PERFORMANCE OF RESISTANCE-BASED MOISTURE METERS AS A FUNCTION OF TIMBER PRESERVATIVE TREATMENT

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ABSTRACT

Three commercial resistance-based moisture meters have been used to measure the moisture content of ten classes of solid timber product specified for use in Australasia. All of the timbers were based on *Pinus radiata* D.Don (Radiata Pine). With the exception of a single untreated classification, the timber specimens were treated with waterborne or light organic solvent-based commercial preservatives. Moisture content data was measured and is presented as a function of relative humidity at 21±2 °C. Verification of timber moisture content was provided by the standard oven-dry method specified by Australian Standards/Standards New Zealand 1080.1. The results presented in this report indicate that standardisation of meter design and electrode geometry beyond that already specified within publications such as Australian Standards/Standards New Zealand 1080.1 may be required. When the individual moisture meter correction values (as supplied with each meter type) were applied to the directly measured timber resistance derived data, all of the meters were able to accurately determine the moisture content of untreated *P. radiata* to within ±1 moisture meter units (% wt./wt.). In many instances, however, the introduction of preservative treatments significantly lowered the accuracy of the meters to a degree which was dependent on the timber preservative type and the mode of meter operation. Of particular concern was the inability of some meters to accurately determine the moisture content of typical framing timbers containing light organic solvent preservatives or certain waterborne preservatives (equilibrated at 65% and 75% relative humidity) within at least ±2 moisture meter percentage units.

Keywords: moisture meter; timber preservative; ionic resistance; *Pinus radiata*; CCA; ACQ; LOSP; boron.

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INTRODUCTION

Determination of Timber Moisture Content

When considering decay and corrosion of building materials, the determination of moisture content (MC) within timber is essential for the assessment of durability and water management. However, accurate assessment of moisture levels in timber using portable meters may be complicated by the presence of waterborne ionically-conductive preservative treatments such as copper-chrome-arsenate (CCA) and alkaline copper quaternary (ACQ) formulations (Simpson, 1996). Additional problems, including localised preservative overloading and excessive surface MC, may also complicate a global approach to calibration of the effects of timber additives (Kear, 2004). The species type, temperature, orientation and localised density of the wood structure (for example, sapwood, heartwood, discontinuities and knots) also have to be considered (Forsen & Tarvainen, 2000). It is prudent in practice, therefore, to assess meter accuracy and reproducibility in relation to the more accurate oven-dry method of MC analysis (Probett, 2007; Simpson, 1996). However, it is commonly acknowledged that this is not generally practical for condition surveys within the built environment and commercial hand-held moisture meters are widely applied under field conditions (Timber Research and Development Association [TRADA], 1991; Simpson, 1996; U.S. Department of Agriculture, 1966; Burkinshaw, 2002). It must be conveyed to the building industry, however, that a practical understanding of the limitations of accuracy of these measurements is important. In New Zealand it is standard practice that internal wall linings are not to be installed until a specific minimum moisture content of timber framing is attained. There can be considerable financial penalties due to delayed projects, if measurements are in error on the high side, and potential liabilities for rework if the error is on the low side and fasteners move as the timber dries further.

Currently, there is a requirement for a clear understanding of moisture meter application in treated timbers (Burkinshaw, 2002). In Australasia, the only standard solution (AS/NZS 1080.1:1997) involves the application of calibration curves to a generic type of resistance-based commercial meter (Australian Standards/Standards New Zealand, 1997). However, this document does not present a rigorously defined moisture meter design with reproducible electrode spacing, geometry or buried area. Moreover, compliance with this standard is not enforced by any acceptable solution to the national building codes. For example, the use and application of test methods for the determination of moisture in timber structures is covered in the New Zealand Building Code (NZBC), Clause E2/AS1 (New Zealand Department of Building and Housing, 2005) where it is stated that moisture meter usage shall be limited to the recommendations given in the New Zealand Forest Research Institute (NZFRI now Scion) publication *Measurement of Moisture Content of Assembled Timber Framing* (1993). This code document also cross-references another NZFRI publication (Simpson, 1996) and only recommends and describes the use of resistance-based meters.

The primary aim of the work presented here is to define the issues associated with the determination of MC in preservative treated timber and to stimulate improvements in moisture management practices within the built environment. From practical use in Australasia, it is apparent that many of the correction values supplied by the various manufacturers are not applicable to many of the available timber treatments. Also, recently introduced treatments are not covered by AS/NZS 1080.1. One question that will be answered is whether calibration curves produced for specific timber treatments can be equally applied to a number of commercially distinct resistance-based meters. In addition, the effect that different preservative treatments have on the accuracy of commercially available moisture meters will be fully quantified and discussed. Three resistance-based moisture meters were used to measure the MC of ten classes of fully moisture equilibrated timbers from *P. radiata*. The data is presented as a function of moisture equilibration under conditions of 65% and 75% relative humidity (RH) at a temperature of 21±2 °C. Meter response for timbers equilibrated in moisture saturated air is also examined. Verification of performance was provided by the oven-dry method as specified by AS/NZS 1080.1:1997 (Australian Standards/Standards New Zealand, 1997). Considering meter performance, an overall positive result for universal meter calibration may be assumed if a statistically identical correction value for each timber treatment can be applied to all of the meters investigated. Moreover, universal calibration curves would greatly simplify meter use in the field.

The capacitance mode of operation was not considered in this work as it has been thought that it is generally not possible to standardise commercial meters of this class, which apply a considerable range of frequencies and sensor shapes (Forsen & Tarvainen, 2000). It has also been shown that, under laboratory conditions, capacitance meters generally have a lower accuracy than the resistance type of meter (Kear, 2004) and they are not described in AS/NZS 1080.1:1997 or any acceptable solution to an Australasian building code.

Classification of Treated Timber

Of particular interest to this work is treated timber used for framing or joining at the H1.2 or H3.1 hazard classes as defined by NZS 3640 (Standards New Zealand, 2003a). These classes are specified for dry or periodically wetted locations, and they are most likely to be interrogated for MC in practice. Typical in-service conditions pose a number of hazards; hazard classes summarised by NZS 3640 for New Zealand, for example, are presented in Table 1. In some cases, the H3.2 hazard class may also be applied within similar environments to that of H3.1 and the appropriately treated CCA- and ACQ-treated materials were also included in this study. Untreated *P. radiata* was included for comparison purposes.

Principles of Resistance-based Moisture Meters

Water acts as an electrolyte for potential solutes (Atkins, 1992), the dissolution and migration of which, in timber, increases with moisture content (Lin, 1965). Solutes derive from the timber structure itself and, if present, from ionic species present in timber preservatives. Conductivity-based moisture meters operate on the assumption that the electrical resistance of timber will decrease in a monotonic and continuous manner over a given range of MC as the concentration of free water, and the ionic conductivity, increases (Burkinshaw, 2002; TRADA 1991; Crissinger, 2006a; Crissinger, 2006b). However, the resistance response of timber measured as a function of MC is not linear (Samuelsson, 1990) and calibration for each individual timber species at a number of established moisture contents and temperatures using empirical measurements is certainly recommended (Forsen & Tarvainen, 2000; Simpson, 1996). Derivation of such relationships for treated timbers is beyond the scope of this work and calibration has only been performed at a constant temperature over a relatively limited range of MC. This data can be directly compared with both the tabulated correction values supplied by each manufacturer and those values published within AS/NZS 1080.1. However, it should be understood that the inherent accuracy of this approach is limited as timber in general is a highly variable and anisotropic material and preservative treated specimens may differ in the quantity and quality of preservative loading.

TABLE 1: Hazard classification as described in NZS 3640:2003 (Standards New Zealand 2003a).

Hazard class	**Exposure**	**Service conditions**	**Biological hazard**	**Typical uses**[a]
H1.2	Protected from the weather, above ground, but with a possibility of exposure to moisture	Protected from the weather, but with a risk of moisture content conductive to decay	Borers and decay	Wall framing
H3.1	Exposed to the weather above ground	Periodic wetting, not in contact with the ground	Decay, fungi and borers	Cladding, fascia, joinery
H3.2	Exposed to the weather, above ground, or protected from the weather, but with a risk of moisture entrapment	Periodic wetting, not in contact with the ground, more critical end uses	Decay, fungi and borers	All H3.1 uses plus structural and decking

[a] NZS 3602 (Standards New Zealand, 2003b)

AS/NZS 1080.1 – General Recommendations

AS/NZS 1080.1 states that oven-drying of the timber under controlled conditions is the preferred method of moisture concentration determination and it is recommended for calibration of resistance-based meters. This standard also states that the electrical resistance-based moisture meter response is generally limited to acceptable accuracy between MC values of 8% to 25% moisture wt./wt. The accuracy of the resistance type of meter is accepted to be 1% error within the range of 8% to 10% (wt./wt.) values of MC (Australian Standards/Standards New Zealand, 1997). The magnitude of this error increases in direct proportion to MC and so the performance of the meters tested in this study were also examined as a function of moisture content. Moreover, the use of 'short [needle or pin] electrodes' is known to result in misleading values for timbers thicker than 25 mm. AS/NZS 1080.1 notes that the depth of electrode should be correlated with the required depth of moisture analysis and insulated electrodes should be used in those cases where an analysis of the core of timber thicker than 25 mm is required. The use of both needle/pin and insulated hammered electrodes, therefore, was included in this research in an effort to quantify the effects of electrode depth and separation. Unfortunately, only needle/pin electrodes (commonly attached to the case of the meter) are supplied with many models of commercial instrumentation that are used in the Australasian building industries. The consequent demonstration of the limitations of such an approach, therefore, is also of considerable value.

AS/NZS 1080.1 also notes that needle/pin electrodes should be inserted into the timber at their fullest length. Practical experience has shown that this is usually impossible to achieve without damaging the electrodes. In this regard, at least, the more robust probes of the hammer type assemblies with longer and more robust electrodes, which are insulated up to, but not including, the electrode tip, may be considered to be the more accurate of the electrode geometry types.

Existing Tables of Correction Figures

Early Australasian tables of correction figures for resistance-based moisture meters (described at the time by AS/NZS 1081.1:1972) were authored by Simpson and published by the NZFRI (Simpson, 1996). These tables included corrections for temperature and timber species commonly utilised in Australasia. Currently, AS/NZS 1081.1:1997 presents the widest range of correction figures for both Australasian and international timber species (including some classes of preservative treated *P. radiata*). A comprehensive review of publications which led to the AS/NZS 1081.1 correction value tables is available from Appendix A of this particular standard. As will be seen later, however, these tables are not exhaustive, especially in terms of the timber materials examined in this work. Moreover, two of the moisture meters examined in this work were produced in the USA and Canada and are supplied by the manufacturer with correction figures that, in most cases, do not correlate with those presented in AS/NZS 1081.1:1997, or with the work of Simpson.

MATERIALS AND METHODS

Timber Specimens

Pinus radiata was either sampled from New Zealand retail outlets or supplied directly by the respective New Zealand treatment plant in multiples of 3 m lengths dressed to a 45 x 90 mm cross-section. Subsequently, all of the timber was cut to 1 m lengths prior to moisture equilibration (refer to the procedure illustrated in Figure 1). The timbers were specifically chosen for maximum purity in grain and a general lack of structural discontinuity. The classes of treated timbers examined are described and identified in Table 2. The light organic solvent preservative (LOSP) treatments were bis-(tri-*n*-butyltin) naphthenate (TBTN), bis-(tri-*n*-butyltin) oxide (TBTO), propiconazole and tebuconazole, iodo propynyl butyl carbamate (IPBC) and copper naphthenate (CuN). The waterborne preservative systems were CCA- oxide, ACQ and two boron-based preservative systems. The specific quantification of the treatment hazard class, active preservative and treatment plant was obtained *via* analysis of the timber branding (when available) as described in NZS 3640:2003 (Standards New Zealand, 2003a). Uniform preservative loading was assumed throughout; any visual evidence of the non-compliance of the treated timbers in this respect resulted in immediate rejection of the sample prior to analysis. Complete moisture equilibration was achieved under conditions specified by ASTM D 4933 4933 (American Society for Testing and Materials, 1999). The achievement of equilibrium moisture content was indicated by constant weight with time.

The H1.2 boron treatment (Timber D) may vary from alternative boron-based preservatives due to the significant variations in formulations and processes used in the New Zealand timber preservation industry. The Timber D boron material, supplied by Red Stag, New Zealand (as noted in Table 2), would have been treated by a traditional 'diffusion' process. Alternatives (such as Timber F) may be treated with glycol-borate formulations. A resistance-based moisture meter could respond very differently between these two types of preservatives (due to considerations related to solvent polarity and ionic strength) and entirely independent correction figures may have to be considered.

Instrumentation

The MC of each timber sample was measured using six instrumental conditions involving a range of meters and associated electrode assemblies (Table 3). The nomenclature X, Y and Z relates to the three different manufacturers/brands (anonymously) and the notation (i) and (ii) relate to different models originating from a single manufacturer. E, H and C relate to the type of electrode assembly: 'E' is externally held bi-needle/pin-system which is pushed into timber separately from the case of the instrument, 'H' relates to hammer electrodes (robust and electrically insulated - excluding tip), and 'C' – bi-needle/pin-system directly attached to the case of the instrumentation. The electrode tip separation and mean penetration distances are also listed in Table 3. The latter data were generally dictated by physical feasibility of application without chronic electrode damage.

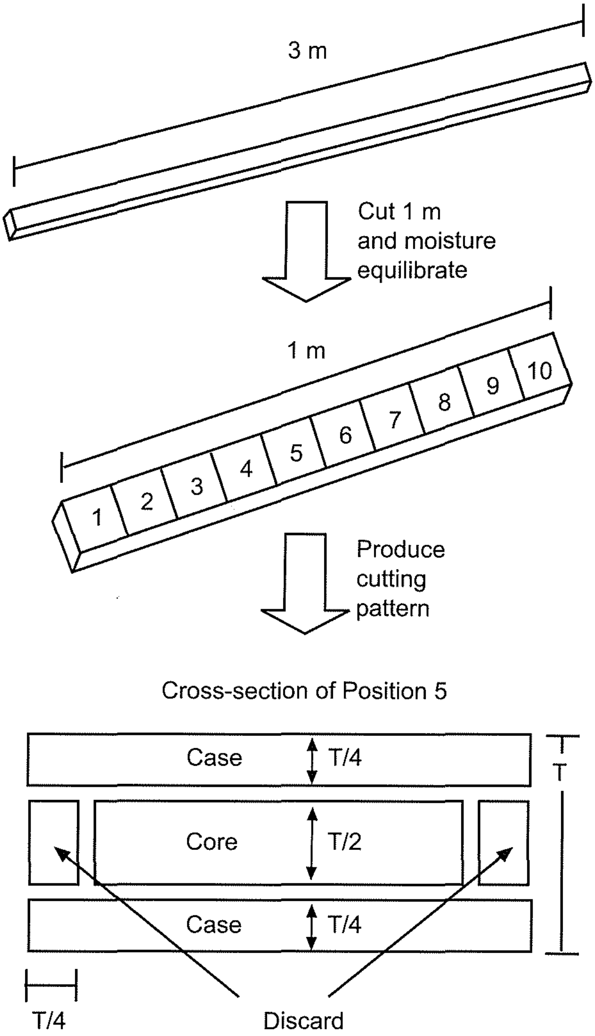

FIGURE 1: Cutting and sequencing of the timber specimens according to Cutting Pattern (a) as described in AS/NZS 1080.1. The thickness of the cross section of the timber in the shortest dimension, T = 45 mm (drawing not to scale).

TABLE 2: Wood-product identification and hazard class of the treated specimens *(Pinus radiata)*.

ID	Generic description	NZS 3640 hazard class	Active preservative ingredients (brand number)	Treatment plant (WOODmark® brand number)*, †
A	LOSP	H3.1	(64) Propiconazole and tebuconazole	(098) WPI Sawmilling, Tangiwai, Ohakune
B	Untreated	–	–	–
C	Waterborne	H3.2	(90) Alkaline copper quaternary (ACQ)	(285) Eastown Timber Products, Whanganui
D	Waterborne	H1.2	(11) Boron	(168) Red Stag Timber, Rotorua
E	Waterborne	H3.2	(01) CCA oxide	(756) Davis Sawmilling Ltd, Featherston
F	Waterborne	Non-approved hazard class (T1.2)	(No brand) T1.2 Boron	(058) South Pine, Nelson
G	LOSP	H1.2	(63) IPBC	(131) Papakura Timber Processors Ltd, Papakura
H	LOSP	H3.1	(56) TBTO	(131) Papakura Timber Processors Ltd, Papakura
I	LOSP	H3.1	(62) TBTN	(144) Hunters (1998) Ltd, Richmond, Nelson
J	LOSP	H3.1	(No brand) CuN	(No brand) Source: Koppers Arch

* Woodmark (NZ Timber Preservation Council Inc) Licensees

† Date of timber treatment is variable

TABLE 3: Moisture meter origin, usage and arbitrary identification nomenclature.

ID	Brand	Model	Origin	Electrode assembly type	Electrode spacing/mm	Penetration depth
X(i)E	X	(i)	USA	External hand-held needle/pin electrodes	13 mm	2–5 mm*
X(i)H	X	(i)	USA	Hammer electrodes	23 mm	15 mm †
X(ii)E	X	(ii)	USA	External hand-held needle/pin electrodes	13 mm	2–5 mm*
X(ii)H	X	(ii)	USA	Hammer electrodes	23 mm	15 mm †
Y(i)H	Y	(i)	New Zealand	Hammer electrodes	23 mm	15 mm †
Z(i)C	Z	(i)	Canada	Case attached needle/pin electrodes	15 mm	6–10 mm*

* Dependent on hardness of timber at time of measurement

† Only bottom 8 mm of both electrodes active due to shaft insulation

Moisture Meter Measurements

The cut, 1 m long, moisture and temperature (21±2 °C) equilibrated lengths of timber were superficially marked into 10 segments (each 100 mm in length). As shown in Figure 1, these segments were then labelled from 1–10 and examined in turn with each of the six instrumental conditions. The timber was never re-measured in an identical location, *i.e.*, the electrode pins were not re-inserted at any single point along the length of the timber. The timber specimens were always supported above the floor of an air-conditioned and humidified work space using two wooden 'saw-horses' and measurements were made away from imperfections such as the minor knots and other surface defects (if present). Pin orientation was applied against the grain of the timber in all cases.

Calibration of each meter was performed according to the manufacturer's instructions using the as-supplied calibration circuits. The general precautions for the use of resistance-based meters were followed, when applicable, as specified in AS/NZS 1080.1, Appendix E (Australian Standards/Standards New Zealand, 1997). The raw data was produced without the use of correction values and standard deviation, when shown, was calculated at 95% confidence limits.

Oven-dry measurements

The oven-dry MC verification was performed according to AS/NZS 1080.1 (Australian Standards/Standards New Zealand, 1997). Samples for oven-dry measurements were cut immediately after each moisture meter-based analysis and were always taken from the mid-point of the timber lengths at Position 5 (a location greater than 0.4 m from the end of each length of timber). The Position 5 timber sample was then cut into test pieces for the determination of moisture distribution according to Cutting Pattern '(a)' from AS/NZS 1080.1 (as also shown in Figure 1). This pattern results in a single 'core' with two 'case' components, all of which were 100 mm in length. These three timber components were then oven-dried at 103±2 °C until constant mass was achieved. Oven-dry percentage moisture content (MC_{od}) was then determined through the relationship (Australian Standards/Standards New Zealand, 1997):

$$MC_{od} = \frac{(M_i - M_o)}{M_o} \times 100 \qquad [1]$$

where, M_i is the initial mass of the test piece and M_o is the oven-dry mass of test piece.

RESULTS AND DISCUSSION

Distribution of Moisture Content

Examples of the distributions of meter-derived moisture content (MC_m) at three different relative humidities as measured along the 1 m lengths of the moisture equilibrated timbers are given for untreated timber (B; Figure 2), one waterborne treated timber (C; Figure 3) and one LOSP treated timber (I; Figure 4), respectively. These data provide an indication of the magnitude of deviation in the response between each instrument condition at constant RH. The Position 5 core and case oven-dry MC_{od} values are presented for comparison as the unbroken and broken straight lines. The oven-dry data shown in these figures strictly apply only to the moisture meter measurements made at Position 5 on the timber specimens and comparison between the oven-dry and the electrical resistance methodology types should only be made for this location. In Figures 2 to 4 all six instrument conditions are shown from meter conditions X(i)E to Z(i)C as defined in Table 3. The output response of meters Y(i)H and Z(i)C were limited to integers, while the meters signified by the manufacturer 'X' were capable of presenting data to a single decimal place. Meter responses displaying an 'error' message (indicating moisture values in excess of that recommended for display by the manufacturer) are not shown in these Figures.

From a qualitative examination of the moisture content distribution data for all the timbers, significant variation was observed between the different timber specimens in terms of the distribution of MC_m across the length of the samples. Moreover, the relative deviation of uncorrected MC_m between each instrument condition for a given timber specimen and position was generally not constant. This immediately indicates that universal correction factors cannot be applied to all of the meters studied. As predicted by the literature, considerable deviation was also observed in some instances between the oven-dry moisture data and the meter values for timber equilibrated in moisture saturated air. This was due to the large error associated with meter measurements made at very high water contents (30% to >100%) (Australian Standards/Standards New Zealand, 1997). At these levels the conductivity of timber electrolytes change very rapidly with small increases in water content (Samuelsson, 1990) .

For a given model of meter, the mode of operation, *i.e.*, hand-held needle/pin probe *vs.* hammer electrode, had a significant influence over the value of the uncorrected MC_m data. This effect cannot be simply assigned to depth of sampling alone as large variations were observed between moisture contents derived using the 'shallow sensing' hand-held needle/pin probes and the oven-dry case sections which were taken from the surfaces of the original timber specimen. In fact, contrasting results were observed between the different electrode assemblies even when using an identical parent meter.

The response of the electrode cell was certainly influenced by a combination of electrode spacing, depth of sampling and pin/needle diameter. However, no correction for such

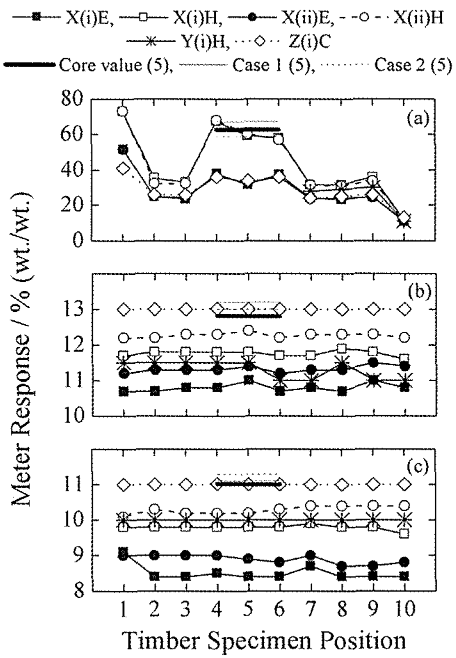

FIGURE 2: Timber B (untreated) - distribution of meter response in terms of estimated moisture content at (a) air at moisture saturation, (b) 75% RH and (c) 65% RH. Core and case values refer to moisture content derived from oven-dry analyses.

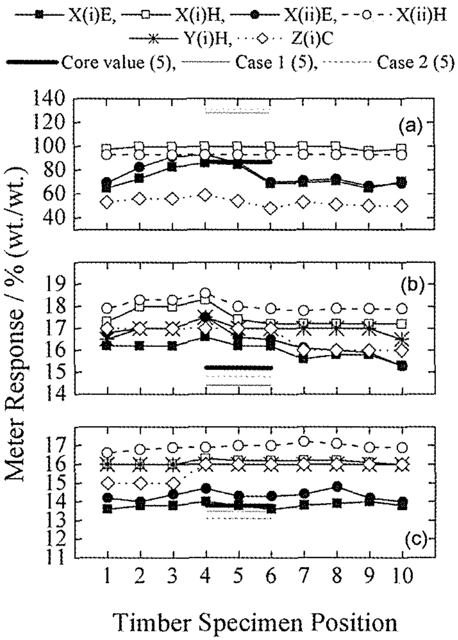

FIGURE 3: Timber C (H3.2 ACQ) - distribution of meter response in terms of estimated moisture content at (a) air at moisture saturation, (b) 75% RH and (c) 65% RH. Core and case values refer to moisture content derived from oven-dry analyses.

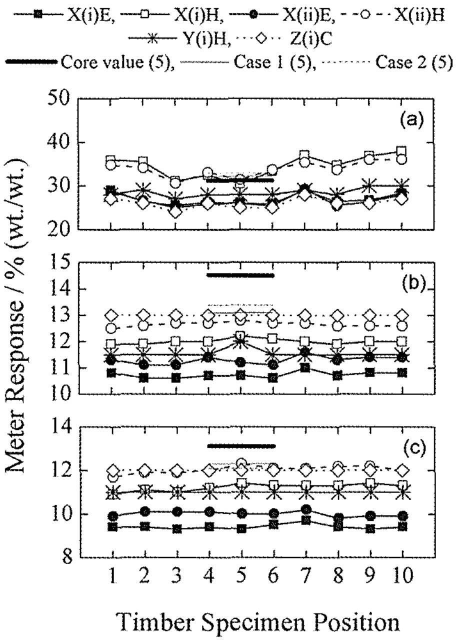

FIGURE 4: Timber I (H3.1 LOSP TBTN) - distribution of meter response in terms of estimated moisture content at (a) air at moisture saturation, (b) 75% RH and (c) 65% RH. Core and case values refer to moisture content derived from oven-dry analyses.

geometrical effects was supplied with any of the meters that incorporate multiple electrode geometries. Thus, in addition to the requirement for a distinct calibration figure for each meter, a number of distinct correction figures would also be required for application to a single model of meter if more than one geometrical electrode assembly is used.

Comparison of Meter Performance with Oven-dry Data

The oven-dry moisture contents of the various timber samples at timber Position 5 are presented in Table 4 and Figures 5 and 6 post moisture equilibration at 65% RH, 75% RH and in moisture saturated air. When held under ambient conditions of relatively high atmospheric water concentration, the untreated timber and the products containing the waterborne preservatives consistently retained moisture at levels in excess of that of the LOSP-based treated products. This is probably due to the non-polar (generally hydrophobic) nature of the LOS-based (light organic solvent-based) preservative solutes and solvents. The solvents are based on mineral turpentine/white spirit, which may linger within the structure of the timber to some extent. Although such a clear distinction between waterborne and LOSP could not be made at 65% and 75%, the untreated timber tended to contain the least moisture of all the timbers at equivalent RH values. However, relatively high core and case water contents at 65% and 75% RH were measured for three of the five LOSP treated timbers (A, H and J) and one of the four waterborne treated timbers (E).

The untreated timber (B) consistently showed no difference between core and case at all the RH values examined in this work. However, for the treated timbers exposed at 65% and 75% RH, the highest MC_{od} was generally measured within the core of the timber. Exceptions were Timber G at 75% RH and Timber D at both 65% and 75% RH.

This trend was reversed (with the exception of Timber E), when the wood was equilibrated at moisture saturation for air and was probably due to an elevated rate of water vapour deposition at the surface in excess of either:

- the moisture content capacity of the core; or
- the rate of moisture content equilibration within the core.

If the latter is assumed, then the timber cannot be taken to have reached steady state moisture content even though constant weight was achieved during the moisture equilibration procedure. The absolute value of moisture content is of academic interest, although the ability of the moisture meters to replicate the data derived using standard oven-dry procedure is of prime importance.

The absolute MC_{od} values obtained from timber equilibrated at 65% and 75% relative humidity, and after exposure to air at moisture saturation are detailed in Figs. 7 (LOSP), 8 (waterborne) and 9 (untreated). The percentage error of the MC_m values relative to MC_{od} results of each moisture meter type and electrode condition is presented in Table 5. The experimentally determined individual correction figures for each condition are also given in this Table.

TABLE 4: Timber oven-dry moisture content values for timbers equilibrated at 65% RH, 75% RH and air at moisture saturation.

				MC_{od} (% wt./wt.)		
Speciman ID	**Treatment**	**Position**	**Test piece**	**65% RH**	**75% RH**	**Moisture Sat. air**
A	LOSP	5	case 1	13.8	13.2	29.4
			core	15.2	15.5	27.8
			case 2	13.4	13.6	30.2
B	Untreated	5	case 1	11.1	13.2	67.2
			core	11.0	12.8	62.6
			case 2	11.3	13.0	58.8
C	Waterborne	5	case 1	13.5	14.4	128.1
			core	13.8	15.2	86.7
			case 2	13.1	14.8	131.5
D	Waterborne	5	case 1	13.9	15.2	80.7
			core	13.4	14.9	49.9
			case 2	13.1	15.2	78.8
E	Waterborne	5	case 1	15.3	16.0	47.4
			core	16.1	17.2	45.1
			case 2	15.4	16.5	45.2
F	Waterborne	5	case 1	12.4	14.2	130.0
			core	13.3	15.8	73.4
			case 2	12.2	14.0	132.5
G	LOSP	5	case 1	11.9	12.1	35.2
			core	13.5	12.3	30.9
			case 2	12.7	11.9	36.9
H	LOSP	5	case 1	14.6	15.6	44.2
			core	15.4	16.4	31.3
			case 2	14.6	15.6	39.2
I	LOSP	5	case 1	12.3	13.1	32.2
			core	13.1	14.5	31.3
			case 2	12.1	13.4	32.9
J	LOSP	5	case 1	14.3	16.2	25.1
			core	16.4	17.0	25.4
			case 2	15.4	15.8	27.1

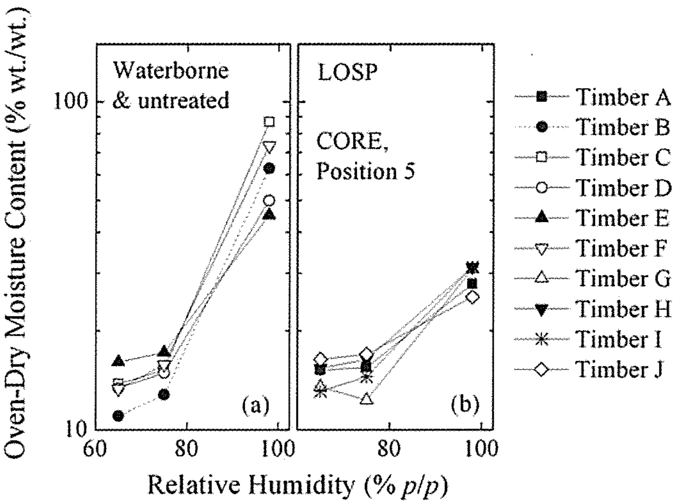

FIGURE 5: Oven-dry, core moisture content values of the waterborne preservative treated and the untreated timbers given as a function of relative humidity.

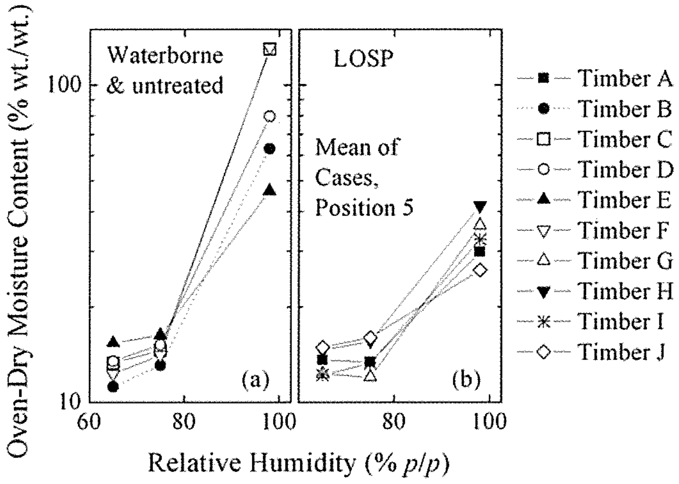

FIGURE 6: Oven-dry, mean of cases moisture content values of the LOSP-based preservative timbers given as a function of relative humidity and classification of carrier solvent.

TABLE 5: Percentage error (wt./wt.) of the uncorrected meter derived moisture levels relative to the oven-dry data post equilibration of the timber at 65% RH, 75% RH and within moisture saturated air. Individual meter correction figures are also given in parenthesis for both timber core and the mean of the timber cases at the specific moisture contents presented in Table 4 at 21±2°C.

	Percentage error (experimental correction figure in parenthesis)					
Timber A	X(i)E	X(i)H	X(ii)E	X(ii)H	Y(i)H	Z(i)C
65%, core	-25.7 (+3.9)	-9.2 (+1.4)	-23.7 (+3.6)	-3.3 (+0.5)	-14.5 (+2.2)	-14.5 (+2.2)
65%, mean of cases	-16.9 (+2.3)	+1.5 (-0.2)	-14.7 (+2.0)	+8.1 (-1.1)	-4.4 (+0.6)	-4.4 (+0.6)
75%, core	-29.0 (+4.5)	-10.3 (+1.6)	-28.4 (+4.4)	-9.0 (+1.4)	-12.9 (+2.0)	-9.7 (+1.5)
75%, mean of cases	-17.9 (+2.4)	3.7 (-0.5)	-17.2 (-2.3)	+5.2 (-0.7)	+0.7 (-0.1)	+4.5 (-0.6)
Sat. air, core	-11.9 (+3.3)	+18.0 (-5.0)	-18.7 (-5.2)	+15.1 (-4.2)	+0.7 (-0.2)	-10.1 (+2.8)
Sat. air, mean of cases	-17.8 (+5.3)	+10.1 (-3.0)	-24.2 (+7.2)	+7.4 (-2.2)	-6.0 (+1.8)	-16.1 (+4.8)
Timber B	X(i)E	X(i)H	X(ii)E	X(ii)H	Y(i)H	Z(i)C
65%, core	-23.6 (+2.6)	-10.9 (+1.2)	-19.1 (+2.1)	-7.3 (+0.8)	-9.1 (+1.0)	0.0 (0.0)
65%, mean of cases	-25.0 (+2.8)	-12.5 (+1.4)	-20.5 (+2.3)	-8.9 (+1.0)	-10.7 (+1.2)	-1.8 (+0.2)
75%, core	-14.1 (+1.8)	-7.8 (+1.0)	-10.9 (+1.4)	-3.1 (+0.4)	-10.2 (+1.3)	+1.6 (-0.2)
75%, mean of cases	-16.0 (+2.1)	-9.9 (+1.3)	-13.0 (+1.7)	-5.3 (+0.7)	-12.2 (+1.6)	-0.8 (+0.1)
Sat. air, core	-49.7 (+31.1)	-5.1 (+3.2)	-47.6 (+29.8)	-3.5 (+2.2)	-100.0 (-)	-45.7 (+28.6)
Sat. air, mean of cases	-50.0 (+31.5)	-5.7 (+3.6)	-47.9 (+30.2)	-4.1 (+2.6)	-100.0 (-)	-46.0 (+29.0)
Timber C	X(i)E	X(i)H	X(ii)E	X(ii)H	Y(i)H	Z(i)C
65%, core	0.0 (0.0)	+17.4 (-2.4)	+3.6 (-0.5)	+23.2 (-3.2)	+15.9 (-2.2)	+15.9 (-2.2)
65%, mean of cases	+3.8 (-0.5)	+21.8 (-2.9)	+7.5 (-1.0)	+27.8 (-3.7)	+20.3 (-2.7)	+20.3 (-2.7)
75%, core	+6.6 (-1.0)	+14.5 (-2.2)	+9.2 (-1.4)	+18.4 (-2.8)	+11.8 (-1.8)	+11.8 (-1.8)
75%, mean of cases	+11.0 (-1.6)	+19.2 (-2.8)	+13.7 (-2.0)	+23.3 (-3.4)	+16.4 (-2.4)	+16.4 (-2.4)
Sat. air, core	-2.5 (+2.2)	+15.2 (-13.2)	-0.3 (+0.3)	+7.2 (-6.2)	- (-)	-37.7 (+32.7)
Sat. air, mean of cases	-34.9 (+45.3)	-23.0(+29.9)	-33.4(+43.4)	-28.4 (+36.9)	- (-)	-58.4 (+75.8)
Timber D	X(i)E	X(i)H	X(ii)E	X(ii)H	Y(i)H	Z(i)C
65%, core	+16.4 (-2.2)	+12.7 (-1.7)	+20.1 (-2.7)	+22.4 (-3.0)	-10.4 (+1.4)	+26.9 (-3.6)
65%, mean of cases	+15.6 (-2.1)	+11.9 (-1.6)	+19.3 (-2.6)	+21.5 (-2.9)	-11.1 (+1.5)	+25.9 (-3.5)
75%, core	+16.8 (-2.5)	+21.5 (-3.2)	+20.8 (-3.1)	+24.2 (-3.6)	+7.4 (-1.1)	+20.8 (-3.1)
75%, mean of cases	+14.5 (-2.5)	+19.1 (-2.9)	+18.4 (-2.8)	+21.7 (-3.3)	+5.3 (-0.8)	+18.4 (-2.8)
Sat. air, core	+25.3 (-12.6)	+100.2 (-50.0)	+30.1 (-15.0)	+86.2 (-43.0)	- (-)	-5.8 (+2.9)
Sat. air, mean of cases	-21.6 (+17.3)	+25.3 (-20.2)	-18.6(+14.9)	+16.5 (-13.2)	- (-)	-41.1 (+32.8)
Timber E	X(i)E	X(i)H	X(ii)E	X(ii)H	Y(i)H	Z(i)C
65%, core	-28.0 (+4.5)	-7.5 (+1.2)	-24.2 (+3.9)	-6.2 (+1.0)	-13.0 (+2.1)	-13.0 (+2.1)
65%, mean of cases	-24.4 (+3.8)	-2.9 (+0.5)	-20.5 (+3.2)	-1.6 (+0.3)	-8.8 (+1.4)	-8.8 (+1.4)
75%, core	-20.3 (+3.5)	-6.4 (+1.1)	-15.7 (+2.7)	-1.2 (+0.2)	-9.9 (+1.7)	-12.8 (+2.2)
75%, mean of cases	-15.7 (+2.6)	-0.9 (+0.1)	-10.8 (+1.8)	+4.6 (-0.8)	-4.6 (+0.8)	-7.7 (+1.3)
Sat. air, core	-4.0 (+1.8)	+76.1 (-34.3)	-3.3 (+1.5)	+90.0 (-40.6)	- (-)	-2.4 (+1.1)
Sat. air, mean of cases	-6.5 (+3.0)	+71.5 (-33.1)	-5.8 (+2.7)	+85.1 (-39.4)	- (-)	-5.0 (+2.3)

TABLE 5 continued.

	Percentage error (experimental correction figure in parenthesis)					
Timber F	X(i)E	X(i)H	X(ii)E	X(ii)H	Y(i)H	Z(i)C
65%, core	+6.8 (-0.9)	+9.8 (-1.3)	+15.8 (-2.1)	+20.3 (-2.7)	-9.8 (+1.3)	+20.3 (-2.7)
65%, mean of cases	+15.4 (-1.9)	+18.7 (-2.3)	+25.2 (-3.1)	+30.1 (-3.7)	-2.4 (+0.3)	+30.1 (-3.7)
75 %, core	0.0 (0.0)	+1.3 (-0.2)	+1.9 (-0.3)	+3.8 (-0.6)	-8.2 (+1.3)	+1.3 (-0.2)
75%, mean of cases	+12.1 (-1.7)	+13.5 (-1.9)	+14.2 (-2.0)	+16.3 (-2.3)	+2.8 (-0.4)	+13.5 (-1.9)
Sat. air, core	+36.1 (-26.5)	+36.1 (-26.5)	+26.6 (-19.5)	+26.6 (-19.5)	- (-)	-14.2 (+10.4)
Sat. air, mean of cases	-23.9 (+31.4)	-23.9 (+31.4)	-29.2 (+38.4)	-29.2 (-38.4)	- (-)	-52.0 (+68.3)
Timber G	X(i)E	X(i)H	X(ii)E	X(ii)H	Y(i)H	Z(i)C
65%, core	-28.9 (+3.9)	-13.3 (+1.8)	-23.0 (+3.1)	-4.4 (+0.6)	-3.7 (+0.5)	-3.7 (+0.5)
65%, mean of cases	-22.0 (+2.7)	-4.9 (+0.6)	-15.4 (+1.9)	+4.9 (-0.6)	+5.7 (-0.7)	+5.7 (-0.7)
75 %, core	-13.8 (+1.7)	-5.7 (+0.7)	-12.2 (+1.5)	0.0 (0.0)	-2.4 (+0.3)	+5.7 (-0.7)
75%, mean of cases	-11.7 (+1.4)	-3.3 (+0.4)	-10.0 (+1.2)	+2.5 (-0.3)	0.0 (0.0)	+8.3 (-1.0)
Sat. air, core	-12.9 (+4.0)	+23.3 (-7.2)	-11.0 (+3.4)	+21.0 (-6.5)	+3.6 (-1.1)	-12.6 (+3.9)
Sat. air, mean of cases	-25.4 (+9.2)	+5.7 (-2.1)	-23.7 (+8.6)	+3.7 (-1.4)	-11.2 (+4.1)	-25.1 (+9.1)
Timber H	X(i)E	X(i)H	X(ii)E	X(ii)H	Y(i)H	Z(i)C
65%, core	-21.4 (+3.3)	-5.2 (+0.8)	-18.2 (+2.8)	+0.6 (-0.1)	-9.1 (+1.4)	-2.6 (+0.4)
65%, mean of cases	-17.1 (+2.5)	0.0 (0.0)	-13.7 (+2.0)	+6.2 (-0.9)	-4.1 (+0.6)	+2.7 (-0.4)
75 %, core	-9.1 (+1.5)	0.0 (0.0)	-7.3 (+1.2)	-0.6 (+0.1)	-2.4 (+0.4)	-2.4 (+0.4)
75%, mean of cases	-4.5 (+0.7)	+5.1 (-0.8)	-2.6 (+0.4)	+4.5 (-0.7)	2.6 (-0.4)	+2.6 (-0.4)
Sat. air, core	+19.5 (-6.1)	+68.1 (-21.3)	+13.4 (-4.2)	+70.9 (-22.2)	- (-)	+8.6 (-2.7)
Sat. air, mean of cases	+14.9 (-4.9)	+61.6 (-20.1)	+9.1 (-3.0)	+64.4 (-21.0)	- (-)	+4.5 (-1.5)
Timber I	X(i)E	X(i)H	X(ii)E	X(ii)H	Y(i)H	Z(i)C
65%, core	-29.0 (+3.8)	-13.0 (+1.7)	-23.7 (+3.1)	-6.1 (+0.8)	-16.0 (+2.1)	-8.4 (+1.1)
65%, mean of cases	-23.8 (+2.9)	-6.6 (+0.8)	-18.0 (+2.2)	+0.8 (-0.1)	-9.8 (+1.2)	-1.6 (+0.2)
75 %, core	-26.2 (+3.8)	-15.9 (+2.3)	-22.8 (+3.3)	-11.7 (+1.7)	-17.2 (+2.5)	-10.3 (+1.5)
75%, mean of cases	-19.2 (+2.6)	-7.9 (+1.1)	-15.5 (+2.1)	-3.4 (+0.4)	-9.4 (+1.3)	-1.9 (+0.3)
Sat. air, core	-16.9 (+5.3)	-2.9 (+0.9)	-16.9 (+5.3)	+0.3 (-0.1)	-10.5 (+3.3)	-20.1 (+6.3)
Sat. air, mean of cases	-20.1 (+6.6)	-6.6 (+2.2)	-20.1 (+6.6)	-3.5 (+1.2)	-14.0 (+4.6)	-23.2 (+7.6)
Timber J	X(i)E	X(i)H	X(ii)E	X(ii)H	Y(i)H	Z(i)C
65%, core	-27.4 (+4.5)	-10.4 (+1.7)	-22.6 (+3.7)	-6.1 (+1.0)	-14.6 (+2.4)	-14.6 (+2.4)
65%, mean of cases	-19.9 (+3.0)	-1.0 (+0.2)	-14.5 (+2.2)	+3.7 (-0.5)	-5.7 (+0.9)	-5.7 (+0.9)
75 %, core	-17.6 (+3.0)	-7.1 (+1.2)	-15.9 (+2.7)	-4.1 (+0.7)	-11.8 (+2.0)	-11.8 (+2.0)
75%, mean of cases	-12.5 (+2.0)	-1.3 (+0.2)	-10.6 (+1.7)	+1.9 (-0.3)	-6.3 (+1.0)	-6.3 (+1.0)
Sat. air, core	-13.0 (+3.3)	+0.8 (-0.2)	-13.4 (+3.4)	-0.4 (+0.1)	-7.5 (+1.9)	-13.4 (+3.4)
Sat. air, mean of cases	-15.3 (+4.0)	-1.9 (+0.5)	-15.7 (+4.1)	-3.1 (+0.8)	-10.0 (+2.6)	-15.7 (+4.1)

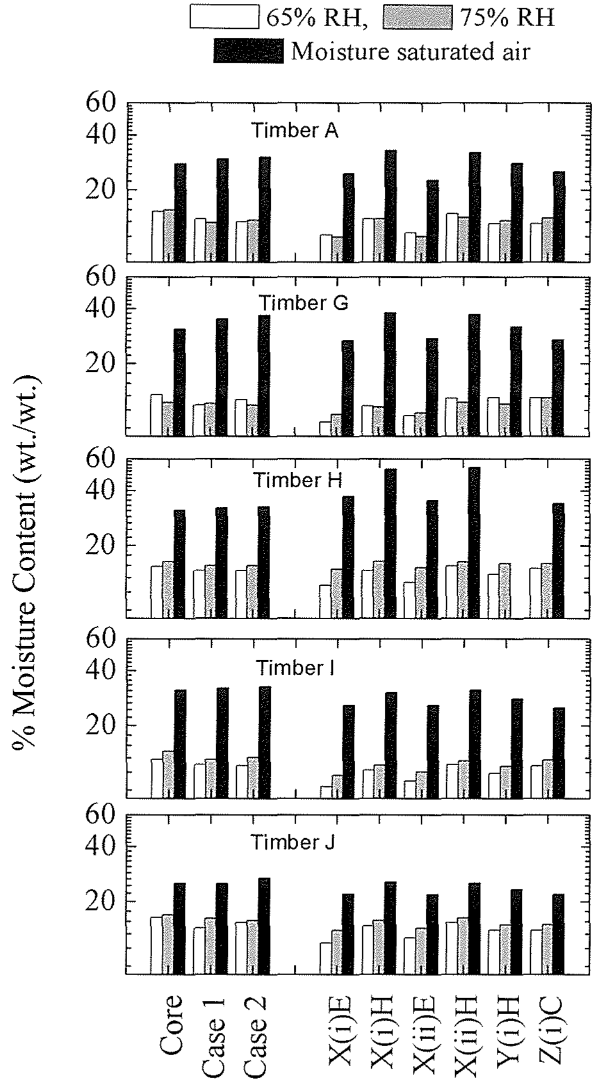

FIGURE 7: LOSP-based treated timber at 65% and 75% relative humidity and exposed to air at moisture saturation - comparison of oven-dry and uncorrected instrumental moisture content methodologies at Position 5. The missing data for the Y(i)H instrumental assembly indicates an 'error' response.

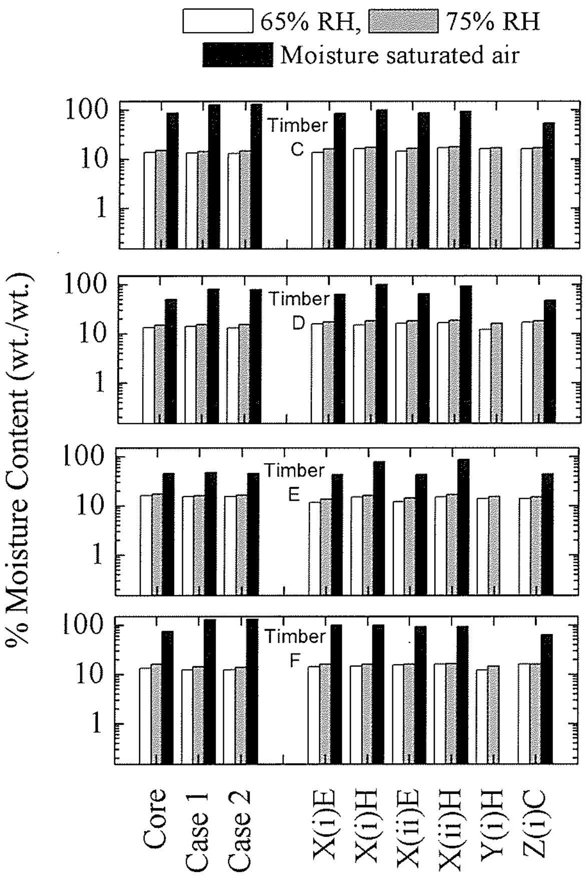

FIGURE 8: Waterborne-based treated timber at 65% and 75% relative humidity and exposed to air at moisture saturation - comparison of oven-dry and uncorrected instrumental moisture content methodologies at Position 5. The missing data for the Y(i)H instrumental assembly indicates an 'error' response.

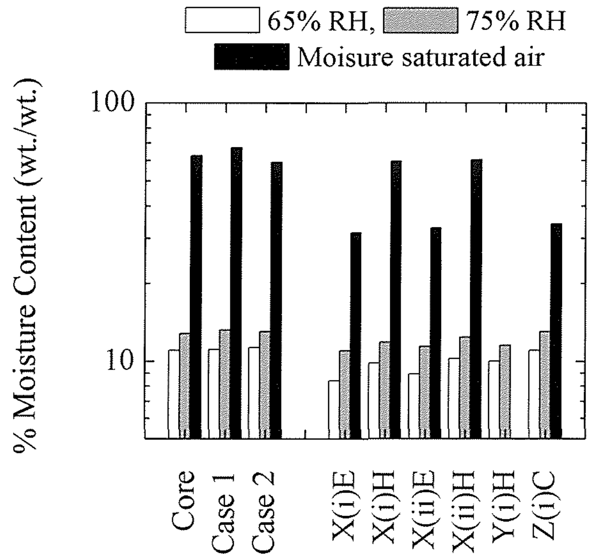

FIGURE 9: Timber B (untreated) at 65% RH, 75% RH and air at moisture saturation - comparison of oven-dry and uncorrected instrumental moisture content methodologies at Position 5. The missing data for the Y(i)H instrumental assembly indicates an 'error' response. The missing data for the Y(i)H instrumental assembly indicates an 'error' response.

Considering the untreated timber specimens exposed at 65% and 75% RH, only one of the instrumental conditions (Z[i]C) was able to accurately reproduce the oven-dry moisture content at Position 5 without the introduction of a correction figure. Although the 'X' and 'Y' class of meters clearly required correction in order to simulate the moisture content of untreated *P. radiata*, the uncorrected accuracy of the X-branded meter increased significantly with the use of the hammer probes relative to the hand-held external needle/pin electrodes. The difference in MC_m when using the hammer probes led to measurements which were only approximately 1% to 1.5% meter percentage units lower than the oven-dry response of both the core and the cases at Position 5. When using the needle/pin probes, as supplied with X-branded meter, the equivalent concentrations were 2 to 2.5 percentage units lower than the oven-dry values. This was not due to a difference in moisture content in the timber itself (from Table 4 it can be seen that the oven-dry untreated core and case values were very similar and within an absolute deviation of 0.5% wt./wt. MC), but certainly due to the change in electrode/timber contact area geometry (refer to the electrode parameters in Table 3).

A relatively positive increase in the value of the directly measured value of uncorrected apparent MC_m with use of the X(i) and X(ii) meter type hammer probes was also observed with Timbers A, E, G, H, I and J at both 65% and 75% relative humidities. With the exception of Timber E all of these conditions included LOSP-based preservatives. With the waterborne-treated Timber C, however, the use of the hammer probe reduced the uncorrected accuracy. No significant difference between probe types was measured when the two boron-treated timbers (D and F) were interrogated when exposed to both 65% and 75% RH.

The data produced for meter type Y(i)H showed highly variable behaviour in some instances, which was entirely inconsistent with the results produced using the alternative X- and Z-branded meters. Such responses were also replicated following immediate re-calibration and repetition of the testing. Note, for example, the behaviour of meter Y(i)H at 65% and 75% RH for Timber D and F; both of which were boron-based treatments. For these timbers, the meter produced significantly lower MC_m values of than the other five instrumental conditions.

Clearly, the LOSP and waterborne classes of preservatives do not have an identical or an entirely consistent influence over the response of the meters. The calibration figures presented in AS/NZS 1081.1 assume that the principle of operation of electrical resistance meters is identical in each case, but the results of this work indicate that universal calibration curves for treated timber may not provide an ideal correlation for all brands of commercially available moisture meters. Indeed, the data in Table 5 can be used to show that the error associated with each type of meter can be equivalent in some cases, but rather discontinuous in others at 65% and 75% RH. For example, considering the core samples at 65% RH and excluding external hand-held needle/pin electrodes, Timber A produced X(i)H, X(ii)H, Y(i)H and Z(i)C errors of -9.2%, -3.3%, -14.5% and -14.5%, respectively. At 75% RH the equivalent values were -10.3%, -9.0%, -12.9% and -9.7%. In this example, all the errors are negative, of a similar order and demonstrate that, for some timbers at least, an overall correction figure may be introduced with a maximum estimated error in the corrected moisture reading of 10% to 15%. Favourable correlations of a similar order of error were also found for Timbers C and E (waterborne), and Timbers H, I and J (LOSP). In contrast, the two waterborne boron-treated timbers (D and F) produced percentage errors, relative to MC_{od} core values ranging from, -10.4% to +26.9% for Timber D and from -9.8% to +20.3% for Timber F at 65% RH. Untreated timber (B) also produced an imperfect correlation in percentage error between the meters (as did Timber G). The discrepancy noted for the untreated timber is certainly due to an inherent difference in the base-line value of ionic resistance assigned by the manufacturer during factory calibration.

It may be proposed that the use of small needle/pin electrodes at a relatively reduced depth will result in a higher accuracy in the determination of the MC of the case components close to the surface of the timber specimens (Australian Standards/Standards New Zealand, 1997; Simpson, 1996). This electrode cell geometry is used by the instrumental conditions X[i]E, X[ii]E and Z[i]C. Conversely, the hammer electrodes, which are used at greater depth, have been assumed in the same literature to produce values closer to that of the timber core. In practice, the dominant trend of comparatively low MC_{od} values measured at 65% and 75% RH in the case components was almost universally replicated by lower MC_m values when using the needle/pin electrodes of the X brand of meter (as apposed to the hammer electrodes of the same instrument). In most instances, however, the differences in MC_m measured between the needle/pin electrodes and the hammer electrodes were considerably greater than the deviation between the oven-dry results of the core and case components. The differing diameter of the electrodes would also significantly reduce the validity of such a direct comparison and a comparative treatment of depth of sampling using the result presented in this work, therefore, cannot be recommended.

Application of Instrumental Correction Figures

In this section, the manufacturer's correction figures (when available) have been used in order to compare the accuracy of each instrument as intended for use in the field. Specific correction is essential because it is clear that at least one of the manufacturers has calibrated the factory applied resistance/MC calibration response of their instrument in variance to their competitors. In order to illustrate the extent of variation, an example set of correction figures (in units of % wt./wt.) have been presented in Table 6 for an arbitrarily chosen uncorrected MC_m of 16% at 21°C. As the data in this Table has only been derived for a single value of uncorrected MC_m, the correction figures are only to be viewed as an indicative guide. Indeed, all of the data discussed in the remainder of this work have been corrected using tabulated data individually correlated with each experimentally obtained value of MC_m. However, since only a single set of correction figures was supplied with the X-branded instrument, which utilizes various electrode cell geometries, the deviation in the magnitude of response between hand held and hammer electrodes will certainly influence the values of MC_m post-correction. Moreover, there is a distinct lack of correction figures available for many of the timber preservative systems examined. This was certainly the case for Timber F (boron T1.2). In these instances no external correction factor could be applied.

Using the manufacturers' suggested correction figures for each instrument, the experimental MC_m data was re-calculated and presented in terms of absolute deviation from the core and mean case MC_{od} values (all in units of percentage moisture concentration [% wt./wt.]):

$$\text{Value of deviation} = MC_m - MC_{od}. \qquad [2]$$

The uncorrected and corrected moisture content estimations for the untreated timber (B) core and cases are shown in Figure 10, where it is clear that the manufacturer correction figures (where required) were able to significantly improve the correlation of all the meter readings with the oven-dry method to within ±1 MC unit (% wt./wt.). Success with the untreated timber samples, however, did not lead to a universal improvement in the correlation when the treated timbers were examined. Figure 11 gives the absolute values of deviation of the corrected MC_m values from MC_{od} as a function of meter assembly type and application of the available correction figures for the various treated timbers. For brevity, only comparison with the core specimens is shown. The application of the relevant correction factor for meter X led to grossly over-estimated actual MC for the ACQ waterborne treated timber (C) and the one of the waterborne boron-treated timbers (D). This can be explained by the ionic resistance of the timber structure being considerably lower than that predicted by the corrected figures. In contrast, the application of the relevant correction factor for meter X led to a much more accurate MC_m for the CCA waterborne treated timber (E). This is in agreement with previously published work, (Kear & Wu, 2006), where it was noted that CCA treated timber *P. radiata* has a higher inherent ionic resistance than the same wood species preserved with an ACQ-based product.

Meter Y(i)H was the most accurate meter for boron-based timber preservatives, but it may be observed that a very large discrepancy is possible if the X-brand of meter is used in conjunction with the '+3' correction figure as presented in the instrument manual (Table 6). This value of correction is recommended for *P. radiata* treated with 'waterborne preservatives'. This recommendation is extremely non-specific and will lead to considerable error if the preservative in question does not exhibit similar characteristics to that of CCA-based preservatives.

The corrected measurements produced with the LOSP treated timbers were ineffective (Figure 11), and in many cases a minimum accuracy of at least ±2 moisture meter units could not be achieved. The application of correction figures did not generally improve the correlation to any significant degree, as there was a general lack of applicable correction data provided both with the meters and in AS/NZS 1080.1. Although the correction figures supplied with the Y(i)H meter improved the correlation with the oven-dry data in some instances (refer to Figure 11, Timbers A and I), the universal application of these figures also increased the error in the measurement of MC_m relative to MC_{od} for Timbers G, H and J (Figure 11). It may be assumed that the mechanisms responsible for erroneous meter readings result from ionic mobility considerations of the organic compounds tested and consequent changes in the resistance properties of the timber.

TABLE 6: Manufacturers' correction figures (as taken from tabulated data supplied with each meter). Exemplar data is presented in this table for a temperature of 21±2 °C (corrected if necessary) at an arbitrarily chosen example uncorrected meter reading of 16% moisture (wt./wt.) for sapwood.

ID	Generic description	NZS 3640 hazard class	X(i)E -	X(i)H -	X(ii)E -	X(ii)H -	Y(i)H	Z(i)C	AS/NZS 1080.1[1]
A	LOSP[2]	H3.1	+1.5%	+1.5%	+1.5%	+1.5%	+3%	-	-
B	Untreated	-	+2.5 to +3.5%	+2.5 to +3.5%	+2.5 to +3.5%	+2.5 to +3.5%	+1%	0%	+1%
C	Waterborne[3] ACQ	H3.2	+2.5 to +3.5%	+2.5 to +3.5%	+2.5 to +3.5%	+2.5 to +3.5%	-	-	-
D	Waterborne[3] Boron	H1.2	+2.5 to +3.5%	+2.5 to +3.5%	+2.5 to +3.5%	+2.5 to +3.5%	-2%	-	-2%
E	Waterborne[3] CCA[4]	H3.2					-	-	+1%
F	Waterborne[3] T1.2 Boron	Non-approved hazard class (T1.2)	-	-	-	-	-	-	-
G	LOSP[2]	H1.2	-	-	-	-	+3%	-	-
H	LOSP[2]	H3.1	-	-	-	-	+3%	-	-
I	LOSP[2]	H3.1	-	-	-	-	+3%	-	-
J	LOSP[2]	H3.1	-	-	-	-	+3%	-	-

1. Applies to AS/NZS 1080.1 data tabulated for *Pinus radiata* (NZ).

2. Manufacturer's instruction for LOSP treated *Pinus radiata* as follows: 'Indicative values only – must be used with caution'. Correction figure of +3% derived as follows: +1.5 of *Pinus radiata* with an additional (+1 to +2%) for water-based preservative. This treatment gives a range of +2.5 to +3.5% (3.0±0.5%).

3. Waterborne preservative class as defined as +2.5 to +3.5% by Manufacturer 'X'. A mean value of +3% is applied for all the waterborne preservative corrections used in this work using 'X' meters.

4. 'Tanalith', as quoted in some texts, is taken in this report to mean CCA-salt treated timber as described in AS/NZS 1080.1. Since the CCA treated timber used in this work is of the oxide type, no correction can be made for 'Tanalith' as presented in many of the moisture meter manuals. This may cause confusion as, for example, 'Tanalith C' (as used in this work) is composed of CCA-oxide and Tanalith E is a copper azole- (CuAz-) based treatment (neither of which conform to the AS/NZS 1080.1 definition of Tanalith). AS/NZS 1080.1 states that 'Boliden' is more representative of CCA-oxide treated timber. Only correction figures associated with this nomenclature will be applied to the correction of values measured in CCA-oxide treated timber.

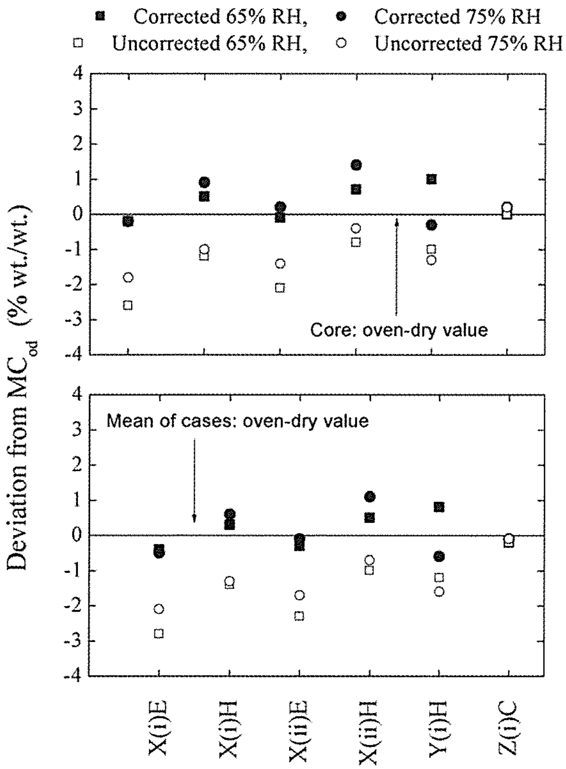

FIGURE 10: Percentage deviation of the uncorrected meter derived moisture contents compared with oven-dry values for the core and cases (mean) at Position 5 for untreated timber (B) at 65% and 75% relative humidity. The corresponding corrected values were determined using manufacturers correction figures. Correction figures were not applicable for the moisture contents determined post equilibration in moisture saturated air.

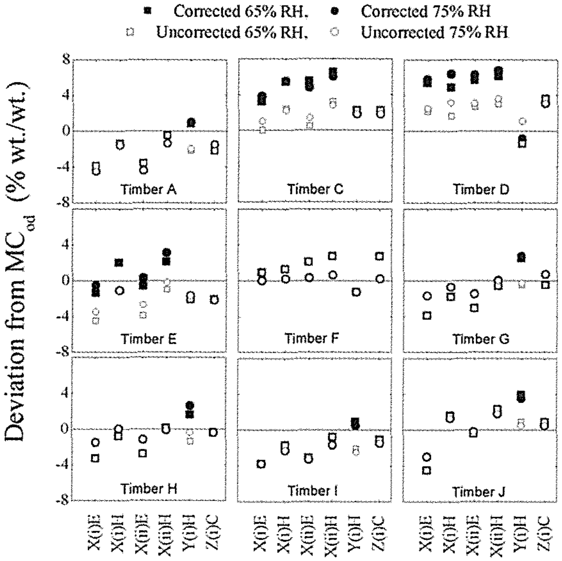

FIGURE 11: Percentage deviation of the uncorrected meter derived moisture contents compared with oven-dry values for the treated timbers relative to the equivalent core oven-dry data. The corresponding corrected values were determined using manufacturers correction figures. Correction figures were not applicable for the moisture contents determined post equilibration in moisture saturated air so values derived from exposure to air at moisture saturation are not presented.

CONCLUSIONS

When individual moisture meter correction figures, as supplied with each meter type, were introduced to the directly measured resistance-based data, all of the meters were able to accurately determine the moisture content of untreated *P. radiata* to within ±1 moisture meter units (% wt./wt.). In many cases, however, the introduction of timber treatments led to erroneous readings from the meters. The magnitude of the error varied with preservative type, brand of meter and class of electrode cell geometry. In some instances, after applying the manufacturers' correction figures, the meters were unable to accurately determine the moisture content of ACQ, one boron and various LOSP treated products within ±2 moisture meter percentage units. Such shortcomings are of concern as the latter two classes of preservative are commonly used in New Zealand for internal wooden framing and would be the subject of the majority of meter investigations in the field.

The results presented here strongly indicate that the application of universal correction figures in Australasia does not appear to be feasible without international standardisation. Although the 'X' and 'Z' branded meters examined in this work were produced outside

Australasia, they are instruments that are commonly sold in the region. In many instances, the X and Z meters did not reproduce the behaviour of the 'Y' brand, which, it is reported by the manufacturer, was produced and calibrated to the specifications and the correction figures laid out in AS/NZS 1080.1. It is clear that the baseline resistance/moisture content initial calibration value varied between meters. The application of the correction values reproduced in AS/NZS 1080.1, therefore, will lead to erroneous readings in many instances. Standardisation of the calibration base value for each actual value of moisture content is required in addition to the establishment of continuity in electrode cell geometry (width, depth and spacing, etc., of active areas). Neither condition is defined in AS/NZS 1080.1.

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