



Designation: **D4444 – 08 D4444 – 13**

# Standard Test Method for Laboratory Standardization and Calibration of Hand-Held Moisture Meters<sup>1</sup>

This standard is issued under the fixed designation D4444; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the Department of Defense.*

## 1. Scope

1.1 This test method applies to the measurement of moisture content (MC) of solid wood products, including those containing additives (that is, chemicals or adhesives) for laboratory standardization and calibration of hand-held moisture meters

1.2 This test method makes no distinction between meter measurement technologies for standardization and calibration requirements. Provision is made for test specimen size to accommodate specific meters. **Appendix X1** provides an explanatory discussion and history corresponding to the mandatory sections. Fundamental measurement technologies are described in **Appendix X2** when available.

1.2.1 Meters employing differing technologies may not provide equivalent readings under the same conditions. When this test method has been applied, it is assumed that the referenced meter is acceptable unless otherwise specified. Meters shall be calibrated with respect to MC by direct measurement as determined by Test Methods **D4442**.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>2</sup>

**D1990 Practice for Establishing Allowable Properties for Visually-Graded Dimension Lumber from In-Grade Tests of Full-Size Specimens**

**D2915 Practice for Sampling and Data-Analysis for Structural Wood and Wood-Based Products**

**D4442 Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials**

**D4933 Guide for Moisture Conditioning of Wood and Wood-Based Materials**

**D5536 Practice for Sampling Forest Trees for Determination of Clear Wood Properties**

**D7438 Practice for Field Calibration and Application of Hand-Held Moisture Meters**

### 2.2 Other ASTM Sources:

**ASTM Standards on Precision and Bias for Various Applications, 1992**

## 3. Terminology

### 3.1 Definitions of Terms Specific to This Standard:

3.1.1 *conductance meters*—Conductance meters are those that measure predominantly ionic conductance between points of applied voltage, usually direct current. Direct-current conductance meters are commonly referred to as “resistance” meters. Most commercial conductance meters are high-input impedance (about  $10^{12} \Omega$ ), wide-range ( $10^4$  to  $10^{12} \Omega$ ) ohmmeters.

3.1.2 *dielectriccapacitive-admittance meters*—**DielectricCapacitive-admittance** meters transmit electromagnetic wave energy into the wood to detect the influence of moisture in the wood on these waves as an estimate of MC. Wave energy is most often in the radiofrequency range; hand-held meters commonly are placed directly on the wood surface.

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee **D07** on Wood and is the direct responsibility of Subcommittee **D07.01** on Fundamental Test Methods and Properties.

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<sup>2</sup> For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard’s Document Summary page on the ASTM website.

## 4. Significance and Use

4.1 Hand-held meters provide a rapid means of sampling MC of wood-based materials during and after processing to maintain quality assurance and compliance with standards. These measurements are influenced by actual MC, a number of other wood variables, environmental conditions, geometry of the measuring probe circuitry, and design of the meter. The maximum accuracy can only be obtained by an awareness of the effect of each parameter on the meter output and correction of readings as specified by this test method.

4.1.1 This test method employs controlled conditions and straight-grain, clear wood specimens to provide measurements that are reproducible in a laboratory. The controlled conditions prevent moisture and temperature gradients in the test specimen.

4.1.2 In laboratory calibration, the reference direct moisture measurements (for example, Test Methods **D4442**) shall be made only in the area of direct measurement of the meter. This minimizes error associated with sampling of differing areas of measurement between this test method and that of the reference (Test Methods **D4442**).

4.2 Most uses of hand-held moisture meters employ correlative (predictive) relationships between the meter reading and wood areas or volumes that exceed that of the direct meter measurement (for example, larger specimens, pieces of lumber, or lots). These correlative relationships are beyond the scope of this test method. (See Practice **D7438**.)

## 5. Standardization

5.1 *General*—Standardization provides a measured relationship to a standard reference material that can be used to ensure that a meter is operating properly. Standardization shall be performed to establish the integrity of the meter and electrode. Standardization shall be done before calibration and use. If alternate electrodes can be used with a meter, standardization shall be done for all electrode types and alternate assemblies.

5.2 Standardization shall be based, where feasible, on the direct measurement region of the meter as supplied by the meter manufacturer. If not supplied by the manufacturer, the area of direct measurement shall be determined by test.

5.2.1 If the manufacturer recommends an area, a method, or a standard specimen for standardization that does not reflect the entire direct measurement area of the meter, this shall be noted as the manufacturer recommendation.

5.2.2 The meter circuit and electrode shall be tested with external reference material to verify the precision and bias in the meter response range of anticipated use. The meter shall be evaluated over the range of environmental conditions recommended by the manufacturer. The sensitivity of this standardization procedure to temperature of the meter shall be part of the evaluation.

5.2.2.1 The sensitivity of the standardization reference material to the range of environmental conditions in **5.2.2** shall be evaluated.

5.2.3 *Report*—The report shall indicate (in the meter manual, on the meter or meter scale, or on the supplied reference standard) the meter model, and the electrodes for which the standardization is valid. The sensitivity of the meter, the electrode assembly and the reference material, as evaluated in **5.2.2.1**, shall be reported.

5.2.3.1 The manufacturer's recommendation on frequency of standardization shall be included in the report.

## 6. Calibration

6.1 *General*—Calibration of a meter and the electrode shall establish reference data to adjust meter response for species, ambient conditions, and specimen variables, such as size and density. Meter and electrode assemblies shall be standardized in accordance with Section 5 prior to calibration.

### 6.2 *Calibration:*

6.2.1 *Area of Measurement*—Calibration shall be based, where feasible, on the direct measurement region of the meter as supplied by the meter manufacturer. If not supplied by the manufacturer, the area of direct measurement shall be determined by test. Every effort shall be made to quantify the capability of the meter assembly to estimate moisture content by reducing extraneous sources of error.

6.2.2 *Sampling and Analysis*—This calibration procedure is designed for full-scale calibration of the meter and electrode assembly. If only a limited portion of the scale requires calibration, the number of equilibrium moisture content (EMC) levels can be reduced to as low as two. Calibration should not be extrapolated below the lowest value. Extrapolation above 21 % EMC to the fiber saturation point is permissible, provided that caution be taken in regression extension beyond the moisture data high end point. Calculation of confidence limit envelopes are recommended with use of regression in this fashion. Stratified sampling and analysis of variance, or both, can be applied to quantify sensitivity to wood characteristics. If the test material is other than solid wood, it shall be prepared and tested in a manner consistent with the solid wood calibration procedures.

6.2.2.1 *Wood Characteristics*—Wood characteristics that need to be treated as measurement variables because they may influence meter readings shall be represented in the calibration sampling. Examples of these variables are density and mineral content. These characteristics shall be included, identified, and measured as part of random sampling from a target population or they shall be sampled separately as part of a strategy of stratified sampling.

6.2.3 *Sample Preparation*—The sample size shall be based on the sampling principles of Practice **D2915**, Section 3.4, based upon subsequent subdivision of the sample into sub-sets for conditioning and testing. Specimen size shall be selected to encompass the direct measurement region of the meter/electrode assembly with minimal excess material. Specimens must be free of visible

irregularities such as knots, decay, reaction wood, and resin concentrations. The specimens shall be conditioned at  $25 \pm 1^\circ\text{C}$  and selected relative humidities to each of five *EMC* levels between 7 and 21 % (see Guide [D4933](#)). Alternatively, specimens may be equilibrated (following a desorption path) at each of the five *EMC* conditions.

6.2.3.1 *Species*—Species shall be identified. If the sample represents a species group, the individual species of each specimen shall be identified if anatomically possible.

6.2.3.2 *Sapwood/Heartwood*—Specimens shall be chosen to be entirely sapwood or heartwood, or two separate groups of each, but not mixed in the same specimens. It shall be reported if sapwood/heartwood mixing is unavoidable.

6.2.3.3 *Wood Characteristics*—Specimen selection for wood characteristics shall be considered in setting sample size.

6.2.4 *Testing*—There are two steps in the testing phase of calibration. The first is meter measurements on the wood samples following the procedures of this test method and the applicable criteria provided by the manufacturer. The second step is conducting a direct moisture content determination following Test Methods [D4442](#).

6.2.4.1 *Meter Measurement*—The equilibrated specimens are numbered, weighed, and a meter measurement taken with the electrode aligned on the specimen in accordance with the manufacturers recommendation. The speed of response of the meter will determine the timing of the meter reading; manufacturer’s recommendations shall be followed unless this variable is examined as part of the calibration process.

6.2.4.2 *Direct Moisture Test*—The MC of each specimen shall be determined by the appropriate direct method (Test Methods [D4442](#)) after the meter measurement. Procedures shall be followed to prevent moisture gain or loss from the specimens between the meter measurement and the direct test.

6.2.5 *Correction Factor Determination*—The corrections applied to moisture meters and the precision and bias of the meters may differ significantly between the technology employed and manufacturing variables. Wood characteristics, species, temperature and chemical additives are specimen variables that may require correction factors. The following procedures shall be followed to determine correction factors for meters.

6.2.5.1 *Correction for Wood Sample Characteristics*—The moisture meter scale readings determined from [6.2.4.1](#) procedures shall be related to the corresponding MC from [6.2.4.2](#) for each specimen in the sample by regression or analysis of variance analysis.

(1) Species calibrations that are intended to represent an entire species (for example, to correspond to globally-determined design values assigned to structural products) shall be obtained only by conducting species-wide sampling.

(2) The species sampling suggested in this test method is not required to be species-wide. Species representation claims based on less-than species-wide sampling shall be correspondingly limited.

6.2.5.2 *Correction for Wood Sample Temperature*—This correction shall be applied after the meter has been standardized in accordance with Section [5](#) and calibrated in accordance with [6.2.5.1](#). The options for this correction are to use a standard temperature correction or to conduct a laboratory calibration.

(1) *Determination of Temperature Correction*—The correction shall be based on samples prepared as specified in [6.2.2](#) except that specimens of known MC (Guide [D4933](#)) at  $25 \pm 1^\circ\text{C}$  ( $77 \pm 1.8^\circ\text{F}$ ) shall be placed, with electrodes and temperature probes attached, in a sealed container. The change in indicated MC (meter indication) shall be recorded while changing temperature through the desired range. A final meter reading must be made at  $25 \pm 1^\circ\text{C}$  ( $77 \pm 1.8^\circ\text{F}$ ) to confirm that the MC has not varied from the temperature cycling.

(2) *Standard Temperature Correction*—If a laboratory determination is not made for conductance meters, the following relationship shall be used to correct MC below the fiber saturation point over the temperature range of 0 to  $40^\circ\text{C}$ .

$$MC_2 = MC_1 + (0.06MC_1^{0.5})(T_2 - 25) \quad (1)$$

where:

$MC_1$  = the MC at  $25^\circ\text{C}$ .

This information is presented in [Appendix X2](#).

6.2.5.3 *Correction for Chemical Additives*—Meter assemblies applied to wood materials that have been treated with additives and have adhesives interspersed with the fiber, or both, shall be calibrated with those materials following the precepts of this and previous sections on sampling and preparation. Some discretion is appropriate on temperature and moisture levels, depending on the end use of the products.

6.2.6 *Report*—The following wood sample information shall be recorded: MC, size (dimensions in each plane), species and method of species identification, sapwood/heartwood percentage, density or specific gravity, growth rate (rings/25 mm) and ring orientation, and earlywood/latewood percentage. For other materials, the appropriate wood sample information shall be recorded together with adequate data to identify the product and its constituents. The following meter information shall be recorded: manufacturer and model, reference temperature, and electrode type and configuration. The following standardization and calibration information shall be reported: method of analyses and presentation, influence of wood characteristics (variables), influence of temperature and method of correction, and details of electrode placement.

6.2.6.1 If a meter is not accompanied by the calibration data of [6.2.5](#) or by a discussion of sensitivity of the meter to operating characteristics, it shall be acknowledged that the influence of these operating variables is not known. Measurement of precision and bias for such a meter may have limited merit.

## 7. Presentation of Corrections and Precision and Bias Statements for Moisture Meters

7.1 Meters meeting the requirements of this test method shall have standardization procedures and corrections presented in formats that permit response to the MC, and wood and environmental variables to which the meter may be subjected.

7.1.1 The precision and bias of a meter may differ between the technology and manufacturing variables. If a meter is not accompanied by the calibration data or by a discussion of sensitivity of the meter to operating characteristics, it shall be acknowledged that the influence of these operating variables is not known. Measurement of precision and bias for such a meter may have limited merit.

7.2 Generic statements of precision and bias for hand-held meters are not available at this time.

## 8. Precision and Bias for this Test Method

8.1 Statements for the precision and bias of this test method have not yet been developed.

### APPENDIXES

#### (Nonmandatory Information)

#### X1. COMMENTARY

##### INTRODUCTION

The purpose of this appendix is to supply auxiliary information on the basis for and practice of this test method. It is organized with paragraphs that correspond by section number to those in the mandatory text; text paragraphs needing no explanation are not listed. This concept permits changes at any time in order to keep the standard current and to improve its usefulness.

This is a laboratory test method; thus, “uses,” including field calibrations, are not considered in this test method.

**TABLE X1.1**

Section	Comments
<a href="#">1.1</a>	Oven-dry measurements had been the basis of calibration in this test method for many years. In 2004, the oven-dry requirement following Test Methods <a href="#">D4442</a> was replaced by reference directly to Test Methods <a href="#">D4442</a> . This infers that any Test Methods <a href="#">D4442</a> method is acceptable as the direct reference for a meter. It is anticipated that oven-dry measurement will remain the primary method; however, more flexibility was desired to accommodate newer technologies and specimen needs.
<a href="#">1.2</a>	<del>The principal concepts of this test method as first incorporated in Test Method D2016 in 1965 and then in subsequent versions of this test method, addressed only meters based on the change of wood conductance or dielectric properties with MC. Specific electrode configurations were anticipated, based on early commercial use. Conductance and dielectric meters were separated in this test method; no provisions were made for other measurement technologies. This test method now anticipates other and combined technologies, or both, and makes no distinction in requirements. In addition, it makes provision for specimen sizes to relate to the specific measurement technology of the meter.</del>
<a href="#">1.2</a>	<u>The principal concepts of this test method as first incorporated in Test Method D2016 in 1965 and then in subsequent versions of this test method, addressed only meters based on the change of wood conductance or dielectric properties with moisture content. Specific electrode configurations were anticipated, based on early commercial use. Meters were classified as “resistance-type” and “dielectric-type”; no provisions were made for other measurement technologies. Meters are now classified as “conductance” rather than “resistance-type,” and “capacitive-admittance” rather than “dielectric-type” to better reflect current understanding of the underlying physics of their function. This test method is formatted to permit technologies other than conductance and capacitive-admittance, as well as combinations of technologies; no distinction is made in requirements. In addition, this method makes provision for specimen sizes to relate to the specific measurement technology of the meter.</u>
<a href="#">4.1.1</a>	Laboratory use of only the direct area of meter measurement is a change from using an empirical specimen size for all meters of the same generic type. Meter manufacturers need to specify the area of direct measurement of the meter; this may differ by electrode. Specimen sizes used in calibration will differ by meter type and electrode. The resulting calibration will minimize the contribution of wood variable error in the calibration and more uniformly reflect the measurement capability of the meter. Meters “field calibrated” may employ specimens that are different than were used for the direct Test Methods <a href="#">D4442</a> measurement. While useful, and perhaps essential, for a specific use, this is not a basic calibration of the meter, since the introduction of material (wood, air, support, and so forth) not tested by both techniques does not provide an accurate measure of the meter function. Consequently, field calibration is addressed in Practice <a href="#">D7438</a> .
<a href="#">5.2</a>	<i>Standardization</i> —This is based on the direct area of measurement of the meter unless otherwise specified by the manufacturer to parallel the requirements for calibration. An example is the use of external reference resistors to standardize the insulated pins of a conductance moisture meter.
<a href="#">5.2.1</a>	This recognizes that some meters and electrode systems, or both, may be difficult to standardize in the manner anticipated in <a href="#">5.2</a> ; consequently, the manufacturer may offer alternatives, noting they are exceptions for physical or mechanical reasons. An example is the use of external reference resistors applied to the tip of uninsulated pins to standardize a conductance moisture meter.

**TABLE X1.1** *Continued*

Section	Comments
5.2.2	The standard reference material should be mechanically and physically stable under the environmental conditions of the standardization. It should be non-hygroscopic and provide a minimum of one and preferably two reference points on the measurement scale. The meter should be evaluated over the range of environmental conditions recommended by the manufacturer. The manufacturer should indicate (in the meter manual, on the meter or meter scale, or on the supplied reference standard) the meter model, wood species, and the electrode configuration for which the reference standard is valid.
5.2.3	The intention is to standardize at the temperature of use, comparing the result with the laboratory and manufacturer data, or both, on temperature sensitivity for corrections or adjustments as needed.
6.2	Laboratory calibration is intended to provide reference data under controlled conditions which include both the wood and the ambient environmental variables.

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**TABLE X1.1** *Continued*

Section	Comments
6.2.2	Sampling design is to ensure that wood variables that influence meter performance are included in order that meter sensitivity is correctly measured in calibration. This will permit this influence to be reported appropriately in Section 7. It may be appropriate for some meter technologies to establish calibration points above the fiber saturation point; however, these should be analyzed separately from the data below the fiber saturation point.
6.2.2.1	Meter sensitivity to wood variables is evaluated in the laboratory calibration. Examples of these variables are density, growth ring characteristics, and mineral content. If these are not measured and represented adequately in analysis, the bias of the meter will be affected and the effect of these variables cannot be applied as a correction. Wood species, wood characteristics, and the influence of site can be of sufficient importance to justify the focus of a dedicated study. A study plan that identifies the target variables can assist in establishing the appropriate sampling and set the variable boundaries within which the study applies.
6.2.3	Typically five subsets have been specified for the calibration; however, the complexity of the sampling and analysis may suggest more subsets or a different experimental design. Traditionally a minimum of 75 green, flat-sawn specimens 20 mm thick by 75 mm (minimum) wide by 100 mm along the grain were required for a given species for calibrating conductance meters. For dielectric meters, 20 or 40 thick by 125 by 125 mm specimens were specified. This sample was then divided into five groups of 15 each for conditioning and testing—one group at each of five EMC levels. Depending on the variability of the MC reading of the meter, wood characteristics being studied and the Test Methods D4442 measured moisture variability, or both, this requirement may be too small or too large. Practice D2915 guides the selection of sample size based on the variability of the sample property with the goal of estimating the true mean reading of the subset within a stated amount and with confidence. Typically 95 % confidence that the mean MC of a subset has been estimated within 5 % would be a reasonable basis. The size of the test specimen for laboratory calibration is determined by the region of test measurement of the meter/electrode assembly. This reduces calibration error due to the Test Methods D4442 test evaluating material not tested by Test Methods D4442 or the reverse where meters examine large specimens. In the tradition of the 20 by 75 by 100 mm specimens, much of the specimen was outside the test area for a conductance meter with small pin spacing and not thick enough for long conductance pin electrodes. For dielectric meters, the two depths were used to identify if a depth effect existed; yet only the two depths were used for calibration, rather than the depth at which the manufacturer (or laboratory test) determined the limit of sensitivity. Interpolation was permitted between the results at the two depths and extrapolation beyond 40 mm. Some electrode configurations and meter technologies may be difficult to calibrate on the basis of measurement area or volume. In these cases, the manufacturer should identify the basis of calibration.
6.2.3	Typically five subsets have been specified for the calibration; however, the complexity of the sampling and analysis may suggest more subsets or a different experimental design. Traditionally a minimum of 75 green, flat-sawn specimens 20 mm thick by 75 mm (minimum) wide by 100 mm along the grain were required for a given species for calibrating conductance meters. For capacitive-admittance meters, 20 or 40 thick by 125 by 125 mm specimens were specified. This sample was then divided into five groups of 15 each for conditioning and testing—one group at each of five EMC levels. Depending on the variability of the MC reading of the meter, wood characteristics being studied and the Test Methods D4442 measured moisture variability, or both, this requirement may be too small or too large. Practice D2915 guides the selection of sample size based on the variability of the sample property with the goal of estimating the true mean reading of the subset within a stated amount and with confidence. Typically 95 % confidence that the mean MC of a subset has been estimated within 5 % would be a reasonable basis. The size of the test specimen for laboratory calibration is determined by the region of test measurement of the meter/electrode assembly. This reduces calibration error due to the Test Methods D4442 test evaluating material not tested by Test Methods D4442 or the reverse where meters examine large specimens. In the tradition of the 20 by 75 by 100 mm specimens, much of the specimen was outside the test area for a conductance meter with small pin spacing and not thick enough for long conductance pin electrodes. For capacitive-admittance meters, the two depths were used to identify if a depth effect existed; yet only the two depths were used for calibration, rather than the depth at which the manufacturer (or laboratory test) determined the limit of sensitivity. Interpolation was permitted between the results at the two depths and extrapolation beyond 40 mm. Some electrode configurations and meter technologies may be difficult to calibrate on the basis of measurement area or volume. In these cases, the manufacturer should identify the basis of calibration.
6.2.3.3	When examining the effect of a wood characteristic as part of the meter calibration, a sufficient sample size is needed to identify the sensitivity to the characteristic. This may require “side” studies to determine the variability anticipated so that sampling takes place that is appropriate to the anticipated analysis.
6.2.4.2	Placement will depend upon the type of technology and configuration of the electrode. For example, with conductance meters in solid wood, it is recommended that pins be aligned so that the current flow is parallel to the grain. Traditionally it has been recommended that dielectric meter electrodes be supported on low-density polystyrene foam at least 50 mm thick to reduce the chance of signal bias due to penetration into a material below the target specimen. This or an equivalent procedure should be used even where the specimen thickness has been adjusted to encompass the full depth of the signal penetration.
6.2.4.2	Placement will depend upon the type of technology and configuration of the electrode. For example, with conductance meters in solid wood, it is recommended that pins be aligned so that the current flow is parallel to the grain. Traditionally it has been recommended that capacitive-admittance electrodes be supported on low-density polystyrene foam at least 50 mm thick to reduce the chance of signal bias due to penetration into a material below the target specimen. This or an equivalent procedure should be used even where the specimen thickness has been adjusted to encompass the full depth of the signal penetration.
6.2.5	It is the intent of this test method that meter calibration data shall be provided in a format that permits a user to assess the influence of common wood characteristics and environmental conditions on meter response. This may take the form of correction formulas or hardware or software adjustments. The basis of these adjustments is required in the report of Section 6.
6.2.5.1	ASTM Committee D07 regards species-wide sampling as meeting the principles that guide the sampling required for Practices D5536 and D1990.
6.2.5.2	The following procedure has been found to be satisfactory by some users of resistive and capacitance type meters. The correction for temperature is based on samples prepared as specified in 6.2.3. The specimens are either at a known EMC (Guide D4933) or they are in a green condition. Prior to performing the test each test specimen is weighed so that oven dry MC can be verified at the end of the test in accordance with Test Methods D4442. Any electrodes or thermocouples used to monitor temperature in the test specimen, as well as any sealant used to prevent moisture loss during the application of heat throughout the test, are also weighed. The weights of these materials are then subtracted from the test specimen weight which will be monitored during the test. Electrodes or thermocouples should be placed at different depths in the specimen to ensure that the target test temperature levels are constant for each tested level. Each test specimen is maintained at a constant temperature target level. At each target temperature level, record the meter reading, and weigh the test specimen. Continue this method throughout the desired temperature range. A final meter reading is made at the initial temperature level of the test specimens to confirm that the MC has not varied from the temperature cycling.