Water Absorption and Durability of Wood Plastic Composites

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Abstract

Water absorption in wood plastic composites (WPC) is still a controversial but important issue associated with composite durability.

In this paper, water absorption by WPC boards exposed to exterior conditions in Vancouver, BC for a period of up to 6 years is examined. The boards were made using different material formulations that matched the water absorption characteristics of a variety of commercial products available in North America in 2001 – 2002.

The total water absorption and water distribution within the boards was evaluated with the focus on: (1) period of exposure (2) wood content in composite (3) exposure location (sun or shadow) (4) exposure geographical location (5) wood species (6) presence of UV stabilizers (7) presence of zinc borate. The effect of water absorption on biological activity within the WPC boards as well as mechanical properties will be discussed.

It was found that WPC may absorb a significant quantity of water during prolonged exposure to exterior conditions, and the water content in the material seems to increase during the exposure period. This may be associated with the loss of some mechanical properties and the presence of biological activity, including decay fungi.

Introduction

Water seems to be an environmental factor that affects practically all materials exposed to exterior conditions. Water is present everywhere, and even on dry sunny days we may see long periods of heavy dew formation during the night, from early evening to late morning. It is expected that water may also affect performance and properties of Wood Plastic Composites (WPC) including mechanical properties, dimensional stability, warping, and intensification of biological activity.[(1-17)] For this reason water absorption by WPC's has become our prime interest in research on durability of these new materials. It is widely known that there is some controversy surrounding water absorption by wood plastic composites. From one side there is a perception in industry that wood particles are effectively encapsulated in water impervious plastic. While wood may absorb as much as about 25% water to fiber saturation point, polyolefins, including polyethylene which creates a continuous phase of the composite, may absorb only 0.01% moisture after immersion. There are however, signs that contradict these optimistic expectations. There is published data that indicates expansion, warpage, decay, and even the presence of fruiting bodies of decay fungi on the WPC surface in the field. [(4, 10, 12, 13, 14)] This suggests a rather high water presence in the evaluated materials exposed to weather elements.

To shed some light on this controversy, in 2000 Polymer Engineering Company Ltd. undertook research on water absorption by WPC exposed to exterior conditions to gather scientific data in this respect. The experimental samples used in this work simulated the extreme performance of commercial composites. The samples discussed in this paper were exposed in the mild, temperate climate of Vancouver, BC for up to 6 years, and also an evaluation was done for boards exposed later in tropical Hilo, Hawaii. The objective of this paper is to share with you some our results. Certain results have been discussed in previous WPC conferences in Madison[(15)] and in Toronto[(17)] and they may be repeated here for comparison purposes.

Sample Preparation and Exposure

Samples used for evaluation were made in two groups represented by formulations #5 and #12, containing nominal wood content of 50% and 65%. (table 1). Wood content of 50% and 65% are shown for simplicity. Further, samples #5 and #12 were optionally modified by the addition of a UV stabilizer package containing organic UV absorbers, free radicals scavengers and inorganic pigments, and/or zinc borate biocide. Also, for simplicity, the quantity of HDPE is given as 45% and 30% respectively. A correction to accommodate additives was done accordingly without displaying the relatively small changes required in wood and resin contents.

Formulations #5 and #12 were established so that water absorption in equilibrium and kinetics resembled some commercial WPC with extreme performance with respect to water absorption collected in North America and tested for this purpose during the period from 2000 to 2002. (figures 1 and 2)

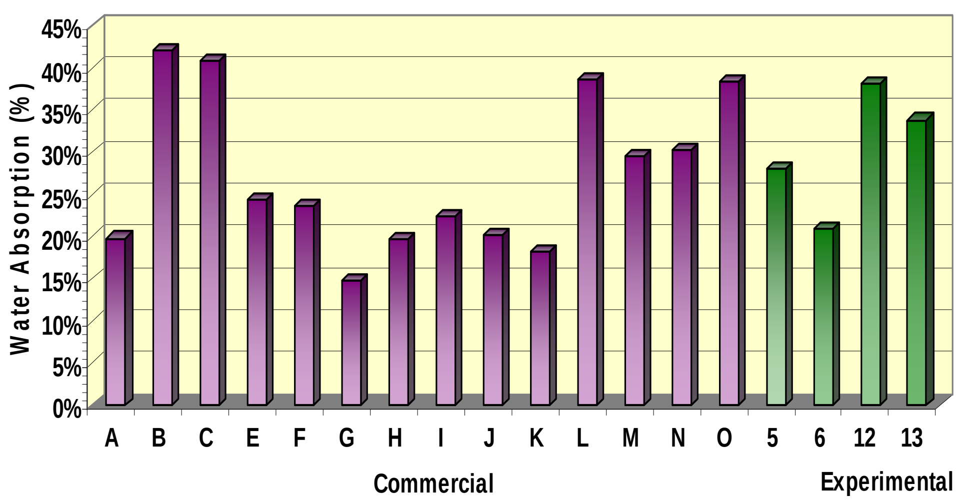

Figure 1. Water absorption in equilibrium for commercial (A-O) and experimental (5, 6, 12, 13) WPC

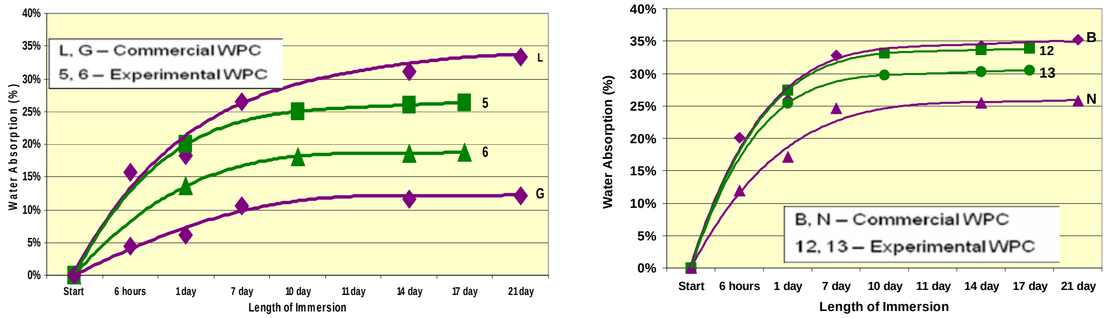

Figure 2. Kinetics of water absorption by selected samples of commercial and experimental WPC

WPC boards used for testing were extruded at Washington State University, Wood Materials and Engineering Laboratory under well controlled conditions using a 55 mm conical counter-rotating Millicron twin screw extruder.

Samples were collected in the field by cutting the end of the exposed board to be cross-sectioned in the laboratory, as shown in figure 3. Care was taken to avoid loss of moisture during material handling.

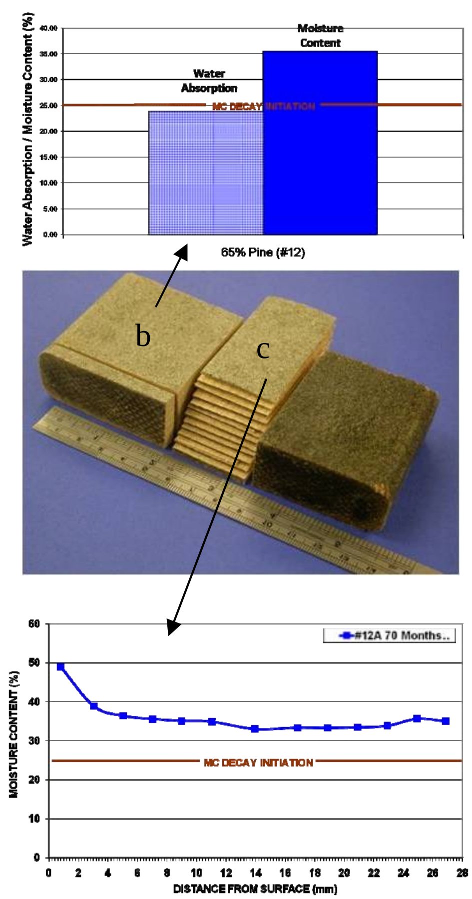

Figure 3. Specimen cutting pattern and presentation of moisture content (MC) and water absorption (WA) in tested samples

By drying section “B”, the average water absorption (WA) for the tested board was established. With the knowledge of the exact wood content in the samples, moisture content (MC) in wood for each specimen was then calculated. This moisture content in wood, as an important factor in composite performance, is shown in bar graphs (figure 3) in this paper. Furthermore, by wafering section “C” of the sample, we were able to find the moisture content distribution within the exposed boards as a function of the board thickness as shown in figure 3. All graphs clearly indicate the moisture content required to initiate decay, which is about 25%.

The tested samples were exposed in sun and shadow in two geographical locations; Vancouver, BC and Hilo, Hawaii. The locations were selected in such a way that they represented a moderate, temperate climate as well as a tropical climate that could be expected to be more aggressive. This aggressiveness with respect to biological activity could be represented by the Scheffer Index: Hilo 331, and Vancouver (Seattle) 49.

Results and discussion

The evaluation of the exposed samples allowed for the collection of information about water absorption, taking into consideration the following factors:

- Period of exposure
- Wood content in composite
- Exposure location (sun and shadow)
- Exposure geographical location
- Wood species
- Presence of UV stabilizers
- Presence of biocide (zinc borate)

As can be seen in figure 4, during the first 4 years moisture content in the tested samples grew rapidly, and later on, between the 4th and 6th years, a plateau seemed to be achieved. However, looking at water distribution within the boards we could see a constant increase in moisture content in the center of the samples, with a decrease in MC near the surface. This could be due to climatic variability prior to sample harvesting. A portion of the specimens exceeded the moisture content required for initiation of decay.

This can also be seen on the majority of the graphs.

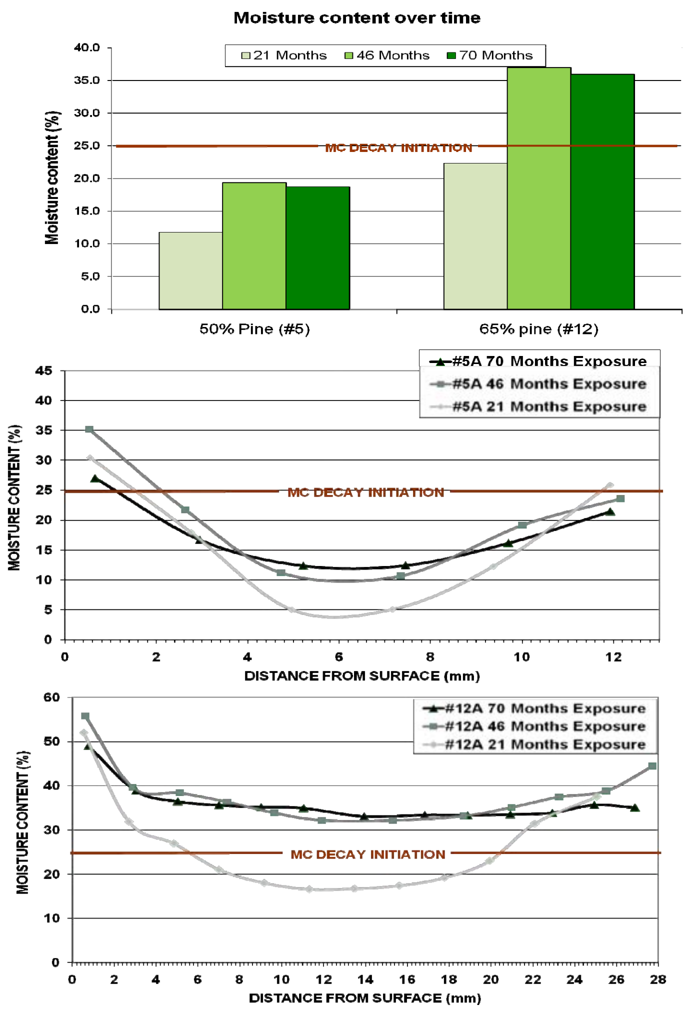

Figure 4. Moisture content and its distribution in samples of WPC exposed in Vancouver, BC (sunny location) for 70 months

Wood content, as expected, seems to be an important factor in water absorption by WPC. Just an increase in pine flour content from about 50 to 65%, caused an increase in moisture content of about 100% regardless of the exposure period (figure 5). There was also a significant difference in moisture distribution within the board, particularly with increased distance from the surface.

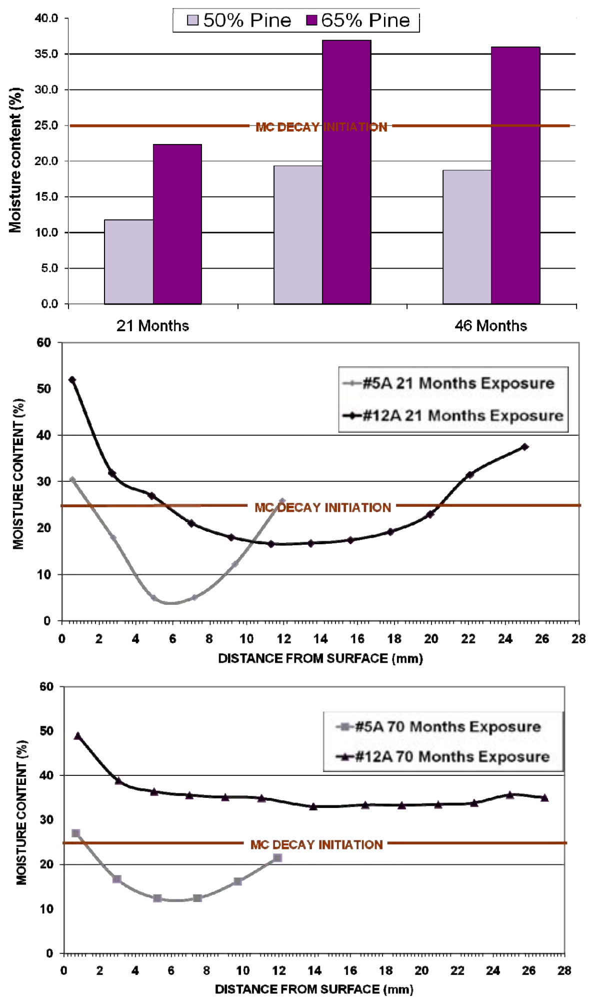

Figure 5. Moisture content and its distribution in samples of WPC containing 50 and 65% wood exposed in Vancouver, BC (sunny location) for 70 months

Surprisingly, there were relatively small differences in moisture content for samples exposed in sun and shadow. Samples exposed in sun seemed to have even higher moisture content, particularly in the case of composites with larger wood content as shown in figure 6.

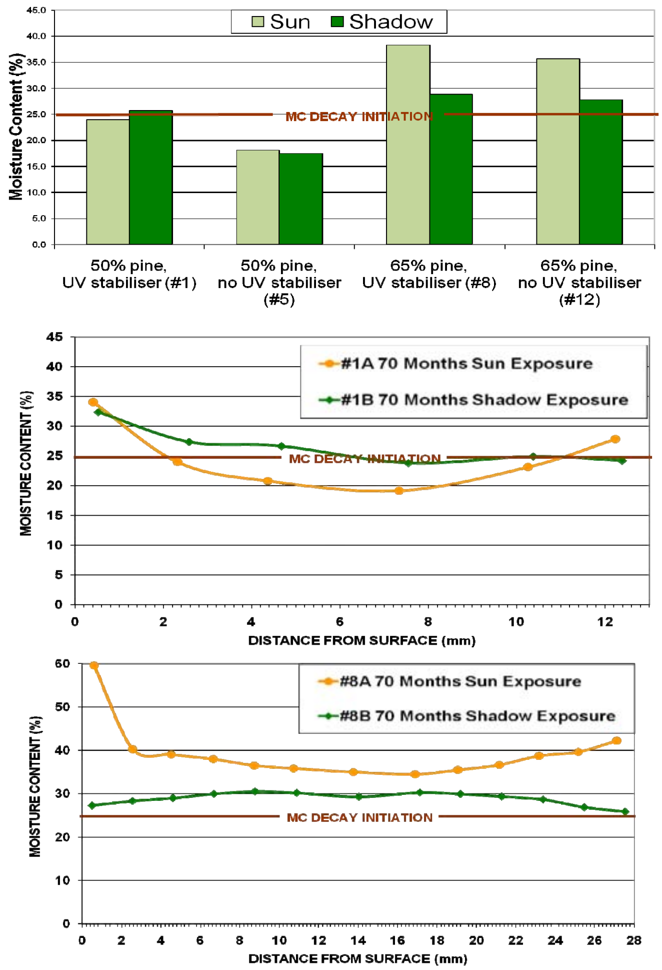

Figure 6. Moisture content and its distribution in samples of WPC exposed in Vancouver, BC in sun and shadow for 70 months

Even more surprising, was the performance of our samples when exposure in a moderate vs. tropical climate was compared. Samples exposed in Vancouver showed significantly higher moisture content than those exposed in hot and very wet Hilo, Hawaii (figure 7). This may be explained by the higher evaporation rate in tropical Hawaii, and the fact that samples were always harvested in Vancouver at the end of the wetter winter months of February or March.

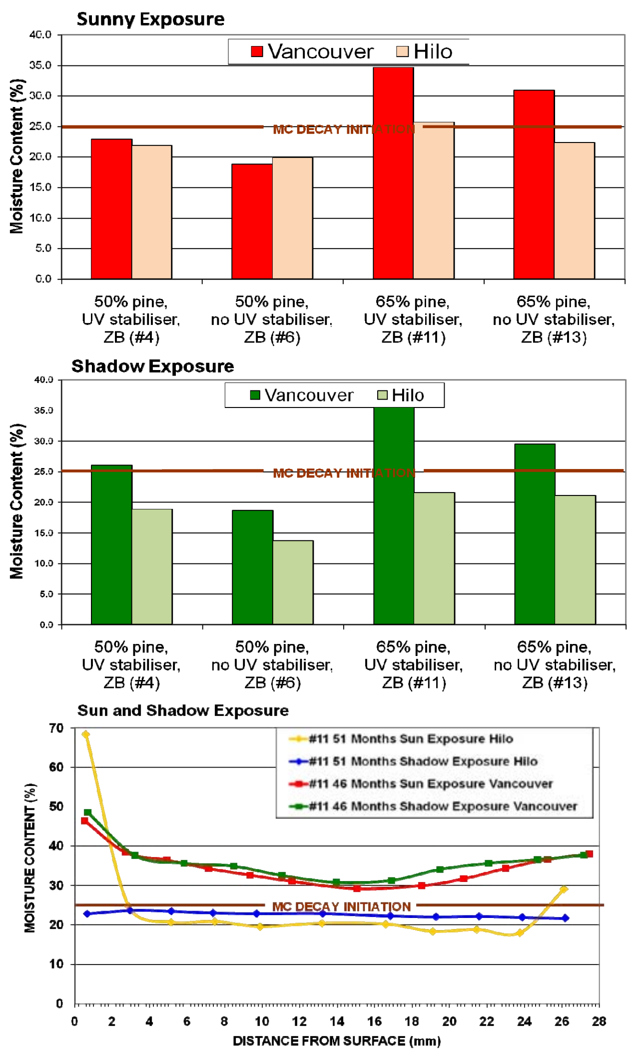

Figure 7. Moisture content and its distribution in samples of WPC exposed for 46 months in Vancouver, BC and 51 months in Hilo, HI

Wood species also seems to influence the water absorption of composites. Samples containing the same quantity of the oak flour always showed lower water absorption in comparison to pine when exposed at the same location (figure 8).

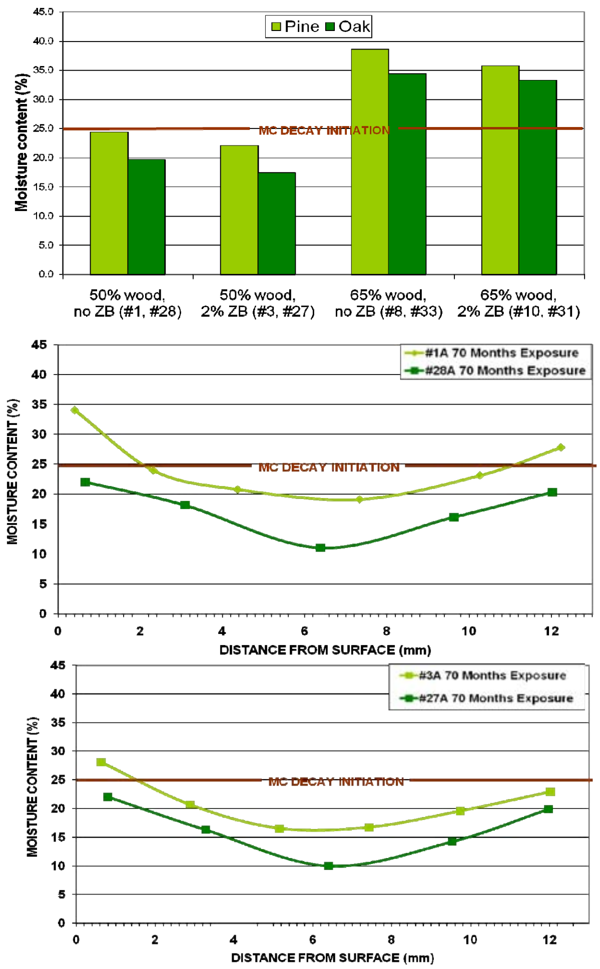

Figure 8. Moisture content and its distribution in samples of WPC made from different wood species (pine or oak) exposed in Vancouver, BC (sunny location) for 70 months

Additives used in our UV stabilizer package seemed to increase the water absorption of the samples as can be seen in figure 9. This applied to both formulations with lower and higher wood content. A large increase in moisture content occurred all across the boards, including the area near the board surface and also in the centre.

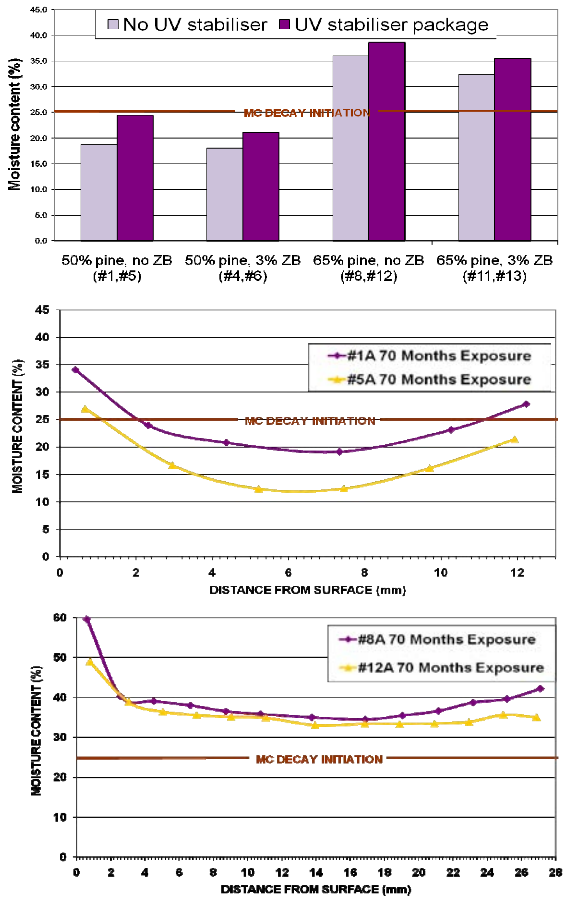

Figure 9. Moisture content and its distribution in samples of WPC, with and without UV stabilizer package, exposed in Vancouver, BC (sunny location) for 70 months

Interesting and unexpected was the addition of zinc borate, known to be effective as a fungicide. The presence of zinc borate seemed to decrease water absorption in practically all of the tested formulations as shown in figure 10.

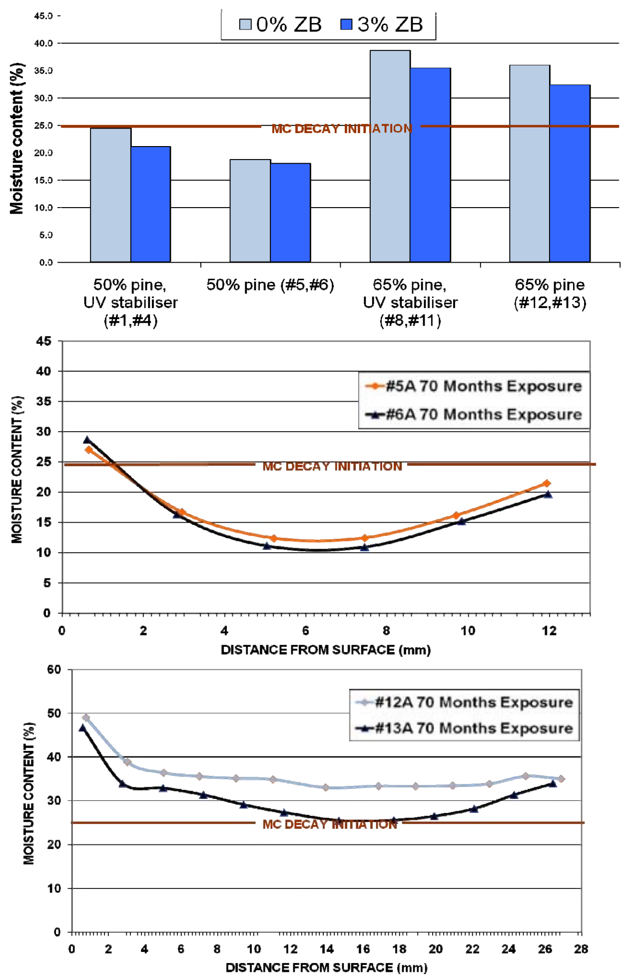

Figure 10. Moisture content and its distribution in samples of WPC, with and without zinc borate, exposed in Vancouver, BC (sunny location) for 70 months

Water absorption affected the durability of the WPC boards. During testing of the flexural properties of boards exposed to exterior conditions in Vancouver for almost six years, we found that the MOE was reduced by about 30%, regardless of sun or shadow exposure (figure 11). Boards exposed in shadow seemed to have a slightly higher MOE but there was only a relatively small variation in MOE between the different exposure conditions. It may be pointed out that the presence of zinc borate once again affected the board performance. While unexposed reference samples containing zinc borate showed lower MOE, all of the exposed samples with zinc borate had statistically significant higher MOE as shown by capital letters on the graph.

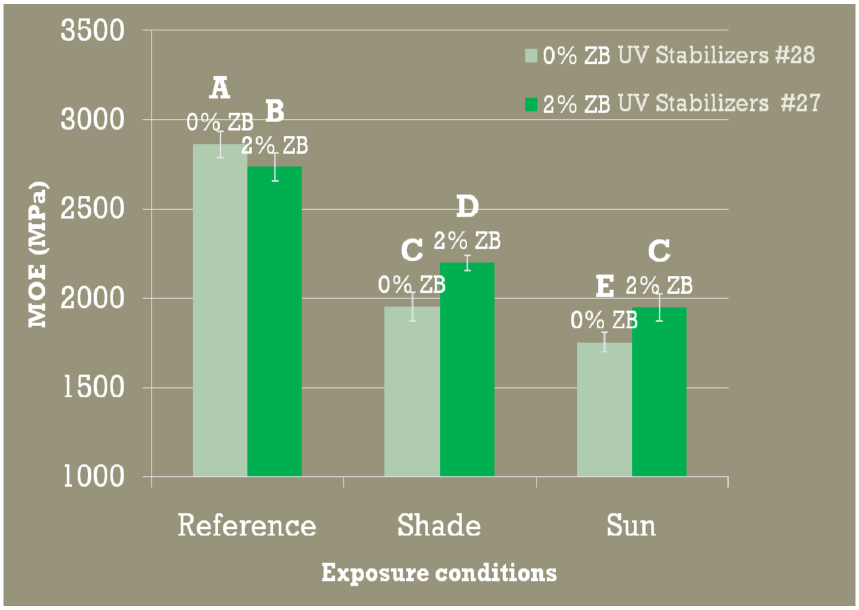

Figure 11. Change in MOE of WPC, with UV stabilizer package, and with and without zinc borate, exposed in sun and shadow in Vancouver, BC for 70 months

Moisture content was also measured in the tested samples directly after removal from the field. In all samples tested, the average MC was well below the decay point. The average MC was initially about 15 to 20 % and decreased during 6 day conditioning (75F, 50% RH) only to about 10 to 15%. Moisture content in the tested samples is shown in figure 12. The reference samples used, which were stored for over six years in a sheltered location that was heated during the winter, had only about 3% MC, even after conditioning. Moisture was typically significantly higher near the sample surface, which likely affected the testing results.

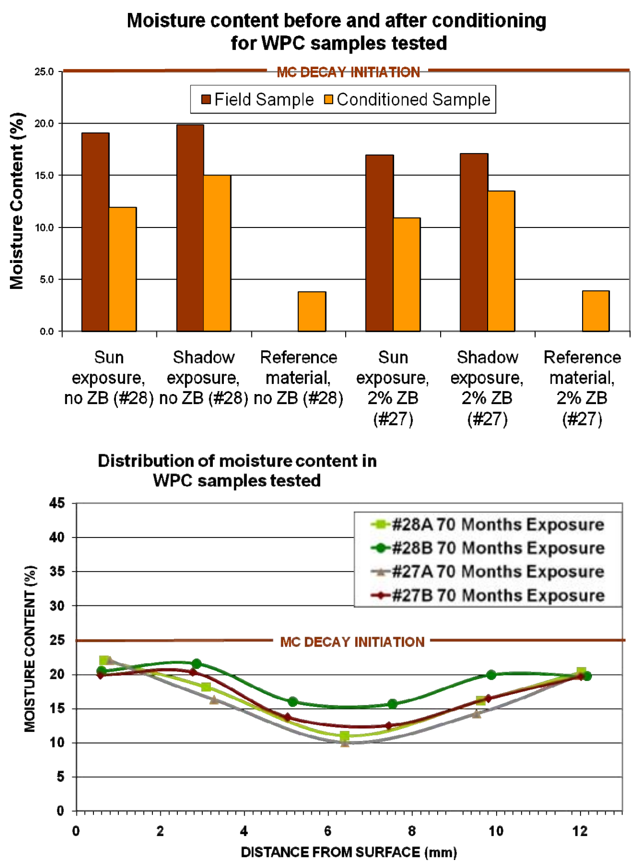

Figure 12. Moisture content and its distribution for samples of WPC exposed in Vancouver, BC for 70 months and tested for mechanical properties (figure 11)

Another consequence of the observed high moisture content, which often exceeded 25% in many samples, seemed to be decay. Decay was found after a thorough inspection of the samples after only 28 months exposure in Hilo. At this point, I would like to repeat what was mentioned earlier, that Hilo is a very aggressive place with respect to decay and has a Scheffer index of about 330, versus only about 50 expected in Vancouver. An initial brief look at the sample did not show anything unusual, only a further careful inspection using a magnifying glass showed some strange surface topography in the centre, and some darker than usual segments of wood. Further examination of the sample, with optical and SEM microscopes, revealed what seemed to be advanced decay with evidence of fungal mycelia in some places (figure 13). It has to be mentioned that the decay region was hard to the touch and was limited to the internal portion of the sample. The external part of the board was undamaged. Samples collected more recently, in Hilo and Vancouver, are still under evaluation in this respect.

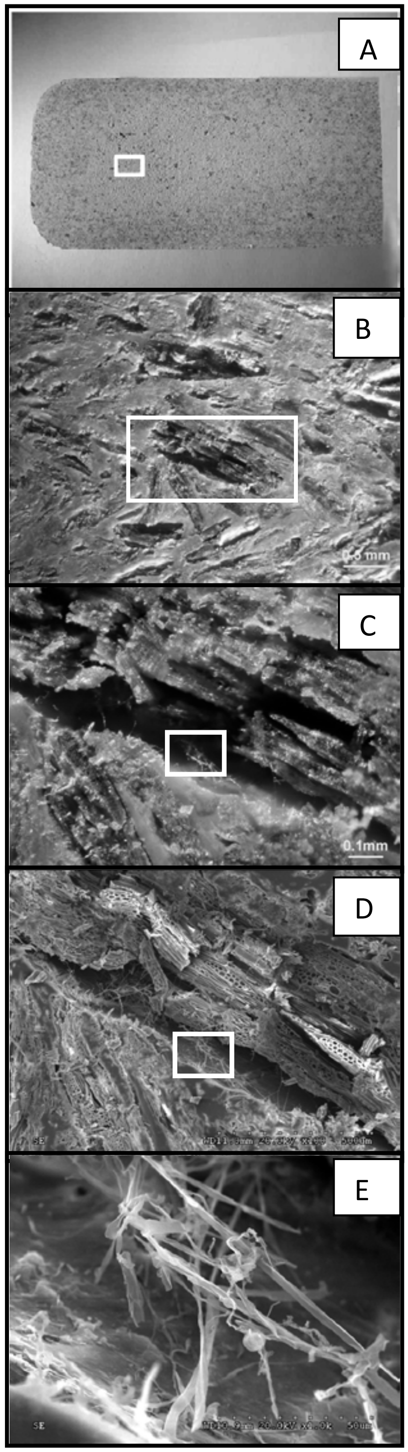

Figure 13. Microscopic inspection of interior of WPC (sample #8) exposed in Hilo, HI (sunny location) for 28 months (A) digital photomicrography (B and C) optical microscopy (D and E) SEM microscopy. Please note the decayed wood in the board centre, and fungi mycelium filling the cavity with remains of the wood. Figures C and D show the identical sample area using optical microscopy and SEM respectively.

Conclusions

- Wood Plastic Composites (WPC) boards progressively absorb a significant quantity of water during exterior exposure. Moisture content distribution in the board cross-sections have a characteristic U-shape, frequently exceeding the concentration required for decay initiation.
- Water absorption is a long process, and even after 6 years exposure in a moderate climate, equilibrium has likely not been reached
- A major factor in water absorption by WPC was the ratio of wood to plastic binder; with the increase of wood content, moisture content progresses very quickly
- Another factor in water absorption is the material composition of WPC. Certain additives may significantly increase or decrease water absorption (for example zinc borate decreased water absorption in the tested formulations)
- Climate and sample location (sun or shadow) may not be a major factor in water absorption
- It was shown that water absorption in exterior exposure most likely influenced MOE of selected samples (decrease ~30%). It was observed that some experimental samples with a significant amount of water absorption underwent decay in exterior exposure.

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