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Field Study of Long-Term Durability of Wood Plastic Composites

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Abstract

Long term durability of wood plastic composites (WPC) exposed to an exterior environment is still a subject that has many unanswered questions. In this presentation, the effect of water absorption, solar radiation, and the processes associated with them, for experimental WPC exposed in the temperate climate of Vancouver, BC, Canada and the tropics of Hilo, Hawaii will be discussed.

Experimental composites that were tested in the field matched the water absorption of some commercial materials. Total water absorption and distribution of water within the composite boards was evaluated and the effect of water absorption on biological activity within the WPC boards was monitored. Ultraviolet degradation was also evaluated for the exposed samples using microscopy and FTIR/ Raman spectroscopy.

It was found that water absorption in WPC seemed to be an important factor that influenced the long-term durability of materials exposed to exterior conditions. Certain composite formulations were found to be prone to biological activity, including decay fungi. Ultraviolet degradation was identified as a mainly surface phenomenon in exposed samples.

Introduction

Wood Plastic Composites (WPC), like all materials employed by humans, undergo changes when exposed to exterior conditions. Knowledge of the processes that WPC undergo during exposure to weather elements is important to allow these new materials to be designed to last. For this reason, our laboratory has been conducting research on aging of WPC exposed to exterior conditions since the year 2000. There are three elements of weather which may significantly influence the performance WPC: water, ultraviolet light and heat associated with the visible and IR spectrum of solar radiation. In this paper I would like to focus mainly on water absorption in WPC and briefly discuss the effect of UV radiation as these are still controversial but important factors that affect composite durability. Water is present everywhere on Earth and even during dry sunny weather we may see long periods of dew formation from early evening to late morning of the following day. It was found by researchers that water absorption by WPC may influence the composites' mechanical properties, dimensional stability, freeze- thaw resistance and intensify biological activity [1-5]. Water absorption by WPC is at the center of some controversy. On one side there is the perception within the industry that wood particles are permanently encapsulated and sealed in plastic impervious to water (figure 1). There are however, signs that some composites under certain conditions may absorb a significant quantity of water, resulting in material swelling and warping [6-8]. There have also been reported signs of composite wood decay and even the presence of decay fungi fruiting bodies which require significant quantities of moisture [3,6].

Also, as mentioned above, solar radiation is a known factor that impacts the properties of exposed materials, including WPC [9-11]. An easily visible effect of UV light interaction with WPC in frequently a distinct change in surface colour.

In this paper, I would like to share with you some results of the evaluation of water absorption and the effect of ultraviolet exposure of WPC, primarily at sunny locations at two sites in different climatic zones.

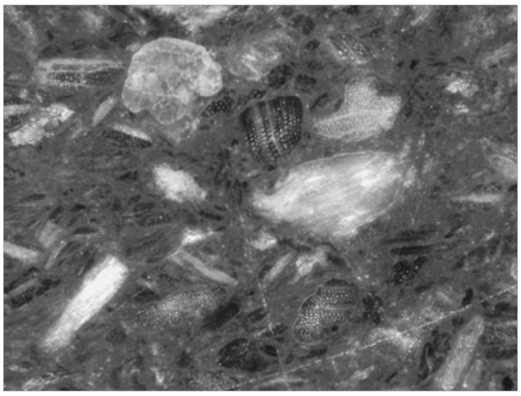


Figure 1. Optical microscopy of WPC cross-section. Visible wood particles encapsulated in resin.

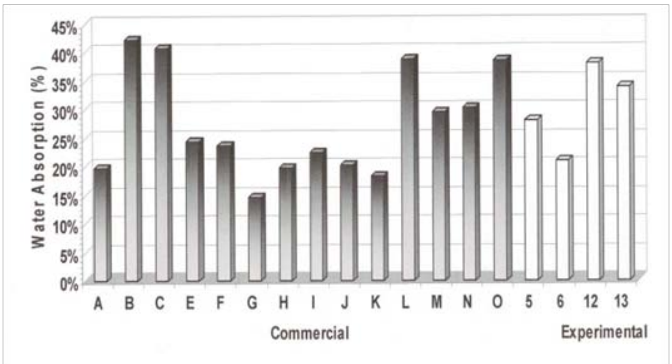


Figure 2. Water absorption in equilibrium for commercial (A-O) and experimental (5, 6, 12, 13) WPC

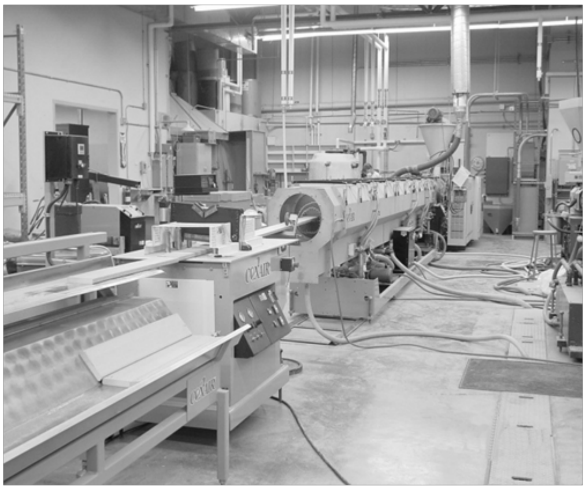


Figure 3. WSU line with 55 mm conical counter-rotating Millicron twin screw extruder

Samples preparation and testing

The basic wood plastic composites used for the experiments (# 5 and #12) were designed in such a way that they matched the water absorption (WA) characteristics and moisture content (MC) of many commercial WPC products available on the North American market between 2000 to 2002 (figure 2). All extruded samples were the size of typical decking board with a width of 15 cm and thickness of 25 or 12.5 mm. They were made in two groups; one contained nominal wood content of about 50% and the second 65%. with wood particles that passed through a 20 mesh screen. The discussed samples were made from pine. A UV stabiliser with metal oxide pigments, organic UV absorber and hindered amine light stabilizer was added to selected formulations. Some samples contained zinc borate (Boroguard ZB®) for protection against potential decay fungi attack. Ingredients used in the abovementioned WPC samples extrusion are summarized in table 1. Table 1 also includes board cross-sections. Sample manufacturing was carried out at Washington State University Wood Materials and Engineering Laboratory under well controlled conditions in a pilot plant scale production. Our line was equipped with a 55 mm conical counter-rotating Millicron twin screw extruder, water cooling system and take off with automatic saw (figure 3).

Ingredients	Formulation ID#											
	1	**3**	**4**	**5**	**6**	**8**	**10**	**11**	**12**	**13**	**31**	**33**
Wood - Pine	50	50	50	50	50	65	65	65	65	65		
Wood - Oak											65	65
HDPE	45	45	45	45	45	30	30	30	30	30	30	30
Talc %	1	1	1	1	1	1	1	1	1	1	1	1
Lubricants %	3	3	3	3	3	3	3	3	3	3	3	3
UV Stabilizers	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	No	Yes	Yes
Zinc Borate %	0	2	3	0	3	0	2	3	0	3	0	0
Board Cross-section (inches)	6x½	6x½	6x½	6x½	6x½	6x1	6x1	6x1	6x1	6x1	6x1	6x1

Table 1. Composition of experimental WPC used in experiments

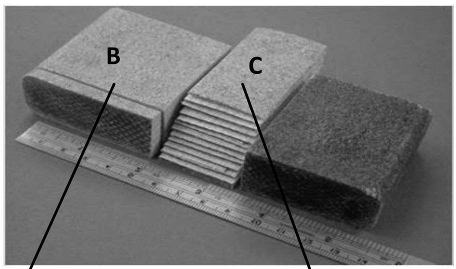
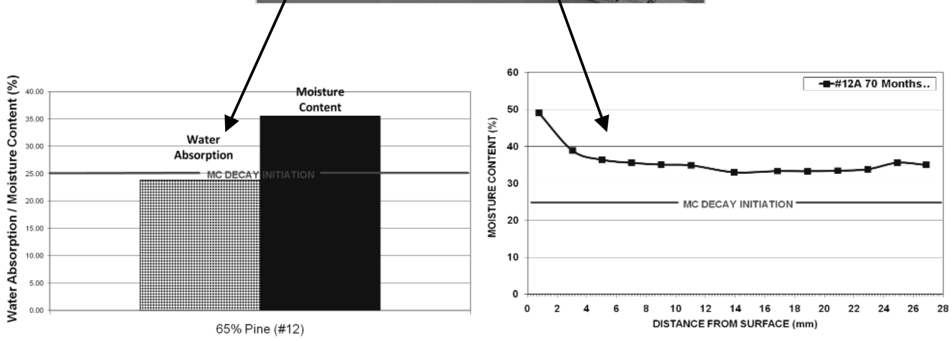


Figure 4. Specimen cutting pattern and presentation of moisture content (MC) and water absorption (WA) in tested samples



These WPC boards were exposed horizontally for up to 70 months at two sites. One site was near Vancouver, BC with moderate temperatures and a relatively wet climate (average annual precipitation about 2000 mm). Another site was selected in Hilo (HI) due to its aggressive wet tropical conditions (annual precipitation 3,200 - 5,100 mm). It has to be mentioned that many places in North America have been assigned the Scheffer index which indicates wood decay hazard calculated from climatic data. The higher the Scheffer index, the more aggressive the climate and biological activity associated with it. The Scheffer index for the selected locations is shown in table 2. It may vary from as low as 10 in very dry places in Nevada to 40-50 around the Great Lakes, 50-60 along the coast of the Pacific Northwest where our Vancouver site was located, 90-150 in Florida, to as high as 330-350 in Hilo. This means that our site in Hilo was one of the most environmentally aggressive places on Earth. Exposed samples were periodically inspected and removed from the sites by cutting the ends of the boards and cross-sectioning them in the laboratory as shown in figure 4. Care was taken to avoid loss of moisture during material handling. By drying section B, the average of the water absorption (WA) for the tested board was established. With the knowledge of the exact wood content in the samples, the moisture content (MC) in wood was then calculated. Furthermore, by wafering section C we were able to find the moisture content distribution of the exposed board within a distance from the surface. Dry samples were additionally examined under optical and scanning electron microscope for signs of decay. Density was measured for selected samples. The surface or cross-section of the selected specimens was also evaluated for photo-oxidation by FTIR or Raman spectroscopy and selected data compared to laboratory weathering in a QUV chamber.

Table 2. The Scheffer index

Location	Scheffer Index*
Vancouver, B.C.	~50
Prairie Provinces	~35
Denver, CO	~35
Phoenix, AZ	~7
Wilmington, NC	~80
Miami, FL	~120
Hilo, HI	~350

*Tool for quantifying climatic exposure conditions and predicting wood above-ground performance – based on Average Annual Temperature and the # days/month with measurable precipitation

Results and discussion

Figure 5 shows moisture content and its distribution in samples of WPC exposed in Vancouver BC in a sunny location for a period up to 70 months. As can be seen, during the first four 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 the moisture content in the centre of the boards with some decrease in MC near the surface. Surface variation could be a result of climatic variability prior to sample harvesting. The minimum moisture content (25%) required for decay initiation was exceeded in a significant number of the specimens which can be seen on these and the majority of the other graphs in this paper.

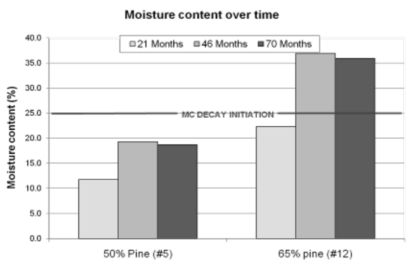
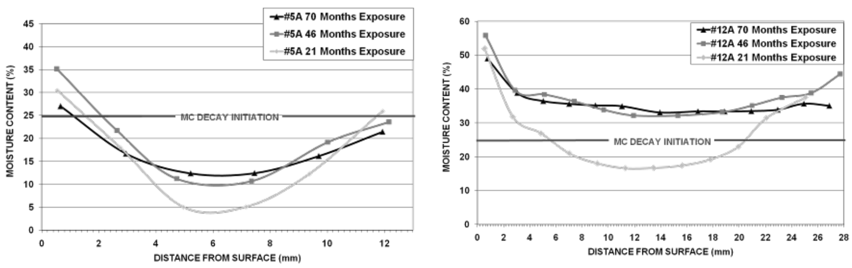


Figure 5. Moisture content and its distribution in samples of WPC exposed in Vancouver, BC (sunny location) for 70 months



Wood content, as expected, seems to be an important factor in the increase of water absorption by WPC as shown in figure 6. Just an increase in wood content from about 50 to 65% caused an increase in moisture content of about 100% regardless of the exposure period. There was a significant difference in MC distribution within the boards caused by both wood content and board thickness variability.

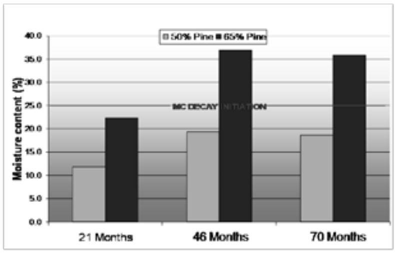
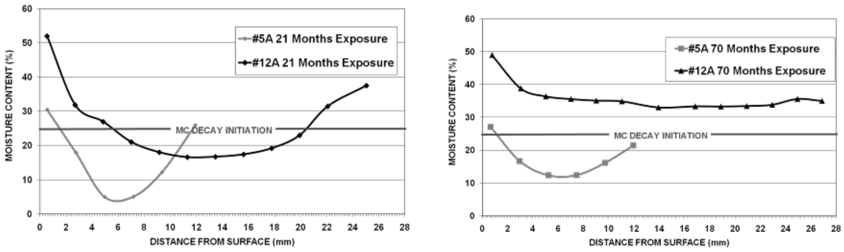
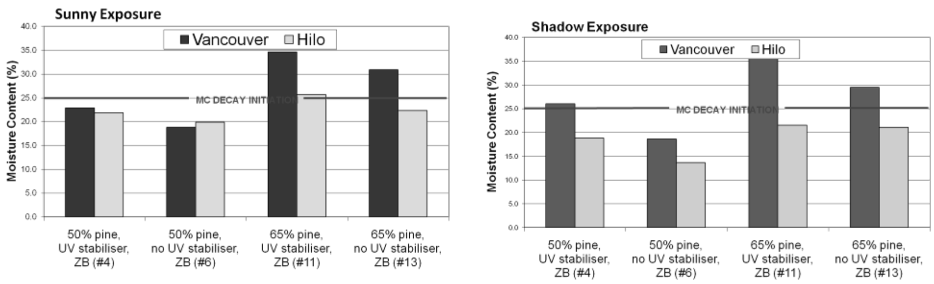


Figure 6. Moisture content and its distribution in samples of WPC containing 50 and 65% wood exposed in Vancouver, BC (sunny location) for 70 months



Also, water absorption seems to be dependant on the wood species used and oak seems to absorb less in comparison to pine. Very surprising were the relatively small differences in moisture content between samples exposed in Vancouver and Hilo as shown in figure 7. Samples exposed in Vancouver showed higher MC that those exposed in warm and very wet Hilo. This may be explained by the higher evaporation rate under the tropical sun and the fact that samples in Vancouver were always harvested at the end of the wet winter months.



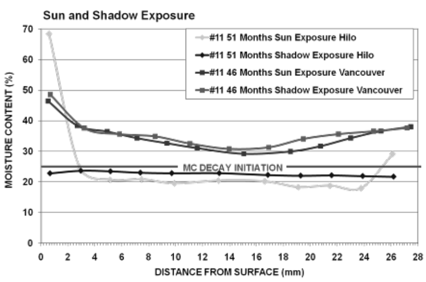


Figure 7. Moisture content and its distribution in samples of WPC exposed in for 46 months in Vancouver, BC and 51 months in Hilo, HI

Additives used in our UV stabiliser package seemed to increase the water absorption and MC of the samples as can be seen in figure 8. This applied to both the formulations with higher and lower wood content. A large increase in MC occurred all across the board area, near the board surface as well as the centre.

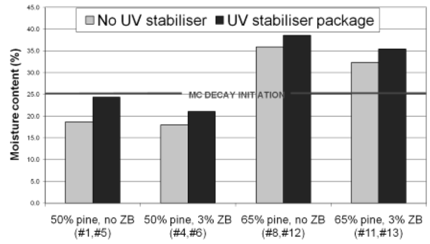
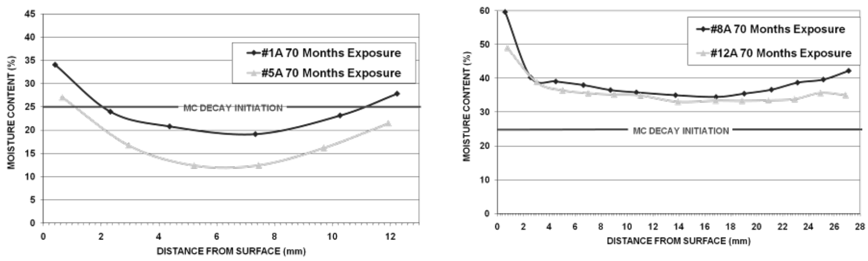


Figure 8. Moisture content and its distribution in samples of WPC, with and without UV stabilizer package, exposed in Vancouver, BC (sunny location) for 70 months



Something interesting and unexpected was the incorporation of zinc borate into the WPC formulation. Zinc Borate is known to be an effective biocide. The presence of zinc borate in the WPC composition seemed to decrease water absorption in practically all of the tested formulations as shown in figure 9. Exposed samples also showed a permanent increase in dimensions and a decrease in density as is shown in figure 10 for board #8 as an example. The large decrease in density in board #8 seen in the tropical climate of Hilo was most likely associated with decay as is discussed further.

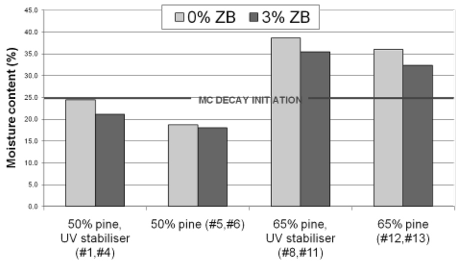
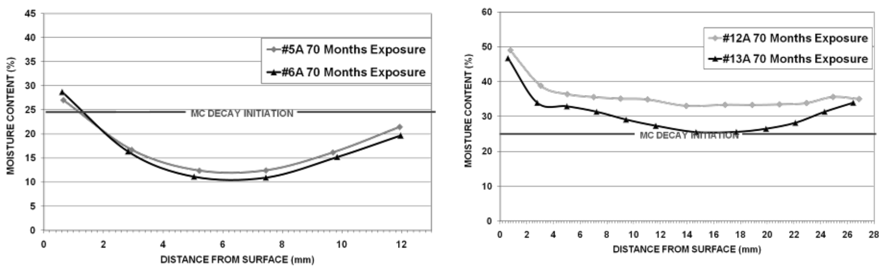


Figure 9. Moisture content and its distribution in samples of WPC, with and without zinc borate, exposed in Vancouver, BC (sunny location) for 70 months



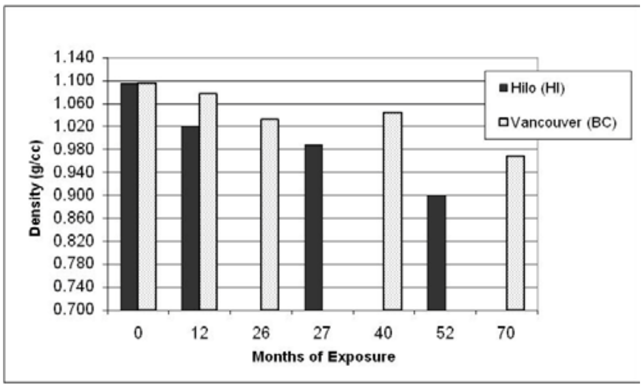


Figure 10. Density of WPC (#8) exposed in different climatic zones

One of the consequences of high moisture content, that exceeded 25% in many of the tested samples, seemed to be the development of wood decay. After a thorough inspection of the samples, the initial signs of decay were found in one of the boards after only 28 months exposure in Hilo. No decay was found in the corresponding samples containing zinc borate (Borogard ZB®). Also, no decay was found during a brief inspection of the samples exposed in Vancouver. Taking the Scheffer index under consideration and the acceleration of biological activity in Hilo, this was not surprising because the site in Hilo is approximately 6.5 times more biologically active than Vancouver. Also, the form of decay observed was interesting. An initial brief look at the sample did not show anything unusual. Only a further careful inspection of the board cross-section using a magnifying glass showed some strange surface topography in the centre, and some darker than usual wood particles. 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 11). It has to be mentioned that the decay region was hard to the touch and was initially limited to the internal portion of the sample. The external part of the board was undamaged.

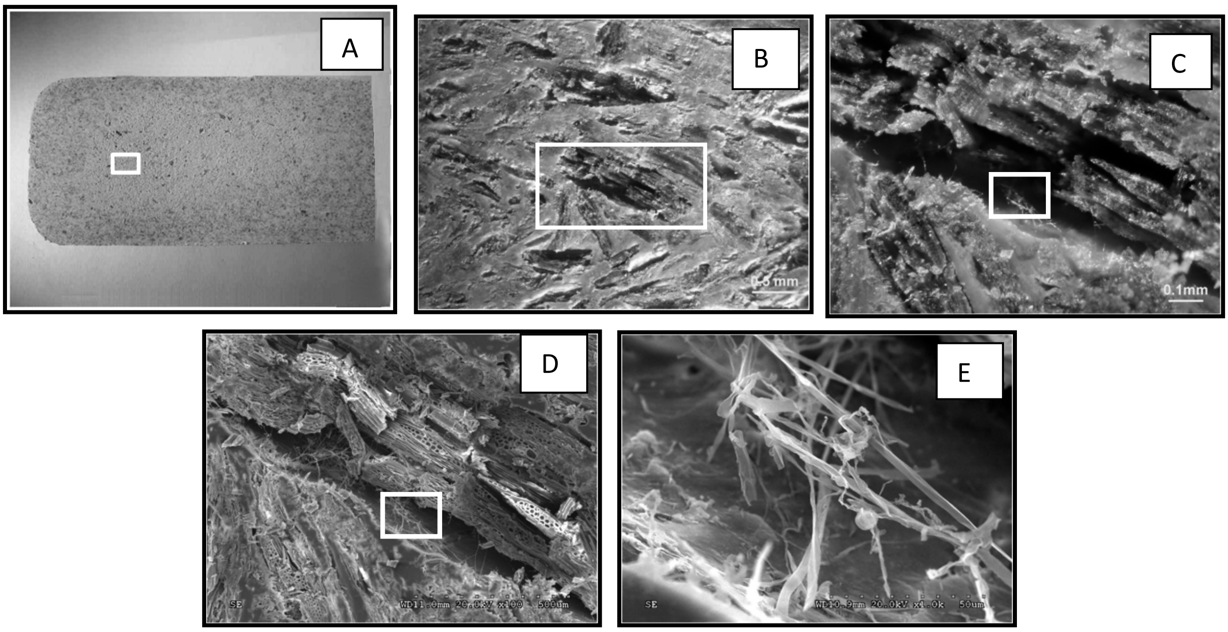


Figure 11. Microscopic inspection of interior of WPC (sample #8) exposed in Hilo, HI (sunny location) for 28 months (A) digital photomicrography (B and C) optical microscopy (D and E) SEM microscopy. Please note the decayed wood in the board centre, and fungi mycelium filling the cavity with remains of the wood. Figures C and D show the identical sample area using optical microscopy and SEM respectively.

Water is only one of weather elements that affects WPC longevity. The UV portion of the Solar radiation spectrum is another. The effect of UV radiation on polyolefins, particularly in polyethylene based WPC, can be identified and measured from the intensity of certain absorption bands created by oxidation in the IR spectrum of the material. This can be expressed as a carbonyl index which is shown in figure 12. By measuring the carbonyl index for polyethylene compounded without wood and the same polyethylene recovered from WPC it was found that oxidation associated with UV degradation of the polyethylene is significantly higher in resin from WPC (figure 13). This means that the presence of wood most likely accelerates the UV degradation of plastics. This acceleration depends on the species of wood, and pine seems to be more aggressive than oak in this respect.

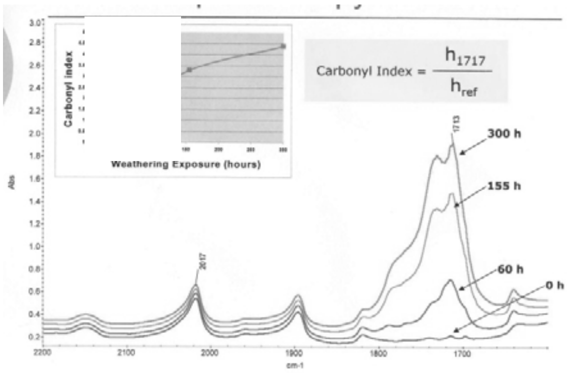


Figure 12. Carbonyl index measurement for oxidized polyethylene

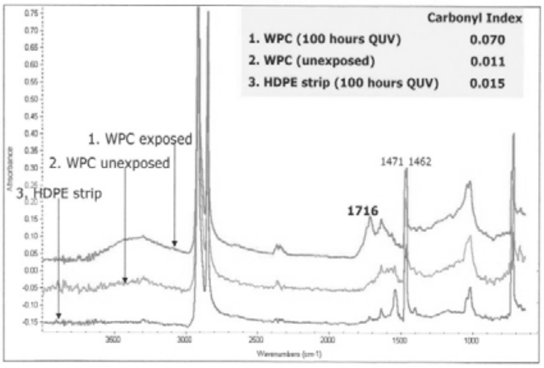


Figure 13. FTIR spectra of HDPE and WPC – unexposed and exposed to 100h QUV accelerated weathering

An interesting comparison can be found between the carbonyl index and WPC surface degradation after exterior exposure. The data presented in figure 14 was obtained for samples containing 50% wood (#1, 4 and 5) exposed in Vancouver for a period of up to 36 months. There is evidence of progressive surface damage caused by UV radiation and a good correlation of this observation with the carbonyl index measurements for the WPC samples, particularly the numbers measured early in the experiment after only 4 months of exposure. This also indicates that the carbonyl index could be used for early assessment of sensitivity of different WPC to UV degradation before surface damage development is evident. Please note that the addition of zinc borate also seemed to inhibit photo-degradation of exposed WPC samples.

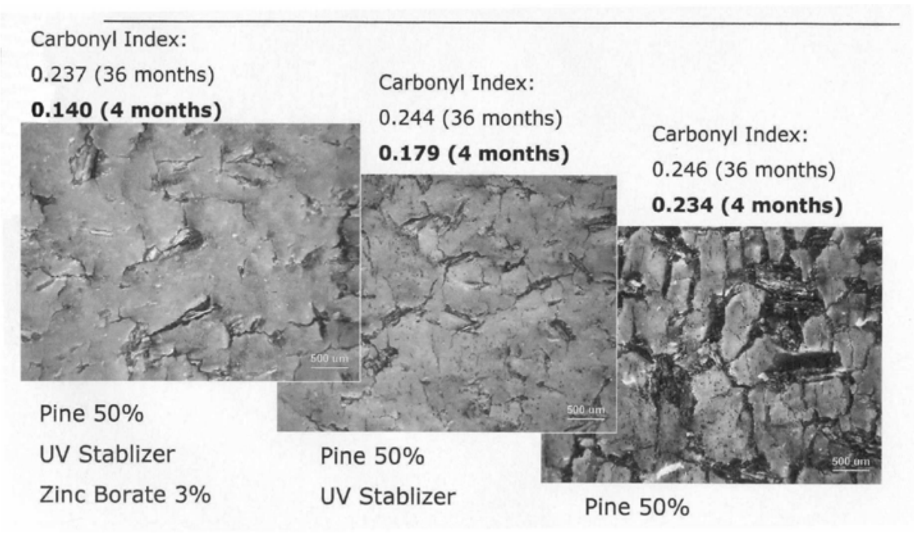


Figure 14. Appearance of samples of WPC vs. carbonyl index value after 36 months exterior exposure

Based on the carbonyl index measurements, we attempted to establish the relationship between laboratory exposure of samples of WPC to accelerated weathering (fluorescent lamp apparatus) and exposure in exterior conditions in different climatic zones (figure 15). Short term exposure indicated that 4 months of summer exposure in Vancouver was the equivalent of approximately 400 hours of accelerated weathering using 340 lamps with irradiance 0.77 W/m^2/nm and 8 hours of light (60^{o}C) followed by 4 hours of condensation (50^{o}C) cycle. A similar comparison showed that 4 months exposure in the cloudy Hawaiian winter in Hilo was equivalent to only about 200 hours of accelerated weathering and 4 months exposure in sunny California equalled approximately 650 hours laboratory exposure. The presented data also indicates that the carbonyl index measured for WPC in exterior exposure is not proportional to exposure time, likely due to some surface erosion and biological activity.

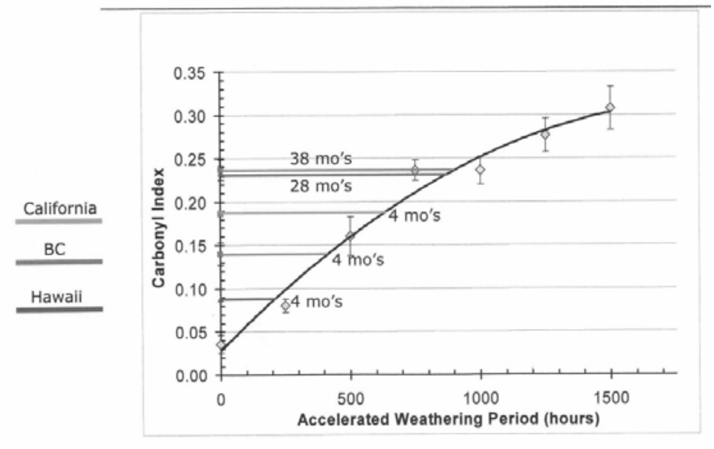
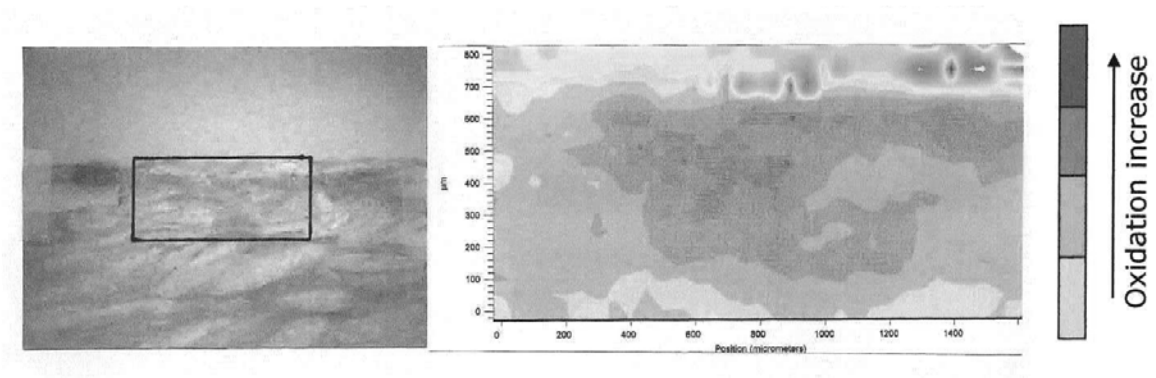


Figure 15. Correlation of accelerated weathering to exterior exposure

UV degradation of WPC is annoying to manufacturers due to material colour fading. However, the depth of the reaction of UV light with the composite not protected by UV absorbing additives is only 0.3 to 0.5 mm, as can be seen in a cross-section of the sample (figure 16) exposed to 2000 hours accelerated weathering (QUV) analysed using Raman spectroscopy.



* Courtesy Thermo Nicolet

Figure 16. Depth of UV degradation after 2000 hours QUV exposure as seen by Raman spectroscopy

Conclusions

- Wood Plastic Composite (WPC) boards progressively absorb a significant quantity of water during exterior exposure. Moisture content distribution in the board cross-sections has a characteristic U-shape, frequently exceeding the concentration required for decay initiation. Decay was observed for some samples exposed in extreme conditions.

- 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 composition of WPC. Certain additives may significantly increase or decrease water absorption (for example zinc borate decreased water absorption in the tested formulations). Climate may not be a major factor here.
- Various FTIR techniques can be used to track the oxidative degradation of polyethylene binder in WPC. Analysis of FTIR spectroscopic data can be used for assessment of the relative progress of weathering and the effect of different additives. FTIR analysis of WPC after a few months of exterior exposure may serve as an indicator of long-term performance.
- Wood can accelerate photo-oxidation of polyethylene in WPC. The intensity of the process seems to be related to wood species. WPC degradation by UV light seems to be only a surface and shallow subsurface phenomenon
- Some additives commonly used in WPC may have a positive or negative effect on polyethylene photo-oxidation. Zinc borate can be seen as an example of a biocidal additive which also inhibits photo-oxidation.

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