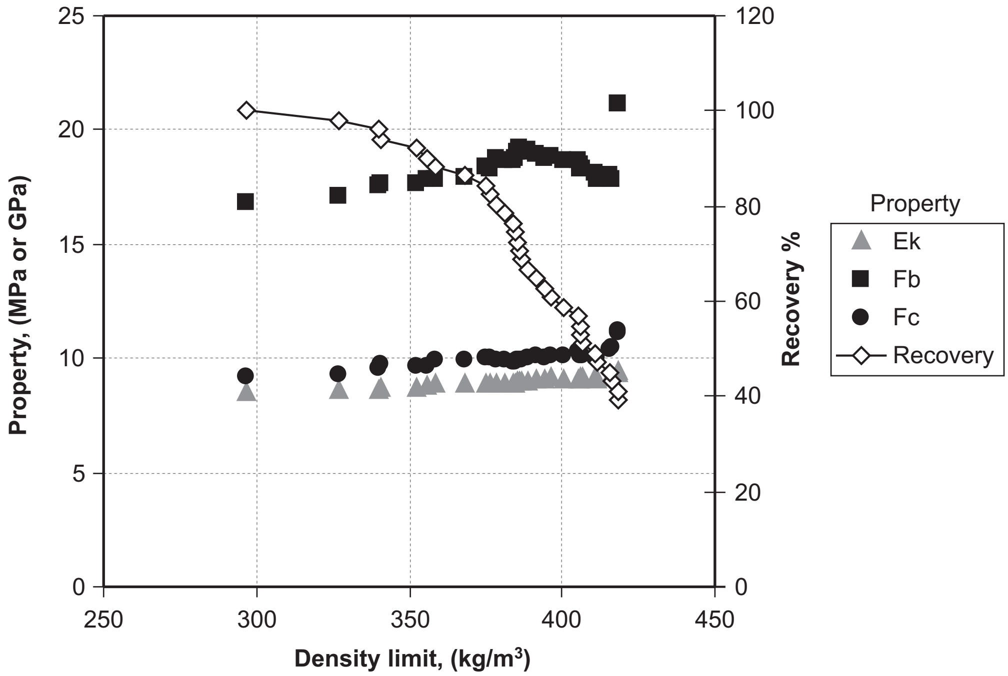

FIGURE 8: Effect of a density limitation on characteristic strength values and recovery for tested poles.

constant (around 1000 kg/m^3). Once poles have been steamed they will be drier than when freshly-felled but will still be above the fibre saturation level. Modulus of elasticity only increases as the wood dries below the fibre saturation level. This means that steaming the poles will not change the MOE but the overall density of the wood will change. Thus, the stress-wave velocity of steamed poles will be higher than that of freshly felled poles. The problem remains to establish an appropriate stress-wave velocity to use as a grade threshold value when poles have been dried below their freshly-felled condition.

Conclusions

1. The sample of poles tested gave a characteristic MOE that met the requirements of poles of "normal density" category but were deficient in bending and compression stress by 60% and 61%, respectively.

2. Stress-wave velocity accounts for 25 to 100% more variability in strength and stiffness properties than does basic density of the outer 20% of the pole diameter.

3. Knot size has no significant effect on MOE, bending or compression strength, at least up to knot diameter ratios of 36%.

4. A minimum stress-wave velocity of 2.8 km/s is recommended which includes most of the resource but would affect the production from two suppliers.

5. The Standards NZS3603 and NZS3605 should be revised to provide amended design stresses, in order to make stress-wave velocity the basis of pole grading, and to relax limits on knot size for steamed, shaved radiata pine poles.

6. Further testing is required, with attention to density, to verify, or perhaps slightly modify, the above values. However, the study reported here has highlighted the significant difference that exists between the characteristic values of the current radiata pine pole resource in New Zealand with that tested for in Standard NZS3603:1993.

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