Use of a Resistance-type Moisture Meter above the Fiber Saturation Point

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ABSTRACT

Moisture content is a key risk factor for decay of wood used above-ground, but is seldom documented for test specimens or in-service structures. Although resistance (conductance) type moisture meters are a simple tool for evaluating moisture content, they are often thought to be of little value for moisture contents above the fiber saturation point (moisture contents approximately between 25 to 30%). This paper discusses a laboratory evaluation of resistance meter readings at moisture contents above 30%, and reports observations of factors that influence the accuracy and precision of those readings. It was found that meter readings above 30% had a coefficient of determination value of R^2 = 0.75 if firm contact was maintained between the wood and electrodes. Wood temperature had a large effect on readings at higher moisture contents, and a temperature correction factor was developed. The results indicate that resistance type meter may have value for evaluating the moisture content of test specimens exposed above-ground.

Keywords: Moisture meter, resistance, fiber saturation point, temperature correction

INTRODUCTION

Moisture content is a critical factor in the risk of biologic and non-biologic degradation of wood used above-ground (Lebow and Highley, 2008; Zabel and Morrell, 1992). In many climates it is the primary determinant of the above-ground decay hazard. It is also the primary cause of biocide depletion from treated wood products used above-ground (Lebow, 2014). Although the importance of moisture content is widely acknowledged, there has been relatively little effort to evaluate moisture content within in-service wood products or within test specimens used to evaluate durability or biocide depletion (Lebow, et al., 2008). Of the current AWPA methods for evaluating the durability of wood products used above ground, only method E28 (Standard Field Test for Serviceability of Decking) suggests any monitoring of wood moisture content (AWPA, 2014). The lack of data on in-service moisture contents limits our ability to understand and predict the range of decay hazards experienced by wood structures, or to correlate the results from test specimens to in-service structures.

The scarcity of information on above-ground moisture contents may be attributable to the difficulty of obtaining useful data. Although there are a wide range of approaches to determining wood moisture content, simple and inexpensive options are more limited. Test specimens can be weighed, but weight-basis moisture content masks any moisture gradients within the specimens. In many cases the moisture content in the inner part of a test specimen may be higher than that of the overall specimen. Determining the weight-based moisture content of in-service structures requires removing wood samples, which is not always desirable. The other simple and practical approach for evaluating wood moisture content is the use of moisture meters. Resistance-type (also referred to as pin-type or conductance-type) moisture meters have the potential for estimating moisture content at various depths within the wood, depending on the placement of the metal pins. Although these meters are widely used in wood drying and monitoring indoor wood moisture content, their use for measuring the moisture content of wood exposed outdoors has been more limited. This is largely because the meters are thought to have little value for measuring moisture contents above the wood fiber saturation point (approximately 25 – 30% moisture content) (ASTM, 2014; James, 1988), and some commercial meters do not display moisture contents above 40%. As shown in Figure 1, resistance drops rapidly as the wood moisture content increases, and above the fiber saturation point changes in moisture content are associated with decreasing changes in resistivity (James, 1988; Glass and Zelinka, 2010).

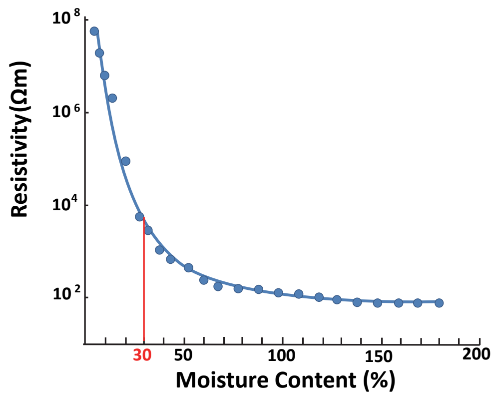

Figure 1. Electrical resistance as a function of wood moisture content. Adapted from Glass and Zelinka, 2010.

However, it is important to note that some change in resistivity does occur at higher moisture contents (Figure 1) and researchers have presented data indicating that measurements above 30% can be at least semi-quantitative (Smith et al., 2007; Brischke and Lampen, 2014). USDA Forest Products Laboratory researchers have been using resistance-type meters to monitor wood moisture contents in various specimen configurations over several years, and have observed that measurements above the fiber saturation point are surprisingly consistent and repeatable. These findings suggest that the potential applicability of resistance-type moisture meters to wood exposed outdoors warrants further consideration.

One of the challenges in comparing moisture meter readings to moisture content calculated from weight loss after oven-drying is obtaining uniform moisture distribution within test specimens. Resistance meters report the highest moisture content between the pins, while gravimetric (oven-dry) moisture content yields the specimen's average moisture content. If a moisture gradient exists within the specimens the moisture meter reading may be either higher or lower than the gravimetric moisture content depending on the placement of the pins. If uninsulated pins are used the meter will detect the greatest moisture content within that gradient. If insulated pins are used the meter will report the moisture content at the end of the pins, which will be a function of pin location within the gradient.

In one moisture meter evaluation Smith, et al. (2007) used "2 by 4" or "2 by 6" dimension lumber that was cut to 25.4 or 30.5 mm (10 or 12 in.) lengths and pressure-treated with preservative or water. The specimens were then end-sealed and allowed to dry slowly in a room maintained at 80% relative humidity. Moisture meter pins were driven to a depth of 0.95 mm (0.38 in.) which the authors felt best represented the moisture gradient within the specimens. The entire specimen was weighed and oven-dried to determine gravimetric moisture content. More recently Brischke and Lampen (2014) used 50 by 20 by 30 mm specimens which were pre-drilled and then pressure-treated with water. The specimens were allowed to air dry to approximately 50% moisture content and then placed in plastic bags for 6 days. Electrodes were then driven into the holes to obtain the resistance measurement. The specimens were subsequently oven-dried to obtain the gravimetric moisture content. Brischke and Lampen (2014) did not report whether a moisture gradient was encountered or expected within the specimens, but it is unlikely that specimens of those dimension had completely uniform moisture distribution.

In this study the relationship between moisture meter readings and oven-dry moisture content was evaluated using small specimens conditioned to a range of moisture contents. Factors that affect the accuracy and precision of those readings are discussed.

MATERIALS AND METHODS

Stainless steel screws were used as electrodes in this study because preliminary trials indicated that the pin electrodes tended to yield lower, and more variable, moisture content readings. Previous researchers have also found that readings from screw-type electrodes are better correlated to oven dry moisture content then pin electrodes because of the need to overcome "contact resistance" between the wood and the electrode (ASTM, 2014; Dai and Ahmet, 2001; Vermaas, 1975). Preliminary trials also indicated that it was difficult to obtain uniform moisture distribution within specimens as large as those used by Smith et al. (2007) or Brischke and Lampen (2014). Even in smaller specimens that were vacuum impregnated with water and allowed to partially air-dry, screws drilled into the center of the specimens tended to yield higher resistance moisture readings than those obtained gravimetrically. This occurred even when the specimens were stored in plastic bags for one or two weeks prior to measurement.

Meter versus Oven-dry Moisture Content

Thin (3 mm thick by 10 mm wide) strips of southern pine sapwood were used to minimize the moisture gradient within the specimens. Six "parent" strips 508 mm in length were cut to obtain 15, 47 mm long specimens. This cutting pattern yielded a total of 90 specimens, but 10 specimens were discarded because of wood defects. The remaining 80 specimens were end-sealed with silicone caulk and assigned to one of 5 drying groups. All specimens were vacuum impregnated with deionized water using an 81 kPa (gauge) vacuum maintained for 30 minutes. They were then spread on a drying rack under ambient laboratory conditions. After 1, 2, 3, 4 or 5 hours of air drying, pre-selected sets of specimens were removed from the drying rack and individually wrapped in plastic film to prevent further drying. After 72 hours the specimens were then unwrapped, weighed, and their resistance moisture content recorded. The specimens were then oven-dried at 104°C to allow determination of gravimetric moisture content. The thin strips used to minimize moisture gradients made it impractical to insert wood screws for use as electrodes. Instead, a device was constructed to simulate the extent of wood/metal contact that would be expected when screws are driven into wood. Stainless steel screws were threaded through an insulator (dry wood) so that they protruded approximately 25 mm. The heads of the screws were wired to the moisture meter. The specimen was laid across the protruding screws, and each end of the specimen was lightly clamped to a machine screw with locking pliers to simulate the contact pressure achieved with wood screws. The moisture meter used in this study was a General Electric Protimeter Timbermaster (www.gesensing.com/protimeterproducts), which displays moisture content readings between 7 and 100%. The internal calibration recommended for southern pine was used in this study. This meter was selected because it was on hand and had been used to record moisture measurements in field specimens.

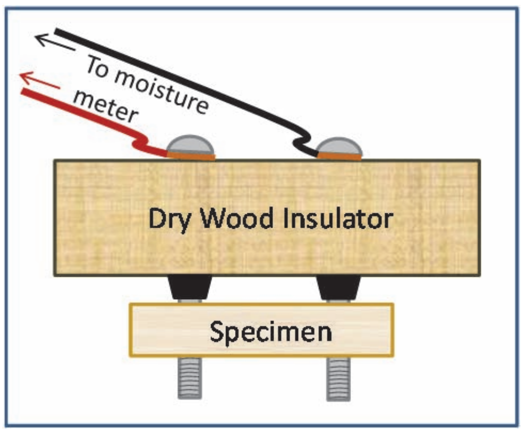

Figure 2. Device used to measure moisture content in thin strips of southern pine sapwood.

Temperature Correction

Electrical resistance declines with increasing temperature, and correction factors are sometimes applied for readings made above or below room temperature. Because existing correction factors were developed for moisture contents below the fiber saturation point, an evaluation was conducted to develop a correction factor at higher moisture contents. Southern pine sapwood strips (9 by 19 by 457 mm) were cut from 5 pieces of 2 by 6 (nominal) dimension lumber. Each strip was cut to obtain 5, 45 mm long specimens which were labeled according to their originating parent strip. The specimen ends were sealed with epoxy resin, and two 3.2 mm diameter holes, spaced 25 mm apart, where drilled through the narrow faces of each specimen. Trim head stainless steel wood screws (#7, 32 mm length, 4 mm thread diameter) were inserted into these holes so that the head of the screw protruded by approximately 13 mm. The specimens were vacuum impregnated with water, and then allowed to air dry for varying time periods to achieve range of moisture contents. Specimens were dipped in several coats of paraffin wax and wrapped in plastic to prevent further drying, and then allowed to sit at room temperature for two weeks. Over the next month the specimens were placed into temperature conditions ranging from 3.6 to 38^{o}C (39 – 100^{o}F), and readings were taken by pressing the meter pins against the heads of the screws. Temperature at the time of the reading was determined using a probe inserted into an additional specimen.

Data Analysis

Moisture meter readings were regressed against oven-dry moisture content, with meter censoring of observations above 100% Moisture Content (MC). A segmented calibration curve was fit to accommodate the observations, and nonlinear statistical methods were used to estimate the parameters (one intercept, two slopes, and a breakpoint where the segments change slope).

A temperature correction was developed for wood at moisture contents above the fiber saturation point and exposed at temperatures between 4 and 38°C (40 – 100°F). Although a multistage model based on local interpolation might have provided a slightly better predictive fit, a simpler, single adjustment model was found to explain the majority of variability associated with temperature. It is based on a mixed effect model assuming a latent factor that interacts with temperature, which causes an increase in the slope with temperature when the underlying moisture is greater.

RESULTS AND DISCUSSION

Comparison of Meter Readings to Oven-dry Moisture Content

The relationship between meter moisture content and oven-dry moisture content is shown in Figure 3. Residual patterns from the initial models indicated a shift in the relationship at the upper MC's, either attributable to increasing variation or some nonlinearity. A fairly simple segmented regression model (with censoring) was found to fit the data well. Nonlinear statistical methods were used to estimate the parameters (one intercept, two slopes, and a breakpoint where the segments change slope), with a final model:

$$MC_{meter} = \begin{cases} 5.77(SE = 5.46) + 1.05(SE = 0.08)MC_{OD} \; if \; MC_{OD} < 78.26\%(SE = 0.12) \\ 87.95 + 0.35(SE = 0.21)MC_{OD} \; if \; MC_{OD} \geq 78.26\% \end{cases}$$
$$\hat{\sigma} = 8.90$$

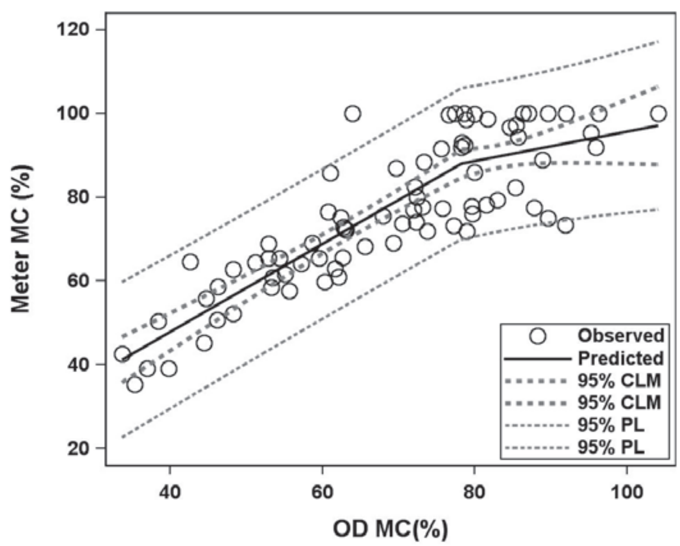

Figure 3. Relationship between resistance meter reading and oven-dry moisture content. CLM = Confidence limit for the mean predicted value. PL=Prediction limit for a single future predicted value.

Assuming censored values are 100% MC, the lower segment of the regression has an R^2=0.72, the upper segment R^2=0.04, and the overall regression R^2=0.75.

Although not as strong as the relationship we would expect for moisture contents below the fiber saturation point, the meter readings at the higher moisture contents do provide a general indication of the range of actual moisture contents. Given our current lack of information on moisture contents within test specimens or within in-service structures, even these relatively rough estimates of moisture content are of some value.

Effect of Temperature

Temperature had a notable effect on the moisture meter readings at higher moisture contents (Figure 4). Meters are typically calibrated at room temperature, and manufacturers provide correction factors (or automatic corrections) for higher and lower temperatures.

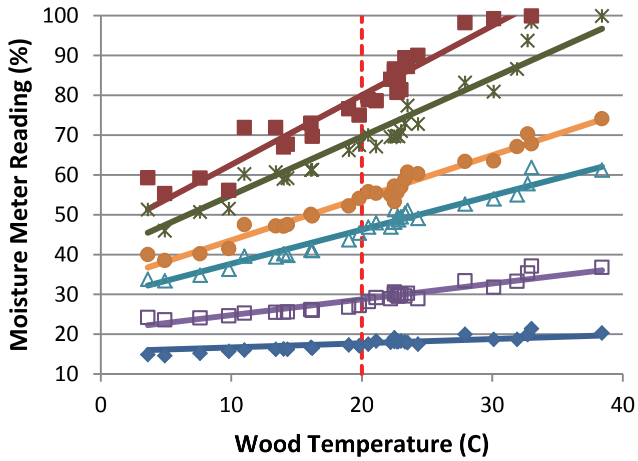

Figure 4. Effect of temperature on meter readings for selected specimens. Markers denote individual specimens and lines show model prediction for that specimen.

Some manufactures indicate that a correction is not needed for wood temperatures between 10 and 32°C, but it is likely that those recommendations are based on measurements of wood below the fiber saturation point. It appears that the temperature effect is proportionally greater at higher moisture contents, and the mixed effect model developed assumes an increase of slope with increasing moisture content. The lines drawn in Figure 4 show the ability of the model to predict the observed moisture meter readings. This model was then used to develop an equation for adjusting a meter reading (M_T, %) observed at a wood temperature (T) to a moisture content adjusted to 20°C (M_{20}, %):

$$M_{20} = 39.96 + 2.11 * \left[\frac{M_T - 26.14 - 0.69 * T}{1 + 0.056 * T}\right]$$

This temperature adjustment model has not been evaluated, and may not be applicable, at temperatures below 4 or above 38°C. It was noted during testing that meter readings obtained from frozen wood were very low, and did not appear to correlate well with those taken before freezing.

When possible, wood temperature, rather than air temperature, should be used for making temperature adjustments. Wood temperature may change more slowly than air temperature during periods of rapid heating and cooling, and wood exposed to direct sunlight may have temperatures well above the air temperature. Wood temperature can be determined by inserting a probe into a hole drilled to a depth similar to that being used for moisture content determination.

Considerations/Limitations

The correlation between meter readings and oven-dry moisture content noted in this study depended on firm contact between the wood and electrodes. Preliminary trials indicated that readings were much more variable when pins provided with the meter were simply held against the wood. Firm contact can be achieved relatively simply with use of stainless steel screws (Glass, et al., 2010) or with other approaches such as use of conductive adhesive (Brischke, et al., 2008). Pins driven into the wood with a slide hammer attachment may also provide better contact than those applied with hand pressure. Other factors that affect measurements below the fiber saturation point, such as wood species, extractive content and presence of advanced decay, would also be expected to play some role in readings at higher moisture contents. It is also notable that only one brand of moisture meter was evaluated in this study, and it is possible that differences in the quality of electrical components and/or computational algorithms could affect the use of other brands of meters at high moisture contents. However an unrelated brand of meter was used by Smith et al. (2007), and Brischke and Lampen (2014) obtained favorable results by calculating moisture contents directly from resistance measurements.

CONCLUSIONS

Although resistance meters clearly lose accuracy and precision above the fiber saturation point, the results of this study indicate that meter readings above the fiber saturation point can provide a useful indication of actual moisture content. A segmented regression model yielded a correlation (R^2) of 0.75 between the meter readings and oven-dry moisture content. This relationship was developed using screws rather than pins as electrodes to ensure consistent contact with the wood.

Wood temperature was found to strongly influence meter readings at higher moisture contents, and this effect was modeled to allow development of a correction factor that can be applied to temperatures above or below 20^{o}C. Currently little information is gathered on the moisture content of test specimens or in-service structures, making it difficult to gauge the relative severity of test conditions. Resistance moisture meters may be a simple and inexpensive option for obtaining useful data on these above-ground moisture contents.

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