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Water absorption of wood polypropylene composite sheet piles and its influence on mechanical properties

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ABSTRACT

The water absorption behavior and durability of extruded wood polypropylene composite (WPC) material used in Z-section sheet piles was investigated. An experimental technique to determine percentage water absorption and its effect on mechanical properties was implemented. Water absorption tests were carried out on specimens cut from flanges and webs of the Z-section by immersion in tap water at 21, 45 and 70 °C. Freeze–thaw resistance of saturated composites was studied by cycling temperatures in the range of 21 to −29 °C. The absorption behavior followed the kinetics of a Fickian diffusion process. This behavior was modeled using an analytical solution based on Fick's second law of diffusion. Quasi-static bending tests were conducted periodically on specimens immersed in water to assess degradation in flexural properties. A significant decrease in mechanical properties of the water-saturated specimens compared to the dry control was observed. Degradation of flexural modulus was found to be a strong function of water absorption with initial decrement as percentage water absorption increased and finally stabilized as the absorption process approached saturation. However, freeze–thaw cycling did not have any significant effect on mechanical properties of saturated composites. A phenomenological model for moisture intrusion and its effect on mechanical properties was implemented and applied to explain the experimental findings.

1. Introduction

Wood polypropylene composite (WPC) materials are increasingly being used for outdoor applications such as deck boards and railings because of their ability to resist moisture intrusion and better stability compared to ordinary wood material [1]. Because of these advantages, there has been interest in using WPC material for load bearing structures. Recently, Z-section sheet piles made of WPC material designed for waterfront structures were fabricated by the extrusion process [2]. The structural performance of this type of WPC sheet piles was further investigated [3]. Performance specifications for composites set by the US Army Corps of Engineers state that water absorption should not exceed 5% for structural applications in the water environment [4]. Additionally, the decrease in the composite material stiffness should be limited to 10% [4]. Therefore, the WPC materials used in waterfront applications as load bearing structures need to be evaluated to assess their integrity in the water environment.

Espert et al. [5] studied WPC materials with various amount of filler loading. It was found that degradation in mechanical properties, and water absorbed at saturation increased with increasing filler loading. In the studies conducted by Espert et al. [5], Rangaraj and Smith [6] and Najafi et al. [7], water absorption complied with the kinetics of a Fickian diffusion process. While Shi and Gardner [8] used a two part equation to describe the moisture absorption process of wood-based composites. Moisture absorption was predicted as a function of time, initial weight of specimen and equilibrium moisture content [8]. Higher temperature was found to accelerate the absorption process due to the increased rate of diffusion [5]. Studies conducted by Cheng et al. [9] showed a decrement of flexural modulus by 40%, after 403 days of immersion in osmotic water at ambient temperature, although, flexural strength was not significantly affected. Even after 403 days of immersion, the equilibrium state was not attained, and the absorption curve was still ascending. Stark and Gardner [10] also demonstrated that the flexural modulus and strength of a saturated WPC material with 40% filler loading decreased by 39% and 22%, respectively.

Most of the studies investigating degradation in mechanical properties on WPC materials due to water absorption were conducted on saturated specimens. Only few studies focused on examining the rate of degradation of mechanical properties with respect

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to water uptake. Being able to model the absorption behavior as a function of time and temperature and relating it to the rate of degradation could be useful not only in understanding the damage mechanisms, but also in finding how to minimize the water uptake and damage accumulation. Therefore, it becomes imperative to conduct long term water absorption tests on WPC material and study its effect on the mechanical properties.

The objectives of the study presented in this paper were to characterize a WPC material including:

(1) Water absorption behavior at different temperatures.
(2) Modeling water absorption behavior as a function of time and temperature.
(3) Rate of degradation in mechanical properties.
(4) Effect of time–temperature history on degradation in mechanical properties.
(5) Resistance to freeze–thaw cycling.
(6) Relationship between water absorption and degradation in mechanical properties.

Absorption tests were conducted at 21, 45 and 70 °C in accordance with the test procedures recommended in ASTM D570 [11]. Quasi-static bending tests were conducted periodically to assess the degradation in flexural properties in accordance with ASTM D6109 [12].

2. Wood polypropylene composite sheet piling

The WPC Z-section hollow cross section sheet piling considered in this study was fabricated at the AEWC Advanced Structures and Composites Center at the University of Maine, Orono using a Davis Standard Woodtruder™ with a gravimetric feeding system (see Fig. 1 and Table 1). This WPC is composed of 46% pine wood flour by weight, 41% enhanced polypropylene resin by weight, commercial lubricant package, ultraviolet light stabilizer with polyethylene colorant base and a coupling agent.

3. Water absorption in WPC material

Water absorption of WPC materials mainly depends on fiber volume fraction, orientation of fibers, exposed surface area, and temperature [1]. It can be assumed that wood flour is solely responsible for water absorption by the WPC material considering the fact that polypropylene is water repellent and does not swell in water [13].

Wood particles increase the stiffness and reduce the cost of the resulting material; however, because of the hydrophilic nature of the wood, the overall performance of the WPC material is penalized when exposed to water or humid environment [14]. Wood flour is assumed to be encapsulated in the polymer matrix, which is not completely valid, especially when the filler content is above 40% [1]. It was found that with higher percentage of filler content, the fillers form extended and contacting chains, which enhances the penetration of water into the core of the material, resulting in increased moisture content of the overall material [1,5,15]. The particle size of wood flour also affected the water transport mechanism with increase in water absorption capability with increase in particle size [1,15].

When WPC material comes in contact with water, the wood particles at the surface absorbs water and starts to swell resulting in localized yielding in polymer matrix, as reported by Joseph et al. [16] (see Fig. 2). Furthermore, micro-cracks start to form in polymer matrix, which decreases mechanical properties and facilitates water intrusion into the core of the cross-section [16]. This process leads to swelling of the wood particles and consequently yielding and cracking of polymer matrix throughout the cross-section [16].

If a wet material is allowed to dry, then because of localized yielding, the polymer matrix will not regain its original shape; while the wood particles will shrink in absence of moisture, leaving a gap between the wood and the polymer surfaces. This results in loss of adhesion between the wood particles and the polymer matrix [10]. Therefore, for a material, which has once been subjected to water or moist environment, it will be easier for water to penetrate deeper the next time in a relatively shorter time, since the residual damage provides a pathway for moisture intrusion [10].

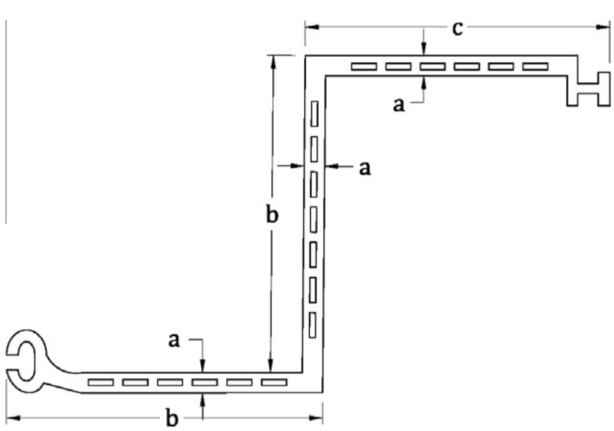

Fig. 1. Cross section of WPC sheet pile.

Table 1
Dimensions of WPC Sheet pile.

Segment	Notation	Thickness (mm)
Thickness (flanges and webs)	*a*	15.5
Width of flange (C-lock) and web	*b*	244
Width of flange (T-lock)	*c*	234

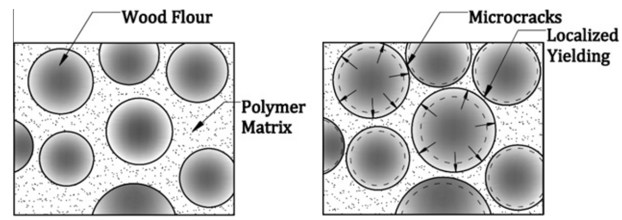

Fig. 2. Cross section representation of WPC material at the constituent level in dry (left) and wet (right) conditions.

4. Experimental work

4.1. Specimen preparation

Specimens for water absorption tests were cut from the Z-section of sheet piles in the longitudinal direction and were identified as C-lock and T-lock flange section, and web section (Fig. 3). Specimens for absorption tests were sealed on the cut edges using an epoxy adhesive so that water penetrates only through the flat surfaces thereby eliminating edge effect.

The dimensions of test specimens are shown in Figs. 4 and 5 and Table 2. For all the specimens, the thickness was 15.5 mm and the length was 304.8 mm. A margin of 5.1 mm from the edge of the void was maintained at each end, which resulted in the width of 165 mm for sections cut from flanges and 185.4 mm for web components.