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Moisture Meter Calibration for Untreated and ACQ-Treated Southern Yellow Pine Plywood

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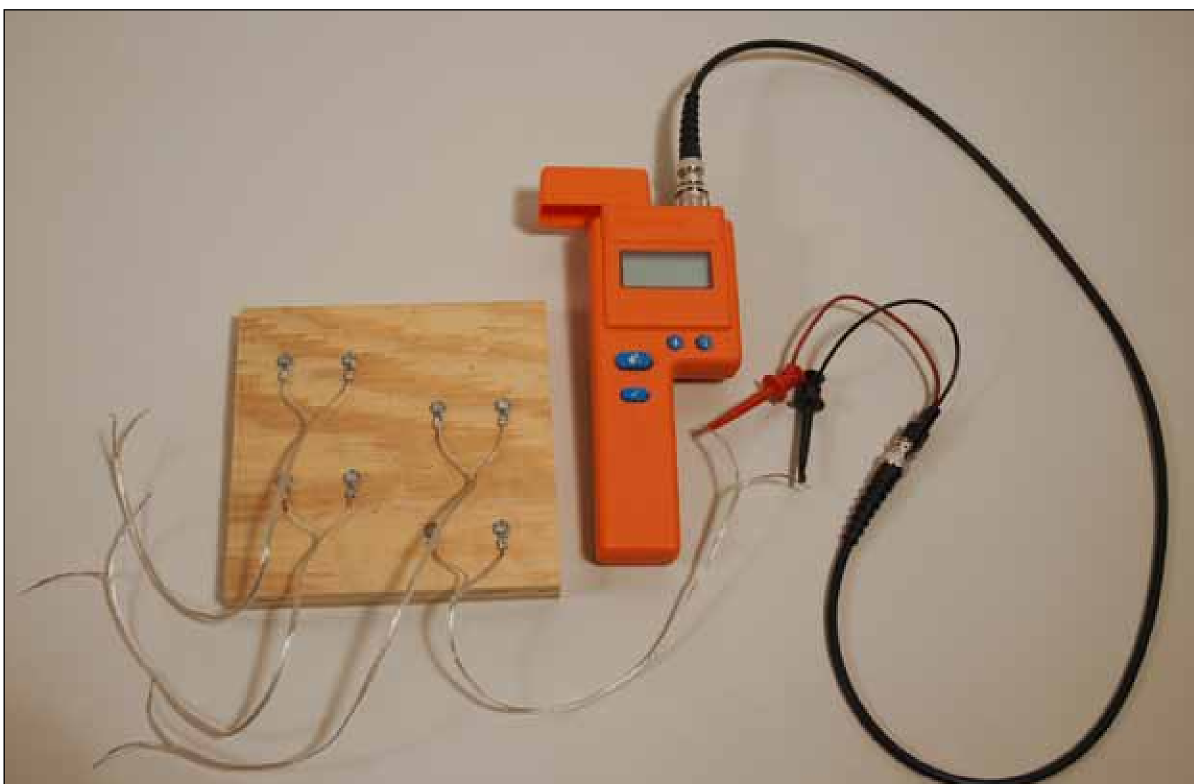

Abstract

Conductance moisture meter readings using stainless steel screws as electrodes were compared with gravimetric moisture content for 1) southern yellow pine (SYP) dimensioned lumber, 2) untreated (underlayment grade) SYP plywood, and 3) SYP plywood treated with alkaline copper quaternary. Meter readings were taken with the meter set to the manufacturer-provided species correction for SYP. In the sample of dimensioned lumber used in this investigation, direct meter readings corresponded closely with gravimetric moisture contents. The manufacturer-provided correction for SYP wood was thus deemed adequate. In contrast, meter readings in plywood, whether treated or untreated, deviated substantially from gravimetric moisture content values. Calibration equations for the plywoods are thus presented for predicting gravimetric moisture content from moisture meter readings.

Keywords: moisture meter, electrical conductance, moisture content, calibration, plywood, alkaline copper quaternary, southern yellow pine

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Introduction

Several methods are available for measuring wood moisture content (MC), defined as the ratio of the mass of water in wood to the mass of oven-dried wood. A typical method for field work is the conductance-type moisture meter, which uses the relationship between electrical conductance and moisture content. Conductance (or its reciprocal, resistance) is measured between two electrodes that are inserted into the wood.

We recently began a cooperative field study in southern Louisiana aimed at characterizing moisture performance of various types of floor insulation in houses with raised floors. The research team decided to measure moisture content in the subflooring of each house twice a month for 12 months. It was necessary to install permanent electrodes or "moisture pins" before the insulation was applied against the subflooring because certain types of insulation could not be readily removed for taking readings with a typical pin-type conductance moisture meter. We wanted to detect the wettest part of the subfloor, so we selected uninsulated electrodes, which read the location of highest conductance or greatest moisture content in contact with both electrodes. We also wanted electrodes that could be easily installed in the field, would not suffer corrosion, and would provide reliable contact with the wood over changing moisture conditions for the duration of the study. Dai and Ahmet (2001) and ASTM (2008) have reported that pre-drilling holes and using threaded screws improves the long-term contact between the electrodes and wood. On the basis of these criteria, we selected stainless steel screws for electrodes.

Several types of subflooring were identified in the houses selected for the field study: southern yellow pine (SYP) plywood panels in newer construction, both untreated and treated with alkaline copper quaternary (ACQ), and untreated SYP tongue-and-groove floor boards in older construction. To obtain accurate moisture content measurements, we needed to establish a calibration for each of these subflooring types.

Although abundant literature exists on moisture meter calibrations for various wood species, no literature could be found for SYP plywood, whether treated or untreated. Palka and Hejjas (1976) established a calibration for 13-mm-thick five-ply Douglas-fir plywood using a conductance moisture meter. However, the meter had four 6.4-mm-long uncoated needles, and care was taken to avoid penetrating the glue line.

The objective of the present study was to calibrate moisture meter readings using stainless steel screw electrodes (which do penetrate the glue lines) in untreated and ACQ-treated SYP plywood and in untreated SYP lumber.

Materials and Methods

Specimens

Three sections of untreated SYP dimensioned lumber, 38 by 89 mm, each less than 800 mm long, were cut into 12 specimens, each approximately 120 to 170 mm long with ovendry mass in the range of 150 to 300 g. None of the specimens contained boxed pith, but all contained rapidly grown wood from near the center of the tree. Some of the specimens contained knots. When specimens were ovendried, differences between specimens with regard to pitch bleed became noticeable. Average specific gravity, based on ovendry mass and volume at 10% MC, was 0.48 ± 0.05 (errors given in this paper represent one standard deviation unless stated otherwise). Groups of four specimens were conditioned to three different equilibrium moisture contents (EMCs). Each group was placed in an environment maintained at relative humidity (RH) values between 50% and 85%. Specimens were allowed to equilibrate for a minimum of two months, and repeated weighing showed that the masses were stable. One group of four specimens was sequentially equilibrated to two sets of relative humidity conditions.

Untreated and ACQ-treated SYP plywood panels were obtained from retail lumber yards. Two 1.2- by 2.4-m panels of each type were selected. Both panel types were 18 mm (nominally 23/32 in.) thick and contained five plies. The untreated plywood had a touch-sanded face and was grade-stamped as Underlayment Grade, according to product Standard PS 1-95 (NIST 1996), and Sturd-I-Floor, according to APA Standard PRP-108 (APA 1994). The face ply was essentially clear sapwood, whereas the back plies contained many knots and some patches of heartwood. In contrast, we could perceive no difference in veneer grade between the

Table 1—Conditions for equilibrating specimens and equilibrium moisture content (EMC) measured gravimetrically

Lumber type	Group	Location	Temperature (°C (°F))	RH[a] (%)	Average EMC (%)
Untreated dimensioned lumber	1	Environmental room	22 (72)	50	10.2
	2	Environmental room	27 (80)	66	11.6
	3	Container with NaCl	22 (72)	75	13.2
	4	Container with KCl	22 (72)	85	16.9
Untreated plywood	1	Environmental room	27 (80)	36	6.6
	2	Environmental room	22 (72)	50	8.3
	3	Container with NaBr	22 (72)	58	9.7
	4	Container with NaCl	22 (72)	75	12.8
	5	Container with KCl	22 (72)	85	15.8
ACQ-treated plywood	1	Environmental room	27 (80)	34	7.8
	2	Environmental room	22 (72)	50	10.8
	3	Environmental room	27 (80)	66	13.0
	4	Container with NaCl	22 (72)	75	14.8
	5	Container with KCl	22 (72)	85	17.5

[a] RH is relative humidity.

front and back faces of the treated plywood. Average ACQ retention (CuO + Quat) in the treated panels was 3.7 ± 0.4 kg m^{-3}, as determined from copper content measured by inductively coupled plasma atomic emission spectroscopy (samples were prepared by coarse grinding and digesting). This retention is roughly consistent with the intended above-ground use of plywood as subflooring, for which target retention is 4.0 kg m^{-3} (AWPA 2008). From each plywood panel, 15 specimens were cut into 150 by 150 mm dimensions, resulting in 30 untreated and 30 treated specimens. The ovendry masses ranged from 200 to 280 g. Average specific gravity was determined for specimens from each panel based on ovendry mass and volume at 8% MC. Values were 0.49 ± 0.02 and 0.53 ± 0.02 for the two untreated panels and 0.54 ± 0.02 and 0.59 ± 0.02 for the two ACQ-treated panels. Groups of six specimens (three from each panel) were conditioned to five different EMCs; each group was allowed to equilibrate in an environment maintained between about 35% and 85% RH.

Table 1 lists conditions to which specimens were equilibrated. Conditions were attained by use of mechanically controlled environmental rooms or saturated salt solutions. Conditions in the environmental rooms were monitored with data loggers (Onset Computer Corporation, Bourne, Massachusetts, model U23-001) and were found to be stable within ±1% RH of the mean. Saturated salt solutions were prepared in polypropylene containers with approximate dimensions 580 by 430 by150 mm. Specimens were suspended above the solution in a given container, each container was placed in a room maintained at 22.4 ± 0.2°C (72.3 ± 0.4°F), and the lids were sealed with aluminum foil tape. Equilibrium relative humidity values over saturated salt solutions are taken from Greenspan (1977).

Gravimetric moisture contents were based on determination of mass of the specimens under two conditions: (1) after equilibration at the desired relative humidity condition (with screw electrodes removed) and (2) after oven drying at 103°C (217°F). Specimens were weighed on a top-loading balance (Sartorius, Goettingen, Germany, model 2254) with a readability of 0.01 g. The calibration of the balance was checked prior to measurements with a 100-g standard and was consistently accurate to 0.02 g. Specimens were oven-dried to a final mass using an endpoint criterion of no more than 0.05% change in mass over a 4-h interval. The error in gravimetric moisture content is estimated at less than 0.1% MC.

In the case of the dimensioned lumber conditioned at 85% relative humidity, some slight mold growth was found on the surfaces. These specimens were cleaned by wiping with a paper towel prior to weighing and metering moisture content. We did not determine whether this minor biological activity had any effect on the equilibrium moisture content or the uniformity of moisture content from the specimen surface to interior.

Instrumentation

Electrodes selected for the study were stainless steel #6 sheet metal screws 16 mm long with hexagonal washer heads (Bolt Depot, North Weymouth, Massachusetts, product 5459). The stainless steel alloy was non-magnetic; it was one of the 300 series stainless steel alloys with nominal composition of 18 wt% chromium and 8 wt% nickel. For leads to connect the screw electrodes to the moisture meter, uninsulated ring terminals (3M, St. Paul, Minnesota, Scotchlok M18-6R/SX) were soldered to 24-AWG insulated

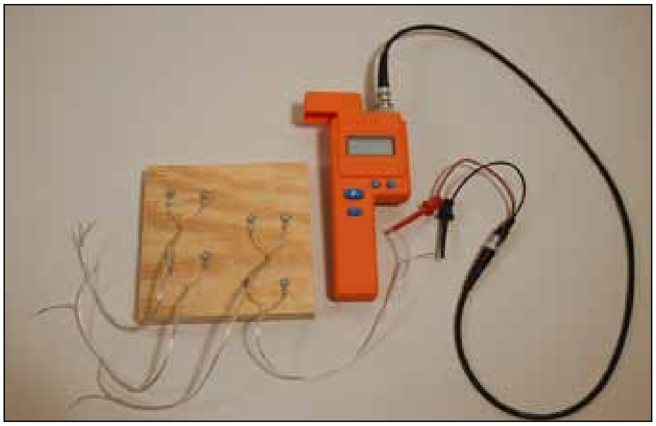

Figure 1—Experimental set-up for moisture meter readings: untreated plywood specimen, stainless steel screw electrodes with leads, moisture meter, and cable assembly with mini hook clips. In the specimen shown, the unsanded surface is sapwood and contains no defects.

Figure 2—ACQ-treated plywood specimen and template used for pre-drilling pairs of holes.

copper wires. A handheld Delmhorst model J-2000 digital conductance moisture meter (Delmhorst Instrument Co., Towaco, New Jersey) was used to acquire moisture content readings in combination with a modified cable assembly (part #315-CAB-0001). The modification involved connecting a mini hook clip to each wire from the cable assembly such that the mini hook clips could then be easily attached to lead wires (Fig.1).

The meter measures conductance and displays readings as percentage moisture content. It can be set to display moisture content readings for a number of different species; for this study the meter was set for SYP. The meter also has a setting for temperature correction, which can be set in units of either °F or °C. For this study, the moisture meter was referenced to a temperature of 70°F (21°C), whereas the laboratory in which readings were taken was maintained at 72.3 ± 0.4°F (22.4 ± 0.2°C). The meter's temperature correction can be set in increments of 5°F (3°C), so the difference between the actual temperature and the meter setting need not exceed 2.5°F (1.5°C). The potential error arising from such a temperature offset amounts to less than 0.3% MC for the moisture content range in this study (James 1988). Two of the environmental rooms in which specimens were conditioned were maintained at 80°F (27°C). After specimens were equilibrated in these rooms, they were sealed in polyethylene bags, transferred to the laboratory maintained at 72°F (22°C), and allowed to reach thermal equilibrium prior to moisture meter readings (the meter being referenced to 70°F as for the other groups). Moisture meter readings for these specimens were also taken in the 80°F environmental room (with the meter referenced to 80°F (27°C)) prior to readings in the 72°F (22°C) room (with meter referenced to 70°F (21°C)). Meter readings at 72°F (22°C) differed from those at 80°F (27°C) by less than 0.2% MC on average, the readings at 72°F (22 °C) being higher on average.

Holes for the screw electrodes were pre-drilled using a 2.4-mm (3/32-in.) drill bit and a template (Fig. 2) machined from mild carbon steel, with two holes each 2.4 mm (3/32 in.) in diameter spaced 31.8 mm (1.25 in.) on center. In each specimen, four pairs of holes were drilled so that moisture readings could be obtained in multiple locations within a specimen (Fig. 1). Measurements using additional specimens indicated that the moisture reading at a given location was not affected by the presence of other screws within the same specimen. Each hole pair was aligned parallel to the grain (in the case of dimensioned lumber) or parallel to the grain of the surface ply (in the case of plywood). In the untreated plywood specimens, measurements were taken from the unsanded side of the specimen (the "crawlspace side" from which field-study measurements are taken). Defects were present in some specimens, but all screw pairs were placed to avoid observable defects. In most cases, heartwood was not present in the area between screw pairs.

Results

Figure 3 shows the moisture meter readings plotted against gravimetric moisture content for SYP dimensioned lumber, SYP plywood, and ACQ-treated SYP plywood specimens. The linear least-squares fit for SYP dimensioned lumber is close to the line of 1:1 correspondence, indicating that the readings, taken with stainless steel screw electrodes,

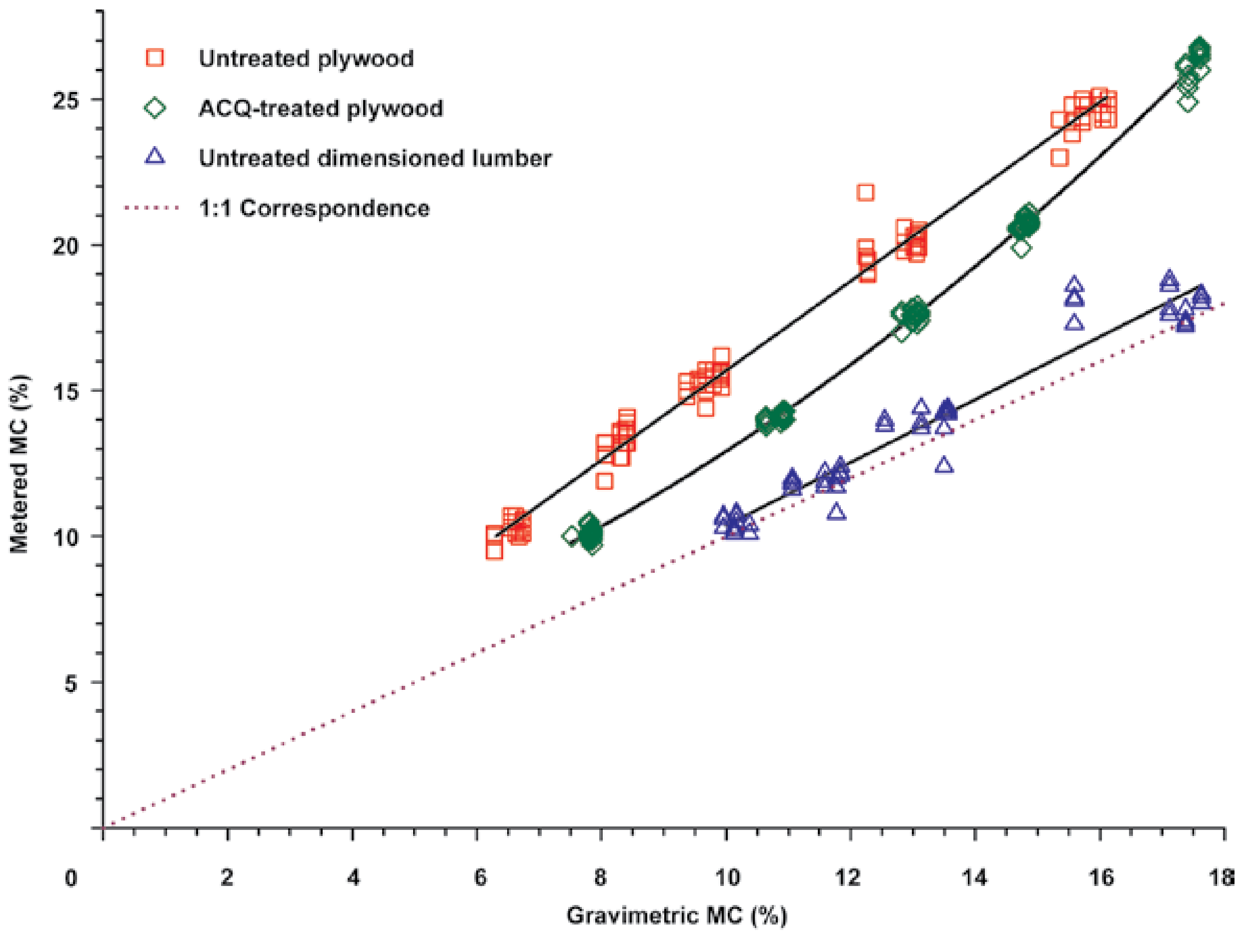

Figure 3—Meter readings for moisture content (MC) versus gravimetric moisture content for southern yellow pine dimensioned lumber (triangles), plywood (squares), and ACQ-treated plywood (diamonds). The data for untreated dimensioned lumber and plywood are fit by linear equations, and the data for ACQ-treated plywood are fit by a quadratic equation. The dashed line indicates 1:1 correspondence.

correspond well with the manufacturer-provided correction for SYP wood (which assumes the electrodes are uninsulated pins). Considerable scatter is apparent in the data as seen in Figure 3; less scatter might be expected for specimens with less variation in anatomical characteristics. In statistical terms, the line of 1:1 correspondence falls within the 95% confidence band of the regression line (Berthouex and Brown 2002). The meter manufacturer's correction for SYP wood was thus deemed adequate for determining moisture content in our sample of SYP dimensioned lumber, taken with stainless steel screw electrodes.

Data for untreated plywood show less scatter than data for dimensioned lumber. Meter readings are high compared with gravimetric moisture content—the slope of the regression line for untreated plywood is greater than one. The intercept is positive, though small. ACQ-treated plywood data show the least scatter. The best fit to these data is a quadratic equation. Interestingly, for a given gravimetric moisture content, the meter reads higher for untreated than for ACQ-treated plywood.

Table 2 gives equations for predicting "true" (gravimetric) moisture content from meter readings. The linear equation for untreated plywood is inverted from the regression line shown in Figure 3. Instead of inverting the quadratic equation for ACQ-treated plywood, we made the data linear by plotting the square root of the meter readings versus gravimetric moisture content (not shown). This method gives a two-parameter fit rather than a three-parameter fit without significantly compromising the quality of the fit.

The accuracy of each equation for predicting gravimetric moisture content from a single meter reading was determined using the approach described by Berthouex and Brown (2002). For a given moisture meter reading (y or MC_{meter}), we calculated the corresponding value of the gravimetric moisture content (x or MC_{grav}) using the calibration equation in Table 2. Next we determined the 95% confidence interval that contained the true value of y 90% of the time based on a single observation. Finally, we calculated the 95% confidence band for the calibration line and translated the confidence limits for y into confidence limits for x. The confidence interval varies with moisture content: it is narrowest at the midpoint of the gravimetric moisture content range and broadens as MC_{grav} is increased or decreased from the midpoint. The intervals given in Table 2 are the widest possible for the given range of moisture content; they are based on the values at the minimum or maximum moisture content. As indicated in Table 2, the calibration for untreated plywood has larger error bars (±1.4% MC) than that for ACQ-treated plywood (±0.8% MC), consistent with the relative data scatter for these groups.

Although derivation of sorption isotherms was not the objective of this study, a comparison of EMC data for plywood (from Table 1) with data from the literature for SYP plywood is shown in Figure 4. The EMC data for untreated specimens concur closely with the adsorption EMC values for SYP plywood at 27°C (80°F) given by Lee and Biblis (1976). Data for treated plywood show higher EMC values than for untreated plywood at equivalent relative humidity levels. Several explanations are discussed below.

The EMC is affected to a minor extent by temperature (Stamm 1964). As shown in Table 1, most specimens were conditioned at 22°C (72°F), but two of the environmental rooms were maintained at 27°C (80°F). However, such a small temperature difference amounts to a change in EMC of less than 0.3 % MC (FPL 1999).

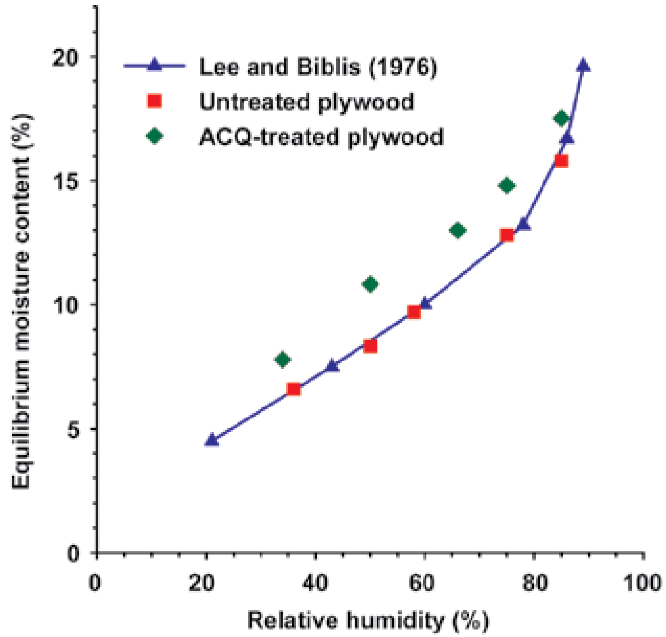

Figure 4—Equilibrium moisture content versus relative humidity for untreated and ACQ-treated southern yellow pine (SYP) plywood. Each point is the average of six measurements. For comparison, the adsorption isotherm is shown for SYP plywood (Lee and Biblis 1976).

Discussion

Equilibrium Moisture Content

One possible explanation for the differences in EMC between treated and untreated plywood shown in Figure 4 is that the ACQ treatment makes wood more hygroscopic, as suggested by Choi and Ruddick (2007). To test this hypothesis, we reconditioned all treated and untreated plywood specimens at 50% RH after oven drying, thus giving adsorption EMC values. Untreated and ACQ-treated plywood did not differ significantly. Both showed a reconditioned average EMC of 8%, which is identical to the value for untreated plywood in Figure 4 (as we found in initial conditioning).

An alternative explanation is that the differences stem from sorption hysteresis, a well-recognized phenomenon affecting EMC values (Stamm 1964). The history of the untreated specimens prior to purchase from the lumber yard is unknown. The panels were, however, stored in a roofed shed in dead stacks at the lumber retailer, and the retailer is a mass marketer generally recognized as having a rapid turn-over of stock. It is thus likely that the untreated plywood approached equilibrium by adsorption. This was confirmed for the specimens at 50% RH; EMC values were essentially identical following ovendrying and reconditioning at the same relative humidity. Additionally, the untreated plywood EMC data concur closely with literature adsorption EMC data, as shown in Figure 4. In contrast, the ACQ-treated specimens were received wet—around 50% MC—and were initially placed in a room maintained at 50% RH. For relative humidity values of 50% or less, equilibrium was thus approached by desorption. For higher relative humidity conditions, the specimens remained in the room at 50% RH for a period of roughly seven weeks prior to conditioning. The EMC values for treated specimens at 66%, 75%, and 85% RH are most likely intermediate between the desorption and adsorption curves.

Moisture Meter Calibration

As shown in Figure 3, the moisture meter readings were higher for untreated SYP plywood than for solid wood.

Table 2—Equations for predicting gravimetric moisture content (MC) from meter readings

SYP plywood type	Calibration equation[a]	Gravimetric range (MC %)	Prediction error[b] (MC %)
Untreated	$MC_{grav} = -0.136 + 0.6459 \times MC_{meter}$	6–16	± 1.4
ACQ-treated	$MC_{grav} = -8.032 + 5.007 \times \sqrt{MC_{meter}}$	8–18	± 0.8

[a] MC_{grav} and MC_{meter} are percentage moisture content based on mass (conditioned and oven-dried) and meter readings, respectively.

[b] Prediction error varies slightly with moisture content; the values given are the largest errors for the moisture content range, calculated for the minimum and maximum MC.

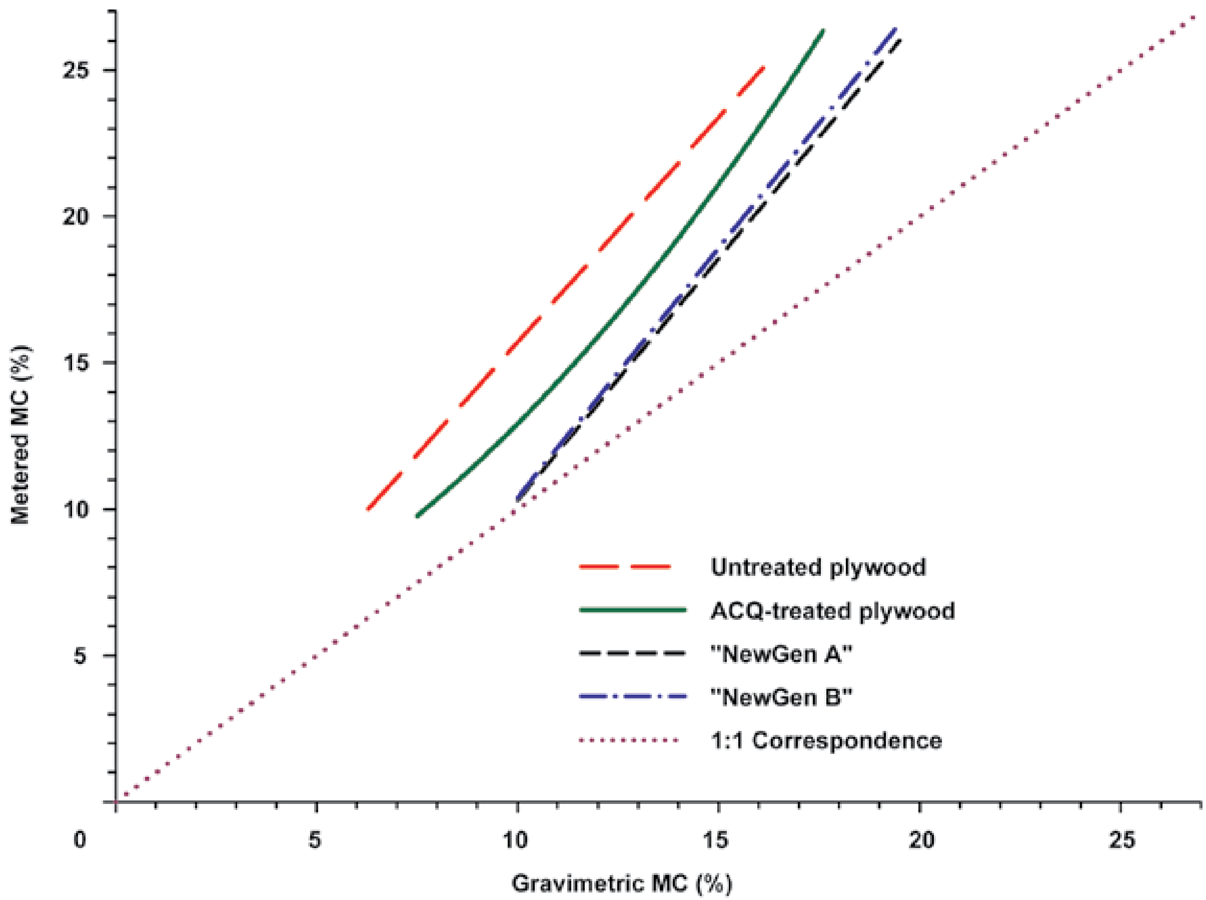

Figure 5—Curve fits for untreated plywood (upper dashed line) and ACQ-treated plywood (solid curve) from this work and for SYP sapwood treated with two "new generation" preservatives (Smith et al. 2007). The dotted line indicates 1:1 correspondence between meter readings and gravimetric moisture content.

Bell and Krueger (1949) examined the effect of 10 different glues on moisture meter readings in Douglas-fir plywood. They found that in phenolic-bonded plywood, conductance meter readings with needle electrodes penetrating the glue lines were, without exception, higher than the corresponding gravimetric moisture contents (although with considerable variation). They attributed this effect to an increase in conductivity from the electrolytes within the glue in the plywood.

As indicated previously, the data for ACQ-treated plywood (Fig. 3) show a distinct curvature. Smith et al. (2007) established moisture meter calibrations for SYP sapwood treated with two "new generation" preservatives, one of which was ACQ (personal communication with Stan T. Lebow, Research Forest Products Technologist at the Forest Products Laboratory, Madison, Wisconsin, October 2007). Smith et al. (2007) found that the meter readings were higher than gravimetric moisture content. Although they fit their data to a linear relationship over the range of 10% to 25% MC, their plotted data show curvature over the range of roughly 18% to 28% MC (at the upper end of the hygroscopic range). The curvature that their plots show over the 18% to 28% MC range is in the direction of higher meter readings, as moisture content increases. This, incidentally, is the same direction of curvature as in Figure 3, although over a different moisture content range.

For the sake of comparison, we present our curve fits for untreated and ACQ-treated plywood together with the linear fits from Smith et al. (2007) in Figure 5. The "new generation" preservatives (one being ACQ) apparently have nearly the same effect on meter readings in SYP sapwood. As indicated by the figure, meter readings are higher for ACQ-treated plywood than ACQ-treated sapwood, though the slopes of the curves are similar. The reason why moisture meter readings are higher for untreated plywood than for ACQ-treated plywood is unclear.

Kear (2006) also studied the influence of ACQ treatment on moisture meter readings, using four different meters, some with more than one type of electrode. Radiata pine dimensioned lumber specimens were conditioned at 65%, 75%, and 98% RH. The meter readings for specimens at 65% to 75% RH (13% to 15% gravimetric MC) varied by meter and type of electrode, but in all cases the ACQ-treated lumber evidently had higher conductance than untreated lumber, in agreement with the results of Smith et al. (2007). We are not convinced of the validity of Kear's data at 98% RH; the gravimetric moisture content values he reported at 98% RH were clearly far above the fiber saturation point.

Conclusions

This study was undertaken to develop calibration curves for predicting "true" (gravimetric) moisture content from direct readings with a conductance moisture meter and stainless steel screw electrodes in untreated SYP dimensioned lumber, untreated SYP plywood, and SYP plywood treated with ACQ. With the meter set to the manufacturer-provided species correction for SYP and with the stainless steel screws as electrodes, direct meter readings corresponded closely with gravimetric moisture content in dimensioned lumber. Thus, no calibration curve for SYP dimensioned lumber appears needed, although there apparently is considerable random error associated with individual readings. In contrast, meter readings in plywood, whether treated or untreated, require substantial correction. The derived moisture content values for plywoods, obtained from the calibration curves, are apparently less subject to random error than are moisture content values for dimensioned lumber. The prediction errors and the range of gravimetric moisture contents over which the equations can be applied are as follows: untreated SYP plywood, ±1.4% MC over 6% to 16% MC; and ACQ-treated SYP plywood, ±0.8% MC over 8% to 18% MC.

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