Evaluation of Relationship between Moisture Content and Biological Degradation of Wood Plastic Composites

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Abstract:

Water absorption is one of the key parameters in microbial growth in wood plastic composites (WPC). There is a strong correlation between an overall water content in WPCs and its susceptibility to biological degradation by fungi. The use of WPC has increased worldwide in recent years and much attention has been received regarding their service life and biological performance related to their compositions and climatic conditions. The wood particles or fibers used as fillers in WPCs are hydrophilic due to their nature even though they are encapsulated by a polymer/plastic in WPC matrix. As a result, the wood fibers are still able to absorb moisture and the outer surfaces in WPCs can be first degraded biologically in the presence of sufficient water and biological agents. Moisture content in the outer surface of WPCs is usually greater than that in the inner parts in outdoor applications. This might be resulted in reductions in durability of the materials against the biological organisms that degrade the surface parts of WPCs. This paper provides a short overview on the importance of moisture content in degradation of WPCs by decay fungi.

Key Terms: Fungal degradation, moisture content, wood plastic composites, fungi

Introduction:

Water and wood as a food source play an important role in colonization and eventually decomposition of wood and wood based materials by fungi. The presence of moisture is essential for biological decay in a given material since wood decaying fungi need a specific amount of water in the wood source to initiate a decay process. It is generally hard to give an optimum moisture content for any particular wood decaying fungi to attack wood since a number of factors affect degree of wood decay such as wood structure and chemistry, density, species, etc. In general, a moisture content of above 25-30% is needed for fungi to colonize the wood. In this moisture content level called “fiber saturation point” (FSP), the pore spaces in the wood are free of water; however, the cell wall is saturated with bound water affecting many properties of wood such as biological resistance, physical and mechanical properties. Since during drying process, the amount of water decreases much below FSP, wood drying help reduce and prevent fungal attack. In contrary, when excessive moisture content is available in the wood, fungal activities are also reduced or diminished. Thus, wood water content limits fungal degradation by Basidiomycetes fungi in two mechanisms: i) lack of water needed for fungal metabolism in the case of low moisture content, and ii) lack of oxygen and air in the case of excessive water.

Relationship between biological performance of wood plastic composites (WPCs) and their moisture content in field and laboratory tests has become major interest in recent years. WPCs are generally known to be more resistant to biodegradation by micro-organisms when compared to solid wood due to encapsulation of wood by the plastic. Amount of decay in general is then much slower than that in solid wood (Schmidt, 1993; Naghipour, 1996; Clemons 2002; Wang and Morrell, 2004; Ramirez et al. 2009; Fabiysi et al., 2011). However, the wood in WPCs might be still susceptible to decay since the wood in the WPC matrix can be contacted with water in some ways (Morris and Cooper, 1998; Mankowski and Morrell, 2000; Verhey et al., 2001, 2002; Ibach and Clemons, 2002; Pendleton et al., 2002; Silva et al., 2002; Simonsen et al., 2002; Ibach et al., 2003; Clemons and Ibach, 2004). Ibach and Clemons (2007) stated that even though the encapsulation theory would prevent moisture sorption and fungal decay, decay and discoloration of WPC by fungi is also possible in service (Morris and Cooper, 1998). In outdoor conditions, WPCs are expected to expose to
biological attack and water (rain water/wetting) but also ultraviolet (UV) radiation (weathering), oxidation, thermal, chemical, and mechanical degradations are resulted in surface degradation and erosion in WPCs. Although WPCs have slower moisture sorption than wood (Rowell et al. 2002, Wang and Morrell 2004), water supports fungal decay of the material in the matrix (Clemons and Ibach 2002, 2004; Shirp and Wolcott 2005).

In general, lower weight losses occurred in WPCs during fungal decay process are closely related with the lower moisture sorption of the composite. Although moisture uptake in WPC occurs relatively slowly, moisture levels in the outer parts of WPCs may have sufficient water content for fungal attack. Wood material having moisture content of 19% or lower does not generally support the growth of mold fungi. WPCs have rarely moisture above 19%, except in the very top and thin layer after rain or immersion in water for long time. However, in some cases such as humid, moist areas, particularly with inadequate ventilation, moisture content in WPCs can exceed 20-25%.

Factors that affect decay of wood plastic composites: There are a number of factors that affect microbial degradation of WPCs such as the degree of porosity of the composite, density of the material, particle size of wood fibers, water absorption or moisture content (preferably 20-30%), presence/absence of biocides and additives (Chow et al., 2002; Verhey and Laks, 2002; Silva Guzman 2003; Klyosov, 2007; McDonald et al., 2009; Morrell et al., 2010). Amount of wood fiber and wood particle size in a given WPC matrix are vital factors for both water absorption and fungal degradation (Silva Guzman 2003; Morrell et al., 2010). In general, the higher wood content in WPCs, the faster water absorption due to presence of more hydrophilic lingo-cellulosic material for moisture uptake (Clemons, 2002; Verhey et al., 2002). Wood particle size can also affect ability of WPCs to absorb water and resistance to fungal attack (Stark and Berger, 1997; Verhey et al., 2002; Silva Guzman 2003). In general, smaller particle sizes in WPCs indicate improved water resistance (Tatakani, 2000) since such particles generally increase the interface between the wood fibers and the plastic, and decrease voids in the interface area that can serve as pathways for moisture movement and colonization by fungi (Mankowski and Morrell, 2000). Since particle size is also an important factor for fungal growth in WPCs, wood particles of as small as 80 mesh to improve biological resistance are currently used in the industry (Clemons, 2002).

Water is crucial for fungal colonization and decay of lingo-cellulosic materials. Water uptake from the other surfaces of WPCs is the key factor since fungal attack is introduced from such surfaces. WPCs containing wood fiber more than 50% noticeably absorb more water (Mankowski and Morrell, 2000). Type of plastic material in the matrix also affects amount of water to be absorbed. For instance, polyethylene composites absorb more water than those made with polypropylene (Naghipour, 1996). Moisture sorption can lead to void formation at wood/polymer interface (Peyer and Wolcott, 2002) and these voids could form pathways for entry by water and fungal hyphae. WPCs were considered as being completely resistant to microbial degradation because wood fibers are completely immersed into plastic. In fact, WPCs are typically porous and the pores are typically open, and available in the whole matrix. Wood fiber is exposed into these pores and throughout such pores moisture movement is possible and also fungal attack into the matrix pores and voids.

On the other hand, incorporation of wood source with high lignin and extractives content in WPC may have a potential to lower water absorption because such compounds show some hydrophobic properties (Fabiyi et al., 2011) suggesting that wood species also is an important factor for WPCs to absorb water.

Even though the resistance of WPCs to fungal degradation is a result of encapsulation of wood fibers in the plastic matrix as a barrier to protect wood fibers from wetting, wood fibers are not completely encapsulated by the plastic in WPC matrix, particularly near the surface. As a result, the wood component in such materials may reach a moisture level more
than 30% which is appropriate for fungal degradation.

Fungal activities in WPCs are generally concentrated on the outer surfaces of the composite and this may cause slow roughening of the composite surface (Pendleton et al., 2002). Degradation of the polymer surface is resulted in more wood fibers being exposed, thus moisture absorption increases (Peyer and Wolcott, 2002). Wood fibers on the surfaces exposed directly to fungi are generally entirely decayed (Pendleton et al., 2002). Fungal mycelium is abundantly found in the interfacial voids between the wood and the plastic, thus main mechanism of fungal degradation in WPCs is hyphal penetration through the voids on the wood/plastic interfaces (Mankowski and Morrell, 2000; Pendleton et al., 2002).

Moreover test specimen size has also an impact on water absorption, thus, decay degree. The specimen sizes increasing surface to volume ratios are likely to result in more suitable conditions for fungal attack.

Processing methods for WPC production may have also an impact on moisture sorption, thus, biological resistance of WPCs. Different manufacturing methods posses different temperatures, pressures, and flows resulting in different composites with varying performance (Clemons and Ibach, 2004). The most common methods for WPC production are extrusion, compression molding, and injection molding. Of those methods, extruded composites are of the highest water absorption capability whilst compression methods result in less water absorption and injection molded WPCs absorb the least.

**Standard tests to evaluate biological resistance of WPCs:** A number of test methods are available to test for fungal degradation of wood and composites/panel products; however, there is no proper laboratory test method currently available to evaluate the fungal performance of WPC. At present, the soil-block test for solid wood has been adopted for fungal durability tests of WPC measuring weight losses in test materials to indicate decay degree. Laboratory fungal decay tests in North America are in general based on the American Wood Preservers’ Association Standard E10 (AWPA, 2012) or ASTM Standard D1413 or D 2017 soil block tests (ASTM, 2010), although agar plate tests are also suggested (Morrell et al. 2010). In most standard tests, mass losses in solid sapwood test specimens usually range from 20 to 65% over a 12-week test period depending on the fungus and wood species tested; however, similar tests with WPC specimens generally produce wood mass losses of only 5 to 10% (Silva et al., 2007). High moisture levels (>30%) are needed by microorganisms to attack wood, but neither of these methods produces sufficient weight losses on WPCs. The relatively slow rate of decay is possibly the slow rate of water absorption by the WPCs. Laboratory-based methods i.e. the soil block tests are less suitable for predicting the performance of WPCs; however, solid wood test procedures can be used with minor modifications. The differences between solid wood and WPCs with regard to decay susceptibility, moisture gradients, and the increased surface area to volume ratio of WPCs are important points in those standard methods (Pendleton et al. 2002; Falk et al. 2000). For these reasons, in 2012, the AWPA modified its soil block standard test (AWPA E10-12) (AWPA, 2012) by adding a conditioning cycle for WPCs before decay tests for WPC specimens. According to the new version of the standard, to simulate long term WPC performance, conditioning of specimens is required prior to fungal exposure to increase the moisture content of the specimens. There are two possible ways for this in the standard recently; (i) immersion of WPC specimens in water for five days at 70°C or (ii) immersion of WPC specimens in water for two weeks at room temperature.

In Europe, the agar-block test, according to EN 113, is commonly used in fungal decay testing. A new European standard, prCEN/TS 15083-1, will be used to identify the natural durability of woods and is currently under review. The soil block test is principally very similar to the agar-block test, however, soil and a so-called feeder strip, made from a non-durable wood species, are used as the substrate for growing the fungus. Modified agar-and soil-block tests are both generally suited for determining weight...
loss in WPC. Dynamic mechanical analysis (DMA) can be also used to evaluate the effects of wood decay fungi in WPC. Dynamic mechanical analysis may have a potential to give valuable molecular and morphological information about a material in the solid state. Field tests also are highly valuable for the durability of WPCs. In such tests, the effects of moisture, fungal and termite degradation and other environmental factors such as UV radiation, thermal cycles and freeze-thaw cycles can be considered. Above ground tests can be also used for evaluation for color mold formation in WPCs. Weathering or aging of WPC prior to fungal testing may be one of the most effective ways to accelerate the laboratory tests in order to simulate outdoor conditions. The fungal species attacking WPCs outdoors may not be the major organisms on WPC during long-term exposure. Thus, studies are needed to find the main fungal species occurring on WPCs for laboratory tests.

Råberg and Hafrén (2008) stated that tests performed on agar or soil media were the most effective factor in determining deterioration of WPC under laboratory conditions. The size of the samples was also an important factor for the deterioration in decay resistance tests. Thicker samples may have lower weight losses than thinner samples since they have slower moisture absorption (Silva et al. 2007).

Conclusion:

Moisture control is the crucial issue to protect WPCs from biological degradation and weathering. WPCs may be subjected to biological attack by fungi in both field and laboratory conditions and water absorption of WPCs is probably one of the most important factors to start decay process in such materials. Wood decaying fungi rely on four basic factors for decay process i.e. food, moisture, oxygen and temperature. The last two are very difficult to control and limit; however, moisture and nutrient might be regulated. In case of WPCs, for instance, nutrient factor can be controlled by encapsulating the wood fibers by plastic in WPC matrix, thus, reducing the amount and size of wood in the matrix. In addition, if the moisture content of the wood can be kept below 19-20%, decay in WPCs may be prevented or limited. On the other hand, the wood may be modified by chemical or thermal modifications before WPC manufacture to decrease water absorption ability and consequently the wood particles in WPCs can turn from hydrophilic to hydrophobic. Thus and modified wood particles may be an alternative to increase their resistance against water uptake and biological attack by fungi.

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