Thickness Swell in Particle Board: A Forensic Tool for the Duration of Loss

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Abstract

When a water loss damages a home and insurance coverage is anticipated, the investigator is often asked a critical question, "When did the loss occur?" Water losses frequently damage cabinetry because composite wood products (i.e., particle board) are vulnerable to thickness swell (TS). TS occurs when composite wood products absorb free water and distort in response to absorption and the release of compressive forces. The study examined five factors that influence TS: product thickness, binding adhesive, presence and type of a coating, surfactants, and particle board density.

Multiple panels (unfaced, vinyl-faced, and melamine faced) were measured for the vertical moisture absorption under conditions of constant moisture exposure, elevated relative humidity (>94% RH), and slight elevated room temperatures (77–81^{o}F) over periods from two to four months. The test results revealed that some circumstances offer a reliable technique to estimate the duration of a one time, continuous water loss when combined with other facts and observations.

INTRODUCTION

TS is a measurable criteria for structural wood panel performance (ASTM D1037-12). TS occurs when a particle board panel is exposed to free (liquid) water and capillary action which gradually increases the moisture content to the fiber saturation point (FSP). The FSP occurs when the moisture content is approximately 27% to 30% wood moisture equivalent (WME). TS occurs when an observable swelling occurs along the face of the particle board as an abrupt bump along the exposed edge (**Photo 1**). The TS height can be identified by running your hand across the particle board panel surface or by using a moisture meter to locate the transition from the ambient moisture content (8 to 14% WME) to the FSP. Both methods can locate the FSP or TS within 1 centimeter accuracy.

When composite wood products absorb moisture beyond the FSP, the swelling effects are irreversible. This characteristic allows the forensic engineer to examine particle board materials months, even years after a water loss and identify the TS height. This paper examines the influence of particle board thickness, adhesive use, coating presence, surfactants, and density on the rate of moisture absorption and TS and the conditions that are favorable to support the duration of water loss.

Photo 1. Thickness swell (1/2") is apparent after 5 days of continuous moisture exposure as identified by both sight and feel.

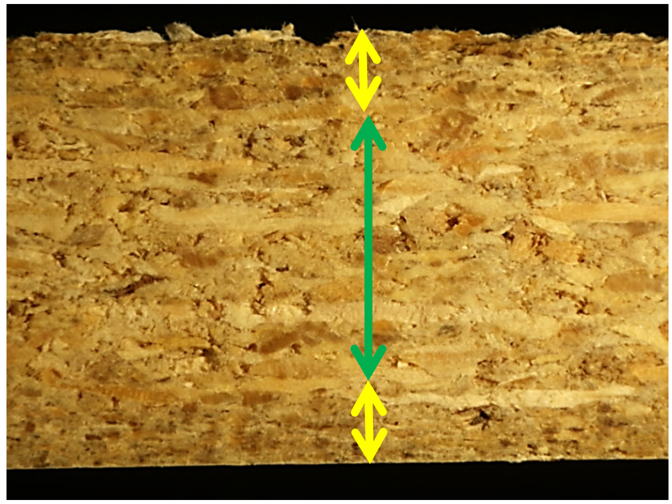


Photo 2. Cross section of ¾" urea formaldehyde particle board sowing the fine particles on exterior faces (yellow arrow) and larger wood pieces in central core (green arrow)..

Particle board is a composite product made from sawdust, shavings, and saw mill waste residues that are bonded together with an adhesive resin (FPL, 1999). Particle board is manufactured by reducing the size of the wood wastes into small particles and mixing them with an adhesive, compressing into a mat with heat (284^{o}F – 325^{o}F) and pressure (100 to 498 lbs/in^2) to create a panel product (ASTM Standard D 1554). The product is produced in three layers comprised of front and back faces of fine, thin wood particles with coarser fibers in the interior core (**Photo 2**). Small wood particles on the outside and larger wood particles on the inside create a panel with a high density surface and a lower density core with better bending properties (Cai *et al*., 2004). Wood panels can be made from any kind of wood specie particles; however, mechanical studies showed no statistical difference among these panels (Wisherd and Wilson 1979). The physical and mechanical properties particleboard grades use a three integer system (*i.e.,* 2-H-2) where the first number corresponds to the adhesive (Type 1 or 2), the second letter corresponds to the density as an "H" (high, 50 pounds per cubic foot (lb/ft^3, "M" (medium, 40-50 lbs/ft^3 and "L" (low, less than 40 lb/ft^3) at 7% wood moisture content. The third number signifies the stiffness (1, 2 or 3)] as specified by ANSI Standard A208.1. Furniture and cabinet manufacturers primarily use Grades 1-M-2 and 1-M-3 (Carll, 1986). Urea-formaldehyde comprises 85% of the interior grade particle board products while the remainder (15%) is used for as floor and mobile home underlayment and solid core doors. Several factors (*i.e*., wood particle size, use of mixed wood species, encased voids, density, heating temperature, adhesive type and wood particle homogeneity) influence the mechanical properties of particle board. However, no previous studies have examined the factors that affect TS following continuous moisture exposure beyond 24 hours (Hofferber et al. 2006; Carll, 1997).

MATERIALS AND METHODS

All control and test studies were conducted in two (7.5’ x 3’ x 4’ and 4’x 2.5’ x 4’) wood-framed test chambers with a ½” thick plywood panel top. The test chamber was constructed with 2”x 3” pine studs secured with exterior grade metal screws (2-inch length). The base of each chamber was constructed using a black plastic liner (10 mil) that formed a water reservoir. One layer of a clean white bath towel was placed along the bottom of the chamber to maintain capillary contact with the particle board specimens. Two HOBO (Onset) monitoring devices were placed inside each chamber to monitor temperature and relative humidity. A plastic evaporation tub (18” x 18” x 4”) containing several inches of water was connected to a horizontal bubbler connected to an aquarium pump (Tetra, Whisper Model 150). The evaporation tub was suspended beneath the plywood top panel to sustain elevated humidity. The entire test chamber was enclosed within clear, 6 mil polyethylene sheeting. Access to the exemplars was gained by detaching the front sheeting panel. Each particle board panel was marked horizontally at 1 centimeter intervals to provide a measurement reference. Whole cabinets or individual cabinet panels were mounted vertically in direct contact with the reservoir base consistent with ASTM D1037 accelerated aging test. Water was added initially and every 3 to 4 days thereafter to maintain a liquid water height of approximately 1 centimeter.

TS measurements were obtained by visual and tactical senses to locate the swelling bump and by a penetrating moisture meter (Tramex) to locate the FSP. Three panel location measurements (front, center, and back) were collected each day during the first two weeks and at lesser frequency thereafter. The measurements were manually logged and graphed immediately after each collection. Temperature and relative humidity measurements were downloaded at the end of each test period.

Control Study: Thickness

Panel thickness was anticipated to influence the TS rate. The particle board materials that were made by the same manufacturer were purchased from a wood distributor (LLT). Four panels for each of three thicknesses (1/2”, 5/8” and 3/4”) were marked as described above, placed in the test chamber for 60 days continuous moisture exposure.

Control Study: Adhesive Resin

Urea and phenol formaldehyde adhesive binders offer different moisture absorption characteristics to particle board products and suggested that the adhesive influences TS rate. Two particle board underlayment panels (2.5’x 3’x 3/4”) containing phenol formaldehyde resin were purchased (Home Depot) and marked as described and tested for 73 days. The panel results were compared to particle board panels of the same thickness containing urea formaldehyde resin.

Control Study: Coatings

Interior particle board cabinetry and furniture are made with a variety of surface coatings (uncoated, vinyl or melamine) that may affect moisture absorption rates and TS. Two of four particle board underlayment panels (2.5' x 3'x ¾") containing phenol formaldehyde resin were sprayed with contact adhesive and covered with clear, flexible 6 mil polyethylene plastic sheeting for comparison to two particle board underlayment panels without plastic sheeting. The panels were marked as described and tested for 73 days.

Control Study: Surfactant Exposure

Water losses can originate from sources that contain surfactants such as P-trap, shower pan, waste arm or garbage disposal leaks. Surfactants lower the surface tension of water and may affect TS behavior. Two identical (1/2") vinyl-faced cabinets (Continental Cabinets, Inc., Dallas, Texas, 36" wide, sink based cabinet) were exposed to a daily surfactant solution (150 ml Dawn dish detergent/1 gallon water) watering (200 ml) from the device described above and monitored for 137 days (Davis *et al.*, 2012).

Test Study: Vinyl and Melamine Coatings

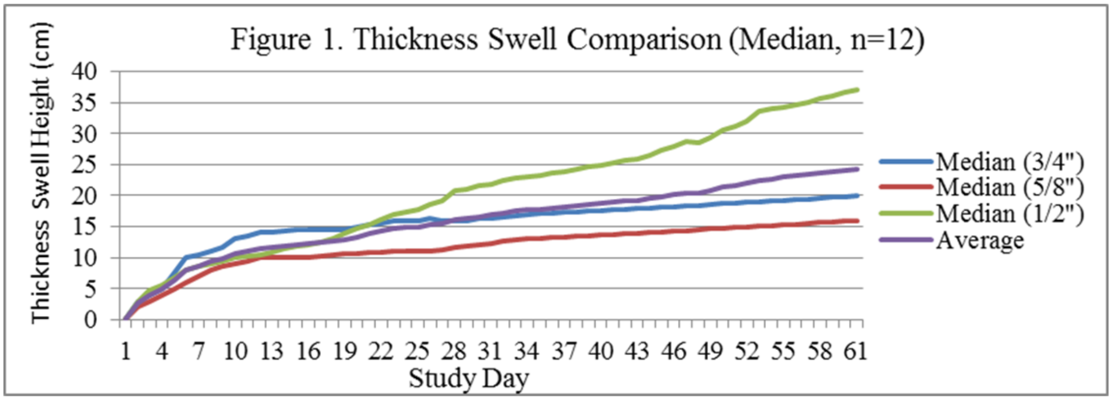
Two parallel studies were conducted using vinyl and melamine-coated cabinets. Four (4) vinyl-faced particleboard cabinets (Martha Stewart (1/2" panel sides), Kraft Maid (1/2" panel sides), American Woodmark (1/2" panel sides), Thomasville (1/2"), 34" x 9" x 22") and two (5/8" panel sides) melamine-faced cabinet boxes (34" x 36"x 22") were used. The cabinets were placed in the test chambers under the conditions as described above and exposed to a continuous source of moisture for 109 days (vinyl) and 138 days (Melamine).

Thickness Swell Test: Density

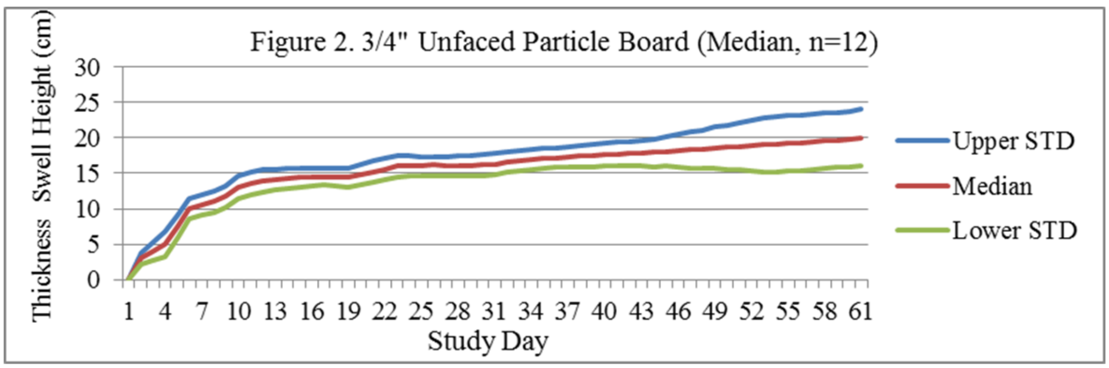
Particle board sections (10" x 2.4") were cut from nine specimens, dried to 7-8% WME in an oven at 170^{o}F, weight and linear dimensions measured using a micrometer (Westward) for comparison to swelling height results obtained at 14, 28, 48 and 60 days.

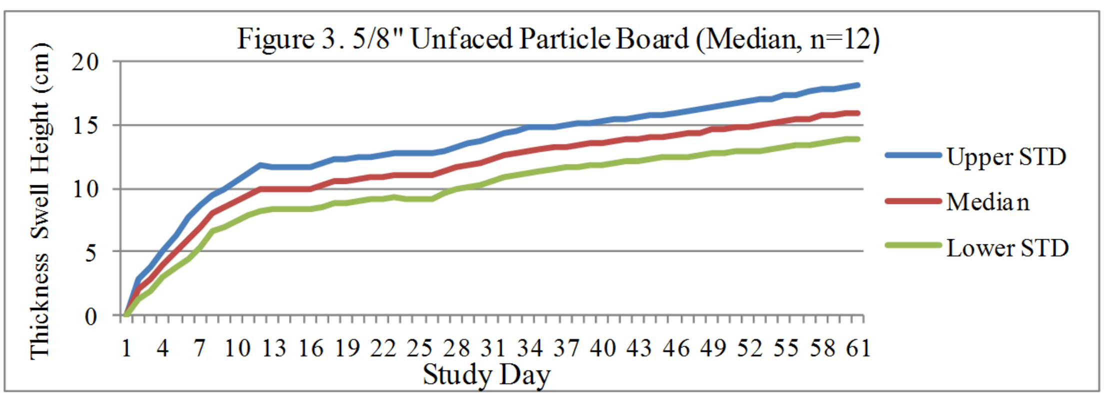
RESULTS

Panel Thickness: Particle board panels of varying thickness exhibited different rates of moisture absorption depending on the duration of moisture exposure (**Figure 1**). Using calculated median and standard deviation values the variation expressed among the panel thicknesses is shown in **Figures 2, 3 and 4**.



TS among three particleboard panels of different thickness: Median TS values were plotted over the course of 60 days in addition to a collective average TS value. The data reveals a characteristic observed throughout the study, rapid initial absorption for a period of approximately 12 days followed by a slower, linear rate that continued for several months. Examination of the median and standard deviation values showed that the TS rates for 1/2”, 5/8” and 3/4” exhibited overlapping ranges during the first 12 days; however, TS rates thereafter appear to differentiate based on thickness with the 1/2” panel migrating the fastest.





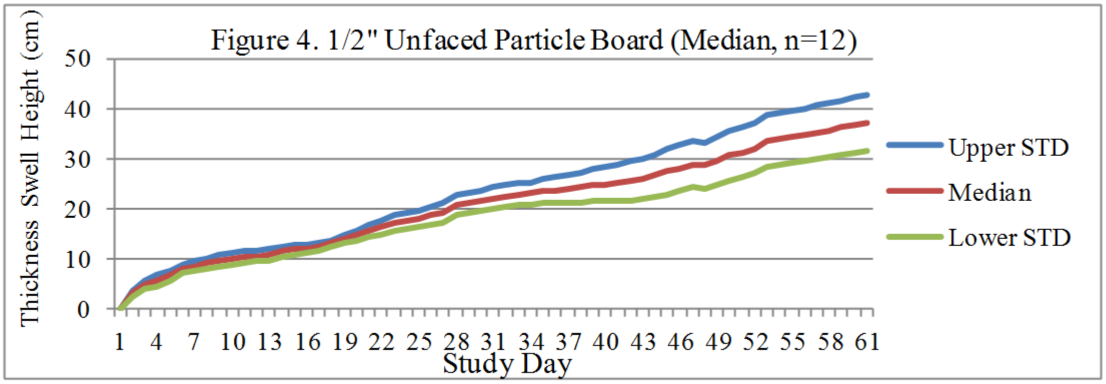


Figure 4. 1/2" Unfaced Particle Board (Median, n=12)

Panel Adhesive: TS comparisons made among particle board panels of the same width (3/4”) but manufactured with different adhesives (urea formaldehyde, n=12 and phenol formaldehyde, n=6) revealed slower (about 1/2) absorption rates among the phenol formaldehyde panels when compared to the urea formaldehyde panels (**Figure 5**).

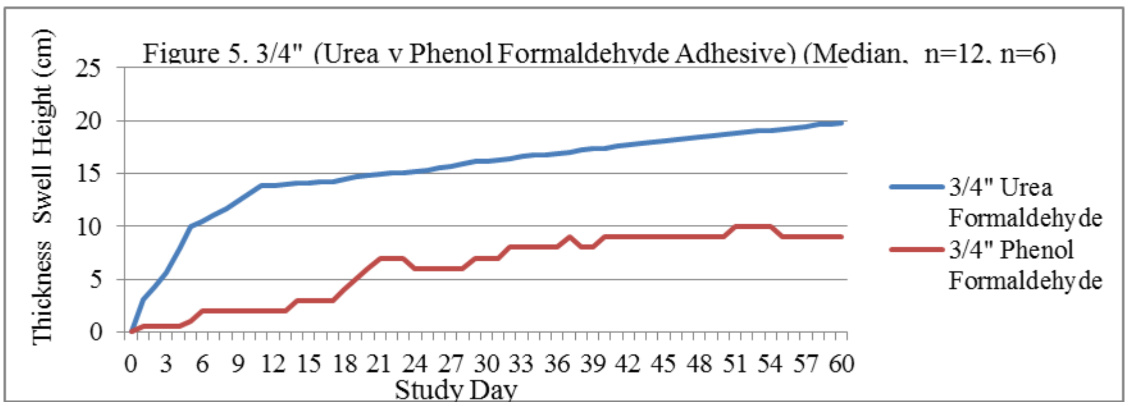


Figure 5. 3/4" (Urea v Phenol Formaldehyde Adhesive) (Median, n=12, n=6)

Faced v Unfaced Panel Coatings: A TS comparison made between (1/2”) particle board panels covered with a 6 mil polyethylene coating showed no statistical difference between coated and uncoated panels (**Figure 6**).

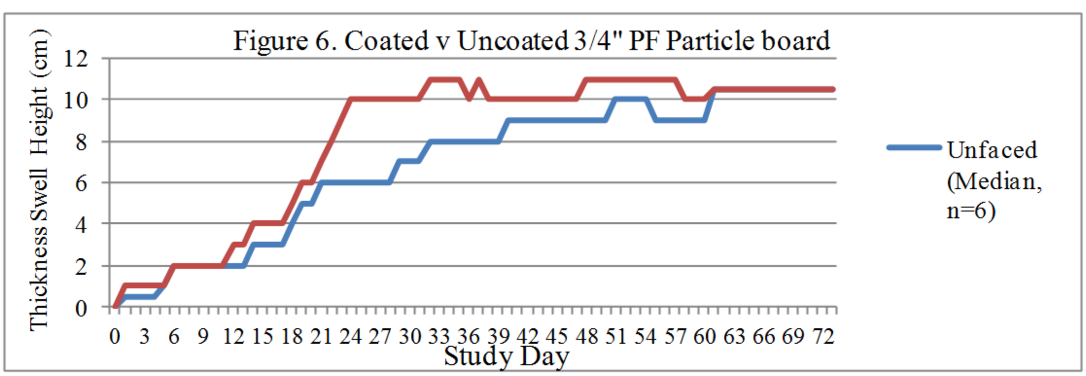
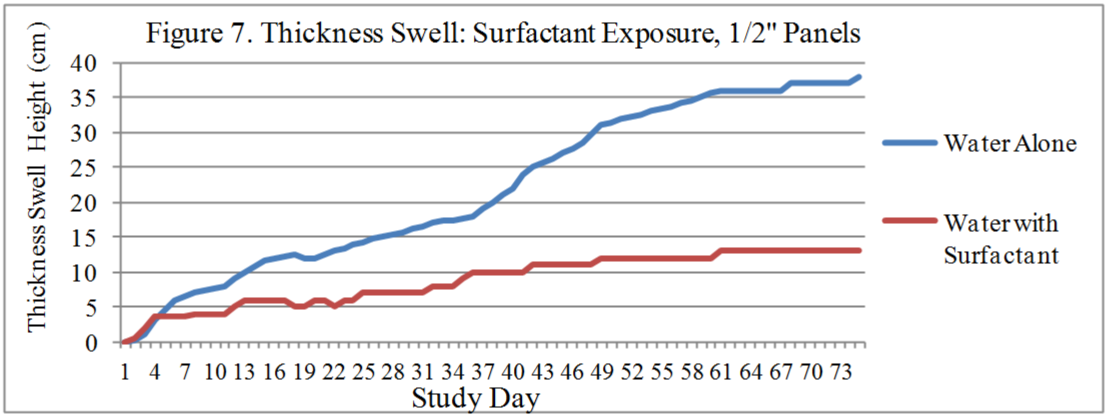
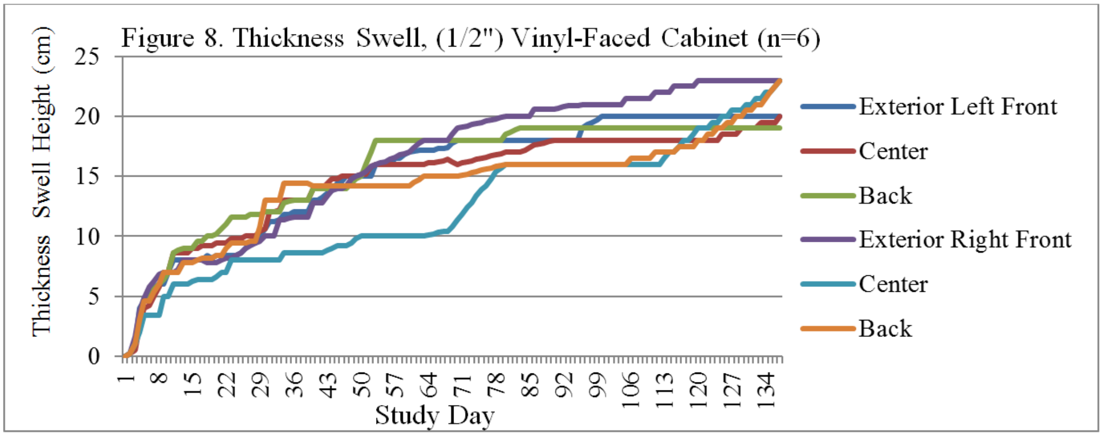


Figure 6. Coated v Uncoated 3/4" PF Particle board

Surfactant Exposure: Identical particle board cabinet panels (1/2") expressed lower rates of TS among the cabinet exposed to surfactants in the water source (**Figure 7**). Depending on the duration of exposure, the rates were 2 to 3 times slower than the water source alone.



Vinyl and Melamine Coatings Comparison: TS (Median values) between two melamine and four vinyl-coated cabinet panels expressed variability among absorption rates. The TS measurements obtained from the one of four vinyl-faced cabinet expressed the inherent variability obtained within the same cabinet (**Figure 8**). The figure shows the six individual TS measurements obtained from six locations around the cabinet over 138 days. These measurements were expressed as a Median with upper and lower standard deviations in **Figure 9**.



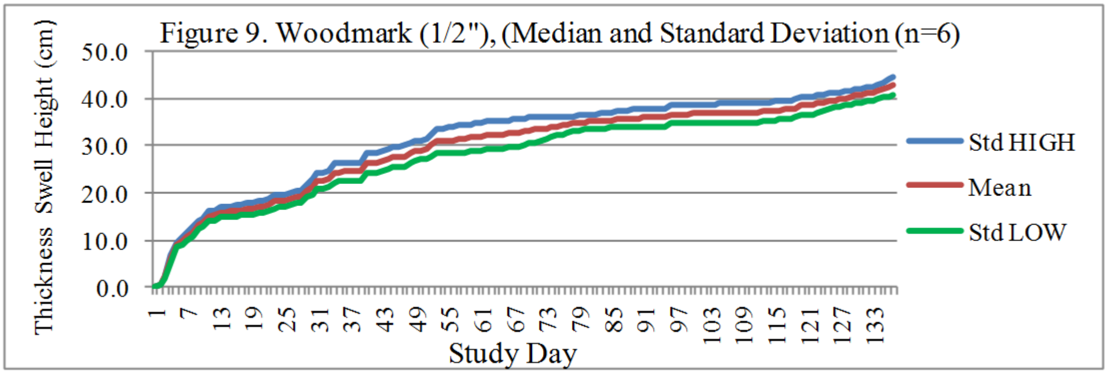


Figure 9. Woodmark (1/2"), (Median and Standard Deviation (n=6)

Collectively, the four vinyl-faced cabinets expressed the characteristic rate of thickness swell with a rapid rate of ascension during the first 12 days and a modest and linear rate from Days 13 through Day 138)(**Figure 10**).

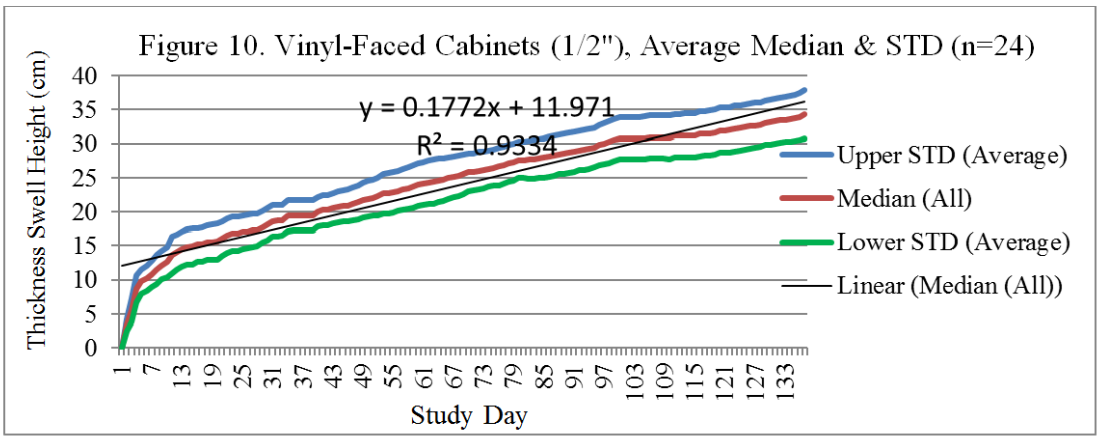
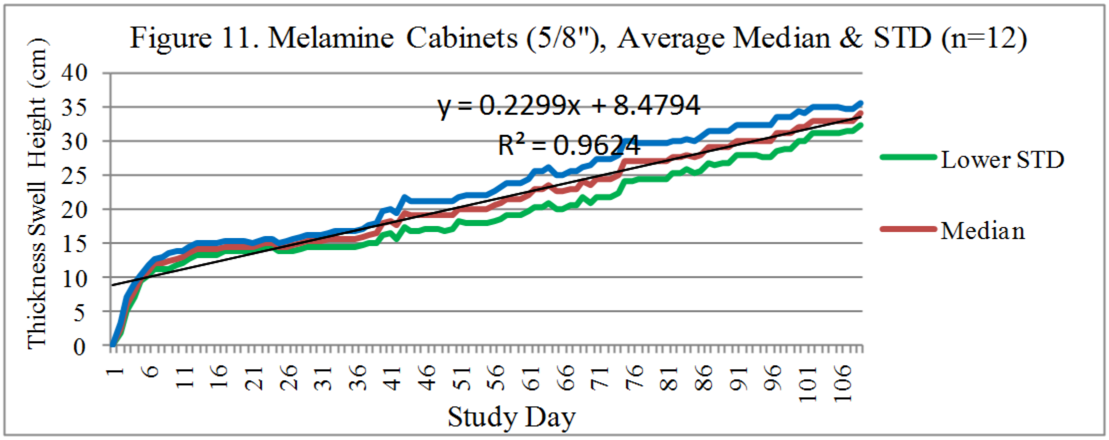
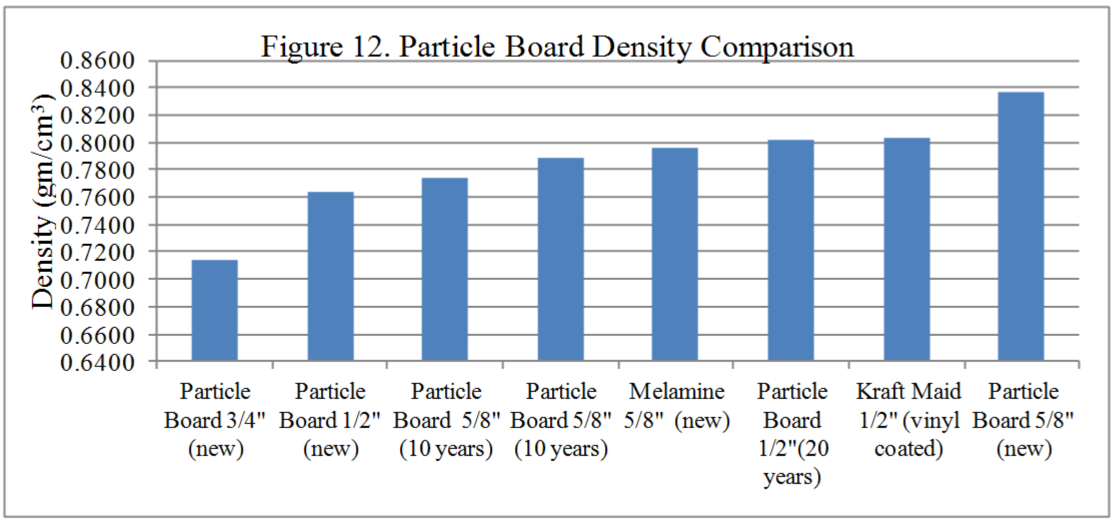


Figure 10. Vinyl-Faced Cabinets (1/2"), Average Median & STD (n=24)

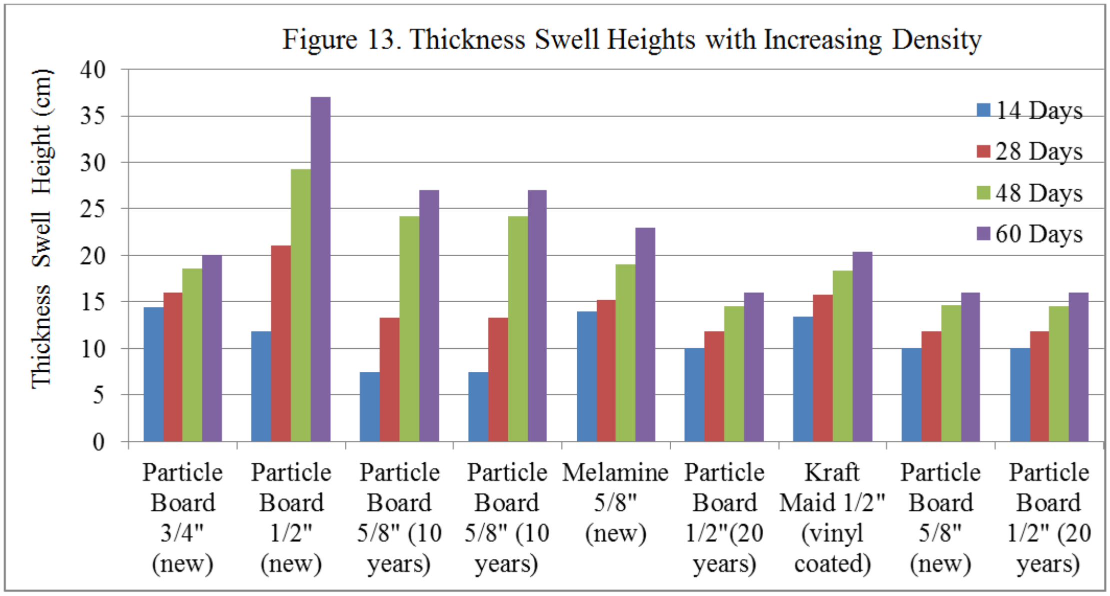
The melamine cabinets expressed the same accelerated TS rate during the first 12 days and linear rate thereafter as did the vinyl cabinets (**Figure 11**). A comparison between the vinyl (1/2”) and melamine (5/8”) TS rates shows that they are similar.



Panel Density Comparison: Nine pieces of particle board materials used in the study were removed and measured for density (**Figure 12**). The results were ranked in order of increasing density and found to represent both medium and high density particle board.



The density values were then plotted against the median TS values obtained after 14, 28, 48 and 60 days of moisture exposure (**Figure 13**). The comparison shows that with the exception of the 3/4" particle board, a trend of decreasing TS rate corresponded to increasing particle board density. The inverse relationship was most prominent after longer periods of moisture exposure (48 and 60 days). The data indicated that high density particle board will absorb moisture slower than low density particle board.



The lower density expressed for 3/4" particle board in **Figure 12** is explained by the large portion of low density inner core materials used for thicker panels. Using 3/4" particle board, the outer layers were separated from the central core so that the volume and weight of each layer could be measured for density (**Photo 3**). The measurements identified two distinctive areas. The outer layers revealed density values of 49.6 and 49.8 lbs/ft^3 while the central core reported a density of 38.1 lbs/ft^3. The results supported our interpretation that faster rates of moisture absorption and TS will occur in the center core where lower density particle board materials are present.

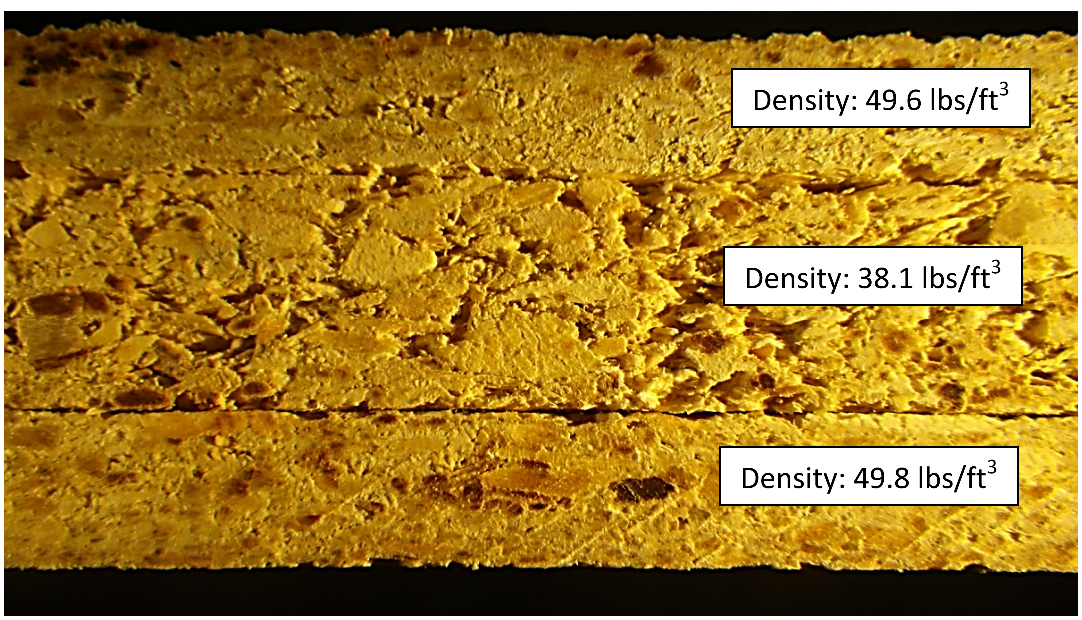


Photo 3. Particle board (3/4" thickness) cut into three sections (outer layers and center core) showing density measurements.

Discussion

Four variables (panel thickness, adhesive selection, exposure to surfactants and panel density) influenced the TS rate in particle board panels. Thin panels (1/2") absorb moisture faster than thick (5/8" and 3/4"). Panel thickness must be known if you intend to use TS as a forensic tool to determine loss duration. The rate of moisture absorption among the 5/8 inch panels was slower than the ½" and ¾" panels. Though manufactured by the same company, materials, adhesive and absent of an exterior coating, we suspect that the 5/8 inch panel were manufactured at slightly higher pressure with resulting higher density.

Higher temperatures express higher rates of capillary action. We assumed that the receiving atmosphere following most water losses is also humid (>90% RH) that will minimize evaporative losses. The temperature regime (77 to 81^{o}F) was within or several degrees above most residential homes. The test offered worst–case conditions that favored the highest achievable moisture absorption and TS rates that error toward faster TS rates.

Panel coatings (polyethylene, vinyl, melamine or none) had no appreciable influence on TS under the humid conditions (>90%RH) examined. Under lower humidity conditions (50-65%), it is anticipated that the TS rate would be slower with more favorable evaporative conditions. We purposefully selected high humidity conditions because it was the easiest condition to sustain inside the test chamber and it offered the most favorable conditions for moisture absorption.

Urea formaldehyde (UF) is the favored particle board adhesive for cabinetry and wood furnishings. UF produces a surface finish is smooth and clear. Phenol formaldehyde (PF) adhesive can be distinguished from urea formaldehyde because it renders a slight yellow color to the wood surface. Oftentimes, wood containing PF will be marked accordingly. The test results suggest that an attempt should be made to confirm the type of adhesive during the investigation.

Water damage losses often encounter water containing surfactants. Dishwasher leaks, washing machine overflows and scrub bucket spills can contribute detergent molecules that lower the surface tension of water. The data indicated that surfactants slow the rate of TS thereby lessening the rate of TS. Height measurements obtained from particle board panels would tend to error on estimating a shorter duration of a water loss. This factor should be kept in mind when conducting an investigation.

Panel density is a key factor that influences TS. It is also complex because each piece of particle board has two densities, high density materials within the outer surface panels and low density materials inside the panel core. Though TS can be felt and seen, if an individual intends to confirm the FSP at a particular height, they must insert the penetrating meter deep enough (1/4 to 3/8" minimum) to intercept the panel core where the moisture content is highest and avoid a possible error.

Particle board will express a higher rate of moisture absorption in the middle core where the density is lowest. Although the distinction between ambient moisture and the FSP may only lie within one centimeter distance, this difference can differentiate several days in moisture exposure duration. This is a critical measurement when distinguishing between a short (14 days or less) and a long-term loss. We encourage marking the TS (or bump height) on the exterior panel with a pen (where appropriate) or blue painter's tape and then document the height measurement with a ruler and photograph. Once multiple TS measurements have been made, the median height is calculated and compared to the results from similar particle board materials (**Figures 2, 3, 4, 10 and 11**).

What conditions may not be appropriate for this forensic method?

- Small pieces of particle board <12 inches in width tend to absorb moisture preferentially along the ends and distorts moisture absorption measurements.

- Highly stippled (bumpy) or irregular absorption after moisture exposure. When the stippled surface extends across the entire surface this technique should not be applied to these materials.

- Particle board exhibiting irregular moisture absorption. TS measurements are intended to reflect moisture absorption along the entire panel width.

Conclusions

Particle board panels absorb moisture at predictable rates depending on panel thickness, adhesive, presence or absence of a surfactant and density. TS offers a reliable tool to predict the duration of a water loss when used appropriately and coupled with other measurements, facts and observations of the loss. More research will establish moisture absorption and thickness swell among more panel products.

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