Potential wood protection strategies using physiological requirements of wood degrading fungi

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Due to the increasing restrictions in the use of wood preserving biocides a number of potential biocide free wood preserving alternatives are currently assessed. Wood degrading fungi require certain conditions in the wood in order to be able to use wood as a food source. This paper discusses the physiological requirements of wood degrading fungi and potential wood protecting strategies based on the limitation of essential requirements of the fungi. Most of these methods are based on reduction of the water and nutrient availability, two factors which can by influenced by the application of some preservation techniques.

Key words: wood, wood degradation, non- biocidal wood preserving strategies

1 Introduction

Wood is a multi-use biological raw material with a high economic importance for a number of industrial sectors such as construction, furniture and the packaging industry. However, its natural durability performance is critical for cost-effective performance over the whole life of a building or construction component and is much more variable than that of materials such as concrete or metal. Under unfavourable conditions, fungal or insect activity or other detrimental impacts, the service life of some wood products can be limited.

In order to overcome the susceptibility of wooden products for wood degrading organisms, wood species with a high durability or biocidal wood preservative treatments are used. The environmental acceptance of many wood preservatives however is very low at present. The EU legislation is restricting the continued use of CCA preservatives and creosote. It is however evident that the importance of wood in the building sector is related to the service life of products made of wood or wooden products.

The question arises which potential non-biocidal alternatives can be applied and at least partly replace the substances that will probably only be used to a small extent in future. In this paper potential non-biocidal developments and methods in wood preservation are discussed.

2 The physiological basis for wood degrading fungi

The activity of micro-organisms and therefore also wood degrading fungi is depending on a number of physical, chemical and biological factors.
The occurrence and ratio of these factors can act as a stimulator or hinder their activity until a complete stop of growth. These factors are therefore considered as important elements in the non biocidal prevention of the degradation activity of wood degrading fungi. The knowledge and use of these factors in order to influence the fungal growth is one of the keys in wood conservation.
Four main points have been identified that offer the potential to influence the fungal activity:

- Wood moisture
- Nutrients
- Oxygen
- Temperature

An optimum of these 4 aspects can lead to high fungal activity. If only one of these factors can be changed in a way that it does not fulfil the fungal requirements, degradation should be limited.

2.1 Wood moisture

The water availability for fungi is influencing the degradation processes to a large extent and is therefore the most important factor in wood conservation. The fungi need water in order to take up the nutrients and for transport processes within the mycelium (Table 1). The enzymes, which are required for wood degradatation, are depending on water and the hyphea of fungi are also consisting of 90% water (Schmidt 1994).
The water occurs in wood as hygroscopic water or as bound water. The hygroscopic water or capillary water is found in liquid form in the lumina and other cavities in the wood, whereas the bound water is located in the cell wall and bound to the hydroxyl groups of the celluloses, hemicelluloses or lignin.
The moisture content of materials is often expressed as the percentage of moisture based on the dry mass of the material.

u [%] = ((mw-md)/md) x 100
u = moisture content
m = mass of wood wet
md = mass of wood dry

Table 1: Range of moisture contents for typical wood degrading fungi (Schmidt 1994):

	Minimum moisture content [%]	**Optimum moisture content [%]**	**Maximum moisture content [%]**
Coniophora puteana (Brown rot)	24- 30	30-70	60-80
Serpula lacrymans (Brown rot)	17-30	30-60	55-90
Coriolus versicolor (White rot)	25-30	35-55	60-90

The micro-organisms however can not use the whole water of the substrate but only the water that is not bound by dissolved substances such as salts, sugars etc.. Finally is not the absolute moisture content the essential factor on fungal activity, but the wateractivity, which is invluenced by matrix potential and pores (Table 2) of the materials. They determine to what extent the water can be used by the micro-organisms. The water activity (a_w) is defined as the ratio between the water vapour pressure of the solution (p_S) and the water vapour pressure of pure water (p_W) (Schmidt 1994, Carlile *et al* 1995).

$$a_w = p_S / p_W$$

Table 2: Water availability in different environments

Water activity	**Water potential**	**Pore radius µm**	**Examples**
1.0	0		Celllumina, pure water
0.9993	-0.1	1.5	Fibre saturation
0.98	-2.8	0.5	Sea water
0.97	-4.2	0.035	Lower limit wood destroying fungi
0.96	-5.6	0.026	Leaf litter
0.90	-14.5	0.01	Ham
0.80	-30		Low limit for Aspergillus and
0.60	-69		Penicillium
			Limit for cell-growth

In order to overcome dry periods the fungi can produce dry resistant mycelium or spores. The mycelia of some basidiomycetes are considered as dry resistant. In tests it was found out that under favourable conditions the mycelium of fungi like *Coniophora puteana* or *Gloeopyllum abietinum* can keep their growth ability for several years.

In most cases however is the forming of dry resistant spores for fungi the most efficient strategy to overcome critical climate conditions.

2.2 Temperature

The temperature is also influencing the fungal activity. In most cases wood degrading fungi cannot be active at temperatures below 0°C. At lower temperatures the water is frozen and the enzymes cannot be active due to lack of liquid water. The temperature optimum depending on the fungus is between 20-40°C, with a maximum of 50°C. At temperatures of more than 50°C the degradation of the proteins is the limiting factor, restricting the synthesis of enzymes. In practise however it is very difficult to influence the temperature of the surrounding of wooden buildings, the application of the higher temperatures to protect the wood is therefore practically limited to remedial treatments.

2.3 Oxygen

Although the reduction of oxygen offers a certain protection potential the method depends in practice on a very high water content in the wood and its surroundings in order to replace the oxygen in the wood. Examples are wooden poles in areas with high ground water and the wood storage under water. The exclusion of oxygen is very much dependent on the surrounding and can therefore not easily be controlled.

2.4 Nutrients

The main components of the world's biomass, polysaccharides and lignin can be degraded by a large number of micro-organisms. Wood consists mainly out of polysaccharides such as hemicelluloses and celluloses (Table 3) and is therefore a potential food source for wood destroying fungi.

Table 3: Proportion of main wood components

	Softwood [%]	**Hardwood [%]**
Cellulose	42-49	42-51
Hemicelluloses	24-30	27-40
Lignin	25-30	18-24
Extractives	2-9	1-10

The different wood components are degraded by the enzyme systems of the fungi and are distinguished according to the degradation patterns. The three main rot types are:

- Brown rot
- White rot
- Soft rot

The degradation patterns are formed by specialized microorganisms with specific enzyme systems. The efficiency of these enzymes to attack wood is depending on several factors:

- Contact with the substrate
- Moisture content
- Interactions with the substrate

The degradation of the wood requires penetration of the enzymes into the cell walls of wood (Figure 1). A number of wood degrading enzymes have been identified, most of them are however too big to penetrate through the micro pores of the wooden cell wall (Kirk 1985).

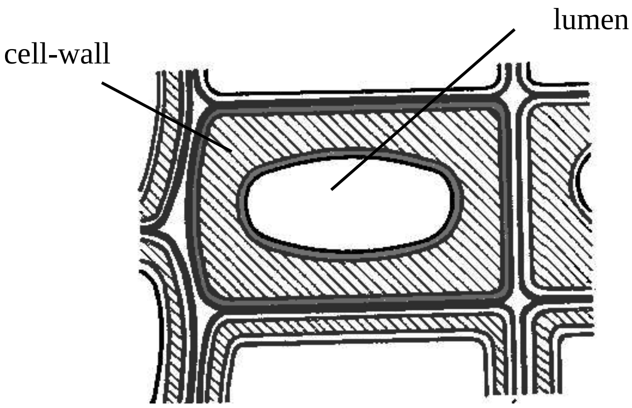

Figure 1: Cell-wall of a typical softwood

How the relative large enzymes manage to penetrate the wood is not yet clear. Most of the pores in the wooden cell wall have a diameter between 2 and 4 nanometer (nm) (Kirk 1985, Rapp 1999, Hale *et al.* 2003) and are therefore too small for most of the enzymes (Table 4).

Table 4: Size of different enzymes

Enzymes	**Size**
Cellulases	5.0 nm spherical or 3.3 x 20 nm if ellipsoidal
Xylanase	7 nm
Lignin peroxidases	4.7 nm (spherical) of 4.3 nm x 6.0 nm

Obviously also some other systems are effective. The penetration of different low molecular wood degrading substances (LMWDAs) is suggested as a possible initial degrading mechanism.

The white rot morphology is characterized by the removal of celluloses and in a later stage the degradation of celluloses. White rot enzymes (peroxidases, laccases and others) are too large for initial cell wall penetration. The LMWDA's play probably an important role especially in lignin degradation.

For the brown rot fungi (*G. trabeum*) a chelator mediated Fenton system (CMFS) is suggested, using Fe, ortho dihydroxy catechol, H_2O_2 and hydroxyl radicals (Hale *et al.* 2003).

3 Non-biocidal wood protection strategies

Based on the physiological requirements of the fungi some potential non-biocidal wood protection strategies are regarded. The main targets are in most cases the moisture and nutrition requirements. Changes in the wood shall restrict the conditions that are required for wood degradation. Principally two different treatments are distinguished: Treatments which do not cause changes within the cell wall and treatments that cause changes within the wooden cell wall. Treatments that cause changes on cell wall level are also known as wood modification. Examples of potential wood treatments are presented in Figure 2.

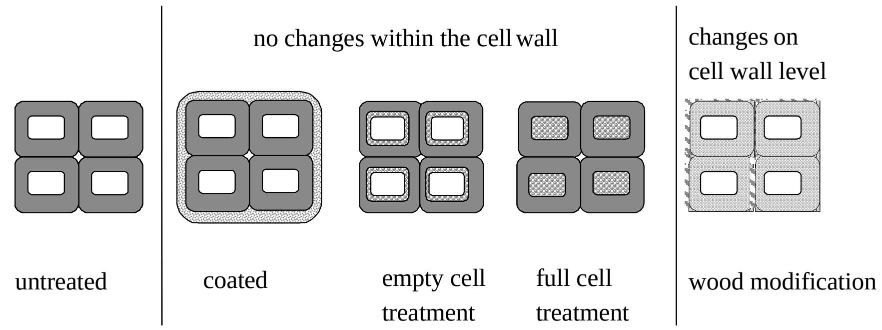

Figure 2: Examples of different potential wood treatments

3.1 Treatments without changes in the call wall

Exceeding a certain moisture content over a period of time is considered as one of the main degradation factors. A wood moisture content of more than 20%-25% is considered as critical and can cause wood rot. The most frequent non-biocidal wood preservation strategy used is therefore the reduction of moisture content. In wood expositions without permanent ground contact is the application of hydrophobic substances on the wood surface a commonly applied method.

Intact coatings possess a strong water repellent effect. A typical character of surface treatments on wood is however the reduced efficiency caused by ageing processes at exposition (Sell 1980**,** Nilsson 1993). At a low vapour permeability of the coatings the water content is often increased within the wood after water penetration through cracks or damages in the coating. This leads to a increased risk of fungal decay (e.g. Sell 1973, Williams 1991).

Because of the non-biocidal efficiency of hydrophobing coatings within the wood and the low surface protection of not film forming impregnations new combination processes have been assessed. The combination of coatings and impregnations with bioeffective substances was tested by a number of researchers (e.g. Evans *et al.* 1992, Williams and Feist 1999**,** Breyne 1999). Also impregnations with hydrophobic resins have been suggested (Peek *et al.* 1992, Sailer *et al.* 1998, Passalis and Voulgaridis 1999). The hydrophobation effect of oil-treatments at Scots pine is demonstrated in Figure 3.

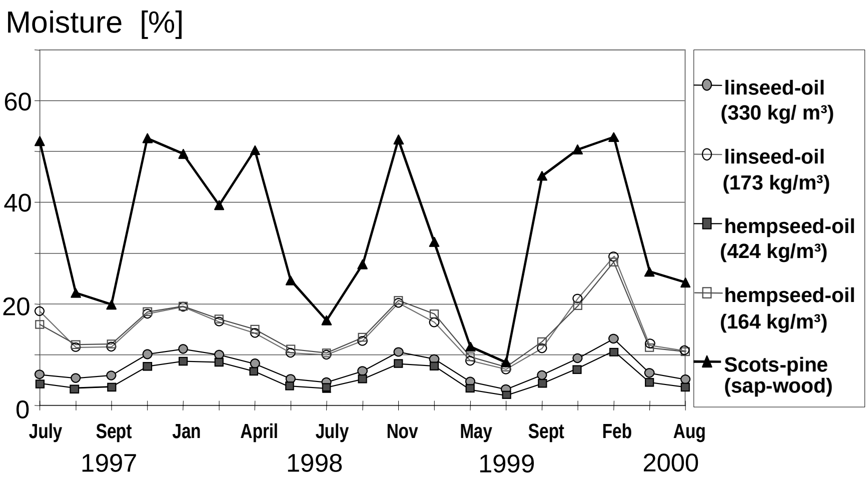

Figure 3: Moisture contents of treated and untreated Scots pine at outdoor exposition

The hydrophobing effect of a filmforming oil-impregnation which is observerd at outdoor exposition can be attributed to the combination of different factors:

1. Intact coatings as received with high oil-loadings and temperature treatment possess a strong water repellent effect.
2. At high retentions of oils is the wateruptake of liquid water via the capillaries delayed (Dirks 1999). The periods with higher moisture contents are in practice very often too short for wood degrading fungi at expositions without ground contact. A high moisture content will be however achieved in permanent ground contact or sourrounding with a high moisture content over a longer period.

3.2 Changes on cell wall level

Enzymes, especially the polysaccharides are very substrate specific. According to Kirk (1985) almost any synthetic modification of the substrate will prevent effective contact with the modification site of the substrate polymer. The most assessed treatment that claims to substitute the hydroxyl groups of the cellulose or hemicelluloses is the acetylation. Other potential wood modification processes are based on the impregnation of the wooden cell wall with substances such as silicates (Figure 4), furfuryl alcohol, melamine resins or the application of higher temperatures, which degrades the wood structure to a certain content (Figure 5).

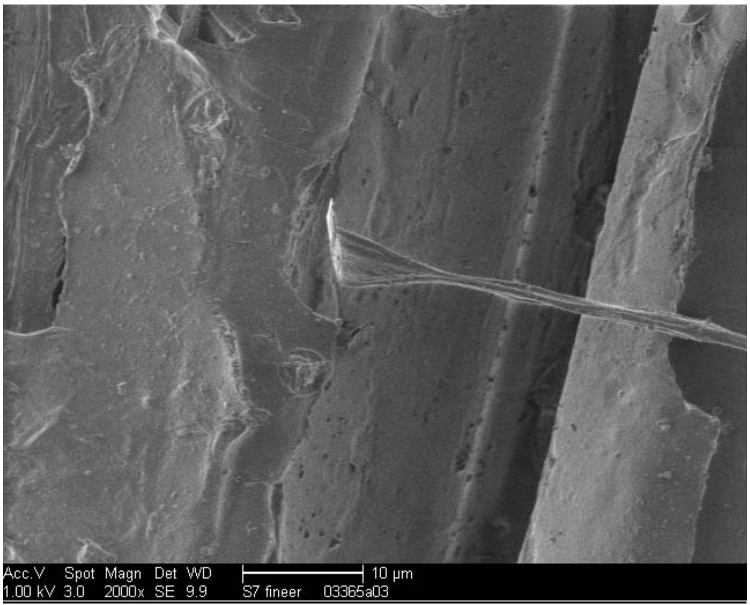

Figure 4: With silanes treated Pinus sylvestris after exposition to the brown rot fungus Coniophora puteana.

Changes in the cell wall

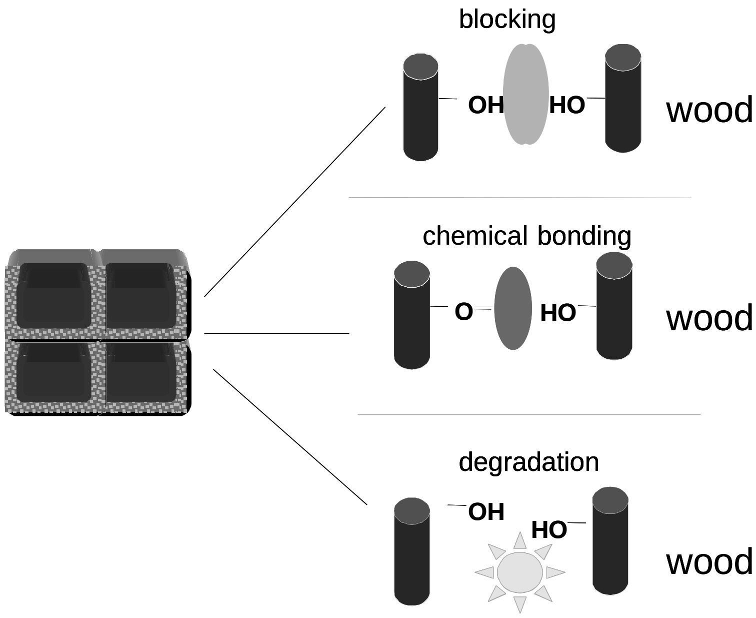

Figure 5: Possible changes in the wooden cell wall with effects on the wood properties

3.3 Combination treatments

Few authors only assessed the combination of modifications of the wood on cell-wall level and an additional hydrophobation by lumen filling substances. Rowell *et al*. (1982) treated pine and marple with propylenoxid-triethylamin and impregnated the wood later with methyl-metacrylat (MMA), Hafizoglu and Yildiz (1990) impregnated acetylated wood with linseed-oil and Sailer *et al.* (2000) combined the heat-treatment of wood with vegetable oils and achieved a good performance of the treated wood in durability tests according to the European standard EN 113. A combination treatment of acetylation and impregnation with melamine resins that resulted in a good durability in sea water is described by Epmeier *et al.* 2003.

3.4 Mode of effectiveness

Since the modification of the wood substance reduces the moisture content in the wooden cell wall (Rapp1999) it is not clear whether decay resistance is due to a hindering of enzyme action or disruption of necessary water relations (Kirk 1985). New research however suggests that the blocking of the space in the cell wall might be one of the effective mechanisms at treatments of wood with different substances (Lukowsky 1999, Hill and Hale 2004). That however implies that the efficiency of wood modification is not necessarily based on chemical changes of the wood substrate but also on the limitation of the accessibility of the wooden cell wall.

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