Determining the manufactured moisture content of installed flooring

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One of the more common issues or complaints with hardwood flooring is gaps. Gaps occur for several reasons, but the common denominator is often shrinkage due to drying. Shrinkage can occur in structural components of the building or the subfloor materials, but more often with the hardwood itself. Solid hardwood flooring is milled at a moisture content (MC) that is expected to keep gapping to a minimum after the floors are installed. Sometimes however, problems occur during milling that result in abnormal gapping. This paper discusses manufacturer-related gapping issues.

Wood Moisture Relations

Wood is a hygroscopic material in that it gains and loses moisture in relation to the Relative Humidity (RH) and temperature of the surrounding air. In a building, temperature variation is usually so small that it can be ignored. When placed in air at a certain RH, the wood will gain or lose moisture until it comes to equilibrium. The MC of the wood at this condition is called the equilibrium moisture content (EMC). The USDA Forest Service publishes tables showing the EMC of wood at various temperature and RH conditions. Based on these EMC tables, indoor wood will typically vary from near 6% MC in the winter to near 10% MC in the summer. (See EMC Table from USDA Wood Handbook.)

Wood expands when it gains moisture, and shrinks (contracts) when it loses moisture. The amount of expansion or contraction per unit change in the MC of the wood is termed the dimensional change coefficient, and varies by species of wood. In the United States, dimensional change coefficients are published by the USDA Forest Service, and outside the US are determined by other research institutions.

Because wood is anisotropic, the dimensional changes resulting from changes in MC are not equal in all directions. This means that wood properties vary depending upon the orientation of the wood. The dimensional change coefficient of wood parallel to the growth rings (tangential direction) is approximately twice that perpendicular to the growth rings (the radial direction). For example, the published dimensional change coefficient for flatsawn (the tangential direction parallel to the wide face of the board) white oak is 0.00365 inches per inch per 1% MC change, and for quartersawn (the growth rings perpendicular to the wide face of the board) is 0.00180 inches per inch per 1% MC change. As a result, quartersawn flooring is more stable than flatsawn flooring.

Indoor Humidity Levels

Wood used in a house will be exposed to varying humidity levels, with higher humidity generally occurring in the summer, and lower humidity occurring in the winter. These changing humidity levels often result in tight flooring/woodwork in the summer, with gaps and squeaks in the flooring in the winter. To reduce the severity of the summer swelling and winter shrinking,
the wood flooring industry prescribes several steps in the manufacture and installation processes of hardwood flooring.

**Hardwood Flooring Manufacturing Standards**

NWFA/NOFMA hardwood floor manufacturing standards specify that flooring is to be milled at a MC between 6 and 9% for unfinished wood, and 6 to 10% for factory-finished, with an allowance of up to 5% of pieces outside that range up to 12% MC. The standards indicate that no flooring can be milled at a MC above 12%. (Milling flooring below 6% MC, or over-drying, is typically not an issue because the wood starts out wet, and requires time and significant energy, and thus incurring costs, to dry. The problems associated with over-drying are not discussed in this article.) These manufacturing MC ranges have a historical basis as producing the most high performance flooring with the least effort throughout the U.S. The standards were also created to provide minimal acclimation periods and installation issues, and help ensure a more uniform product. (NOTE: Pine flooring manufacturing standards allow milling at up to 15% MC.)

In addition to MC constraints, hardwood flooring is typically milled to specific widths. The industry standard tolerance is +/- 0.005 inch from nominal width. This means that a 3-inch wide board can be manufactured at 2.995 to 3.005 inches wide. Modern milling machines are capable of consistently producing and maintaining these tolerances. In contrast to MC where individual boards start out at different moisture levels, dry at different rates in the kiln, and can receive insufficient drying due to production and energy issues, the width at manufacture is easy to set and maintain.

**Acclimation in Hardwood Flooring – it’s a moisture thing, not a time thing**

Acclimation is a step in the installation process that allows hardwood flooring to gain or lose moisture (and size) and come to equilibrium with the expected long-term conditions in the building. The intended result of acclimation is to minimize future moisture-related expansion and contraction problems resulting from normal seasonal changes in moisture levels in the building.

Solid wood flooring manufacturers typically require acclimation of the flooring prior to installation. Installation instructions often call for a minimum of 5-7 days of acclimation. However, acclimation is a “condition”, not a timed event; in other words, it’s a moisture thing not a time thing.

Industry standards state that the MC of 40 boards out of every 1000 square feet of flooring is to be checked verify acclimation. Since manufacturing standards require flooring to be milled within a specific range of MC, checking the MC of this quantity of boards should provide the information needed to determine proper acclimation. Installers are not part of the quality control program for manufacturers, and they are expected to cull obviously defective boards. However, verifying MC for acclimation purposes often results in less than 5% of boards being tested, and boards that are out-of-specification can be easily missed. The out-of-specification boards will continue to acclimate and shrink after installation, resulting in random gaps in an otherwise normal floor.


Gaps

Wood that is milled on the wet end of the allowable range may acclimate quickly in humid areas of the country, but will take longer to acclimate in dryer areas. If the MC of flooring at time of installation is higher than the MC of properly acclimated flooring, gaps can occur days, weeks, or months later. When some of the flooring is milled outside the allowable range, gaps will occur regardless of how well the flooring is acclimated. To differentiate between manufacturing issues and installation issues, the location and size of gaps are important. Several scenarios can occur.

Scenario 1: Relatively uniform gaps during less humid periods. If these gaps close during the humid periods, they are considered normal seasonal gaps, and are a characteristic of wood flooring in a changing environment. Wider boards, less stable species, and flatsawn versus quartersawn boards can have larger seasonal, normal gaps. No manufacturing or installation issues are typically indicated.

Scenario 2: Relatively uniform gaps that do not close in humid periods. These gaps would be considered abnormal gaps. The typical cause of these gaps is improper acclimation. The MC of the flooring at the time of installation was too high, and the floor has subsequently dried to the long-term conditions at the site. These floors acclimated after installation rather than before installation.

Scenario 3: Relatively uniformly spaced gaps. When large gaps appear every four or five boards in a site-finished floor, panelization has occurred. Panelization is the phenomenon where several boards are stuck together and act as a panel rather than a group of individual boards. Shrinkage of the individual boards combines together and becomes shrinkage of a wider “panel”. Most often, this is an installation issue, where the floor finish has “glued” the boards together.

Scenario 4: Random gaps: When random gaps show up in the floor, the MC at the time of manufacture becomes suspect. If all boards were dried to 6% MC, 9% MC or even 15% MC at the time of manufacture, proper acclimation should have brought the whole group of boards to essentially the same MC prior to installation. Boards that are far out of the normal manufacturing MC range, as compared to the majority of boards in the floor, will ultimately dry and shrink, causing random abnormal gaps in the floor.

Moisture Content at the Time of Manufacture

Determining the MC at the time of manufacture is relatively easy. The necessary data include the initial dimension of the board, the final dimension of the board, species, grain orientation, initial and final MC, and the appropriate dimensional change coefficient. The boards can be assumed to have been installed tight together at the time of installation (except in some situations like sports floors). Therefore, the distance from the leading edge of board one to the leading edge of board two is the installed width. This is the same as the current width of the board plus the width of the gap.

Unless the board is known to be quartersawn, the tangential dimensional change coefficient of the wood species is typically used, and further, the board is assumed to be perfectly tangential. Using the tangential dimensional change coefficient in this way provides the most conservative estimate of the MC at the time of manufacture.
The equation for determining MC and dimensional change is presented in the Wood Handbook.

\[ \Delta D = D_i \times D_c \times (MC_i - MC_f) \]  
(Equation 1)

where \( \Delta D \) is the change in dimension of the board,

\( D_i \) is the initial dimension of the board,

\( D_c \) is the dimensional change coefficient,

\( MC_i \) is the initial MC,

\( MC_f \) is the final MC.

As a general example of using the equation, a 3-inch wide piece of flatsawn white oak changes from 9% MC to 6% MC.

\[ \Delta D = 3 \times 0.00365 \times (9-6) = 0.033 \] inches.

Therefore, if boards were installed in a floor at a MC of 9% and a dimension of 3 inches, and subsequently dried to 6% MC, gaps of approximately \( \frac{2}{64} \) inch would occur between the boards. These gaps could occur with properly manufactured flooring, and if they closed in the humid seasons, would be a part of a normally performing floor.

The next step is to separate the MC at installation from the MC at manufacture. Acclimation issues usually result in numerous, relatively consistently sized gaps, or oversized boards at installation. Group board measurements can be used to help determine the actual cause of the gaps.

Example: If an installed board measures \( \frac{5}{64} \) inch smaller than the nominal 3-inch width, and the gap adjacent to the board is \( \frac{5}{64} \) inch, and the current MC is 6%, the first observation is that the board was installed at 3 inches wide. (Sometimes, if there is a delay between installation and finishing, some or all of the gaps will be filled.)

For a board that is undersized by \( \frac{5}{64} \) inches (0.078 inches) and has a gap of \( \frac{5}{64} \) inches, the same process could be used to calculate the amount of MC change required to create that amount of shrinkage and gap. If we know the current MC is 6%, and rearranging equation 1:

\[ MC_i = MC_f + \Delta D / (D_i \times D_c) \]  
(Equation 2)

or

\[ MC_i = 6 + 0.078 / (3.0 \times 0.00365) = 13\% \] MC

From this data, we can infer that the floor board was installed at approximately 13% MC. Since the board needs to be at 13% MC to measure 3.0 inches wide, we can also infer that the board was manufactured at 13% MC. This MC is outside the hardwood manufacturing specifications, and indicates a defective board.

Potential Errors

The MC calculated above is based on basic wood science and precise and carefully measured information. Data collected in the field is seldom as precise as in the lab. Measuring a board width with calipers can yield a measurement good to less than 0.005 inches, but using a ruler on
an installed board can usually only get within 1/128 inch (0.008 inch) of the actual size. Moisture meters may be off by 1/2 % as well. Manufacturers are allowed 0.005 inch width variations. When it comes to the wood itself, species and grain direction are not easily determined. The dimensional change coefficient for commercial red oak is not the same as for southern red oak.

Using some of this imprecision, the MC at manufacture of the above board could really be:

- 4.5/64 undersize: 6 + (4.5/64)/(3.0 x 0.00365) = 12.4% MC at manufacture
- 5.5/64 undersize: 6 + (5.5/64)/(3.0 x 0.00365) = 13.8%
- 6.5% MC: 6.5 + (5/64)/(3.0 x 0.00365) = 13.6%
- 5.5% MC: 5.5 + (5/64)/(3.0 x 0.00365) = 12.6%
- 0.005” undersized: 6 + (5/64)/(2.905 x 0.00365) = 13.4%
- 0.005” oversized: 6 + (5/64)/(3.005 x 0.00365) = 13.1%
- Quartersawn: 6 + (5/64)/(3.0 x 0.00180) = 20.5%
- 45° grain angle: 6 + (5/64)/(3.0 x 0.00273) = 15.5%
- 22.5° grain angle: 6 + (5/64)/(3.0 x 0.00319) = 14.2%

From the above numbers, the grain angle and corresponding dimensional change coefficient are the parameters with the largest impact on potential errors. But multiple measurement errors can occur with the same board. By combining some of the potential errors such as 0.5/64 width measurement error, ½ % moisture meter error and a 22.5 grain angle (rather than flatsawn), the numbers are:

5.5 + (4.5/64)/(3.005 x 0.00319) = 12.8% at manufacture.

As shown in the above example, precise measurement of the current board width and gap width is critical. Also, not many flatsawn boards are truly flatsawn, and not many quartersawn boards are truly quartersawn. Get familiar with face gain patterns to help determine the grain angle in installed boards. The bottom line is that if measurements and calculations indicate that the boards were manufactured wet using the tangential dimensional change coefficient, you can be confident in your number. But potential errors in measurements indicate that the claim of mis-manufactured flooring should probably not be made unless the calculation shows a MC of 13% or higher.

Remember, the manufacturing tolerance is 5% of boards with a MC up to 12%, with none over 12%. If numerous relatively large gaps are present in the floor, checking for boards manufactured between 9% (or 10% for factory finished) and 12% may be warranted. Boards with a manufactured MC above 12% are usually accompanied by several that are above 9%. Use the same process above, but count any board that has a calculated MC at manufacture above about 10% or so (or 11% or so for factory finished).

**Nuances**

Gaps can also indicate acclimation issues. If flooring is not acclimated properly and subsequently dries, gaps can occur. Usually, the gaps are relatively small and spread throughout
the flooring. The same process described above can be used to determine the MC at installation. Use the gap width as the change in dimension. These gaps will usually be smaller than with wet-manufactured wood. Group board measurements can be used to help determine this situation.

In some cases, the flooring is exposed to unplanned or non-beneficial weather or climate events between manufacture and installation. A bundle or pallet of flooring may be left in an unconditioned warehouse or basement prior to installation. Flooring stored in a humid basement may gain moisture and reach 15% MC. If this flooring is properly acclimated prior to installation, the flooring will lose moisture and shrink to acceptable levels prior to installation. Abnormal gapping should not occur, and the fact that the boards gained moisture and swelled sometime between manufacture and installation is not an issue.

However, if the flooring is installed at 15% MC, the flooring will be oversized. A 3-inch wide red oak board manufactured at 7% MC will be near 3 5/64” wide if installed at 15% MC. Once the floor dries to normal conditions, large abnormal gaps will be present. Group board measurements and even individual board and gap measurements will reveal the oversize condition caused by lack of acclimation. Using the process described above, the MC at manufacture will reveal those conditions, and confirm that something caused the wood to expand after manufacture.

**Summary**

Acclimation is used to reduce potential shrink/swell issues. The industry-accepted process of verifying acclimation assumes that floor boards are milled to certain standard specifications, and those specifications are designed to provide relatively short acclimation times as well as minimal installation and post-installation issues.

When boards are not milled at industry standard MC, large gaps and dimensional differences can occur. The current size and MC of the boards can be used to determine whether the boards were milled within industry specifications. Potential errors in the measurement process must be considered before stating that a board or boards were milled out of specification. Potential field measurement errors can amount to approximately 1% MC at manufacture error. Therefore, making the statement that the MC of a board did exceed industry standards at the time of manufacture should not be made until the MC is approximately 1% higher than the industry standards.