Downloaded by grant Kirker on July 14, 2014 | http://pubs.acs.org
Publication Date (Web): June 10, 2014 | doi: 10.1021/bk-2014-1158.ch006

Chapter 6

Above Ground Deterioration of Wood and Wood-Based Materials

Grant Kirker*,[1] and Jerrold Winandy[2]

[1]USDA-FS, Forest Products Laboratory, Madison, Wisconsin 53726
[2]Winandy & Associates, LLC, East Bethel, Minnesota 55011
***E-mail: gkirker@fs.fed.us.**

Wood as a material has unique properties that make it ideal for above ground exposure in a wide range of structural and non-strucutral applications. However, no material is without limitations. Wood is a bio-polymer which is subject to degradative processes, both abiotic and biotic. This chapter is a general summary of the abiotic and biotic factors that impact service life of wood in above ground exposures, and briefly discusses test methodologies commonly used in North America to determine the durability of wood and wood based materials in above ground exposure. Current efforts to improve service life estimates for wood and wood based materials are also discussed.

Abiotic Factors That Impact Service Life of Wood and Wood-Based Materials above Ground

The term "abiotic degradation" refers to any non-biological related type of wood degradation. The two modes of abiotic degradation include chemical pathways and mechanical action. Each has an independent effect and each interacts with the other. The classic commonly recognized practical modes of abiotic degradation include weathering, mechano-sorptive relationships, and friction/ erosion/ mechanical-related damage. Each is discussed below, and in these discussions it will become apparent how each of these above ground abiotic modes of degradation interact and among themselves and with agents of above

© 2014 American Chemical Society
In Deterioration and Protection of Sustainable Biomaterials; Schultz, T., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2014.

ground biotic degradation. Additional information on the abiotic processes the degrade wood can also be found in Phil Evans' chapter from the 2008 ACS book (*1*), and further information on weathering and photostability of modified woods are presented in a separate review, also by Evans (*2*).

Modes of Abiotic Degradation

Weathering

Surface Changes

Weathering is a common term describing the abotic degradation of wood when exposed outdoors to sunlight and the direct "weathering" effects of rain, freeze-thaw, alternating thermal loading and wind (Figure 1). The ultraviolet (UV) portion of sunlight reacts with, and causes, a slow deterioration of the lignin exposed at the wood surface as UV light only penetrates wood a few microns (*3*). As the lignin-rich lamella zones around the wood fibers degrade, the fiber-to-fiber bonding at the wood surface is greatly reduced. This abiotic chemical process of lignin degradation is then followed by a physical/mechanical abiotic process.

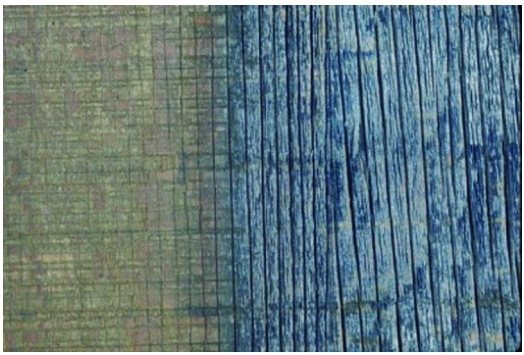

Figure 1. Surface of weathered exterior-grade plywood after 10-years exposure (right side covered from sunlight; left side exposed to sunlight & elements). (Reproduced from reference (3).)

While the cellulose and hemicelluloses remaining in the now carbohydrate-rich wood fiber (i.e., after UV-induced lignin degradation) are relatively resistant to UV, there can be significant reduction in fiber-to-fiber bond strength because of the lignin degradation. This then allows the combined physical/mechanical internal stresses resulting from cyclic swell/shrink, freeze-thaw, and diurnal thermal loadings, combined with the external forces from rain and/or wind, to cause an on-going erosion of the wood fibers from the wood surface. Earlywood has thinner cell walls than latewood and thus earlywood is generally more prone to suffer from weathering than is latewood (*3*). Because of this tendency, weathered wood often has a wavy texture to its surface (Figure 2).

In Deterioration and Protection of Sustainable Biomaterials; Schultz, T., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2014.
Downloaded by grant Kirker on July 14, 2014 | http://pubs.acs.org
Publication Date (Web): June 10, 2014 | doi: 10.1021/bk-2014-1158.ch006

Downloaded by grant Kirker on July 14, 2014 | http://pubs.acs.org
Publication Date (Web): June 10, 2014 | doi: 10.1021/bk-2014-1158.ch006

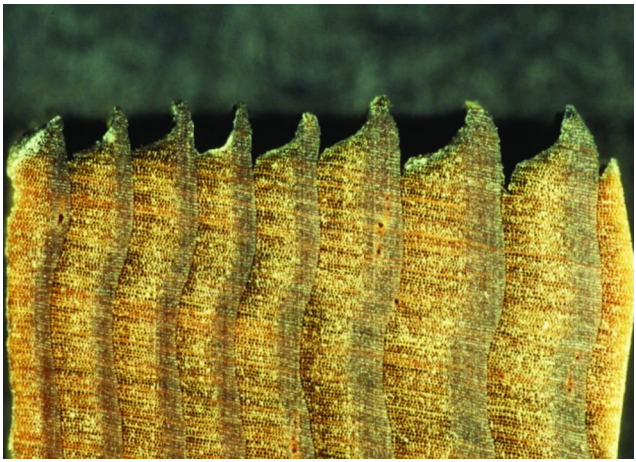

Figure 2. Differential weathering between earlywood and latewood of softwood lumber exposed on radial face. Note how thin-walled earlywood weathers faster than the denser latewood. (Reproduced from reference (3).)

As fresh wood fibers are then exposed to direct sunlight, rain and wind, the process systematically repeats itself on a layer by layer basis (Figure 3).

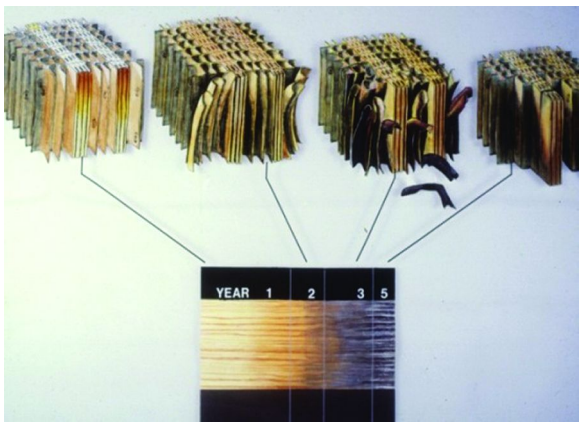

Figure 3. Hypothetical example of the progression of weathering on a softwood surface. Note how the thin-walled earlywood initially weathered faster than the denser latewood, but the latewood fibers also eventually weather and erode away. (Courtesy of R.S. Williams with permission.)

From the previous figure it is apparent that UV weathering is a slow process occurring over many years. When judged on larger wood samples the time required for wood to become fully weathered depends on wood density, species and severity of exposure. In general, weathering is sometimes approximated over a broad range of species/density as 6mm per century (Figure 4).

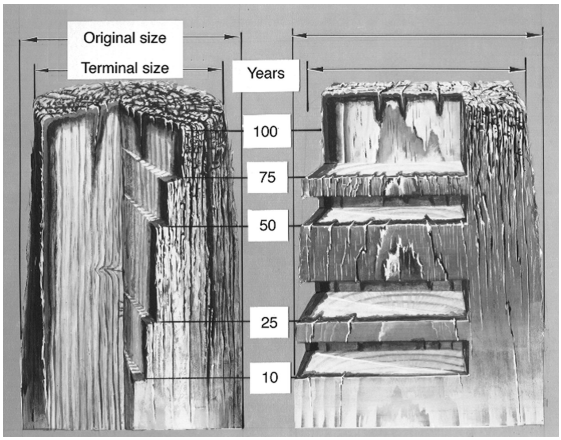

Figure 4. Two hypothetical examples highlighting the progression of the weathering process on the surface of wooden timbers. (Reproduced from reference (3).)

Downloaded by grant Kirker on July 14, 2014 | http://pubs.acs.org
Publication Date (Web): June 10, 2014 | doi: 10.1021/bk-2014-1158.ch006

Weathering can take many forms. Often as the lignin is degraded we notice a yellow/brown-to-grey color change because lignin tends to be brownish in color while the carbohydrates appear grey-white under light in our visual spectrum. As lignin degradation develops, fiber-to-fiber bonding is reduced, this in turn also allows wood to develop deeper surface checking. This checking allows deeper penetration of UV light and enhances deeper moisture absorption/desorption. Because the cellulose and hemicelluloses readily absorb moisture in wet or humid conditions, this promotes swelling. During dry conditions, shrinkage occurs so that this cyclic swelling and shrinkage then creates alternating internal stresses that can also lead to still deeper surface checking. As the wood surface(s) shrinks and swells, the external mechanical forces of rain and/or wind can eventually erode these degraded wood fibers from the wood surface.

Extractives often also impart color to the wood and wood surface. These extractives are most often water-soluble and, as the wood surface is progressively degraded and eroded, deeper access to water occurs which accelerates leaching of the extractives. Progressive wet-dry moisture cycling gradually draws more extractives to the wood surface, where rain can leach these extractives from the wood surface. This loss of extractives can further promote color change in wood.

Biological attack of a wood surface by microorganisms is also recognized as a contributing factor to color change or graying of wood. This biological attack, commonly called mildew, does not cause erosion of the surface, but it may cause initial graying or an unsightly dark gray and blotchy appearance. These color changes are caused by dark-colored fungal spores and mycelia on the wood surface, as discussed later in this chapter. In advanced stages of weathering, when the surface has been enriched by cellulose, it may develop a silvery-gray sheen.

In Deterioration and Protection of Sustainable Biomaterials; Schultz, T., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2014.

Downloaded by grant Kirker on July 14, 2014 | http://pubs.acs.org
Publication Date (Web): June 10, 2014 | doi: 10.1021/bk-2014-1158.ch006

Mechancial Damage

Wood changes dimensions as it gains or loses moisture below the fiber saturation point (FSP). Below the FSP, wood shrinks as it loses moisture from the cell walls, and swells when gaining moisture in the cell walls. This shrinking and swelling can result in warping, checking, and splitting. The combined effects of radial and tangential shrinkage can distort the shape of wood pieces because of the difference in shrinkage and the curvature of annual rings. The major types of distortion as result of these effects are illustrated in Figure 5.

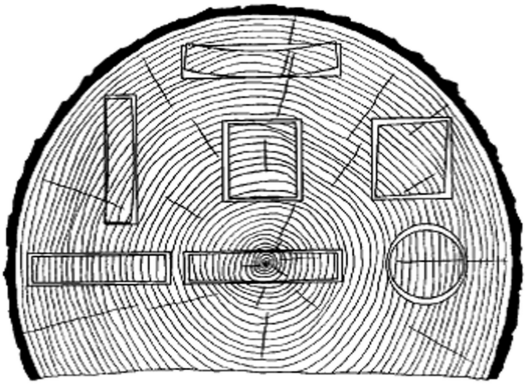

Figure 5. A hypothetical example characterizing how various anatomical orientations can influence the shrinkage in wood with tangential shrinkage being greater than radial shrinkage by an approximate factor of 2x. (Reproduced from reference (3).)

Figure 6. Examples of how once-finished and then unprotected treated-wood decking can experience varying degrees of surface checking and uneven gapping after a 18-year exposure in Wisconsin. (Courtesy of J. Winandy with permission.)

In Deterioration and Protection of Sustainable Biomaterials; Schultz, T., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2014.

Moisture-related shrinkage and swelling can also create non-uniform gaps along edges of decking or, eventually, surface checking on decking surfaces (Figure 6).

Since wood plastics composites (WPCs) are realitively new to the market long dominated by wood, their long term performance is not fully understood. There is a growing body of work focusing on the thermo- and photstability of wood plastic composites, but the effect of the particular wood species and plastic matrix are still not fully understood and new formulations and blends are still being produced which may have alternative weathering properties. Wood plastic composites are succeptible to abiotic effects of weathering. WPCs vary greatly in the compositon of their plastic matric, wood species and other additives, and all of these factors have been shown to impact photostability and above ground performance. Newer generation WPCs are mostly PVC and HDPE based and contain 50% wood or less, but weathering characteristics have been improved through the addition of UV stabilizers, pigments, and cross-linking agents. In addition, moisture-related issues can also affect WPC decking. If the untreated wood fiber gets wet and stays wet for an extended period of time, abiotic moisture absorption can promote above-ground biotic activity. An example of moisture retention in wood-plastic composite decking is shown in Figure 7. A more in-depth review on the effects of weathering on WPCs is presented by Azwa *et al.* (*4*).

Downloaded by grant Kirker on July 14, 2014 | http://pubs.acs.org
Publication Date (Web): June 10, 2014 | doi: 10.1021/bk-2014-1158.ch006

Figure 7. Wood-plastic composite deck boards after a rain shower followed by cloudy conditions. Moisture is retained for days within the decking, especially near joints where end-grain is exposed. (Courtesy of J. Winandy with permission.)

Anatomical/Species Related Issues

As stated earlier, wood density and surface texture can become critical factors in abiotic degradation. Some wood species are denser than others and, within these species, latewood cells are denser than earlywood cells. Aboitic issues such as friction-induced erosion (i.e. erosion on a wearing surface such as flooring or decking) are significantly influenced by wood density and surface texture. Denser woods and tight-grained woods (i.e., wood with many closely spaced growth rings) are more resistant to friction-induced erosion; lower density woods and open-grain woods (i.e. wood with generally faster growth, widely spaced growth rings) are much less resistant. Juvenile wood [see Zobel 1998 (*5*) for an explanation of juvenile wood], used in outdoor decking and exposed to this moisture cycling, greatly increases the effects of surface checking (Figure 8). Species differences in weathering and overall durability of WPCs was investigated by Kim et al. (*6*) and they found enhanced durability of WPCs when incorporating naturally durable woods as feedstock for the WPCs, but also found increased corrosion associated with several species.

Downloaded by grant Kirker on July 14, 2014 | http://pubs.acs.org
Publication Date (Web): June 10, 2014 | doi: 10.1021/bk-2014-1158.ch006

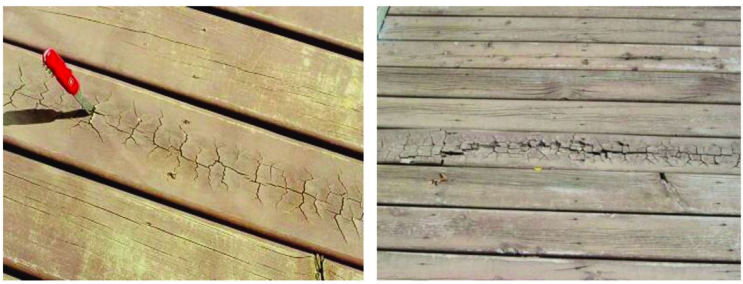

Figure 8. A CCA-treated pine deck board with exposed juvenile-wood surface after 5-years (left) and after 18-years (right) of direct outdoor exposurein Wisconsin. (Courtesy of J. Winandy with permission.)

This surface checking is a mechanical issue that promotes deeper moisture access. In some cases this deeper checking enables moisture to reach the untreated core of treated wood decking, promoting greater checking and warping and sometimes leading to fungal staining or decay (Figure 9).

Downloaded by grant Kirker on July 14, 2014 | http://pubs.acs.org
Publication Date (Web): June 10, 2014 | doi: 10.1021/bk-2014-1158.ch006

Figure 9. An example of how abiotic and biotic issues can work interactively to promote wood deterioration and destroy wood products in above ground outdoor exposures. Note the presence of an un-dentified fruiting body protruding from crack in the board. (Courtesy of J. Winandy with permission.)

Biotic Factors That Impact Service Life of Wood and Wood-Based Materials above Ground

In this section we will review common causes of biotic degradation in wood. Biotic damage generally refers to damage by organisms which include, but are not limited to, fungi and insects, and we review the role of these biological agents in the biological breakdown of wood and wood-based products in above ground exposure. An important consideration to bear in mind is the effect of climate on rates of biological degradation. The same concept applies above ground as it does in ground contact. Areas with higher mean temperatures and annual rainfall typically have higher decay hazard. A decay hazard map was created by Scheffer (*7*), and which was recently updated (*8*, *9*) to reflect shifting zones as a consequence of changing climate.

A major factor when considering longevity of above ground structures is thoughtful design and use. Proper choice of fasteners, code adherence, and wood selection are all important decisions to be made when selecting wood for above ground applications and can have a profound impact on the performance of the material. It is imperative to know and understand the structural limitations of the material in its intended exposure and closely follow recommendations. Moisture management is one of the most critical design decisions to be made. By eliminating areas where water collects and causes wood products to remain wet for long periods of time, many of the problems mentioned below can be avoided.

Wood Decay Fungi

Fungi are multicellular microorganisms that spread and propagate via a threadlike mycelium, persisting in soil, wood, and leaf litter. Fungi can form sexual and asexual fruiting bodies that produce spores, allowing the fungi to also disperse by wind or splashing water. Wood decay fungi are a specialized group that can effectively utilize the structural components of wood as a food source and are typically categorized as described below, listed in descending order of relative importance to wood degradation:

Brown-rot fungi – brown-rot fungi belong to the phylum Basidiomycota (true fungi, many in the family Polyporaceae) and have specialized enzyme systems that effectively break down the polysaccharides cellulose and hemicelluloses. Brown-rot decay has a characteristic rusty brown coloration that develops a cracked, cubical appearance in later stages (Figure 10b). Due to the rapid lowering of the cellulose degree of polymerization in the incipient decaystage, brown-rot can cause rapid strength loss of lumber, leading to in-place failures. Brown-rots are a common problem in softwood lumber.

White-rot fungi – white-rot fungi (Basidiomycota) have the ability to break down all of the structural components of wood (cellulose, hemicelluloses, and lignin). Typical indications of white-rot fungi are white, stringy and bleached decayed wood (Figure 10c) that results from lignin removal and the presence of the remaining undigested cellulose. White-rot fungi are typically more common on hardwood species but are sometimes also found on softwoods.

Soft-rot fungi – Soft-rot fungi (Ascomycota) are a problem in areas of higher moisture and available nitrogen (*10*). These fungi cause a characteristic decay pattern that affects cellulose and hemicellulose in the S2 layer of the inner cell wall. Soft-rot does not penetrate deeply into the wood but causes a gradual sloughing off of the outer surface (Figure 10d) that can lead to decreased structural integrity and in-place failures.

Mold Fungi − mold fungi (primarily Ascomycota) are typically asexual fungi that grow and reproduce prolifically through the spread of conidia. Most of the highly successful molds that are encountered on wood produce conidiophores that contain thousands of spores, either singly or in chains, as in the case of *Paecilomyeces* spp., *Penicillium* spp., and *Aspergillis* spp. These spores are transported by wind and can spread rapidly in the environment (*11*). The mold fungi are synonymous to weeds in the plant kingdom - they are biologically pre-disposed to take up space. Most molds are quite aggressive, grow rapidly and many produce secondary metabolites that often repel surrounding micro-organisms (or even insects). Mold fungi are ubiquitous in nature and usually have little impact on the structural integrity of the wood. However, certain molds have been found to degrade biocides, and surface growths of mould do diminish the aesthetic value of the wood (Figure 10a) and can also degrade paints and coatings. The presence of molds is also an indication of moisture problems which can result in subsequent decay.

Sapstains – Sapstain fungi (Ascomycota) are typically introduced by insects before the lumber is cut or can infect lumber as it is being seasoned. Sapstain is caused by pigmented fungi that colonize the sapwood and cause a blue-green

Downloaded by grant Kirker on July 14, 2014 | http://pubs.acs.org
Publication Date (Web): June 10, 2014 | doi: 10.1021/bk-2014-1158.ch006

discoloration. A very common sapstain is caused by the fungus *Ophiostoma* spp. which is transmitted through feeding by bark beetles. There have been considerable efforts to investigate the effects of sapstain fungi on the strength properties of wood, and it has been found that any strength loss is be dependent on wood and fungus types, particularly in tropical and hardwood species. Although the literature remains unclear on the impacts of sapstain on strength properties, early work by Findlay (*12*) found decreases in toughness and hardness but no decrease in bending and compression strength in *Pinus taeda* exposed to blue stain fungi. Wood permeability can also be increased by the presence of sapstain fungi, which can impact coatings and pressure treatment. For more information on blue stain and it's effects on lumber, see MPBI report (*13*) which details much of the work done on blue-stained lumber. Another resource on the effects of sapstains on wood is presented by Mai *et al*. (*14*) and provides an excellent summary of the colonization and effects of sapstain fungi.

Downloaded by grant Kirker on July 14, 2014 | http://pubs.acs.org
Publication Date (Web): June 10, 2014 | doi: 10.1021/bk-2014-1158.ch006

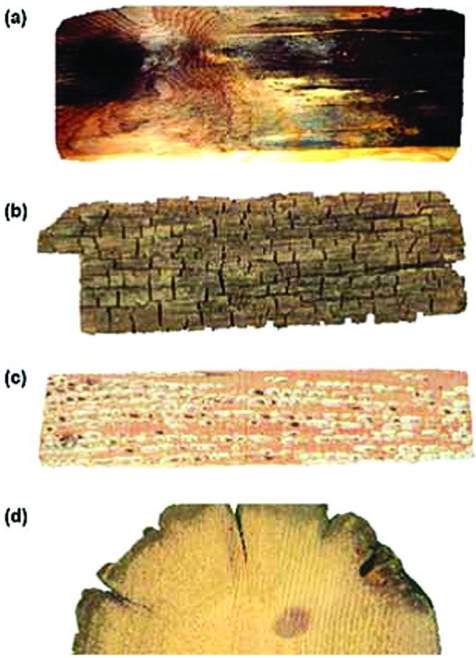

Figure 10. Characteristics of different decay types found on various woods. (a) mold fungi on pine (b) brown rotted pine (c) white rotted maple (d) pole section with soft rot - note the superficial nature of soft rot degradation. (Courtesy of Carol Clausen with permission.)

Yeasts – *Aureobasidum pullulans* is an extremely common fungus that grows on wood. It is currently listed in the ascomycetes, exhibits yeast-like growth and behavior, and is commonly referred to as "black yeast". *Auroeobasidum pullulans*

is an important fungus as it can colonize and persist on painted wood surfaces (*15*). The fungus obtains nutrients from the lignin photodegradation products on the surface of the wood and causes major fouling of painted surfaces. This yeast has also been determined to break down water based paints and is a major cause of paint spoilage (*16*). *Aureobasidum pullulans* exhibits resistance to many different chemical compounds and has also been evaluated as a bioremediation tool due to its ability to breakdown organic compounds and withstand metal ions. An image of *A. pullulans* growing on a treated pine piling is shown below (Figure 11).

Figure 11. Aurobasidum pullulans growing on a CCA-treated pine piling in a marina in South Carolina. (Courtesy of Jim Healey, Cox Industries by permission.)

Downloaded by grant Kirker on July 14, 2014 | http://pubs.acs.org
Publication Date (Web): June 10, 2014 | doi: 10.1021/bk-2014-1158.ch006

Insects

Insects include a diverse group of organisms capable of causing a wide variety of damage to wood and wood products. Some insects require wood as a major part of their diet while others simply use wood as a substrate for growing fungi to be used as a food source or simply inhabit wood for shelter. Regardless, insects can cause significant damage to wood products in an above ground environment. Beetles are not addressed in this overview as they are typically more common in indoor situations.

Termites – Termites can be a serious problem in above ground exposure. Termites are found nearly worldwide and account for billions of dollars in damage to wooden structures annually, mostly due to subterranean termites. Termites rely on wood as their primary food source, relying on specialized gut microbes that aid in cellulose digestion. Termites are primitive social insects and have an organized hierarchy of castes consisting of workers, soldiers, and reproductives. Workers search, retrieve and bring food back to the colonies to feed the soldiers

In Deterioration and Protection of Sustainable Biomaterials; Schultz, T., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2014.

and reproductives. Caste formation is hormonally controlled so that worker forms can develop into soldiers or reproductive should the colony need more of a given caste (*17*). Economically important termite groups are categorized based on their biology and feeding habits as such:

Drywood Termites (Usually *Incisitermes* spp. or *Cryptotermes* spp.) Drywood termites are typically found along coastal areas and can be a problem in above ground wood products. Drywood termites usually enter structures through attic and foundation vents, fascia boards, and through gaps in windows and doors (*18*). Feeding galleries are smooth and evenly cropped with small pellets in connecting chambers (*19*). These small pellets are a clear indication of drywood termite infestation and are usually found near "kick holes" where the termites eject the frass from their galleries (Figure 12). The ornamentation of the fecal pellets can be so specific that they may be used to identify the species of drywood termite present. Prevention of drywood termite damage is extremely difficult, but proper diagnosis and remedial treatments usually yield good results.

Downloaded by grant Kirker on July 14, 2014 | http://pubs.acs.org
Publication Date (Web): June 10, 2014 | doi: 10.1021/bk-2014-1158.ch006

Figure 12. Galleries and frass indicative of western drywood termite, Incisitermes minor. (Courtesy of Whitney Cranshaw, Colorado State. Bugwood.org with permission.)

Subterranean Termites – Subterranean termites are the most common source of insect damage to wood in above and below ground contact. The two most economically important subterranean termite species are:

Reticulitermes flavipes (eastern subterranean termite)- *Reticulitermes flavipes* is native to the US and has a broad distribution. This species causes major damage to wooden structures by excavating the earlywood as it feeds. Members of *R. flavipes* are soft bodied and prone to dessication, so they build shelter tubes out of soil and feces to bridge the soil with their food source (Figure 13). The presence of shelter tubes is often the first indication of an active termite infestation.

In Deterioration and Protection of Sustainable Biomaterials; Schultz, T., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2014.

Figure 13. Soil tunnels indicative of infestation by subterranean termites. (Courtesy of Rachel Arango, Entomologist, USDA-FS, with permission.)

Downloaded by grant Kirker on July 14, 2014 | http://pubs.acs.org
Publication Date (Web): June 10, 2014 | doi: 10.1021/bk-2014-1158.ch006

Common treatments for subterranean termites include soil drenches, barriers, and bait matrices followed by replacement of the damaged wood material. Severe termite damage can cause catastrophic wood failures, especially in cases where the internal damage is extensive and not outwardly visible.

Coptotermes formosanus (Formosan subterranean termite)-*Coptotermes formosanus* is an introduced species that was imported in the 20th century to the southern US mainland and has since spread northward. *C. formosanus* has extremely large colony sizes and can cause catastrophic damage to wooden structures. This species makes "carton material" as a nesting structure from wood/frass/saliva. Carton nests can be found in severely damaged structures and are an adaptation that allows these subterranean termites to carry more soil into higher parts of the structure. This allows them to infest eaves, overheads, and other above ground structures not typically affected by subterranean termites.

Dampwood Termites − Dampwood termites are an occasional problem in wood with excessive moisture. They feed in the earlywood and plug their holes with feces. Dampwood termites typically have rough walled feeding chambers spotted with fecal material. They are an occasional problem in the Pacific Northwest and coastal Florida but are not of major importance on a national scale. Since dampwoods cannot survive in dry wood, eliminating sources of excessive moisture are key to their treatment.

Carpenter Ants – Despite common misconceptions, carpenter ants do not ingest wood but rather excavate it to build their egg chambers, usually in the earlywood bands. They prefer softer wood already degraded by fungi, so the presence of carpenter ants is often indicative of a pre-existing condition brought on by decay or excessive moisture.

In Deterioration and Protection of Sustainable Biomaterials; Schultz, T., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2014.

Carpenter Bees – Carpenter bees are frequent in above ground wood. They prefer uncoated wood and burrow into the wood to nest. The do not ingest the wood as a food source but simply excavate it to reside in, much like carpenter ants. Carpenter bees lay eggs in these galleries from the inside outward; the brood hatch in reverse order. A diagram of the nesting cavity is shown in Figure 14. The bore holes are not only unsightly, but they also cause disruptions in the surface that can serve as entry points for other deteriorating organisms, such as wood decay fungi.

Figure 14. Cross-section of carpenter bee burrow in wood showing brood chambers. (Courtesy of USDA Forest Service Archive, USDA FS, Bugwood.org with permission.)

Downloaded by grant Kirker on July 14, 2014 | http://pubs.acs.org
Publication Date (Web): June 10, 2014 | doi: 10.1021/bk-2014-1158.ch006

Standardized Test Methodologies To Assess above Ground Performance of Treated Wood

In the United States: American Wood Protection Association (AWPA)

Above Ground Tests-AWPA has several standardized test methodologies that can be used to test wood and wood based materials to assess performance of experimental protectants (*20*). They include:

- E9-13: Standard Field Test for Evaluation of Wood Preservatives to be Used Above Ground (UC3A and UC3B); L-Joint Test.
- E16-13: Standard Field Test for Evaluation of Wood Preservatives to be Used Above Ground (UC3B); Horizontal Lap Joint Test.
- E18-13: Standard Field Test for Evaluation of Wood Preservatives to be Used Above Ground (UC3B); Ground Proximity Decay Test.
- E25-13: Standard Field Test for Evaluation of Wood Preservatives to be Used Above Ground (UC3B); Decking Test.
- E27-13: Standard Field Test for Evaluation of Wood Preservatives to be Used Above Ground (UC3B); Accelerated Horizontal Lap Joint Test.

Use Class System-AWPA specifies commodity requirements for all wood products sold in the United States, and assigns the designation of Use Class 3A or 3B to above ground exposed wood products. A listing of approved protectants and target retentions is listed in the Use Class section of the AWPA Book of Standards (*20*).

Outside of the United States

Internationally, there are additional standards writing organizations that are responsible for developing and maintaining standards for wood products, and they are listed in Table 1 along with sources of more information.

Downloaded by grant Kirker on July 14, 2014 | http://pubs.acs.org
Publication Date (Web): June 10, 2014 | doi: 10.1021/bk-2014-1158.ch006

Table 1. Additional International Governing Bodies for Standards for Wood Preservation

Standards Name	*Governing Body*	*Website*
EN Standards	*CEN*	http://www.cen.eu/cen/
Australian Standards	*Standards Australia*	http://www.standards.org.au/
Japanese Standards	*JWPA*	http://www.mokuzaihozon.org/english/
Nordic Standards	*NWPC*	http://www.ntr-nwpc.com/1.0.1.0/2/1/

North American Research Needs for Service Life Prediction in above Ground Use

There has been an international effort to provide more effective methods and models for predicting service life of wood products employed above ground to provide more realistic estimates of the performance of wood and wood based materials in different climates (*21–24*). Researchers in North America are beginning to make significant advances in this area, but the European research community has a substantial lead in the implementation of models to predict service life.

A major goal of these approaches is to better understand the fungal agents that contribute to the decay process and how they differ in a given region or latitude. When we go back to the Scheffer index (*7*), we can see that specific hazards exist for a given climatic region but little information is available on the native fungal communities and how they impact wood service life.

In Deterioration and Protection of Sustainable Biomaterials; Schultz, T., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2014.

Another confounding variable is the incorporation of climate change to the models. It is becoming increasingly clear that climate change is occurring and that increases in mean temperature and carbon dioxide will happen in the near future (*8*, *9*). How these parameters factor into our predictions are currently unknown.

With the increasing volumes of wood plastic composites on the market, a better understanding of the abiotic and biotic factors that effect service life of WPCs needs to be addressed. Lomelia-Romerez et al. (*25*) clearly demonstrated that fungal degradation does occur on WPCs, and several other studies have found similar results. A complete understanding of the fungal specialists that persist on and degrade WPCs are a vital missing component that complicates any real service life estimates of WPCs.

Downloaded by grant Kirker on July 14, 2014 | http://pubs.acs.org
Publication Date (Web): June 10, 2014 | doi: 10.1021/bk-2014-1158.ch006

References

1. Evans, P. D. In *Development of Commercial Wood Preservativees: Efficacy, Environmental, and Health Issues*; Schultz, T. P., Militz, H., Freeman, M. H., Goodell, B., Nicholas, D. D., Eds.; ACS Symposium Series 982; American Chemical Society: Washington, DC, 2008; pp 69–117.
2. Evans, P. D. *Wood Mater. Sci. Eng.*. **2009**, *4*, 2–13.
3. Williams, R. S. In *Wood Handbook: Wood as an Engineering Material*; U.S. Department of Agriculture: Madison, WI, 1999; Chapter 15, pp 15-1–15-37.
4. Azwa, Z. N.; Yousif, B. F.; Manalo, A. C.; Karunasena, W. *Mater. Design* **2013**, *47*, 424–442.
5. Zobel, B.; Sprague, J. R. In *Juvenile Wood in Forest Trees*; Springer Publishing: Berlin, 1998; pp 300–301.
6. Kim, J. W.; Harper, D. P.; Taylor, A. M. *Wood Fiber Sci.* **2008**, *40*, 519–531.
7. Scheffer, T. C. *For. Prod. J.* **1971**, *21* (10), 25–31.
8. Carll, C. G.; Highley, T. L. *J. Test. Eval.* **1999**, *27*, 150–158.
9. Morris, P. I.; McFarling, S.; Wang, J. *Int. Res. Group Wood Prot.* **2008**, 08–10672.
10. Savory, J. G. *Ann. Appl. Biol.* **1954**, *41* (2), 336–347.
11. Alexopoulos, C. J.; Mims, C. W.; Blackwell, M. In *Introductory Mycology*, 4th ed.; John Wiley and Sons: New York, 1996; 869 pages.
12. Findlay, W. P. K.; Pettifor, C. B. *Forestry* **1937**, *11*, 40–52.
13. Byrne, T.; Stonestreet, C.; Peter, B. In *The Mountain Pine Beetle: A Synthesis of Biology, Management, and Impacts on Lodgepole Pine*; Safranyik, L., Wilson, W. R., Eds.; Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre: Victoria, British Columbia, 2006; pp 233–253.
14. Mai, C.; Kües, U.; Miltiz, H. *Appl. Microbiol. Biotechnol.* **2004**, *63*, 477–494.
15. Bardage, S. L. *Holz Roh- Werkst.* **1998**, *56*, 359–364.
16. Schoeman, M.; Dickinson, D. *Mycologist* **1997**, *11*, 168–172.
17. Krishna, K.; Weesner, F. M. In *Biology of Termites*; Krishna, K., Weesner, F. M., Eds.; Academic Press: New York, 1969; Vol. I, 600 pages.
18. Gold, R. E.; Glenn, G. J.; Howell Jr., H. N.; Brown, E. Texas A & M Agrilige Extension Pulbication 2005 E-366.

19. Shelton, T. G.; Wheeler, F.; Appel, A. G. Alabama Cooperative Extension System, 2000; ANR 1170, 4 pages.
20. American Wood Protection Association. In *Annual Book of Standards*; American Wood Protection Association: Birmingham, AL, 2013; 647 pages, ISSN 1534-195X.
21. Rapp, A. O.; Peek, R. D.; Sailer, M. *Holzforschung* **2000**, *54*, 111–118.
22. Blom, Å.; Bergström, M. *Wood Sci. Technol.* **2005**, *39* (8), 663–673.
23. Brischke, C.; Bayerbach, R.; Otto Rapp, A. *Wood Mater. Sci. Eng.* **2006**, *1*, 91–107.
24. Råberg, U.; Edlund, M. L.; Terziev, N.; Land, C. J. *J. Wood Sci.* **2005**, *51*, 429–440.
25. Lomelia-Romerez, M. G.; Ochoa-Ruiz, H. G.; Fuentes-Talavar, F. J.; Garcia-Enriquez, S. *Int. Biodeterior. Biodegrad.* **2009**, *63*, 1030–1035.

Downloaded by grant Kirker on July 14, 2014 | http://pubs.acs.org
Publication Date (Web): June 10, 2014 | doi: 10.1021/bk-2014-1158.ch006