WATER ABSORPTION BY WOOD PLASTIC COMPOSITES IN EXTERIOR EXPOSURE

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ABSTRACT

Water absorption by wood plastic composites (WPC) is an important and controversial issue affecting warpage, dimensional stability, and resistance of material to freeze-thaw cycling as well as fungal growth and decay. The objective of the work presented is to identify water absorption and water distribution in experimental WPC exposed to exterior conditions, and compare these results with the standard water absorption test used by industry.

The WPC formulations used, as well as processing conditions, were selected in such a way that the experimental WPC materials showed water absorption equilibrium and kinetics representative of a large variety of commercial products available on the North American market. Boards were exposed to exterior weathering in Vancouver (BC) in sun or in shadow. The duration of the exposure was 21 months. After collection, the samples were cross-sectioned for moisture content evaluation. The results obtained indicate that there is no obvious correlation between water absorption of WPC measured according to industry standard and moisture content in the same materials exposed to exterior conditions. WPC will absorb a significant amount of moisture when exposed to an exterior environment. The core may have very low moisture content while the surface layer may be significantly saturated with water. The presence of zinc borate in a WPC formulation seems to reduce water absorption by the WPC.

INTRODUCTION

Water absorption is an important factor influencing properties and durability of Wood-Plastic Composites (WPC) materials. The presence of water in these types of materials decreases mechanical properties and durability, including (for example) performance during freeze thaw cycling, dimensional stability, warping and microbiological activity, including decay (1-4,7,13). For this reason, water absorption by WPC is our prime point of interest and the subject of our research described in this paper.

There is some controversy surrounding water absorption by WPC. On one side there is the perception amongst industry that wood particles are effectively encapsulated in water impervious plastics. This can be seen in the microphotograph of a cross-section of a typical WPC sample shown in figure 1. Much of the published commercial data obtained by testing water absorption according to ASTM D-1037 also indicates very low water absorption by wood plastic composites, in the range of under 2%. This would seem to support the encapsulation theory.

There are, however, some signs that contradict these optimistic expectations regarding water absorption in service. There is published data indicating warpage, decay, and the presence of fruiting body decay fungi on wood plastic composites as shown in figures 2 and 3 (4,10,13). It is also known that there is some swelling of WPC boards. These observations suggest a relatively high water uptake by the composites upon exposure to the environment. It is also known that WPC material, exposed over time to water, slowly gains weight for a prolonged period of time frequently without reaching equilibrium as can be seen in figure 4 (6,8,9). These effects are, however, frequently ignored as they appear to have been obtained in unrealistic conditions.

OBJECTIVE

The objective of our work was to shed some light on this controversy, particularly to identify water absorption and the distribution of this moisture in WPC materials exposed to exterior conditions.

The objective could be achieved in two ways:

a. Computer modeling and simulation using a basic equation of diffusion and attempting to quantify all relevant variables

b. Exposure of representative samples of WPC to exterior conditions.

We chose the latter method.

EXPERIMENTAL

Extrusion of WPC

An important part of this work was the preparation of representative samples of WPC. Our formulations contained components frequently used by industry, including pine wood flour, high density polyethylene resin with fractional melt flow index (resin B-53 35H flakes - Solvay), a standard lubricant/compatibilizer system, talc and optional zinc borate (*Borogard*® ZB– U.S. Borax). Four formulations, #5, #6, #12, and #13 (see table 1) were chosen. Boards with cross-sections 6”x1/2” (formulations #5 and #6) and 6”x 1” (formulations #12 and #13) were extruded in the state of the art Materials and Engineering Laboratory at Washington State University using typical conditions for extrusion of wood plastic composite materials. Boards were selected at random from each extrusion run for use in these experiments.

WPC properties

Our formulations and processing conditions were carefully selected in such a way that the extruded material was representative (in terms of water absorption properties) of WPC material commercially produced and available on the North American market[*]. The graph in figure 5 compares 14 commercially available WPC products (bars marked with letters A to O) with the four experimental materials utilized in our study (#5, #6, #12 & #13). As can be seen, our experimental materials encompass the wide range of water absorption equilibrium values (from approximately 15% to over 40%) observed for the commercial products that were evaluated.

Assessment of the kinetics of water absorption by the comparison of weight gain over time after water immersion for two of our experimental materials (#5 and #6) and two selected commercial products (L and G) is illustrated in figure 6 - supporting the claim that our experimental samples have properties similar to those of the commercial products. A comparison was also done for our experimental samples #12 and #13 (which have higher designed water absorption) and commercial samples B and N – these results are shown in figure 7 and also show that our experimental materials are very similar, with respect to kinetics of water absorption, to a wide range of commercial products.

Water absorption was also evaluated according to ASTM D-1037, the historical industry standard and the data is shown in figure 8. The results from these evaluations are very low, at 1% or less, which is in line with the reported values for many commercial products.

WPC Exposure

Samples were exposed to exterior weathering for 21 months in two types of exposure, sun and shade, in the Vancouver B.C. area starting on May 1st, 2003. In this paper, letter A in conjunction with formulation #, will indicate data obtained for samples exposed in sun, and letter B (also in conjunction with formulation #) will indicate data for samples exposed in shade.

Actual weather data for Vancouver, B.C. during the period of exposure is shown in table 2. Please note, that the mean monthly temperatures were above 4^{o}C (40^{o}F) with monthly rainfall ranging from 4.1 mm (~0.2") in August 2003 to 248.2 mm (~10") in October 2003. Rainfall for the 2004 calendar year was 1096 mm (~43.15") and the total rainfall for the 21 month exposure period was in excess of 1950 mm (~ 75").

There is a good correlation between the 2004 rainfall in the exposure area and the data from the Average Annual Rainfall map as shown on figure 9 (12). It is on the low end of the high exposure zone which covers an area with annual rainfall between 40" and 60". Similar conditions exist in most of the southeastern U.S. and many Atlantic regions. It should be noted that some regions in the U.S. and Canada suffer much more extreme conditions with annual rainfall over 60", including many highly populated areas of the Atlantic and Gulf of Mexico coasts, as well as the Pacific Coast Mountain region. It should also be mentioned that during the 2 days preceding sample collection in the field there was no noticeable precipitation in the exposure area.

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[*] As tested on identical specimens 25x50x1mm (1"x2"x0.04") according to the method described in an earlier presentation (10).

Samples Preparation

Samples were cut from the exposed boards in strips approximately 2.5” in length, immediately sealed by wrapping in Saran® film, and quickly transported to the laboratory. In the laboratory, samples were frozen with dry ice for a few hours prior to cutting in order to minimize moisture loss from contact with the saw-blade. Here, samples were cut into four segments as shown in figures 10a and 10b and the segments marked as a, b, c and d. Segments “a” with a thickness of ¼” (6 mm) represented the end area of the boards and segments “b” represented the main body. Segments “c” were sliced into wafers of approximately 1 mm thickness. Six wafers were cut from the ½” thick boards #5 and #6, while 11 to 12 wafers were cut from the 1” thick boards #12 and #13. All specimens were weighed and then dried at 103°C for 16h or until reaching constant weight, and water absorption or moisture content was determined from these data. Please note, that from this point on in the paper, the terms water absorption will be used exclusively with respect to water present in wood plastic composites, and moisture content (also known as %MC) will be used with respect to water present in the wood fraction of WPC materials. The polyolefin plastic used in the tested WPC has very low water absorption (about 0.5%) so it could be safely assumed that all water found in the tested samples was exclusively present in the wood component of the composites. Please note also, that although no correction has been made for the edge effect, this effect would not greatly alter the gradient curve for moisture distribution in segment “c”, and may therefore be considered negligible for the purposes of this study.

RESULTS AND DISCUSSION

Water absorption in the wood plastic composite and the calculated moisture content (%MC) in the wood component for segments “a” is shown in figure 11. The water absorption for these segments lies in the range of approximately 12 to 21%, which reflects moisture content in the wood component of 25-33%. Moisture content in wood of 25% is commonly accepted as the minimum level necessary to initiate decay and this threshold is marked on the graph (11). Examination of the data shows that the average moisture content in all tested samples was close to or above 25%, making the wood vulnerable to decay. Water absorption tested according to ASTM D-1037 is also marked on the chart.

Data are presented in figure 12 for segment “b” representing the main body of the tested board. The measured average water absorption and moisture content in segment b was found to be lower in comparison to segment “a” as expected. Water absorption in segment b varied from approximately 5% to 16% and moisture content for wood from 10 - 12% to approximately 25% for sample #12. Water absorption tested according to ASTM D-1037 is also marked on the chart. Surprisingly, we found that among the boards with higher water absorption, those containing zinc borate showed significantly lower moisture content (in the range of 15% to 19%) than boards made without zinc borate which show water absorption in the range of 23% to 25%. This lower water absorption by materials containing zinc borate can also be observed in figures 4, 5, and 6. Additional work is underway in an effort to understand the significance of this observation.

Wafers cut from segments “c” of the evaluated boards allowed for the determination of water absorption in the board with respect to the distance from the surface, as can be seen in figure 13 (boards #5 and #6). Water absorption found in the tested materials varies from high values at almost 20% near the surface, to rather low values of approximately 2% for the core region. As might be expected, these values change gradually through the board thickness.

For samples #12 and #13, with their 1” thickness and higher designed water sensitivity, water absorption values vary from approximately 36% in the surface area for sample #12A to approximately 10% in the core region. As seen before, these values also change gradually across the board thickness (see figure 14).

Evaluation of water absorption in wood composites, as shown in the previous charts, allowed the calculation of moisture content distribution in the wood component of WPC samples (figure15). As is evident on the charts, moisture content distribution is very similar for samples exposed in sun vs. shade with some differences near the surface. For samples taken from materials #12 and #13, there is also visibly lower water absorption for boards made with zinc borate. Because of the aforementioned similarity in water distribution, only samples #6 and #12 will be discussed in greater detail.

Moisture content distribution in WPC for sample #6 exposed to exterior conditions in sun and shade is shown in figure 16. Moisture content in wood decreased quickly from 40% or 30% at the surface to about 4% at the core, following a U-shaped distribution curve. Recalling that 25% moisture content is necessary to initiate fungal decay in wood, this threshold moisture content is present in the analyzed board to a depth of 1 to 2 mm, or approximately 1/16”, on the exposed side. The threshold for decay is marked on the graph; when total board thickness is taken into consideration, as much as 25% of the board may have moisture content above this threshold.

Moisture content is significantly higher for board #12 than for board #6, as per the experimental design. This moisture content varies from approximately 50% near the surface to approximately 15% in the core region as shown in figure 17. The zone with MC above the decay threshold is wide and reaches approximately 5 – 7mm (¼”) deep on the exposed side of the board. On the reverse side, this zone reached approximately 5 mm deep. The moisture content near the surface is slightly higher for the board exposed to sun, a finding which can be explained by surface weathering. Observation of a similar effect on the opposite side (facing down) of the board indicated that exposure to dew may also be an important factor. It is known that during exterior exposure of materials, they can be in direct contact with liquid water even during sunny and cloudless weather because of dew formation. Moisture from the condensation of dew can be present for as long as 16 hours daily in certain conditions and bears consideration as a potentially significant factor in water absorption by wood plastic composites.

COMMENTS AND CONCLUSIONS

The results of this work can be summarized by the following comments and conclusions:

1. There seems to be no obvious correlation between water absorption of WPC as measured according to ASTM D-1037 and moisture content in the same materials exposed to exterior conditions. Samples tested according to ASTM D-1037 showed approximately 1% water absorption, while the same material exposed to exterior conditions may absorb 15% water in the bulk of composite.

2. Wood plastic composites will absorb significant amounts of moisture when exposed to an exterior environment. This moisture is distributed unevenly across the board thickness. The core may have a very low moisture content while the wood component near the surface may achieve a %MC in excess of that necessary to initiate decay. These findings explain and support the observations from the field where fungal decay has been seen on WPCs in service.

3. Moisture content in the wood component of WPC exposed to exterior conditions may significantly exceed 25% in some sections of the board thickness. This threshold value of 25% MC is widely accepted as the minimum to initiate fungal decay. The areas of high moisture content frequently exceeding 25% are the board ends and the region up to 1-7 mm below the board surface.

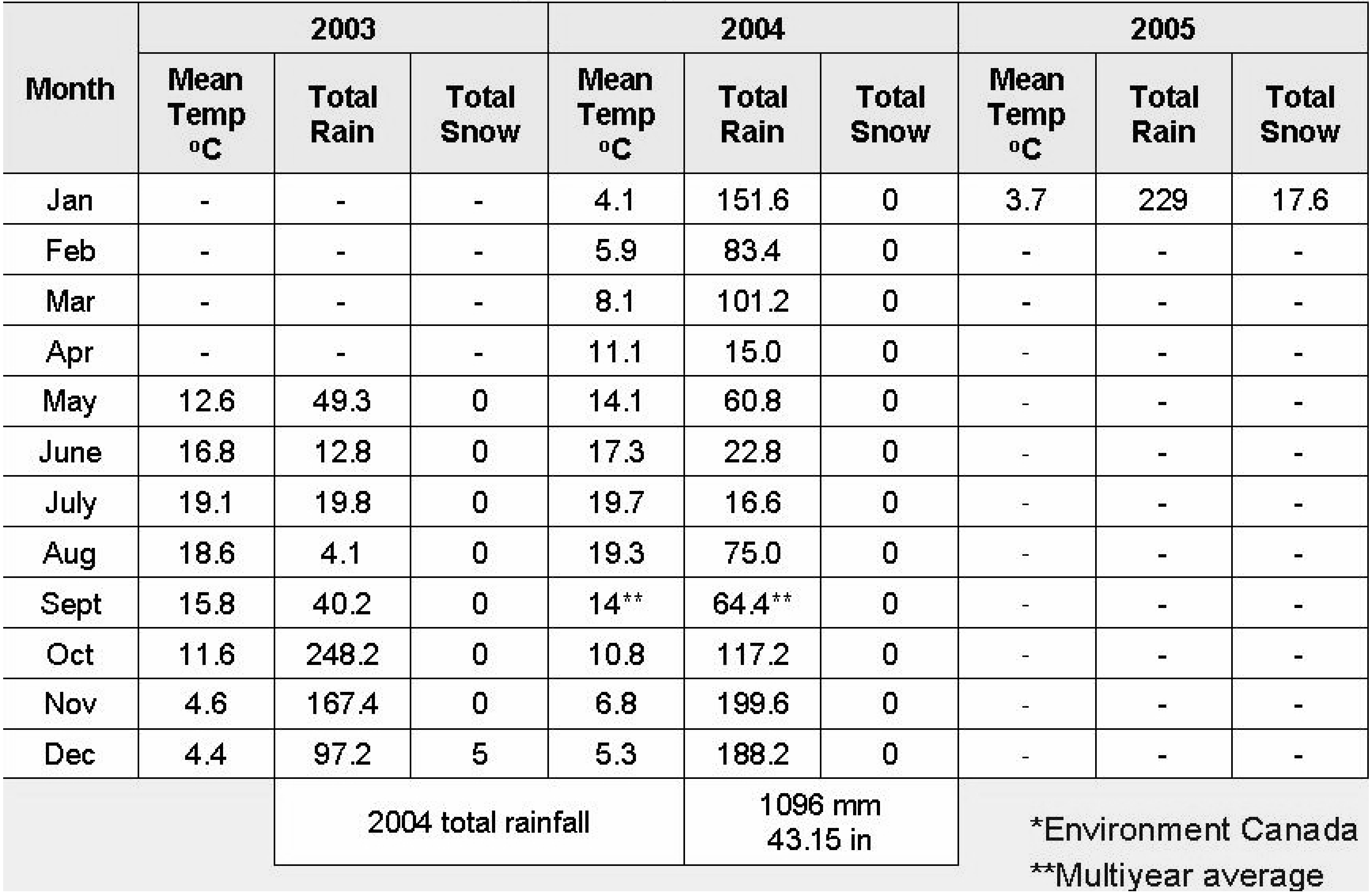
4. Material sensitivity to water entry depends on the material formulation and possibly the processing conditions. Higher wood concentration may promote water absorption and increase the thickness of the layer with high moisture content.

5. The presence of zinc borate in the formulation seems to reduce water absorption by WPC relative to similar formulations which do not contain zinc borate.

Table 1. Experimental wood plastic composite formulations

Ingredients	Formulation			
	#5	#6	#12	#13
Pine wood (20 mesh)	51	48	66	63
HDPE	45	45	30	30
Lubricants/compatibilizers	3	3	3	3
Talc	1	1	1	1
Zinc Borate	0	3	0	3
Boards Cross-section (in)	6 x 1/2	6 x 1/2	6 x 1	6 x 1

Table 2. Weather data for exposure period in Vancouver, BC*



Month	2003			2004			2005		
	Mean Temp °C	Total Rain	Total Snow	Mean Temp °C	Total Rain	Total Snow	Mean Temp °C	Total Rain	Total Snow
Jan	-	-	-	4.1	151.6	0	3.7	229	17.6
Feb	-	-	-	5.9	83.4	0	-	-	-
Mar	-	-	-	8.1	101.2	0	-	-	-
Apr	-	-	-	11.1	15.0	0	-	-	-
May	12.6	49.3	0	14.1	60.8	0	-	-	-
June	16.8	12.8	0	17.3	22.8	0	-	-	-
July	19.1	19.8	0	19.7	16.6	0	-	-	-
Aug	18.6	4.1	0	19.3	75.0	0	-	-	-
Sept	15.8	40.2	0	14**	64.4**	0	-	-	-
Oct	11.6	248.2	0	10.8	117.2	0	-	-	-
Nov	4.6	167.4	0	6.8	199.6	0	-	-	-
Dec	4.4	97.2	5	5.3	188.2	0	-	-	-
		2004 total rainfall			1096 mm 43.15 in				

*Environment Canada

**Multiyear average

Figure 1. Optical microscopy of WPC cross-section. Visible wood particles encapsulated in resin.

Figure 2. WPC warping[1]

Figure 3. WPC fungi growth[2]

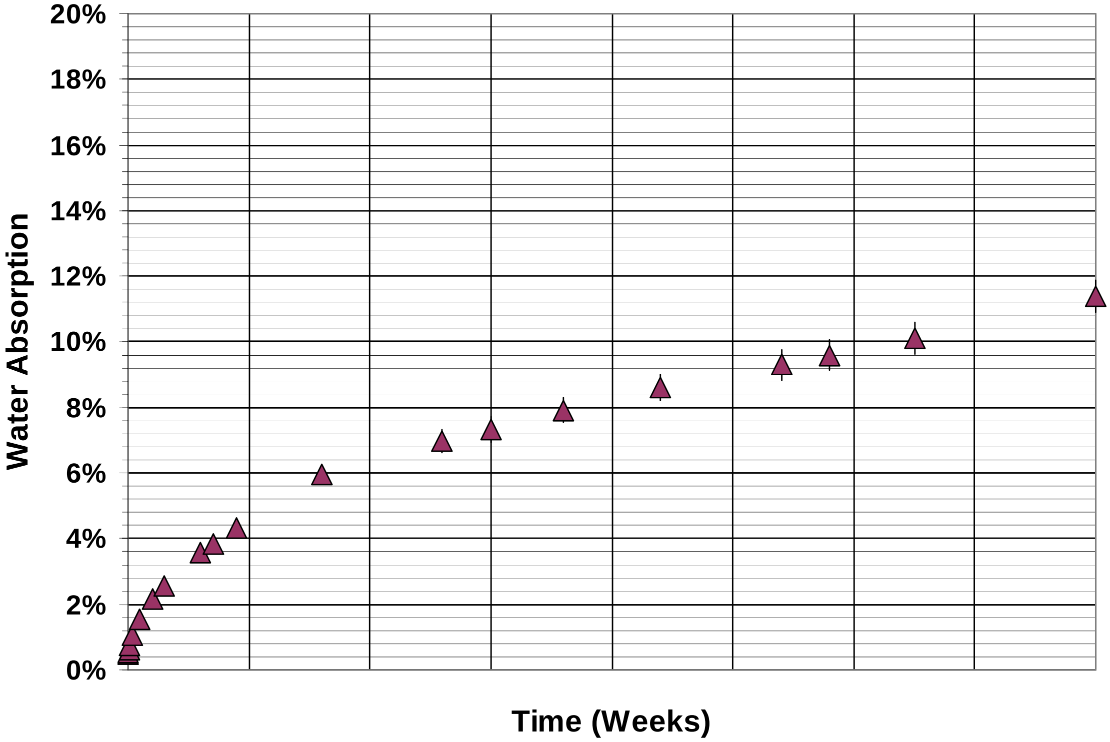


Figure 4. Water absorption vs. time for typical WPC

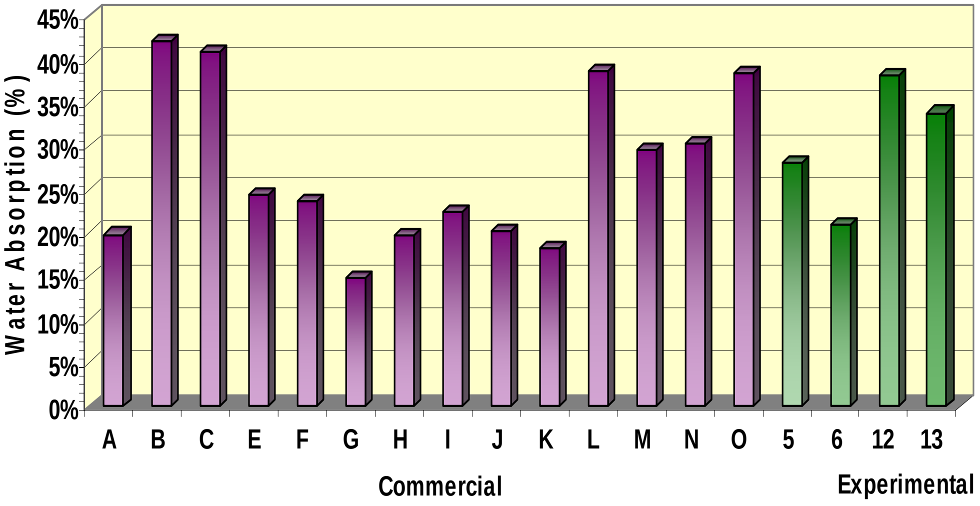


Figure 5. Comparison of water absorption at equilibrium for experimental materials and commercial WPC's

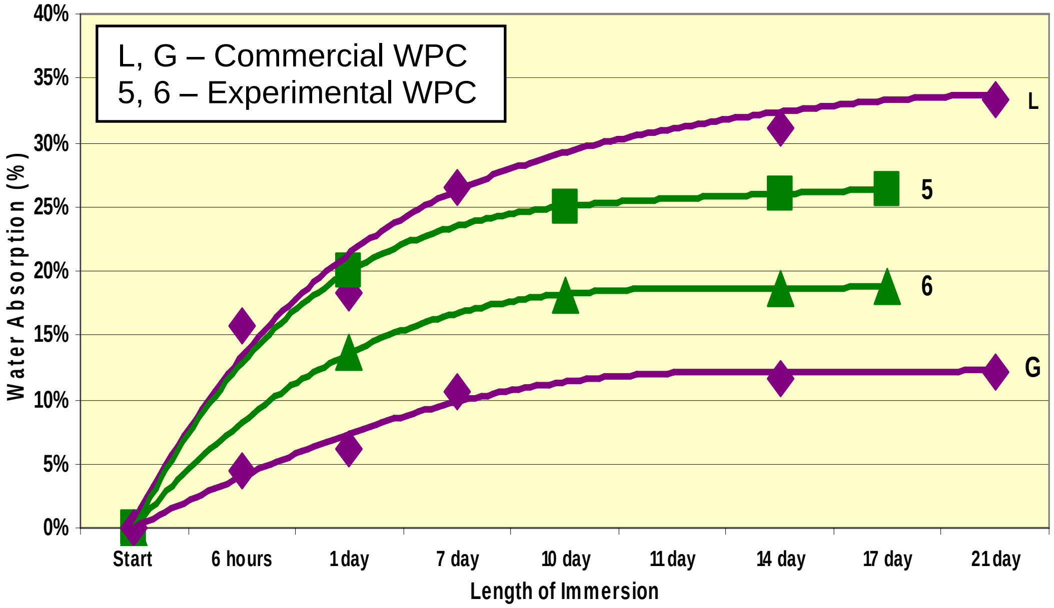


Figure 6. Comparison of kinetics of water absorption at equilibrium for experimental materials and commercial WPC's

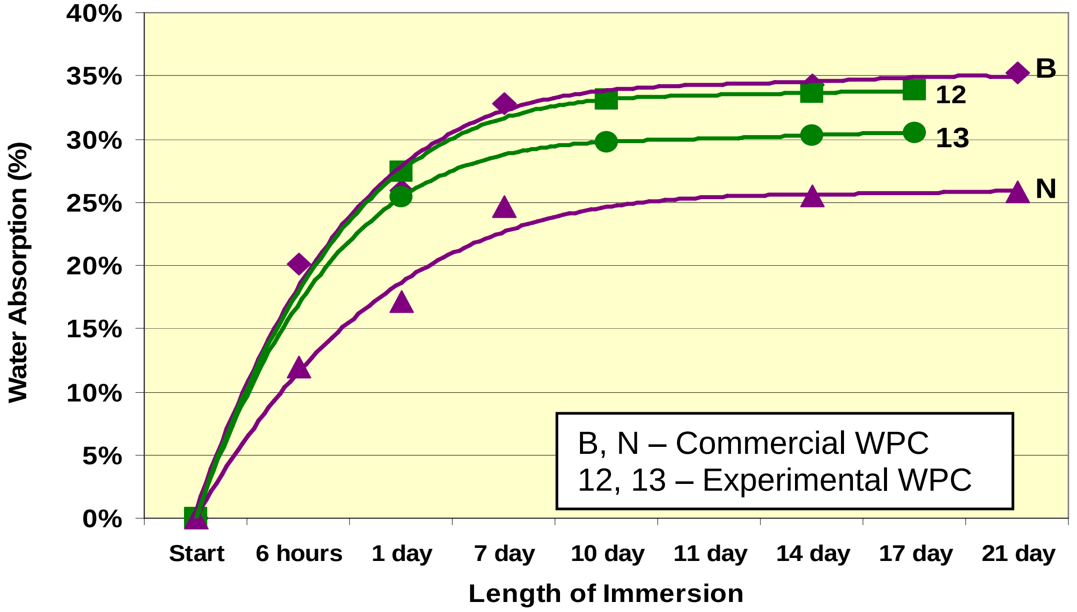


Figure 7. Comparison of kinetics of water absorption at equilibrium for experimental materials and commercial WPC's

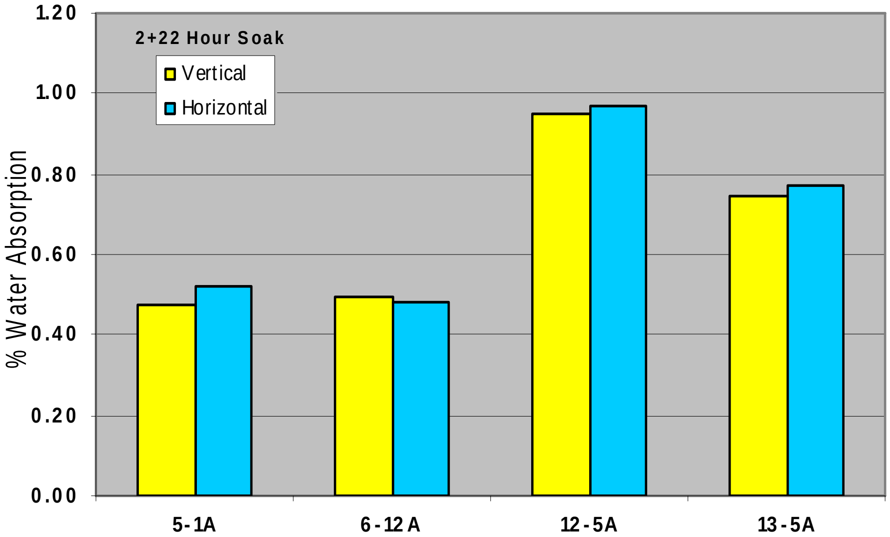
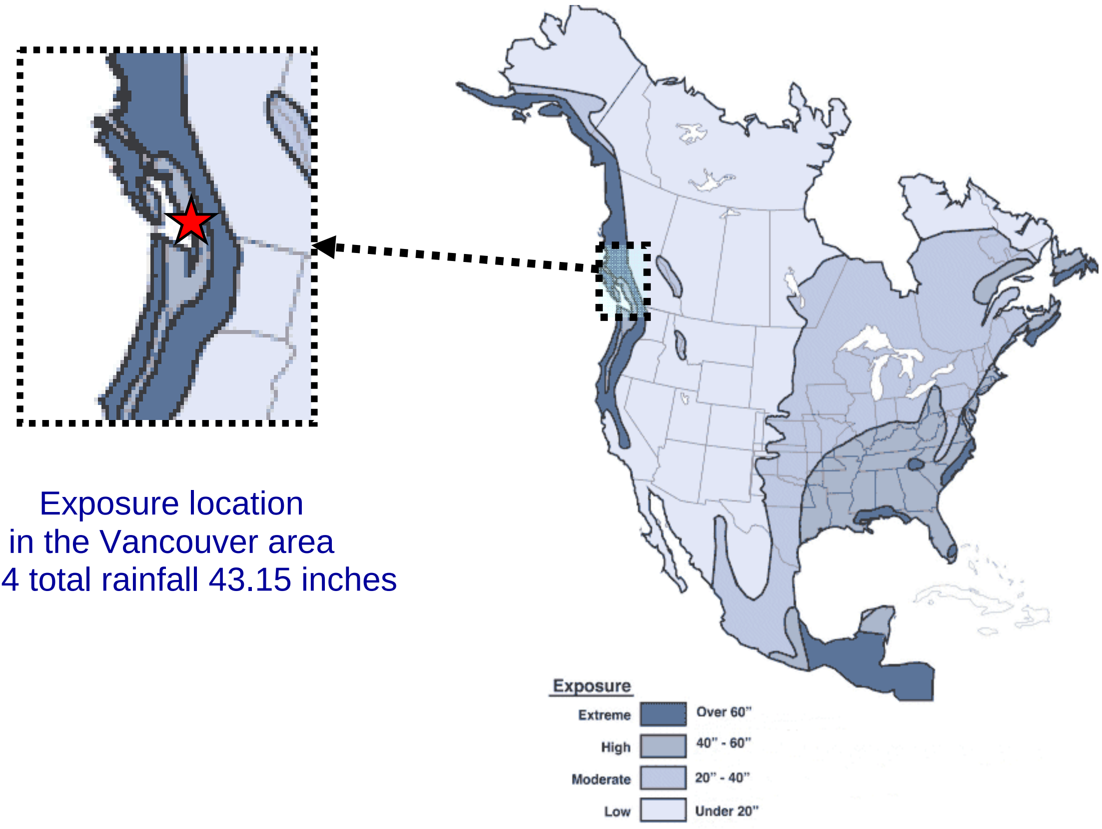


Figure 8. Water absorption tested according to ASTM D-1037



Exposure location
in the Vancouver area
2004 total rainfall 43.15 inches

Figure 9. Annual rainfall map of North America

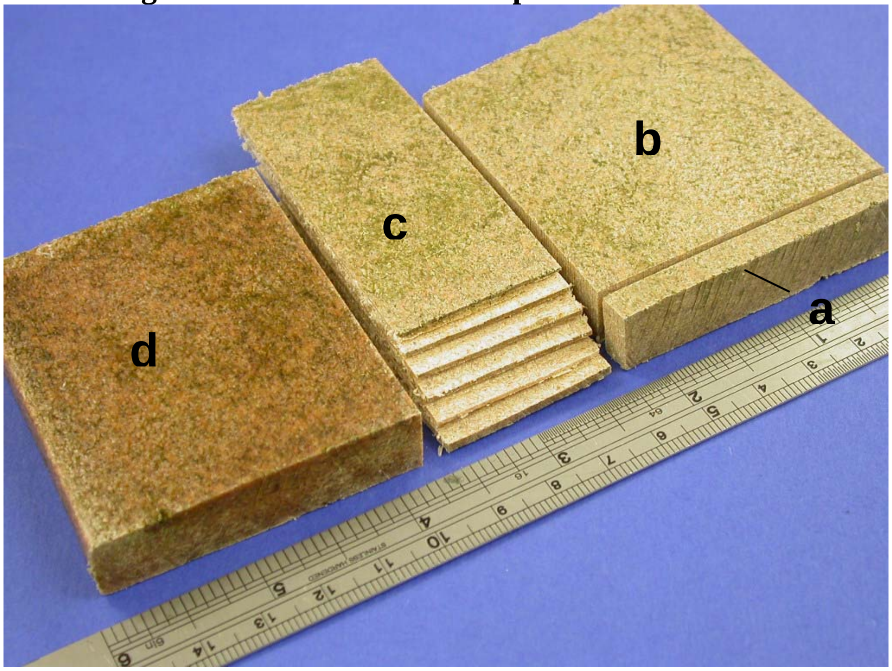


Figure 10a. Cutting of board samples #5 and #6 into specimens

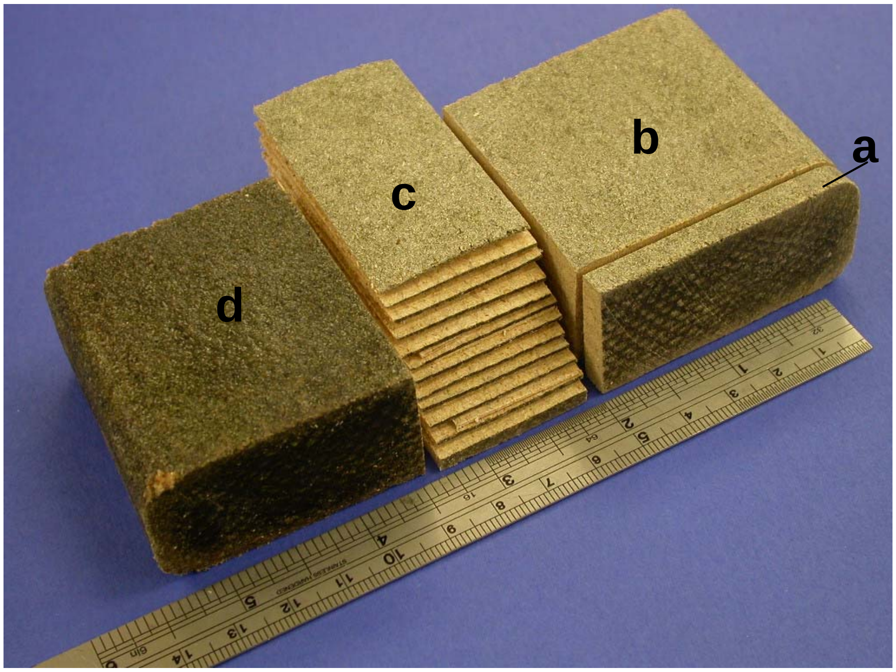
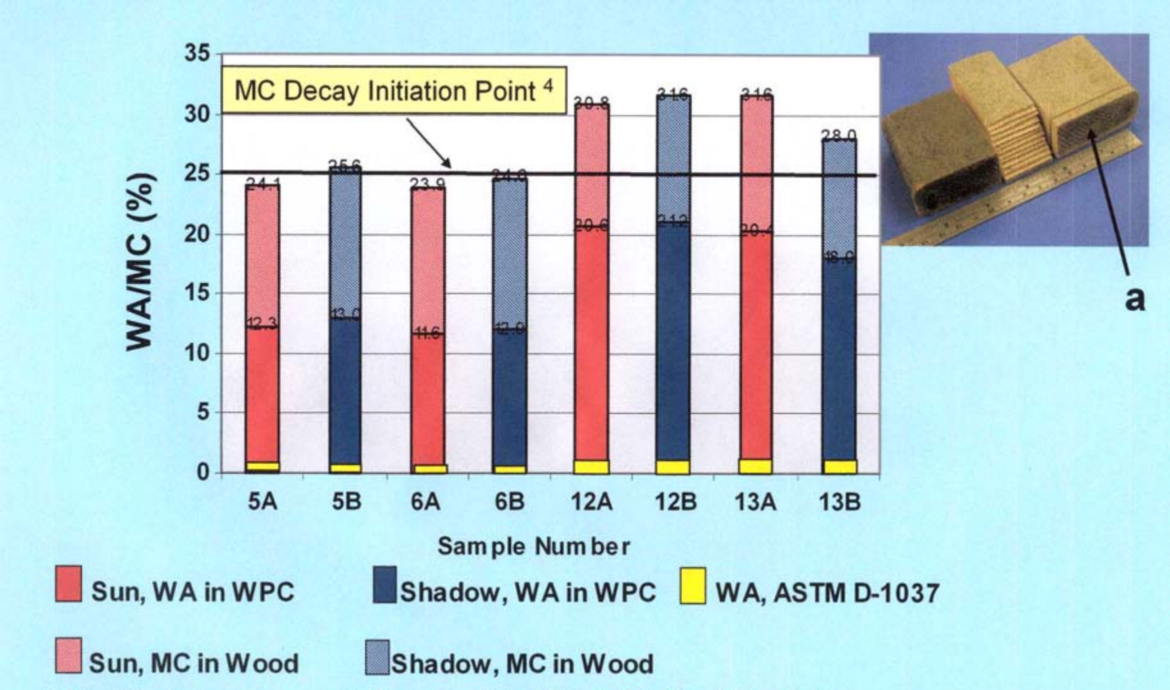
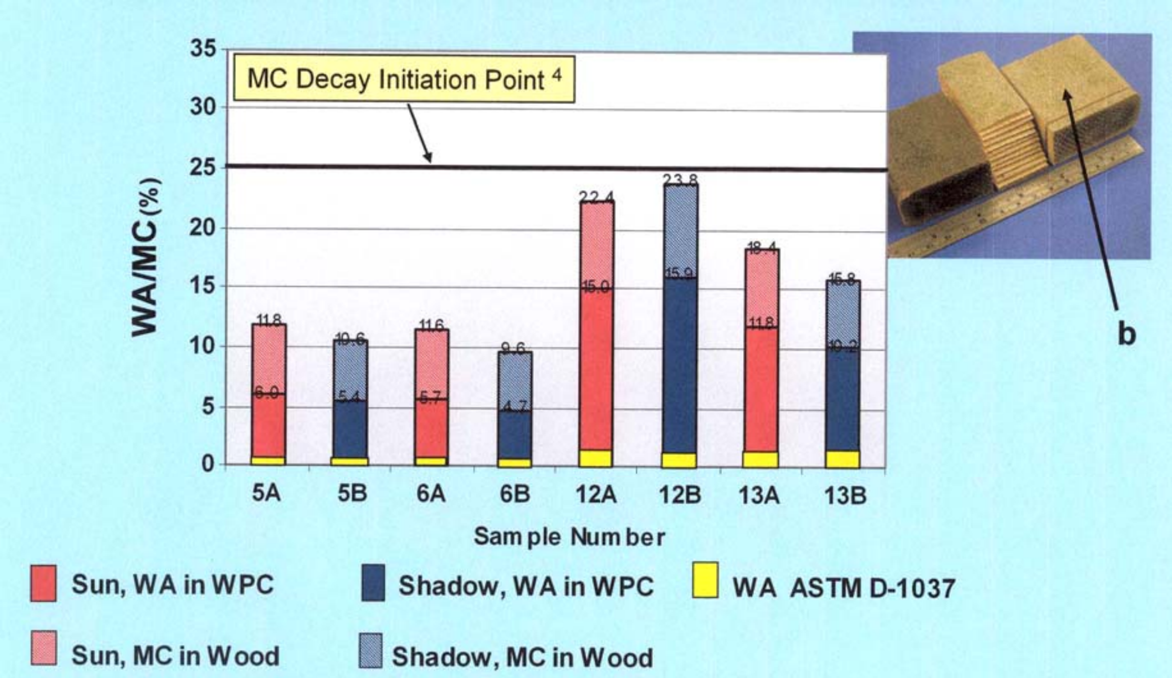


Figure 10b. Cutting of board samples #12 and #13 into specimens



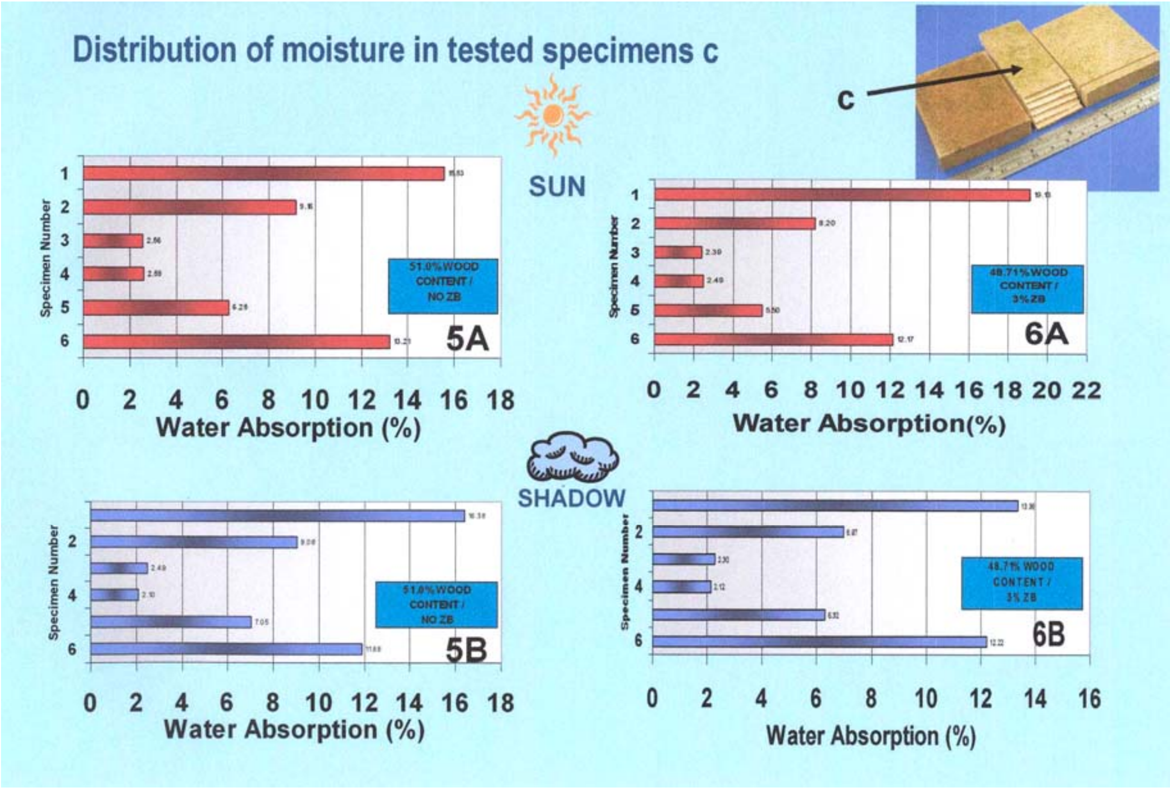
4. Wood Microbiology, Decay and Its Prevention, Robert A. Zabel & Jeffrey J. Morrell, 1992

Figure 11. Water absorption in WPC and moisture content in wood of sections "a"



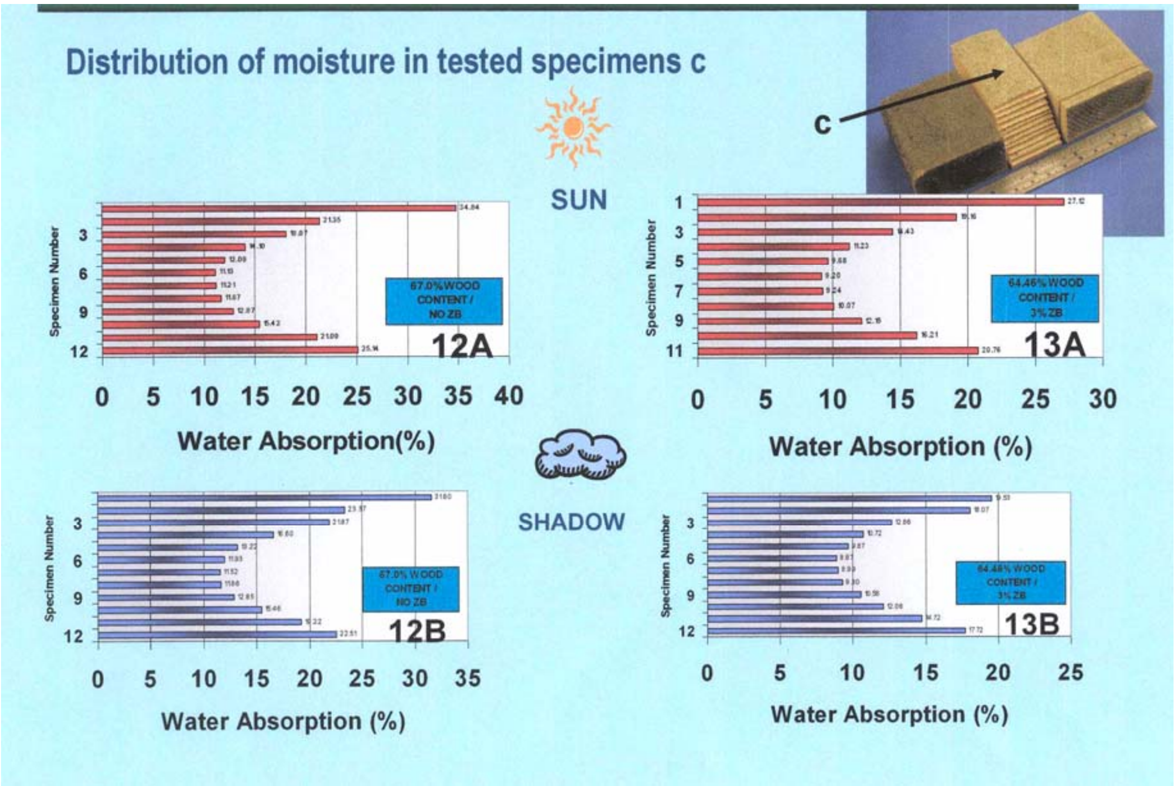
4. Wood Microbiology, Decay and Its Prevention, Robert A. Zabel & Jeffrey J. Morrell, 1992

Figure 12. Water absorption in WPC and moisture content in wood of sections "b"



Distribution of moisture in tested specimens c

Figure 13. Distribution of moisture in tested specimens "c"



Distribution of moisture in tested specimens c

Figure 14. Distribution of moisture in tested specimens "c"

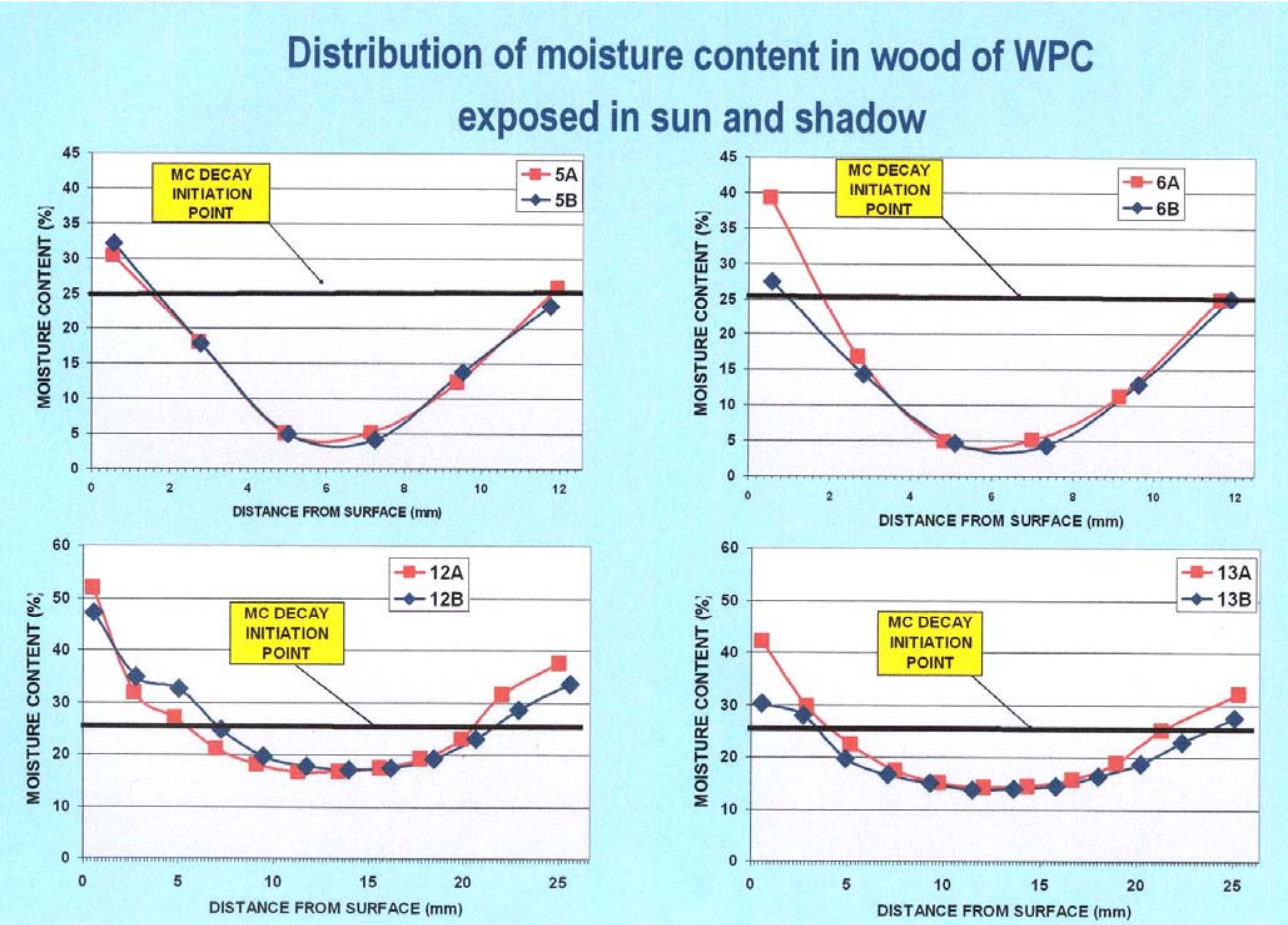


Figure 15. Distribution of moisture content in wood of WPC exposed in sun and shade

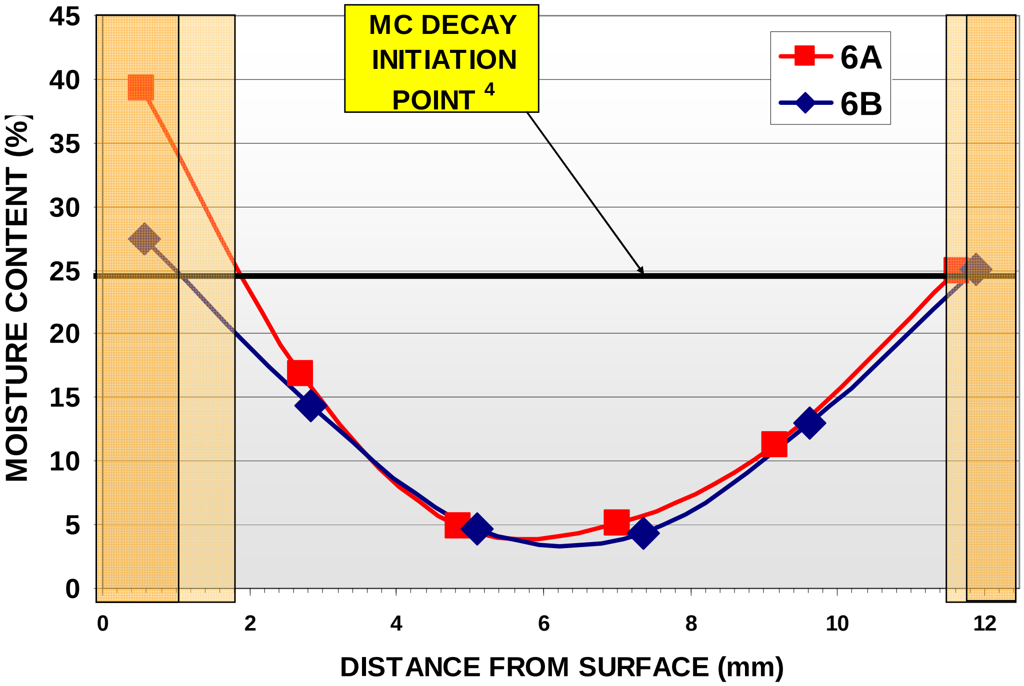


Figure 16. Distribution of moisture content in wood of WPC #6 exposed in sun and shade[4]

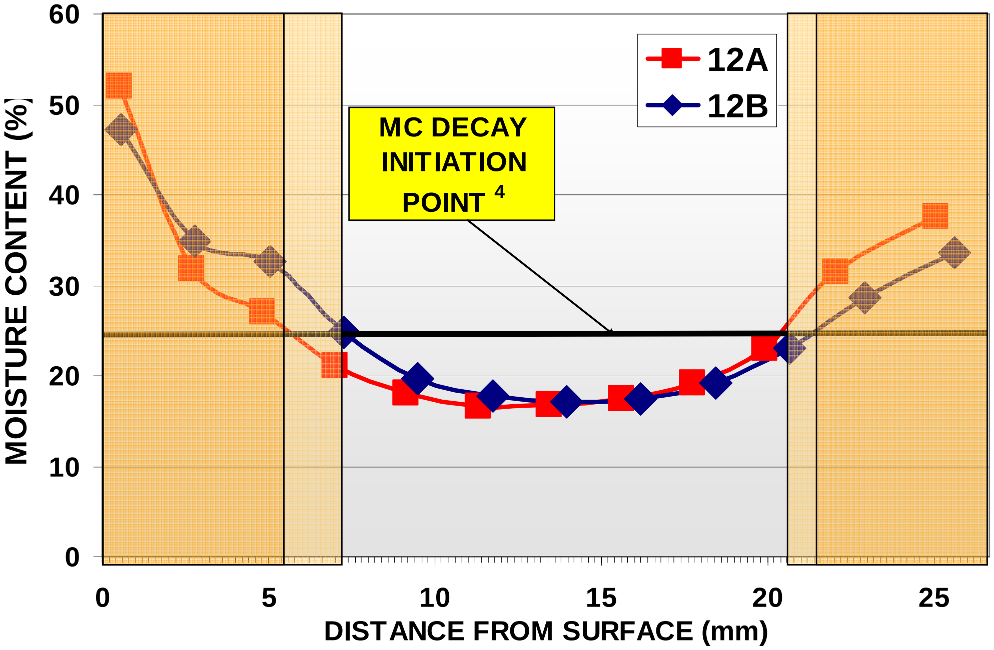


Figure 17. Distribution of moisture content in wood of WPC #12 exposed in sun and shade[4]

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