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Water relations in untreated and modified wood under brown-rot and white-rot decay

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ABSTRACT

One key requisite for fungal decay of wood is water within cell walls. While several reviews have focused on the mechanistic relationship between water and decay of wood, this study is the first review of water relations of decayed wood material. Based on a vast compilation of experimental data from several literature sources, the water relations of untreated and modified wood decayed by brown-rot and white-rot fungi are examined. The aim is to investigate to what extent observations and assumptions regarding brown-rot and white-rot decay can explain changes in water relations observed during and after decay. Although the available experimental data for modified wood is scarce, it indicates that brown-rot and white-rot decay of non-resistant modified wood occurs by similar degradation mechanisms with similar effects on water relations as for untreated wood. From simplistic, mathematical modelling, it is shown that changes in water relations during decay can be partly explained by accompanying changes in chemical composition and void volume.

1. Introduction

Residential and industrial buildings are required to have a long service life of at least 50 years according to European building codes while monumental structures such as bridges should last twice as long (EN, 2002). These requirements can be a challenge when building with wood due to its susceptibility to biodegradation. Under the right environmental conditions, various biological agents will attack and degrade the material decreasing the performance (strength, stiffness, appearance, etc.). Some of the most destructive, efficient and economically important degradation agents are brown-rot and white-rot fungi which appear in 73–85% and 2–27%, respectively, of the cases with fungal decay in wood structures in Northern Europe and the USA (Alfredsen et al., 2005; Duncan and Lombard, 1965; Schmidt, 2007; Viitanen and Ritschkoff, 1991).

One key component in wood decay is water, and a sufficient amount of water within cell walls is a requirement for decay (Thybring, 2013). While recent reviews have focused on the mechanistic relationship between water inside cell walls and decay of wood (Ringman et al., 2014; Zelinka et al., 2016), this study examines the water relations of the decayed material during and after both brown-rot and white-rot decay. Based on a compilation of a vast amount of experimental data from literature, the hygroscopic water uptake and cell wall water capacity is linked with changes in chemical composition and void volume during decay by simplified, mathematical modelling. Furthermore, the possible correlation between change in water content during decay and water production from fungal respiration is investigated. The aim is to investigate to what extent observations and assumptions regarding brown-rot and white-rot decay can explain changes in water relations observed during and after decay. Experimental data for modified wood has been included to the widest possible extent for comparison of effects of decay with that of untreated wood.

2. Literature data, corrections, and analytical models

2.1. Chemical composition data

Data from five different literature sources covering ten different wood species (7 softwoods, 3 hardwoods) exposed to brown-rot fungi and five different wood species (4 softwoods, 1 hardwood) exposed to white-rot fungi has been included in this study, see Table 1. Although a minor amount of extractives (1–4%) have been determined in the original sources, the relative composition

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Table 1
List of literature sources of chemical composition data including wood species and fungi. For the latter the original name used in the source is given along with the current name as suggested by the International Mycological Association. * = same current name as listed in the original source.

Wood species	Brown-rot fungus (name given in source)	Brown-rot fungus (recommended name)	Source
Aspen	*Gloeophyllum trabeum*	*	(Schilling et al., 2012)
	Postia placenta	*Rhodonia placenta*	
Douglas fir	*Gloeophyllum trabeum*	*	(Winandy and Morrell, 1993)
	Postia placenta	*Rhodonia placenta*	
Engelmann spruce	*Poria monticola*	*Rhodonia placenta*	(Kirk and Highley, 1973)
Eucalypt	*Gloeophyllum trabeum*	*	(Monrroy et al., 2011)
	Postia placenta	*Rhodonia placenta*	
Radiata pine	*Gloeophyllum trabeum*	*	(Monrroy et al., 2011)
	Postia placenta	*Rhodonia placenta*	
Sitka spruce	*Lentinus lepideus*	*Neolentinus suffrutescens*	(Kirk and Highley, 1973)
	Lenzites trabea	*Gloeophyllum trabeum*	
	Poria monticola	*Rhodonia placenta*	
Southern pine	*Poria monticola*	*Rhodonia placenta*	(Kirk and Highley, 1973)
Spruce	*Gloeophyllum trabeum*	*	(Schilling et al., 2012)
	Postia placenta	*Rhodonia placenta*	
Sweetgum	*Poria monticola*	*Rhodonia placenta*	(Cowling, 1961)
Western hemlock	*Poria monticola*	*Rhodonia placenta*	(Kirk and Highley, 1973)
Wood species	**White-rot fungus (name given in source)**	**White-rot fungus (recommended name)**	**Source**
Douglas fir	*Bjerkandera adusta*	*	(Winandy and Morrell, 1993)
	Trametes versicolor	*	
Sitka spruce	*Ganoderma applanatum*	*Ganoderma lipsiense*	(Kirk and Highley, 1973)
	Polyporus versicolor	*Trametes versicolor*	
Southern pine	*Polyporus versicolor*	*Trametes versicolor*	(Kirk and Highley, 1973)
Sweetgum	*Polyporus versicolor*	*Trametes versicolor*	(Cowling, 1961)
Western white pine	*Ganoderma applanatum*	*Ganoderma lipsiense*	(Kirk and Highley, 1973)
	Peniophora "G"	?	
	Polyporus versicolor	*Trametes versicolor*	

analysed in this study focuses only on relative fractions of cellulose, hemicelluloses and lignin as function of mass loss. Glucose contents in the composition data from sugar analyses have been assigned fully to cellulose. This yields slightly too high amounts of cellulose, since a small fraction of the glucose is found in softwood and hardwood hemicelluloses (Sjöström, 1993) in ratios of 1 to 2–4 with mannose. Based on determined amounts of mannose, it is estimated that the relative cellulose content might be 1–2% too high and hemicellulose content too low by a similar amount. As these amounts are lower than the scatter of the compiled experimental data, relative compositions have not been corrected for this.

2.2. Moisture content data during decay

Data from five different literature sources covering untreated and five different wood modifications are included in this study, see Table 2. Only data for two wood species (untreated and modified Corsican pine and untreated sweetgum) is included. Moisture contents of decayed samples after exposure to brown-rot or white-rot fungi are in this study compared with the same quantity for sterile controls exposed to similar moisture conditions but without fungi present. Correction of moisture content data for mass gain due to modification (weight percent gain, WPG) as described by Thybring (2013) was already done in the original literature sources. It could be argued that WPG also automatically lowers relative mass loss during decay, and therefore requires a similar correction of mass loss. However, wood modification protocols change the chemistry in a way that is by definition not toxic to fungi (Hill, 2006). Therefore, it is likely that for many modifications the fungal machinery will not bypass added chemical compounds but degrade them as well as wood polymers. As an example, reaction with acetic anhydride (acetylation) increases the amount of cell wall acetyl groups, which are already present in substantial amounts in unmodified wood hemicelluloses. These groups can be chemically detached by acetyl esterase enzymes that are common in wood decaying fungi (Biely et al., 1985; Pérez et al., 2002; Rytioja et al., 2014; Tsujiyama and Nakano, 1996). For this reason, it is speculated that wood modifications which do not markedly change the chemical nature of the cell wall, decay fungi are able to degrade wood polymers with the same biochemistry as used to degrade untreated wood.

2.3. Hygroscopicity data after decay

Data from nine literature sources exposing wood to water vapour, i.e. hygroscopic conditions after decay have been included in this study, see Table 3. These sources cover ten different species (6 softwoods, 4 hardwoods) exposed to brown-rot fungi and five different species (1 softwood, 4 hardwoods) exposed to white-rot fungi. Of all of these sources, only one examines modified wood (acetylated Corsican pine) after decay. For the saturated state, data comes from two sources examining untreated sweetgum using solute exclusion to determine accessible water volumes inside decayed cell walls.

2.4. Modelling changes in moisture content during decay

Moisture contents are often given by mass ratio of water to dry wood material. However, during decay the dry mass is decreasing over time (Fig. 1). In this situation, even when the water mass remains constant, the moisture content increases giving a misleading image of a change in water mass. For instance, if the moisture content in undecayed wood is 30% and water mass remains constant, a mass loss of 20% causes an increase in moisture content of 7.5%. In order to better compare wood samples decayed to various extents, it is therefore necessary to correct for mass loss, i.e. to