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Studies in Moisture Adsorption and Thickness Swelling: Low and High Humidity

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Abstract: Composite wood products (i.e., particleboard, medium density fiberboard, oriented strand board, plywood) used in cabinets, shelving, and base trim express varying degrees of thickness swelling when exposed to a sustained moisture source. Thickness swelling occurs when cellulose fibers adsorb water molecules and swell after attaining a moisture content of 29% to 36%. Observations of thickness swelling were made to refine water loss duration estimates. Thickness swell height is the result of several intrinsic factors (wood species, density, adhesive resin, heat pressing conditions). This study examined an extrinsic factor, humidity, at elevated (>95%RH) and ambient (50%RH) conditions. Specimens subjected to moisture for longer periods (8-10 weeks) experienced gradual darkening from accumulated biomass and fungal deterioration of the wood surfaces. The study revealed that high humidity conditions expressed higher rates of thickness swelling and that estimates of water loss duration should consider the influence of ambient humidity during and following a water release.

Key words: Composite wood, duration of loss, moisture exposure, thickness swell.

1. Introduction

The occurrence of thickness swell in a variety of CWPs (composite wood products) (i.e., hardboard siding, medium density fiberboard, particleboard, oriented strand board) is a behavioral problem for several reasons including the irreversible change in panel thickness. When thickness swell occurs, objections arise as to panel edge expansion, paint adhesion, fastener detachment, and diminished aesthetic appearance. This paper reports the consequences of thickness swelling when CWPs experience wet and dry cycles under conditions of low and high humidity.

CWPs swell because a primary molecular component of wood (cellulose) binds to water (adsorption). Cellulose molecules offer exposed hydroxyl molecules along its surface that allow a hydrogen bond to form between cellulose and water molecules (Fig. 1). As exposed hydroxyl molecules become fully bonded to water molecules, the wood gradually attains moisture saturation and swells. This occurrence is observable in CWP panels when they attain between 29% and 36% wood moisture content (Photos 1 and 2).

Thickness swell in CWPs (i.e., particleboard, medium density fiberboard, oriented strand board, and plywood) is affected during manufacturing by several variables (i.e., wood species, density, adhesive resin, and heat pressing conditions) [1]. In the built environment, the most influential effect of thickness swell is moisture adsorption.

Thickness swelling occurs following high humidity and water immersion exposure and causes the release of compression stress created during the final panel pressing stage of manufacture. When a CWP experiences elevated moisture content and compression stresses are released, the panel does not return to its original thickness after drying. The consequences of thickness swelling are referred to "spring back" because after swelling, CWPs retain deformation permanently.

Corresponding author: Ralph E. Moon, Ph.D., MS, BS, materials testing, fungal deterioration of wood, metal corrosion, duration of water losses.

Moisture exposure studies conducted on CWP demonstrated that the height of water adsorption and thickness deformation was an expression principally of panel density and the duration of moisture exposure. In these studies, wood panels were immersed, and the moisture adsorption rate and thickness swell were measured under conditions of high (>85% RH (relative humidity)) and low (ambient) humidity (40% to 50% RH).

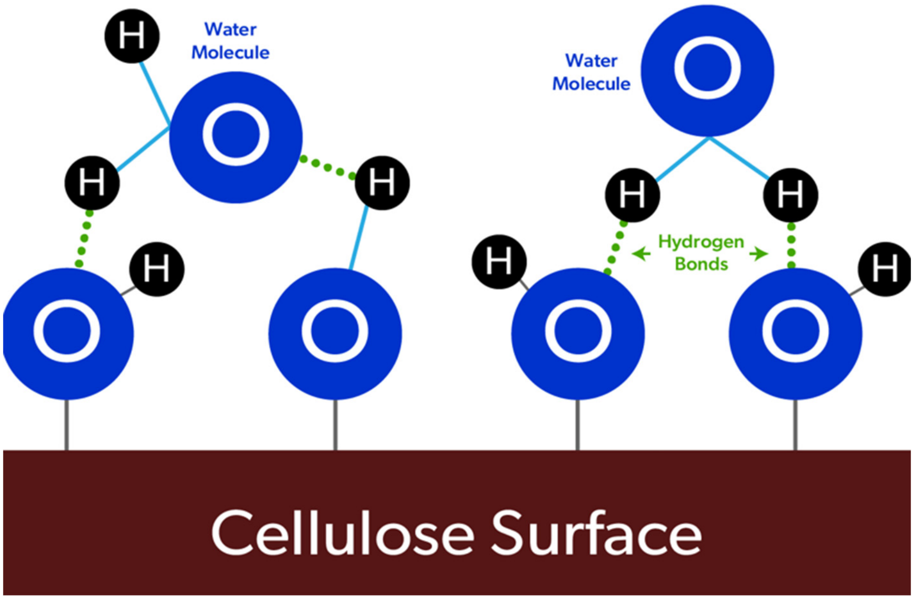

Fig. 1 Cellulose molecule with exposed hydroxyl molecules. Exposure to water molecules allows hydrogen bonds to form between the hydroxyl and water molecules.

Photo 1 Thickness swell in 5/8″ particle board.

Photo 2 Thickness swell in 3/8″ medium density fiberboard.

2. Background

Rain and elevated humidity cause CWP to expand and diminish their structural integrity when exposed to rainy conditions during construction. When wetting occurs, concerns arise toward panel expansion, changes in fastener strength, and ply delamination despite use of exterior grade adhesives [2]. Several authors have described concerns toward excessive expansion [3, 4]. Measurable changes also occur in a residence when moisture contacts non-structural CWP used in kitchen and bath cabinets, shelving, and finish trim. This article examines height and thickness swell measurements to understand the consequences of water losses on CWP materials from plumbing leaks and flooding.

Water exposure and freezing damage comprise the second most frequent insurance claims among insured homes in the United States and affect approximately

29% or 14,000 homes each year (Insurance Information Institute). When water loss claims are investigated, the Forensic Engineer/Scientist is posed two principal questions: what was damaged? and when did the loss occur? When CWPs are water damaged, the degree of discoloration, microbial growth, and dimensional changes are expressions of the duration of moisture exposure [5]. This study examined three aspects of change: (1) moisture adsorption, (2) thickness swell, and (3) changes in surface coloration.

Two moisture exposure apparatuses were used to examine thickness swelling and moisture adsorption rates when various wood panels were immersed under conditions of high humidity (>85% RH) and low humidity (50% to 60% RH). The studies compared the response of CSP under conditions of cyclical moisture exposure.

3. Materials and Methods

3.1 High Humidity (Closed) Test Apparatus

Four wood specimens (3/4″ solid pine, ¾″ exterior plywood, ¾″ faced particle board, ½″ exterior oriented strand board) were used for repeated wet-dry testing. The specimens (8″ × 14″) of solid pine were obtained from a 16-foot plank, while the others were cut from 4′ × 8′ panels. Test (n = 5) and control (n = 2) specimens were labeled and marked at various heights (0.5, 1, 2, 4, 6 and 10 inches) along the middle and side using a black permanent marker.

The apparatus consisted of two 20″ × 20″ × 20″ polyethylene test chambers constructed with covers to maintain high humidity. One layer of a clean white bath towel (20″ × 20″) was placed along the bottom of the chamber with 64 oz of water to maintain capillary contact with the wood specimens. The 20 test specimens were positioned inside a wood support structure made of furring strips and pine dowel rods to support and separate the specimens vertically (Photo 1). The 8 control specimens were held similarly under control conditions.

At the end of the wetting period (2 weeks) specimens were removed and moisture measurements obtained using a Tramex penetrating moisture meter with WME (wood moisture equivalent) measurements taken at heights noted above. The specimens were placed in a drying chamber consisting of a cardboard box. Specimens were stacked sequentially to allow air flow by placing them on three wooden dowel rods (¼ inch diameter and 3 feet long) on the base of the box with three test specimens stacked sequentially between three dowel rods. The specimens were stacked inside the cardboard box, and a second cardboard box of identical size was affixed to the front and a heater fan (Patton, Model No. PUH680, 120 V, AC, 1,500 W) activated to blow warm air over the stacked specimens (forced heat). A thermostat regulated the air temperature at 110 °F. Drying was conducted for one week followed by photography and measurements of moisture content and dimensional change. This procedure was repeated for 18 wet-dry cycles over a 54-week period. For comparison to a parallel study, only the first 6 wet-dry cycles are described herein. Temperature and RH measurements were obtained by placing two monitoring devices (HOBO, U12 Data Loggers, Onset) in the drying and test chambers. A detailed description of the test conditions and measurements is described elsewhere [5]. Results obtained from this test were compared to those prepared as described below.

3.2 Ambient Humidity (Open) Test Apparatus

Four wood specimens (3/4″ solid pine, 23/32″ exterior plywood; ¾″ melamine-faced particle board and 5/8″ exterior oriented strand board) were used. The specimens (7″ × 13″) were obtained from Lowes. The specimens (n = 5) were labeled, and elevations marked using a black permanent marker. The test chamber consisted of a 2 ft × 3 ft open plastic container support structure with wood 2 × 4 boards and wooden dowels to support and separate the 20 test pieces horizontally (Photo 2). The control specimens were held separately under controlled condition.

The specimens were held for two weeks in the test chamber with water added regularly to maintain continuous

Photo 3 Closed test apparatus with the polyethylene lid removed.

Photo 4 Open test apparatus exposed to ambient temperature and RH conditions.

moisture contact with the wood specimens. The water height in the test chamber was maintained at a depth between ¼ to ½ inch with regular replenishment. Dimensional changes and moisture content were recorded after 1 h, 48 h, and at the end of the 2-week wet cycle. After completion of the wetting period, the specimens were removed and photographed with a control exemplar, measured for percentage moisture content (i.e., wood moisture equivalent) and thickness at selected intervals above the water source (0.0, 0.5, 1.0, 1.5, 2.5, 4.5, 6.5, 7.0 inches) along the side and middle.

A General MMD4E moisture meter was used to obtain moisture measurements. Dimensional changes were obtained with a dial caliper (Starrett). Following data collection, the test specimens were returned to the apparatus with replenished water and control specimens returned to control conditions. The test specimens were stacked horizontally with wooden dowels between the specimens for drying at room temperature for a 2-week dry cycle. Drying was followed by photography, moisture, and dimensional measurements. This procedure was repeated for 6 wet-dry cycles over a 22-week period. Temperature and RH measurements were obtained by placing two monitoring devices (HOBO, U12 Data Loggers, Onset) in the drying and test chambers.

4. Results

4.1 Wet/Dry Moisture Content Change

Moisture and thickness measurements obtained at the 2- and 4-inch heights are compared below for the closed (high humidity) and open (ambient humidity) apparatuses. Results from these two heights were instructive in understanding how their moisture adsorption and thickness swell performances were similar or different. Four general observations were made for solid pine specimens (Figs. 2 and 3).

- The amplitudes of moisture adsorption (height) were lower under ambient conditions when compared to high humidity conditions.
- Specimens wet under conditions of ambient humidity absorbed less moisture than those held under high humidity conditions.
- Specimens dried under both ambient conditions and forced heat returned to within a range of 5%-10% WME following one week of drying.
- Moisture measurements at 2″ were higher than those at 4″ under ambient conditions.

The moisture exposure response of plywood specimens is shown (Figs. 4 and 5).

- The moisture adsorption (height) amplitudes were lower under ambient conditions when compared to high humidity conditions.
- Specimens wet under conditions at ambient humidity retained more moisture after drying than specimens dried with forced heat.
- Specimens dried under ambient conditions retained moisture (15% to 25% WME) did not return to the

initial moisture content (10% WME). Specimens dried under forced heat returned to near their initial moisture content (10% WME).

- Moisture measurements at 2″ were higher than those at 4″ under ambient conditions. Moisture measurements under high humidity and forced heat attained comparable heights and depths at 2″ and 4″.

The moisture exposure response of OSB specimens is shown (Figs. 6 and 7).

- The moisture adsorption (height) amplitudes at 2″ were comparable at both ambient and high humidity conditions. The moisture adsorption amplitudes at 4″ were identical under high humidity and forced heat drying conditions. Specimen response to ambient conditions varied with most measurements above 15% WME.
- Specimens wet under ambient humidity conditions retained more moisture after drying than specimens dried with forced heat.
- Specimens dried under ambient conditions retained moisture and returned to near their initial moisture content (10%-20% WME). Specimens dried under forced heat repeatedly returned to their initial moisture content (10% WME).
- Moisture measurements at 2″ were higher than those at 4″ under ambient conditions. Moisture measurements of specimens under high humidity and forced heat attained comparable heights and depths at 2″ and 4″.

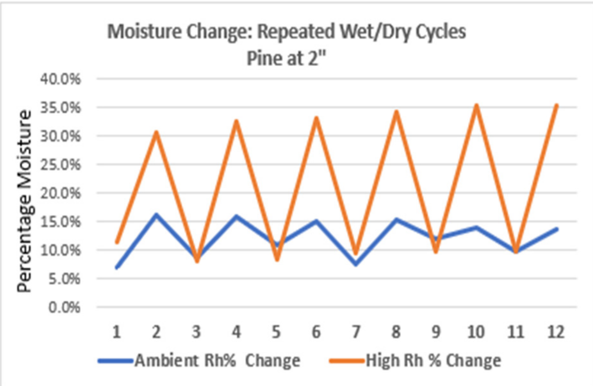

Fig. 2 Moisture content at 2″ above the source in pine specimens exposed to cyclical wet/dry conditions.

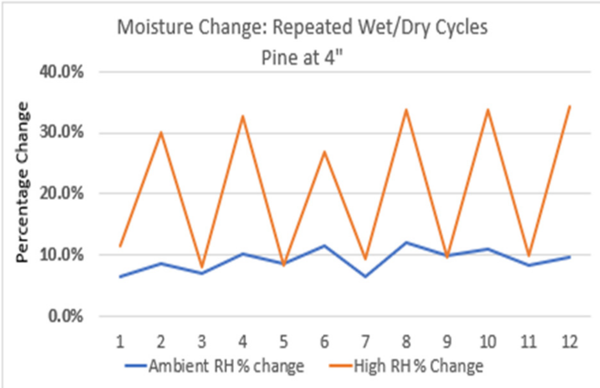

Fig. 3 Moisture content at 4″ above the source in pine specimens exposed to cyclical wet/dry conditions.

Note: Pine wood specimens held under ambient conditions were placed horizontally on the wet surface. This configuration was not optimal for moisture adsorption because the xylem cells were not in direct contact with the moisture source.

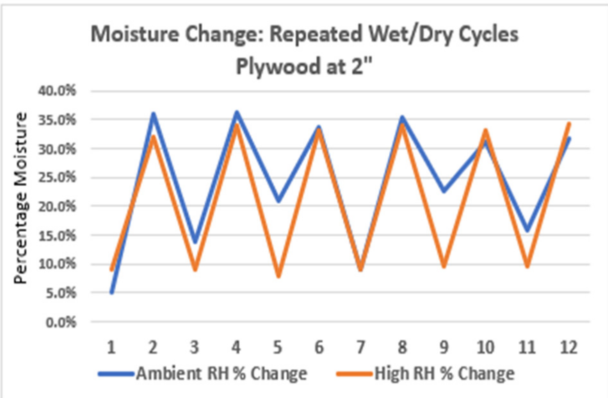

Fig. 4 Moisture content at 2″ above the source in plywood specimens exposed to cyclical wet/dry conditions.

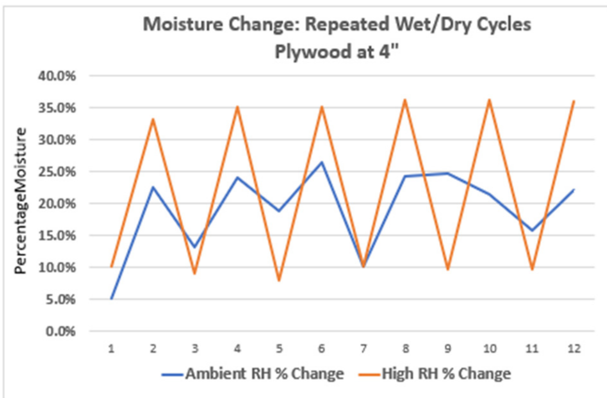

Fig. 5 Moisture content at 4″ above the source in plywood specimens exposed to cyclical wet/dry conditions.

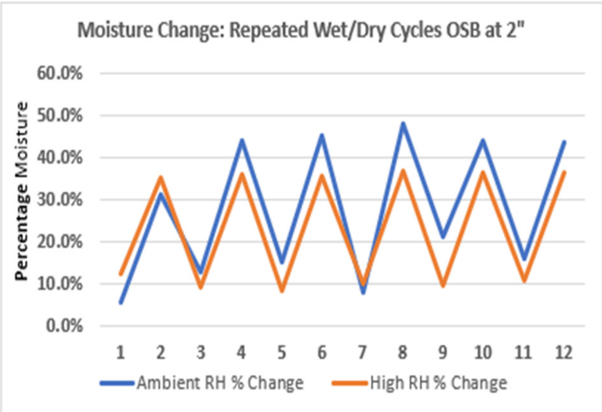

Fig. 6 Moisture content at 2″ above the source in OSB specimens exposed to cyclical wet/dry conditions.

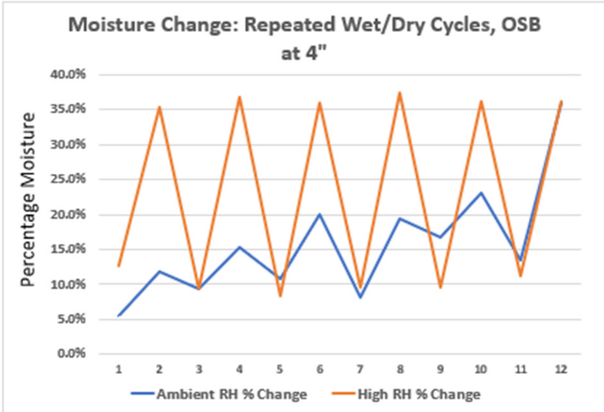

Fig. 7 Moisture content at 4″ above the source in OSB specimens exposed to cyclical wet/dry conditions.

Note: Moisture measurements for particleboard under high humidity and forced heat drying were arrested after 6 cycles because the particleboard specimens were severely fragmented and swollen. This condition did not allow for meaningful measurements.

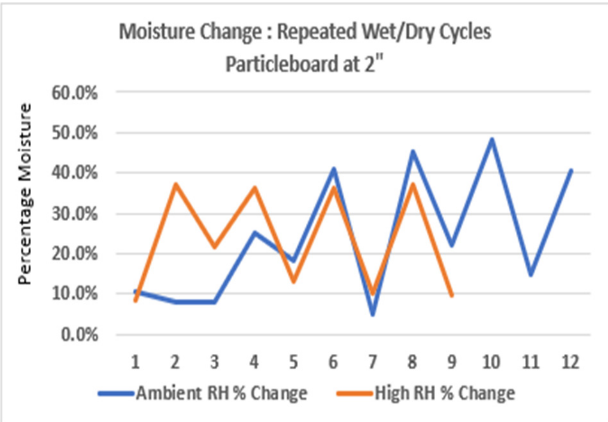

Fig. 8 Moisture content at 2″ above the source in particleboard specimens exposed to cyclical wet/dry conditions.

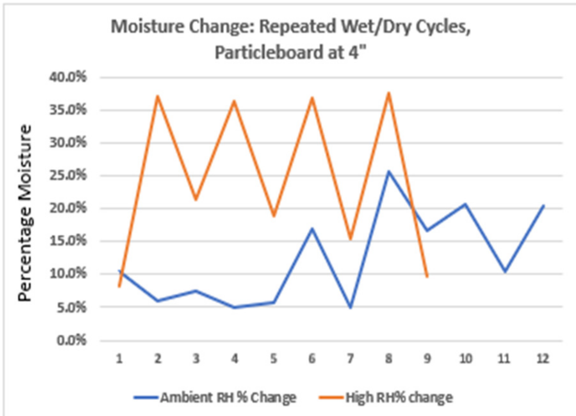

Fig. 9 Moisture content at 4″ above the source in particleboard specimens exposed to cyclical wet/dry conditions.

The moisture exposure response of particleboard specimens is shown (Figs. 8 and 9).

- The moisture adsorption (height) amplitudes were comparable at 2″ under ambient conditions and high humidity conditions. The moisture adsorption amplitudes at 4″ were higher under high humidity conditions.
- Specimens wet under both ambient humidity and high humidity retained more moisture (15% to 20% WME) after drying.
- Specimens dried under ambient conditions retained moisture and frequently did not return to the initial moisture content (10% WME). Specimens dried under forced heat returned to near their initial moisture content (10% WME).
- Moisture measurements at 2″ were higher than those at 4″ under both ambient conditions and forced heat drying conditions.

4.2 Thickness Swell Change under Wet/Dry Cycles

Thickness swell measurements obtained from four types of specimens allowed comparison under opposing humidity conditions. The measurements indicated similarities and differences depending on the specimen type. Measurements of thickness swell in pine specimens are shown (Figs. 10 and 11).

- Pine specimen thicknesses responded repeatedly and similarly to wet and forced drying conditions. The amplitude of TS change ranged between the initial thickness to approximately 5% under humid conditions. TS amplitudes at both 2″ and 4″ were highest under high humidity conditions and forced heat drying. Ambient temperature drying generally ranged at 0% to a 1% increase.

• Pine specimens subjected to high humidity and forced heat drying exhibited similar repeatability in height and depth of response; slight cracks were observed. Specimens under ambient wet and drying conditions exhibited modest thickness ranges.

• Pine specimens either returned (forced heat) to their original dimension or remained approximately 1% thicker (ambient) after drying.

Measurements of thickness swell in plywood specimens are shown (Figs. 12 and 13).

• Plywood specimen thicknesses responded repeatedly and similarly to high humidity and forced heat drying conditions. The amplitude of TS change ranged between the initial thickness to approximately 8% under humid conditions. TS amplitudes at both 2″ and 4″ were highest under high humidity conditions and forced heat drying. Thickness swell under ambient humidity and drying ranged between 2% and 4%. Specimens did not return to the initial moisture content.

• Plywood specimens exhibited an amplitude range between 2% and 8% and did not return to their initial thickness after drying.

• None of the plywood specimens returned to their original dimension after drying.

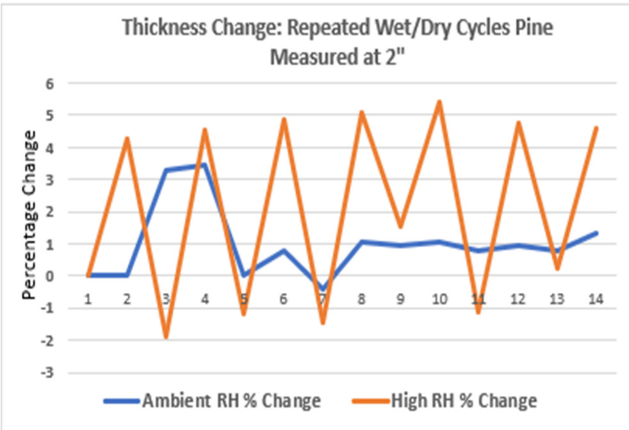

Fig. 10 Thickness measurement changes in pine specimens exposed to cyclical wet/dry conditions at 2″.

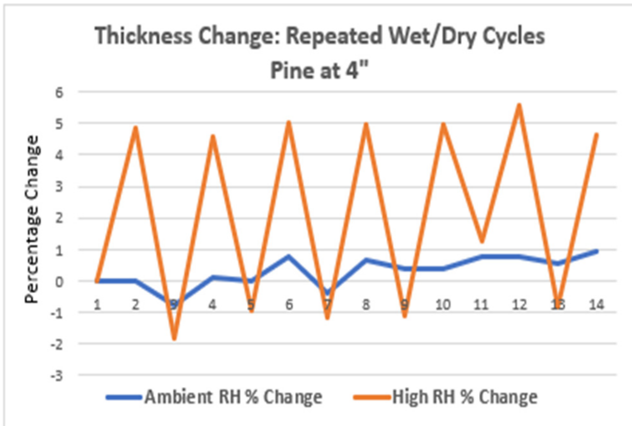

Fig. 11 Thickness measurement changes in pine specimens exposed to cyclical wet/dry conditions at 4″.

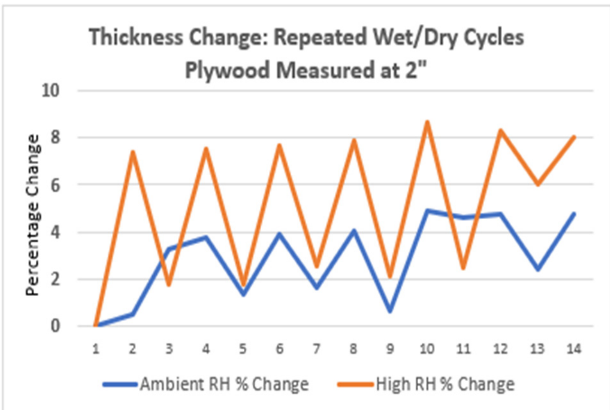

Fig. 12 Thickness measurement changes in plywood specimens exposed to cyclical wet/dry conditions at 2″.

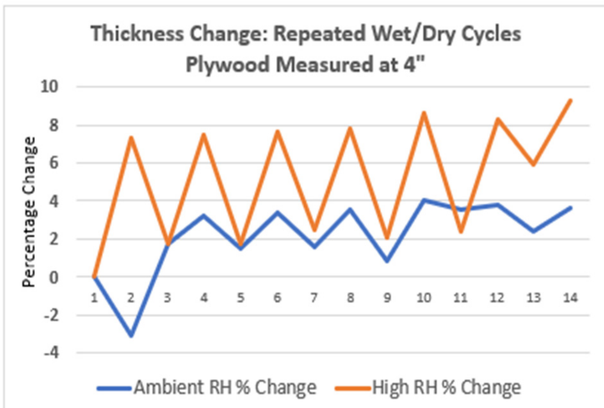

Fig. 13 Thickness measurement changes in pine specimens exposed to cyclical wet/dry conditions at 4″.

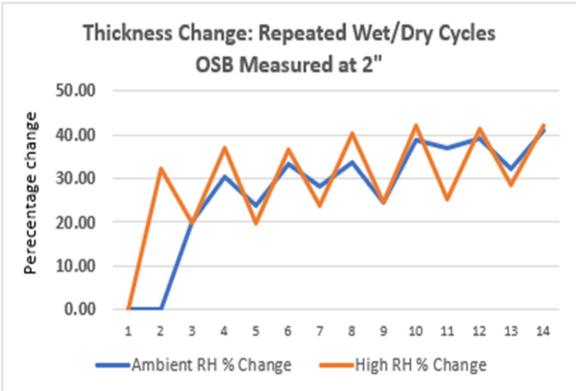

Fig. 14 Thickness measurement changes in OSB specimens exposed to cyclical wet/dry conditions at 2″.

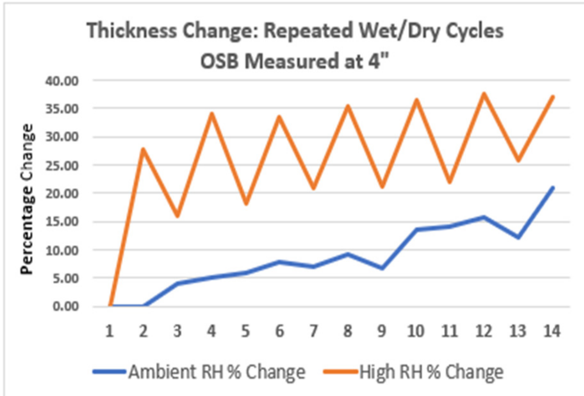

Fig. 15 Thickness measurement changes in OSB specimens exposed to cyclical wet/dry conditions at 4″.

Measurements of thickness swell in OSB specimens are shown (Figs. 14 and 15**)**.

- OSB specimen measurements exhibited a parallel trend of increasing thickness at 2″ with repeated wetting and drying. At 4″ an abrupt separation in thickness measurements was recognized. An upwards thickness trend was recognized with repeated wet/dry cycles.
- TS amplitudes at both 2″ and 4″ ranged up to 40% from initial (high humidity and forced drying). Wet/dry cycles under ambient conditions also exhibited a thickness range from 20% to 40% at the 2″ height. Thickness ranges from approximately 5% to 20% were measured at the 4″ height.
- None of the OSB specimens returned to their original dimension after drying.

Measurements of thickness swell in particleboard specimens are shown (Figs. 16 and 17).

- Particleboard specimen thickness measurements were distinctive when compared between ambient and high humidity and forced air drying at the 2″ and 4″ levels.
- An increasing thickness trend was measured that ranged up to 20% under ambient drying conditions and 80% to 100% at the 2″ and 4″ levels under high humidity and forced heat, respectively.
- The particleboard specimens exhibited a modest level of “spring back” of approximately 10% after drying. None of the particleboard specimens returned to their original thickness dimension.
- Specimens subjected to high humidity and forced drying exhibited large separations in the particle board matrix and severe fragmentation upon completion of the fourth wet/dry cycle.

4.3 Wood Decay Wet/Dry Cycles

Wood is an energy source for fungi. When wood absorbs moisture, it is vulnerable to fungal deterioration because the components of wood (cellulose, hemicellulose and lignin) are used by fungi for energy, growth and reproduction. Deterioration of solid wood products does not progress quickly. CWPs are compressed wood fibers; they more easily deteriorate and biodegrade because thickness swelling exposes the wood fibers to fungal infestation more easily.

There are four stages of wood decay: incipient, early, intermediate and advanced [6]. The incipient decay stage is unseen and results in a 2% to 10% weight reduction and diminished mechanical properties. The second stage of wood decay represents slight changes in appearance (color and texture). The third stage of wood decay represents distinctive changes in color and texture. The fourth stage is advanced wood decay that changes the wood strength and may require replacement.

All study specimens underwent visible changes that were attributed to moisture adsorption, fungal infestation, accumulated fungal biomass, and surface deterioration from fungal use of available sugars. These attributes caused the wood surface to darken when exposed for

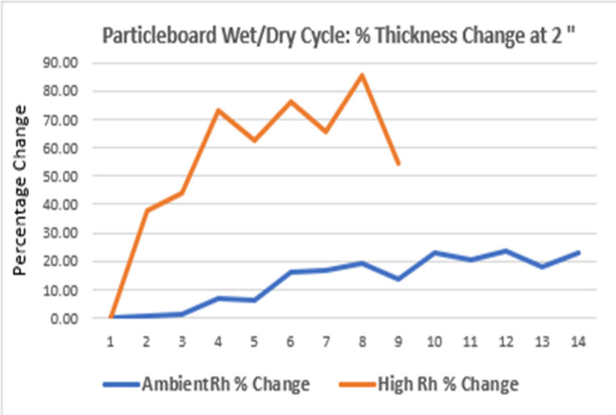

Fig. 16 Thickness measurement changes in particleboard specimens exposed to cyclical wet/dry conditions at 2″.

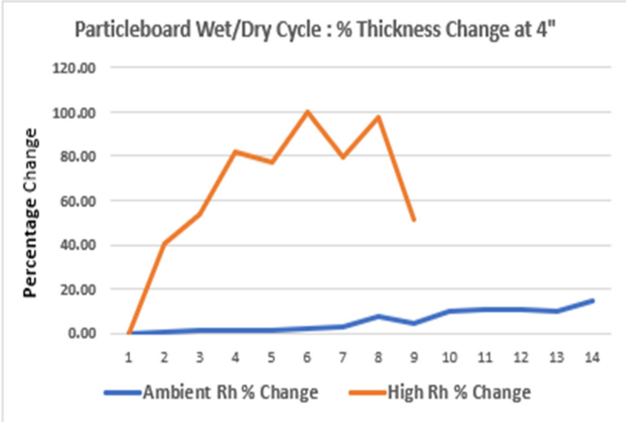

Fig. 17 Thickness measurement changes in particleboard specimens exposed to cyclical wet/dry conditions at 4″.

Photo 5 Solid pine moisture adsorption in ambient RH, 6 cycles.

Photo 6 Solid pine moisture adsorption in high humidity, 6 cycles [5].

longer periods. The solid pine specimen exposed to water with xylem parallel to the moisture source showed moisture adsorption to approximately 2 inches (Photo 5). Limited moisture adsorption was attributed to the orientation of the pine specimen. Wood in a horizontal position to moisture offered few pores that allow moisture to flow into the wood (xylem) cell. Where moisture adsorption did occur, the underlying wood was dark with fungal growth and dead debris.

The pine exemplar positioned vertically allowed water to flow through the xylem cells and attain a height of approximately 9 inches when repeatedly wet. The underlying wood surface was dark with accumulated debris, surface wood deterioration and moisture adsorption (Photo 6).

The plywood exemplar was also exposed to water parallel to the moisture source and showed moisture adsorption to approximately 5.5 inches (Photo 7). Plywood is constructed with an odd number of plies that are placed at 90º from each other. This may allow water to flow upwards in those plies that are vertical to the moisture source. In this circumstance, the exposed outer ply may not represent the visible extent of moisture adsorption.

The plywood exemplar positioned vertically allowed water to flow through the xylem cells and attain a height of approximately 9 inches when repeatedly wet. The underlying wood surface was dark with accumulated debris, surface wood deterioration and moisture adsorption (Photo 8).

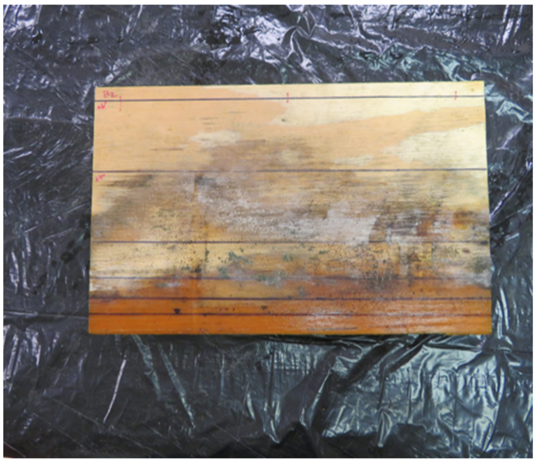

Photo 7 Plywood moisture adsorption in ambient RH, 6 cycles.

Photo 8 Plywood moisture adsorption in high humidity, 6 cycles [5].

Photo 9 OSB moisture adsorption in ambient RH, 6 cycles.

Photo 10 OSB moisture adsorption in high humidity, 6 cycles [5].

The OSB exemplar exposed to water under ambient RH showed moisture adsorption to approximately 5 inches (Photo 9). OSB is constructed with wood wafers of similar size and purposefully cross-oriented on a moving roller bed prior to hot pressing. This manufacturing method exposes wood chips and fibers to moisture adsorption via capillary action. The rate of moisture adsorption depends on the pressing strength and temperature, adhesive characteristics, panel density and thickness.

The OSB exemplar positioned vertically attained a height of approximately 10 inches when repeatedly wet. The underlying wood surface was darkened with fungal growth and moisture adsorption (Photo 10).

The particleboard exemplar exposed to water under ambient RH showed moisture adsorption to approximately 5 inches (Photo 11). Particleboard is constructed in three layers with the highest density particles placed near the outside for a smoother finish and lower density inside for increased strength [7]. The manufacturing method exposes wood chips and fibers to moisture adsorption via capillary action. The rate of moisture adsorption depends on the pressing strength and temperature, adhesive characteristics, panel density and thickness.

Under conditions of high humidity and forced drying, the vinyl-coated particleboard specimens adsorbed moisture to approximately 10 inches when repeatedly wet. The exposed surfaces were swollen, cracked, distorted, and they supported no visible mold growth (Photo 12).

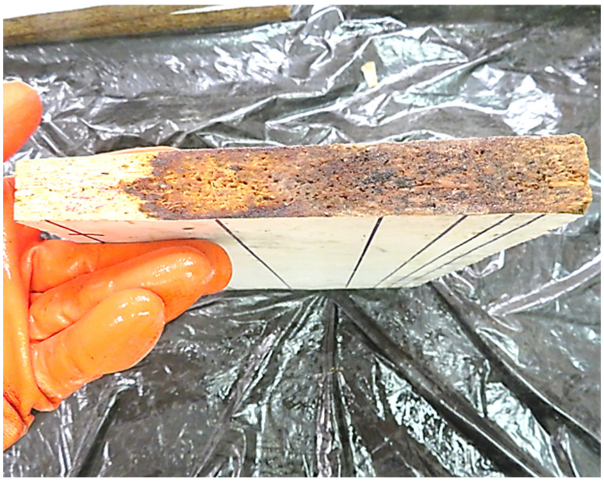

Photo 11 **Vinyl-faced particleboard moisture adsorption in ambient RH, 6 cycles.**

Photo 12 **Vinyl-faced particleboard moisture adsorption in high humidity, 4 cycles [5].**

Photo 13 **Vinyl-faced particleboard moisture adsorption in high humidity, 4.5 cycles [5].**

Repeated wet/dry cycles under humid conditions and forced drying caused the wood particles to swell and separate causing the specimens to self-destruct. No further testing could be conducted with particle board specimens after 4.5 cycles (Photo 13).

5. Findings

The study comparisons revealed several findings that were relevant to water loss claims involving wood materials.

Thickness swell and moisture adsorption are affected by RH. High RH conditions surrounding wood materials will cause faster moisture adsorption by capillary action because of moisture retention and diminished evaporation.

The density of microbial growth, discoloration and wood decay will become more pronounced with the duration of consistent moisture exposure.

The amount of thickness swell and heights of moisture adsorption diminished with increasing distance from the moisture source in all specimens.

Estimates of water loss duration should consider whether the environment was under ambient humidity or high humidity. Low RH surrounding a water release will slow the rate of moisture adsorption, encourage evaporation, and diminish surface discoloration, microbial growth, and physical deterioration. Materials exposed to high RH will experience faster rates of moisture adsorption, surface discoloration, and rates of thickness swell.

A poorly vented environment will produce higher moisture adsorption and thickness swell. Water damaged cabinet panels positioned inside cabinets, behind or between cabinet panels will exhibit faster rates of moisture adsorption and greater thickness swell than well vented areas or adjacent refrigerators, and stoves.

Estimates of loss duration based on the extent of microbial growth alone may be influenced by the sugar content of the wood. The sugar content will vary among wood species. Maple, for example, inherently has higher sugar content than pine or oak. Using this feature alone may make estimate of duration less precise.

Particleboard and OSB materials were most vulnerable to thickness swell; pine and plywood the least.

Pine and plywood materials increased 5%-8% in swelling thickness before returning to their original dimension after repeated wet/dry cycles. Composite wood materials increased 40% to 100% in swell thickness and did not return to their original dimension after repeated wet/dry cycles.

Pine specimens placed horizontally during water exposure testing simulate conditions similar to sill plate framing and demonstrate the limited extent of moisture absorption during the first 22 weeks of exposure.

Solid and composite wood panels experience higher moisture content (5% to 20%) than their initial measurement after ambient drying.

Microbial growth on wood building materials is an expression of the available sugar content on the wood surface. The sugar content will vary with wood species and the growth period (spring, summer, or fall) the tree was cut. The duration of moisture exposure based on the coverage and types of microbial growth is less precise.

6. Discussion

Moisture adsorption and thickness swell are influenced by relative humidity because the capacity of wood to adsorb moisture is dependent on the ambient humidity. The lower the humidity, the lower the capacity of the wood to adsorb moisture from an outside source such as rain, plumbing leaks, and other sources of water intrusion into a home. Wood swells (expands) and shrinks (contracts) in response to moisture content. Wood expansion and contraction pose dimensional instabilities that affect the mechanical properties of the wood, promote biological degradation, and affect its appearance.

The effects on mechanical properties include a reduction in strength and a loss of stiffness with increased moisture levels and fungal infestation. Elevated moisture reduces the capacity of structural wood elements to resist bending, compression, and tension stresses, which decreases the load bearing capacity. Elevated moisture in structural wood elements causes a loss in stiffness due to a reduction in the modulus of elasticity. A reduction in the modulus of elasticity of the wood leads to increased deflections and sagging, which can affect serviceability. Elevated moisture levels also promote growth of wood-degrading organisms, such as fungi and mold, and increase the susceptibility to termites that affect the strength and serviceability of wood. Elevated moisture and fungal infestation will also cause surface discoloration, damages to finishes, warping, cupping, and bowing and further affect the serviceability of wood elements and components.

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