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DURABILITY OF NATURAL FIBER PLASTIC COMPOSITES

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1. What are Natural Fiber Plastic Composites?

Natural fiber plastic composites are composites made out of wood flour or wood fiber or any other natural flour or fiber (*kenaf, rice husks, flax, wheat straw, hemp, others)*, and plastic. High Density Polyethylene (HDPE) and Polypropylene (PP) are the most common plastics used for the composites, but also Polyvinyl Chloride (PVC) and Polystyrene (PS) are used as raw materials in this industry.

The composition of plastic vs. fiber varies, but 50% plastic and 50% flour is commonly used as a commercial formulation. Because most of the manufacturing process comes from the plastics industry, extrusion is by far the dominant technique of production, followed by injection molding and to a lesser extent compression molding. Additives are applied to improve performance of the composites. Coupling agents enhance mechanical properties; fungicides, insecticides, fire retardants and antioxidants increase durability. Proper combination of chemical agents is required to avoid inhibition of individual effects among these agents.

2. Uses and market

The decking industry is the dominant market for wood plastic composites in North America, while the automotive parts sector is the dominant market in Europe. Other uses of the composites are fences, window and door frames, furniture, molded articles and playgrounds. The wood plastic composites market share grew from 2% in the decking market in 1997 to 8% in 2000, and it is expected to more than double by 2005 [1].

A recent study by Principia Partners [2] projects a 14% average annual growth rate for the total market through the remainder of this decade. It is also reported by Principia Partners [3] that injection molding of wood plastic composites will reach a $300 million dollars by year 2007, representing about 20 times its current size. Because of the fast growing market and the large potential of the composites for many applications, some of the large wood product companies (Weyerhaeuser, Georgia Pacific, Louisiana Pacific, Boise Cascade and Universal Forest Products) are already involved in their manufacturing or distribution.

3. Durability

Promotion of decking products by manufacturers has been based on low maintenance and long life of wood plastic composites. It was initially assumed that because of the encapsulation of the fiber by the plastic, the moisture absorption would be negligible and the products would have high durability. Several research studies and practical evidence of commercial products in service have shown variable performance of the composites, turning durability into an important issue. Because of the service life uncertainty and the large potential for exterior applications, a lot of effort has been dedicated to research on durability of wood plastic composites.

Durability is measured through performance and appearance. When physical and mechanical properties as well as aesthetic properties deteriorate, the service life of the product shortens. Some of the most common damaging effects in the composites are: color change and fading, surface erosion, loss of mechanical properties and weight loss.

Environmental factors, including weathering agents and biological agents could affect the performance and appearance of wood plastic composites. Within the weathering factors, moisture, temperature and ultraviolet (UV) light are relevant agents, whereas fungi are the main biological agents affecting the service life of the products.

The functional groups of the composite's polymers (lignin and plastic, mainly) absorb UV energy and are involved in the photoreactions (free-radical reactions) that take place during the service life of the material [4].

3.1 Research on durability of natural fiber plastic composites.

Results of research studies on UV exposure of wood plastic composites are variable because the distinct conditions (wood and plastic composition, type of plastic, UV source, etc.) under which the experiments have been conducted. Results of research conducted by Stark and Matuana [5], illustrate significant changes in flexural strength (MOR) and stiffness (MOE) of HDPE/wood composites after 2000 hours of exposure. Falk et al. [6] studied the effects of colorants and UV exposure on these properties. They found a 24% reduction in the modulus of elasticity (MOE) and 19% reduction in the modulus of rupture (MOR) for a wood plastic composite protected with a red pigment and containing 50% wood flour after 1500 hours of exposure to UV light. Li [7] reports loss of the same properties after 5000 hours of exterior weathering in a wood-flakes HDPE composite. He found that the composite retained about half of its initial strength and two thirds of its initial toughness after outdoor weathering for 205 days.

Matuana and Kamden [8] report discoloration of a wood flour/PVC composite and retention of mechanical properties after 2600 hours of UV exposure with a fluorescent lamp.

After Morris and Cooper [9] reported brown and white rot fungi growing on a wood plastic composite in service in Florida, scientists have dedicated a large effort to conduct research studies on this topic. Verhey and Laks [10], Pendleton et al. [11] and Mankowski and Morrell [12] found a correlation between the wood content and the weight loss in composites exposed to fungal decay. The higher the wood content, the higher the weight loss because the higher is the moisture absorption. A similar relationship has been found by Verhey and Laks [13] with the particle size of the composites. The higher the particle size, the higher the weight loss because the lower is the encapsulation of the wood particle by the plastic and the higher the moisture absorption.

Zinc borate, which is used by the industry, has been found to be an effective preservative against fungal decay and insects in laboratory studies at concentrations of 1% and higher.

Verhey and Laks [14] found that zinc borate was mobile and leached from the composite stakes in the field in Hawaii. Especially boron was rapidly lost from the composite, reaching a content of 25% of its original level after 12 months of exposure. The same authors in a different paper [15] conclude that, even low levels of fungal decay can have an impact on the strength of compression molded wood plastic composites.

Ibach and Clemons [16] found that preconditioning wood plastic composites by 1000 hr of UV exposure and soaking for 2 weeks accelerated the weight loss due to fungal decay when compared to a 2 weeks-water soak preconditioning.

3.2 Research at the University of Toronto

3.2.1 Objectives.

In the Faculty of Forestry at the University of Toronto we are conducting short-term and long-term tests as part of an ongoing study on durability of natural fiber plastic composites. The main objectives of this study are:

- In the short-term tests we want to determine the effect of moisture, temperature, UV radiation and their interactions on mechanical properties of the composites under stress.
- We are developing a standard test method to predict durability of natural fiber plastic composites in the long term, based on results of short-term accelerated tests.
- We want to know the chemical changes taking place in the composite's materials (plastic and fiber) to understand the mechanisms of degradation.
- We are developing a method to evaluate fungal decay on wood and non-wood flour materials, commonly used as raw materials for the composites.

3.2.2 Materials and methods.

The materials used in the short- and long-term tests are extruded profiles made out of agro-residues and HDPE.

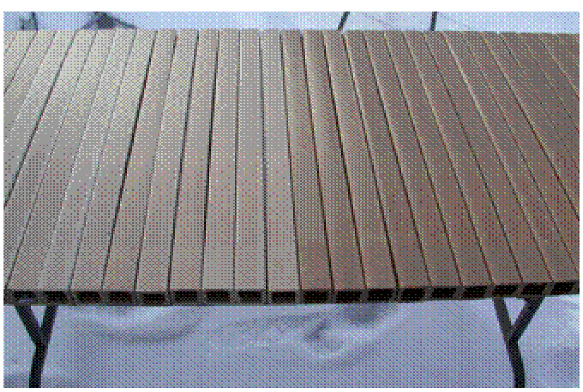

Figure 1. Extruded profiles of natural fiber plastic composites exposed in the short- and long-term tests.

In the fungal decay tests we will use natural flour materials as well as specimens of the composites. We will use flour of flax, hemp, rice husks, softwoods and hardwoods. In Table 1 we see thirteen species of fungi that will be used to develop the standard method of materials fungal decay. Tests on fiber furnish will be described in a later paper.

Table 1. Species of fungi used to develop standard test method of fungal decay.

Group of fungi	Species of fungi
White rot	***Trametes versicolor*** ***Xylobolus frustulatus*** ***Pleurotus ostreatus*** ***Irpex lacteus***
Brown rot	***Gloeophyllum trabeum*** ***Postia placenta*** ***Coniophora puteana*** ***Neolentinus lepideus*** ***Antrodia xantha***
Other fungi	***Rhyzoctonia solani*** ***Fusarium oxysporum*** ***Colletotrichum truncatum*** ***Bipolaris sorokiniana***

3.2.2.1 Short-term tests

The combinations of two temperatures, three levels of relative humidity, and UV vs. no UV exposure, make the set of treatments to which the stressed specimens will be exposed in the short-term tests. A uniformly distributed load of 800 lbs/ft^2 is applied on the specimens of the composite. This load is the recommended design load for structural applications, but we have used it here to accelerate the effect of short term exposure and also to see the potential of these composites in structural applications. The composite is designed to support this load without breaking under ambient conditions.

Figure 2. Specimens of natural fiber plastic composites exposed to UV light and a load of 800 lbs/ft^2.

Mechanical properties of the specimens are measured after 2000 hours of exposure for each treatment.

3.2.2.2 Long-term tests

In the long-term tests, the natural fiber plastic composites are exposed to weathering factors on the roof of the Faculty of the Forestry building at the University of Toronto. Unloaded and loaded specimens are tested to simulate real life product service conditions.

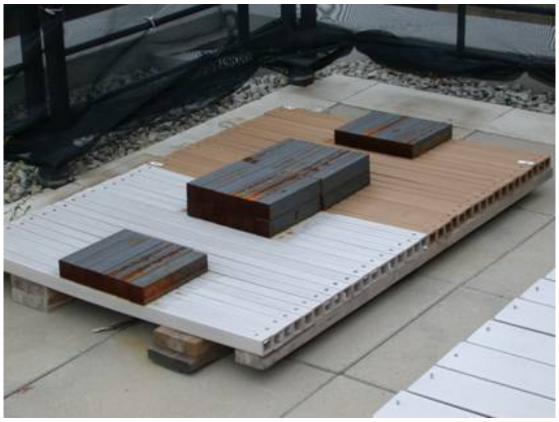

Figure 3. Specimens of natural fiber plastic composites exposed to exterior weathering factors and different loads.

Mechanical properties of the specimens will be measured every 6 months for a period of 5 years.

3.2.2.3 Mechanical properties

Bending tests are conducted to measure force at break and deflection using the four point method. Flexural strength (Modulus of Rupture-MOR) and Stiffness (Modulus of Elasticity-MOE) are calculated according to standard ASTM-D 6109 [17].

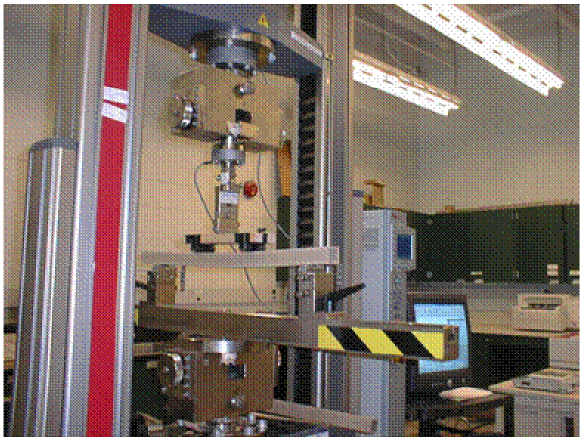

Figure 4. Four point bending test for measuring deflection and force at break, and calculating flexural strength (MOR) and flexural modulus (MOE) of exposed specimens of a natural fiber plastic composite.

Hardness test is carried out on all the exposed specimens according to standard ASTM-D 143 [18], using the modified Janka Ball test. In this test we measure force at break.

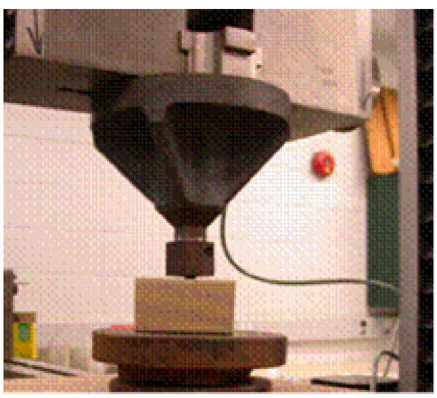

Figure 5. Hardness test to measure force at break of exposed specimens of a natural fiber plastic composite.

Impact resistance test is done on coupons of exposed specimens, measuring energy at break with the cantilever beam impact machine according to standard ASTM-D 256 [19].

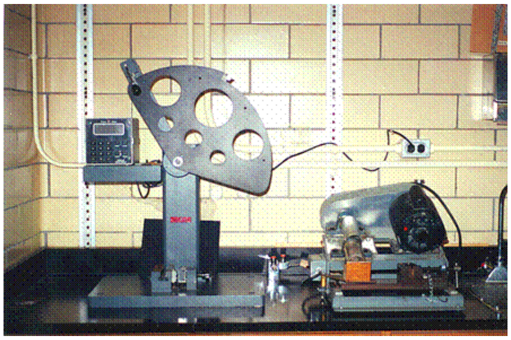

Figure 6. Impact resistance test to measure energy at break on exposed specimens of a natural fiber plastic composite.

In our approach to the standard method development of durability, we evaluate changes and make comparisons of mechanical properties of a natural-fiber plastic composite between long-term weathering exposure and short-term accelerated exposure to predict the service life of this material. The Acceptance Criteria AC174 from the International Conference of Building Officials (ICBO) Evaluation Service, Inc. for deck board span ratings and guardrail systems [20] is used as a reference to assess durability of the composites. According to these criteria, the average flexural strength of exposed test specimens shall be within 10% of the average flexural strength of unexposed test specimens.

3.2.2.4. Mechanisms of degradation

We are working with two techniques to detect and analyze chemical changes taking place in the composite's materials:

X-ray-photoelectron spectroscopy (XPS): We will estimate changes in the functional groups at the surface of the exposed composites.

Susceptibility of materials (fiber and HDPE) to different wavelengths (UVA vs. UVB): We will measure and compare changes of mechanical properties and color under different wavelengths to determine where the photoreactions are taking place.

3.2.2.5 Fungal decay tests

- ***Fungal Decay Method Development***

Combinations of fungi and flour materials indicated in **Table 1.** make up the treatments of our experimental approach to develop the fungal decay test. Measure of CO2 production will be used as the indicator of fungal decay in this case.

- ***Soil Block Test***

A soil block test was conducted as part of this effort to develop a fungal decay method for flour materials, following similar procedures to those specified in standard ASTM D2017.

Blocks of natural fiber plastic composite were exposed to white and brown rot fungi usually found on wood, as well as to *Rhyzoctonia solani* found on rice plants. Blocks of wood of three different species: spruce, maple and western red cedar were used as controls in the experiment. All the specimens were preconditioned, soaking them in water for 10 days. Eight replicates of each material were evaluated in the test. Weight loss was measured for all the blocks after 16 weeks of exposure.

3.2.3 Results

Partial results of the soil block test are shown in Table 2, in which the weight loss of the wood component of the composite is depicted for seven species of fungi.

Table 2. Weight loss of the wood component of a natural fiber plastic composite after 16 weeks of exposure in a soil block test.

FUNGUS	***WEIGHT LOSS OF THE WOOD COMPONENT (%)***
Gloeophyllum trabeum	**10.7**
Irpex lacteus	**10.0**
Trametes versicolor	**9.7**
Neolentinus lepideus	**9.0**
Antrodia Xantha	**4.7**
Rhyzoctonia solani	**4.0**
Xylobulus frustulatus	**3.5**

All fungi had active growth on the surface of the natural fiber plastic composite blocks, but not all of them had the same level of fungal decay. Both, brown and white rot fungi attacked the lingo-cellulosic fiber of the composite, consuming part of the cell wall and causing weight loss. In Figure 7 shows an image of *Trametes versicolor* actively growing and covering the hollow specimens of the composite in the soil block test.

Figure 7. *Trametes versicolor* growing on blocks of a natural flour plastic composite in a soil block test.

The weight loss of the wood blocks of spruce, maple and cedar compared to the weight loss of the wood component of the composite can be seen in Figure 8. The natural resistance of cedar to fugal decay is obvious from the graph. Spruce and maple show susceptibility to fungal attack from brown and white rot fungi, indicating the viability of the strains used in the experiment.

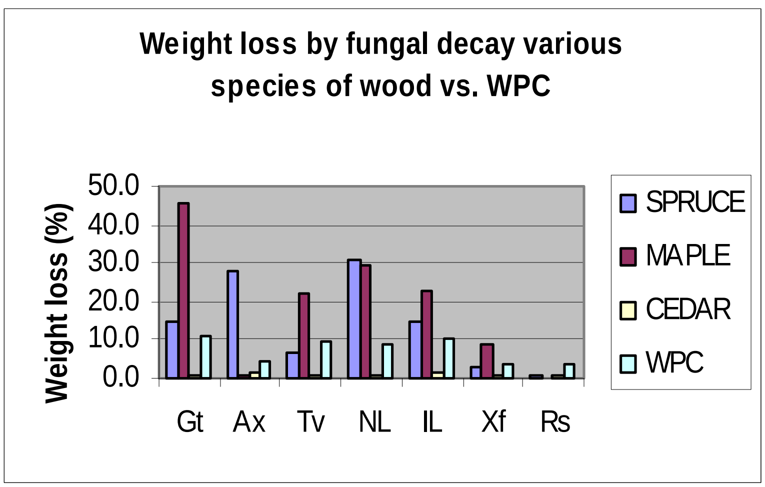

Figure 8. Weight loss by fungal decay of wood blocks from spruce, maple and cedar, compared to weight loss of the wood component of a natural fiber plastic composite in a soil block test.

In summary, at the University of Toronto we are developing a method to predict durability of the natural fiber plastic composites in the long term, based on results of short-term accelerated tests. We are also searching for the mechanisms of degradation of the composites through detection of chemical changes at the surface and the bulk of the materials. Finally, we are developing a method to know the susceptibility to fungal decay of different fibers used as raw materials in the composites.

Acknowledgments

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