Durability of Wood-Plastic Composites

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Introduction

Markets for wood-plastic composites (WPCs) have grown at an astounding rate, despite their higher overall costs compared to naturally durable or treated wood. Surveys suggest that these products have excellent reputations for durability and environmental friendliness, and there is an overall perception that WPCs are maintenance free.

When they first entered the market, WPCs were touted as impervious to biological attack because the plastic was presumed to completely encapsulate the wood particles, thereby protecting them from both moisture and fungal attack. Observation of early WPC decks in Florida, however, showed evidence of fungal fruiting bodies on the surfaces within a few years of installation illustrating that these materials were still susceptible to biodeterioration. An array of subsequent studies have clearly illustrated that the wood in many WPCs remains susceptible to degradation (Laks et al. 2000, Mankowski and Morrell 2000, Pendleton et al. 2002, Verhey et al. 2001) (contact the authors for a fully referenced paper and complete list of citations).

While great improvements have been made in product formulations designed to increase durability, it is clear that these materials are not completely immune to deterioration. But, how susceptible are they?

Deterioration is broadly defined as any negative effect on the properties of a material. The effects can be due to biological attack or to various non-living agents (sunlight, moisture, temperature), but often, deterioration results from a combination of factors. Nowhere is this more evident than with WPCs, owing to the marriage of dissimilar materials. This article examines agents that can damage WPCs, explores methods for limiting this damage, and then addresses long-term methods for assessing WPC properties related to durability.

Biological Agents of Damage

A variety ofbiological agents can attack wood and plastic either as a food source (primarily wood) or to create shelters (both wood and plastic). For practical purposes, the agents most commonly associated with wood-plastic composite (WPC) applications include fungi, insects, and marine borers. Although organisms that colonize the surface but do not necessarily degrade the material, such as lichen and algae, might also be considered agents because of the exceptionally high dependence on surface appearance for WPC product quality.

Fungal Decay

The first reports of biological attack on WPCs involved a white-rot fungus, clearly showing that wood particles in this material remain susceptible to fungal attack. These observations led to a number of laboratory studies showing that various decay fungi could cause substantial weight loss under the proper conditions. Fruiting bodies, however, do not always correlate with substantial losses in material properties. One observation from laboratory trials was that brown-rot fungi appear to be more capable of attacking these materials, even WPCs composed of hardwood particles.

Decay tests have typically been performed using the American Wood-Preservers' Association Standard E10 or ASTM Standard D 1413 or D 2017 soil block tests, although agar (used for solidifying growth media in the artificial cultivation of microorganisms) tests are also used. In general, the primary difficulty in assessing WPC durability has been wetting the blocks. The inherent resistance of WPCs to moisture uptake can sharply limit fungal attack for much of the period traditionally used in these tests. Once wetted, however, wood in the WPCs will degrade. The degradation rate then becomes a function of the wood:plastic ratio, the use of additives, the particle size of the wood, and the wood species. All of these factors indirectly relate to moisture uptake and accessibility of the wood to the fungus.

While fungal attack has clear effects on the wood, the effects on WPC properties are less clear cut. A number of studies have shown substantial losses in bending properties after relatively short fungal exposures (Stark 2001); however, microscopic examination of specimens from at least one study found little or no evidence of fungal attack. The absence of substantial fungal attack suggests that the damage was more likely caused by disruption of the wood:plastic matrix by wetting and drying. This suggestion is further supported by studies involving long-term wet/dry cycling. This effect appears to be associated with the first few moisture cycles.

Insect Resistance

plastic is largely resistant to insect attack except as it might be mined or grazed to create galleries for rearing by social insects, such as carpenter ants or termites, or inadvertently by adult beetles and wasps as they emerge from adjacent wood. While insects might be capable of obtaining some nutrition from the wood particles, substantial insect attack of WPCs is unlikely. Given the density of most WPCs, it is also unlikely that social insects such as carpenter ants would mine galleries, since they tend to seek softer materials.

Marine Borer Resistance

Plastic is largely immune to marine borer attack. Studies have shown that the primary marine borers, gribbles (related to pill bugs) and shipworms (wood-boring clams), which obtain at least part of their nutrition from wood do not directly attack either plastic or WPCs. Small, inadvertent damage to the plastic or WPC by shipworms has been observed when WPC or plastic is placed adjacent to wood attacked by these borers. Rock-boring clams, such as piddocks, are capable of carving out a home within materials softer than their shells but damage to wood or plastics in the ocean by these organisms is rare.

Physical Agents of Deterioration

Although biological damage is often considered the primary factor in material deterioration, physical and chemical agents can have a substantial impact on the properties of a WPC. For WPCs these effects are primarily surface related but the damage is particularly critical because these products are sold for a premium on the basis that their surfaces will resist such changes.

Chemical Discoloration

Many wood species are susceptible to a variety of chemical stains and this susceptibility does not appear to diminish in a WPC. These stains can result from reactions of extractives with metals, or by thermal degradation, or they can be mediated by bacterial enzymes. Often, the discolorations are dark and appear to be of a biological origin, but the time in which they form and the lack of fungal growth suggest otherwise. These stains have little impact on WPCs that are produced in darker colors, since the background masks any discoloration, but they are particularly damaging in materials produced to look like wood. Numerous dark blotches can develop within a month after exposure and, because the stain is often beneath the surface, it is difficult to remove. Careful selection of wood species may help reduce the potential for stain. This, however, can be difficult, and it may be more practical to add oxidative inhibitors to the mixture prior to extrusion. These materials must also be capable ofwithstanding the elevated temperatures associated with extrusion.

Moisture Cycling

Early in the history of WPC lumber, it was often suggested that WPCs were resistant to moisture because the wood was completely encapsulated by the plastic. While plastic imparts some resistance to moisture uptake, once moisture enters the matrix, the damage begins.

Moisture absorption by WPCs can lead to a degradation of mechanical properties. This is largely due to the fact that as wood particles absorb moisture they swell. As the wood particle swells, three things happen to the composite:

1. the interface breaks down due to repeated wood swelling and shrinking,
2. microcracks in the plastic are created, and
3. the wood particles fracture internally due to restrained swelling

For example, in one study, moisture content increased to 9 percent, while flexural modulus and strength decreased by 39 percent and 22 percent, respectively, when an injection-molded WPC containing 40 percent wood flour was soaked for 2,000 hours (Stark 2001).

The manufacturing method can have a tremendous influence on the surface quality of the WPC, thereby influencing moisture absorption. Extruded WPCs absorbed roughly four times as much moisture as injection-molded composites in a 2-weekwater soak. Injection-molded surfaces were smoother than extruded materials and had a plastic rich layer which inhibited moisture penetration.

Freeze-Thaw

There have been suggestions that the limited degree of bonding between the hydrophilic ‘’water loving” wood and the hydrophobic “water hating” plastics can also be disrupted by physical activities such as freezing and thawing. This would be a critical performance issue in many northern temperate exposures. Testing of small samples showed some loss in properties after freeze-thaw cycling; however, there were no significant effects on the flexural properties of freeze-thawed cycled commercial samples. Others have shown losses in flexural strength and stiffness of 5 percent and 15 percent, respectively, after exposure to five water soak-freeze-thaw cycles. A large portion of the mechanical property loss was associated with moisture absorption rather than the freeze-thaw cycle.

Ultraviolet Degradation

Both major components of WPCs undergo photodegradation, upon exposure to ultraviolet (UV) light. While all components of wood are susceptible to photodegradation, lignin absorbs 80 to 95 percent of the total amount of UV light absorbed by wood and only constitutes 25 to 30 percent of wood. As lignin oxidizes, the lignin (and wood) content at the surface decreases. As a result, the surface of degraded wood is typically hairy and cellulose-rich. The plastic matrix theoretically should not undergo photodegradation. Unfortunately, residual solvent in polyvinylchloride, other impurities in polyolefins, and photo-oxidized wood can sensitize the matrix to photodegradation. The degradation reaction propagates via free radical mechanisms and can lead to oxidation of the polymer chain, chain scission, and/or crosslinking. The result is a loss of surface quality, increase in UV absorbing characteristics, and a decrease of mechanical properties.

Ultimately, photodegradation of WPCs results in changes in color, surface composition, and small changes in mechanical properties. Weathering is a combination of photodegradation in the presence of water/moisture and heat. Extruded WPCs exposed to UV radiation for 2,000 hours in an accelerated test lightened 13 percent, while flexural modulus of elasticity (E) decreased 12 percent, and no significant change in strength occurred. In contrast, exposing similar samples to 2,000 hours of UV radiation with a water spray cycle produced 46 percent lightening, and flexural E and strength decreases of 52 percent and 34 percent, respectively. W exposure in conjunction with water exposure is deleterious because oxidation reactions are accelerated in the presence of water, swelled wood particles facilitate W light penetration into the WPC, and the degraded wood (loss of lignin) becomes more water absorbent. These actions exacerbate the degradation. Clearly, W light penetrates only a short distance into the material and its effect on overall properties would be small. However, the effects on surface characteristics cannot be ignored, particularly for a product that is marketed on an appearance basis.

Methods for Improving Resistance

Biotic Degradation

As it became evident that the wood in WPCs was susceptible to degradation, some manufacturers began to add zinc borates to their mixtures. Borates are excellent fungicides and insecticides. Zinc borate is especially attractive because it has very low water solubility and does not appear to affect or be affected by the manufacturing process. One disadvantage of boron is its inability to protect against many mold fungi, a particularly important characteristic given the appearance issues inherent in the products. There is a continuing search for other compounds that might be suitable mold inhibitors; however, the search is hampered by the lack of heat stability in many of the common mold inhibitors used to protect solid wood.

Abiotic Degradation

A variety of technologies are available for protecting WPCs against photodegradation. Adding photostabilizers to the plastic is the most common strategy. Common types of photostabilizers include ultraviolet absorbers (UVAs) which protect the matrix by preferentially absorbing UV light and hindered amine light stabilizers which protect the matrix by interfering with the free radical degradation mechanism. Both materials have been shown to offer some protection to WPCs. Pigments in WPCs can also act as light-blockers, limiting the penetration of W light into the matrix.

There is little information available regarding protecting the wood component in WPCs from photodegradation independently. However, UVAs and pigments in the matrix should offer some protection, and pigments would also mask some discoloration of the wood component.

Perhaps the most important issue for improving WPC durability is moisture. Moisture uptake can be limited by either altering the hygroscopicity of the wood particles or by changing the structure of the final composite. Wood particles can he protected by the addition of coupling agents such as maleic anhydride grafted polyolefins which react/interact with the hydroxyl groups present on the wood surface to improve plastic and wood particle interactions. Other approaches involve wood surface chemical modification, such as acetylation to reduce hygroscopicity of the particles. The resultant WPC has very low water absorption characteristics; however, the process adds additional costs. Changes in the processing variables can also alter WPC surface quality and directly affect the composite's moisture resistance. For example, altering process conditions (heat, line rate) may produce smoother surfaces that reduce moisture uptake, thereby delaying surface degradation. Other methods for reducing moisture sorption include coating the WPC and co-extrusion with an unfilled thermoplastic cap.

Accelerated Testing

One of the issues that has arisen with WPCs in the market place is the lack of long-term field data on durability. Instead, manufacturers have depended upon limited laboratory testing using artificial weathering, wet/dry cycles, and decay tests. The methodologies employed in these tests have been largely derived from wood-based materials. Given the moisture sorption characteristics of these materials, there is every reason to believe that these methodologies, while useful for comparative studies, are largely inadequate to predict service life because they fail to provide a sufficient exposure period.

There is a continuing need to develop realistic methods for assessing the many aspects of WPC durability, and these methods will continue to evolve as material scientists refine these composites to improve properties.

Conclusion

It is clear that the wood in WPCs must be protected from both biotic and abiotic damage: however, it is equally apparent that technologies are available to achieve this goal. As these products continue to evolve, expect to see increasingly durable materials that overcome biological, moisture,. and UV degradation to produce materials that retain their appearance and structural properties.

Literature Cited

Note: This list of references is abbreviated due to space limitations. The authors can provide a more complete list of references upon request.

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