Protection of timber constructions by using electro osmotic pulsing technology (PLEOT)

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Abstract Timber constructions are often built in combination with other materials such as concrete. These materials can influence the timber construction. Moist concrete can e.g. lead to development of molds which creates an unhealthy living area for people. Furthermore, moisture in wood buildings can negatively affect the wood material, which can lead to negative biological activity in timber and possible reduction of strength properties of timber constructions.

The present paper introduces a new innovative method of timber protection and describes the influence of moisture on wood and concrete.

The new environmental friendly system for protection of timber has been tested on wood destroying fungi and termites. It can be shown that wood protection by means of electro osmotic pulsing technology can preserve wood in laboratory trials. The wood moisture content is reduced when the protection system is installed. Trials on protected wood against subterranean termites showed lower wood moisture content after test of protected samples compared to untreated samples. However, termite activity could not be reduced to a larger extend as the termite living surroundings were not included.

It could be shown that humidity in pores of concrete in cellar walls is reduced using electro osmotic pulsing. The drying of concrete when combined with timber constructions can additionally help to reduce timber degradation as all protection measures that lead to a drier building are positive for fungi and subterranean termite control.

Keywords electro osmotic pulsing technology, subterranean termites, wood destroying fungi, concrete

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1. INTRODUCTION

Wood and water in buildings

The use of wood as building material is desired for stability-, environmental- and esthetical reasons. Wood has good strength properties and is at the same time a low weight building material. Only a few building materials possess the environmental benefits of wood. It is a natural and renewable resource and the appearance of wood is generally regarded as natural and positive.

The esthetics and even the stability of wood can be altered when moisture is affecting the wood material. Due to the biodegradable characteristics of wood it is obviously vulnerable when negative factors such as water and microorganisms access wood.

Moisture can play a key role in the accessibility of microorganism to wood. This can affect human comfort and health and can have an influence on building durability. Consequently, more maintenance and repair activities are required. Additionally, moisture can reduce the insulation performance of materials which leads to increased energy consumption.

Termite attack

Subterranean termites may cause extensive damage to wood. Protection of wood structures against termite attack is therefore an important task, especially in temperate and tropical climates. However, with global warming phenomenon, this problem may spread through other areas. The effort of protecting wood structures has been based mainly in the direct application of chemical treatments, although when this application is done to wood in service, it is very difficult to guarantee full control of the problems. Besides, the negative impact and the persistence of some of these compounds in the environment and human health have lead to the search of “green” termite control technologies (Nobre and Nunes 2007).

Wood moisture content is one of the most important factors for subterranean termite attack, since they need earth contact and a source of moisture to successfully infest a building component. Various sources of moisture can affect buildings. It can be surface runoff of precipitation from land areas, ground water or wet soil, precipitation or irrigation water that falls on the building, indoor humidity, outdoor humidity, moisture from use of wet building materials or construction under wet conditions, and errors, accidents, and maintenance problems associated with indoor plumbing (Wacker 2010). The control of wood moisture content may be a key factor in the prevention of a subterranean termite attack.

Wood in combination with concrete

When used in combination with wood, porous building materials such as concrete and other composite construction materials made of cement, as well as sand-, clay-, or rock-based materials are accessible for water and can therefore strongly influence, wood moisture content therefore leading to a higher risk of degradation.

Wood protection

Wood products from wood species with low natural durability are traditionally protected from attack by decay-fungi, bacteria, insects or marine-borers by applying chemical wood preservatives. The current application of wood preservatives is linked to several restrictions and directives concerning biocides (arsenic, chromium, creosotes etc.). Alternatives to conventional preservatives have become more important in European and North American markets, leading to the development of organic and inorganic chromium-free wood preservatives (Murphy 1998; Read 2003).

Besides conventional wood preservation, new wood protection technologies have been introduced, such as wood modification with furfuryl alcohol, acetylation of wood, interlace treatment with DMDHEU and heat treatment, which modify the chemical structure of wood (Hill 2006).

Wood is eco-efficient during its entire life cycle. Carbon storage can be extended by increasing the lifespan of wood products. Wood and wood products are among the most commonly used materials for recycling into new products. Nevertheless, the disposal of wood preservative treated material causes restrictions in its later use or recirculation into the eco-cycle.

New technology to protect wood in buildings – PLEOT

Lately, a new technology has been tested against fungal and termite attack in wood (Treu and Larnøy 2010). The technology, wood protection by electro osmotic pulsing (PLEOT), is based on the application of an electric field. The electro osmotic pulsing technology is used also in buildings in order to remove water from wet parts of concrete or other porous material. These materials can be dehydrated when electrodes are placed across the material and a low direct current is applied. A certain pulsing pattern carries ions from one electrode side to the other, bringing with them water molecules that clump around the ions. Several patents on “a method for dehydrating capillary materials” (Utklev 1998; Kristiansen 2006) were filed by the Norwegian company EPT and sold to the United States. The patents claim the invention of a pulse pattern structure by which optimum dehydration of a substrate can be obtained.

Wood has a low specific conductivity and is considered as a dielectric material (Torgovnikov 1993). Water plays therefore an important role. With increasing wood moisture content a favorable environment for fungi development is created. At the same time, increasing wood moisture content increases the conductivity in wood and PLEOT can protect the material. Wood can be considered as naturally protected against fungal attack at a wood moisture content <20%. It could be shown, that a protection by means of PLEOT can be achieved even at higher wood moisture content (Treu and Larnøy 2010).

Wood in contact with other porous building materials, such as concrete, can be protected by stopping or reducing water to access wood. This can be done by drying the surrounded materials. A system based on electro pulsing can also be used to dry these buildings materials. A permanent installation in both wood and the surrounding material could lead to drier buildings even in areas where water is present either due to precipitation or other access of water. Capillary water can be moved to one direction and the opposite pole area can be dried to certain degree.

Aim of study

This study investigates a method to reduce moisture in materials such as wood and concrete. Therefore, the anti fungal effectiveness of PLEOT, which is closely related to moisture, is tested against white rot fungi (*Coniophora puteana* and *Trametes versicolor*) in a mini block test using Scots pine sapwood and beech wood samples. Additionally, Scots pine sapwood samples are exposed to subterranean termites (*Reticulitermes grassei*). The wood moisture content, influenced by PLEOT, is investigated and the effect of electro osmotic pulsing on relative humidity in pores of concrete walls is evaluated.

2. MATERIAL AND METHODS

2.1. Electro osmotic pulsing technology

Electro osmotic pulsing technology (PLEOT) is an installation that needs to be connected in order to protect the material tested. Negative and positive electrodes were connected in lab trials on each wood sample and are part of the test setup. Conductive polymer is used to connect the wood samples to PLEOT. The conductive polymer is inserted into holes on each transversal side of the wood samples. An asymmetric pulsed, low electrical voltage is applied during the whole test, whereas the current within the treated region of the wood material will be less than 1mA. This ensures effective treatment without risk to humans or animals coming into contact with the material.

2.2. Test on fungal degradation of protected wood

Non-leached beech (*Fagus sylvatica*) and Scots pine (*Pinus sylvestris*) sapwood samples with dimensions of 10 x 5 x 30 mm³ (miniblocks) were tested on the white rot fungus *Trametes versicolor* and brown rot fungus *Coniophora puteana* for 4 and 8 weeks according to Bravery (1978) using 40 V/1 kOhm of PLEOT. Additionally, PLEOT was connected after 4 weeks of trial. This was tested in order to simulate a protection during attack. The samples were connected to PLEOT by drilling 5 mm deep and 2.1 mm wide holes in diameter into the center of each transversal end side of the samples.

2.3. Test on degradation by subterranean termites

Reticulitermes grassei were collected from broken trees and stubs in a forest of *Pinus pinaster* in Portugal, situated at N38º32.436’ W009º07.848’. Termites workers were kept in a rearing chamber (T: 24 ± 2ºC; RH: 80 ± 5%) for a short period before testing.

Choice tests with treated and untreated wood specimens were established. Non-choice tests for both treated and untreated wood (controls) were started at the same time. Fontainebleau sand humidified with water at a proportion of 1:4 (v/v) was used as a substrate. Groups of 250 termite workers, belonging to the same colony, were distributed for each pair of choice test containers and for each non-choice test and control containers. The trials were placed in the testing chamber for 4 and 8 weeks (full description and results in Treu *et al*. 2010).

In the end of testing, each wood sample was evaluated, using the rating system according to EN117 (2005) for termite attack. The number of living termites was registered, as well as the final dry mass of wood sample and the results analyzed. An analysis of similarities (ANOSIM) was performed to determine the significance of possible differences among types of treatment and type of test, using Primer version 5.2.6 statistical package (Clarke and Warwick, 1994).

2.4. Moisture reduction in concrete

Electro osmotic pulsing was installed in a cellar of a building in Fredrikstad, Norway, with outside walls of 250 – 400 mm site concrete. Walls on the inside of the cellar had 150-250 mm concrete with 20 mm plaster on the inside of the wall.

The floor of the cellar was made of 300-400mm concrete (concrete quality B300, LP watertight (Betokjem) is added). On top of this, a layer of 120-250 mm gravel was added with another layer of concrete flooring. This floor construction was used in order to reduce the amount of water transported from the ground, which was in very wet conditions (cellar is under groundwater level, 220 cm under ground level), into the cellar.

The house was built in 1965-1967. The electro osmotic pulsing was installed in summer 1999. 7 sensors (Vaisala HMP44) were installed in the walls of three rooms in different depths and heights of the walls (table 1) in the summer of 1999 in order to log the data on temperature and relative humidity [%]. The data logging was done over a period of 6 years.

Table 1 – Positioning of temperature and humidity logger in cellar walls

Temperature and r. H. [%] logger	Place	Depth [mm]	Height [mm]
A	Inner wall, archive/panic room	50	290
B		100	250
C	Outer wall	50	200
D	Outer wall, arch	200	300
E		200	1200
F	Outer wall, wardrobe	100	300
G		50	300

3. RESULTS AND DISCUSSION

3.1. Protection against fungal attack

Mass loss due to fungal degradation was > 30% on untreated beech wood samples exposed to *Trametes versicolor* and > 20 % for Scots pine sapwood samples exposed to *Coniophora puteana* which verify the test. The mass loss both after 4 and 8 weeks was higher for the hardwood species beech than for the softwood species Scots pine for the respective period of exposure to *Trametes versicolor*. The opposite trend was observed on the two wood species exposed to *Coniophora puteana*. Wood samples, both beech and Scots pine, had nearly no mass loss after 4 and 8 weeks of exposure to *Trametes versicolor* or *Coniophora puteana* when protected by PLEOT (figures 1 and 2).

Wood samples that were exposed 4 weeks to *Trametes versicolor* and protected after these 4 weeks for the rest of the test duration showed significantly lower mass loss than untreated control samples after 8 weeks of exposure. It was therefore concluded that the protection could stop or slow down the fungal attack after 4 weeks. It is therefore believed, that PLEOT installed in infested buildings or samples could stop infestation. However, this could not be shown on beech and Scots pine samples when exposed to *Coniophora puteana*.

The brown rot fungi have degraded the untreated wood samples, especially Scots pine, to great extend already after 4 weeks when compared to the mass loss after 8 weeks of exposure. The mass loss of untreated Scots pine sapwood samples and beech wood samples shows no significant difference between 4 and 8 weeks when exposed to brown rot. In contrary, the mass loss of untreated samples exposed to white rot show significant differences in mass loss after 4 and after 8 weeks.

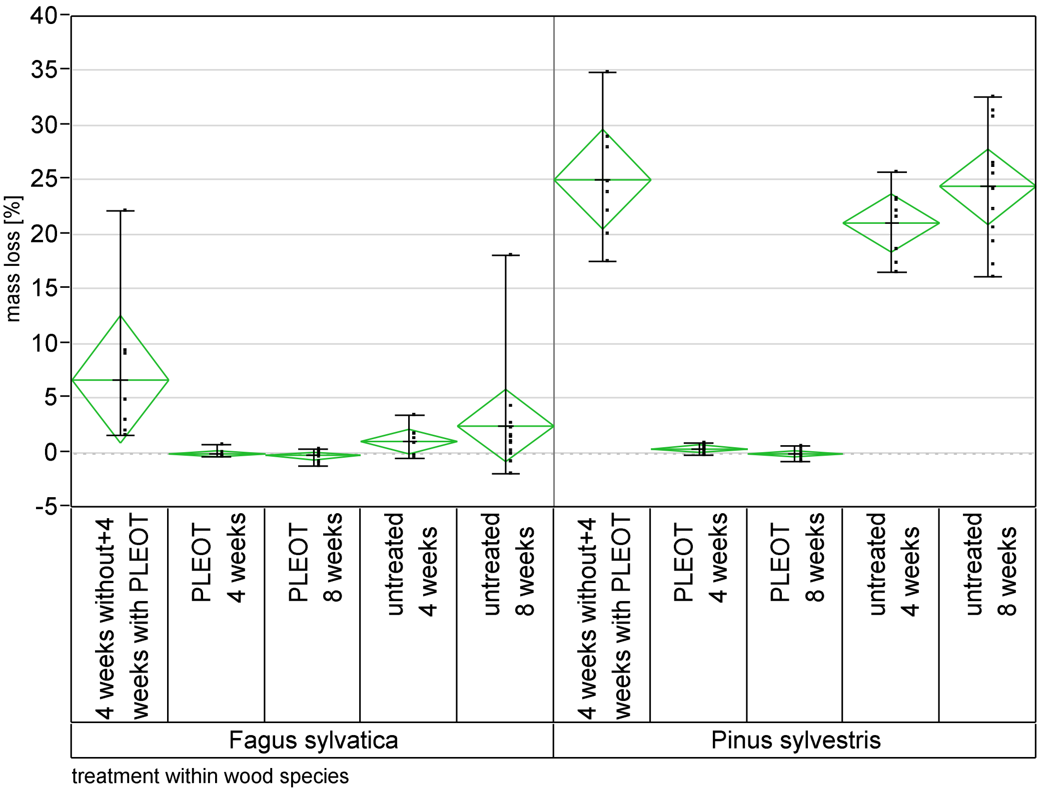

Figure 1 – Mass loss of PLEOT protected and untreated beech and Scots pine sapwood samples after 4 and 8 weeks of exposure to *Coniophora puteana*.

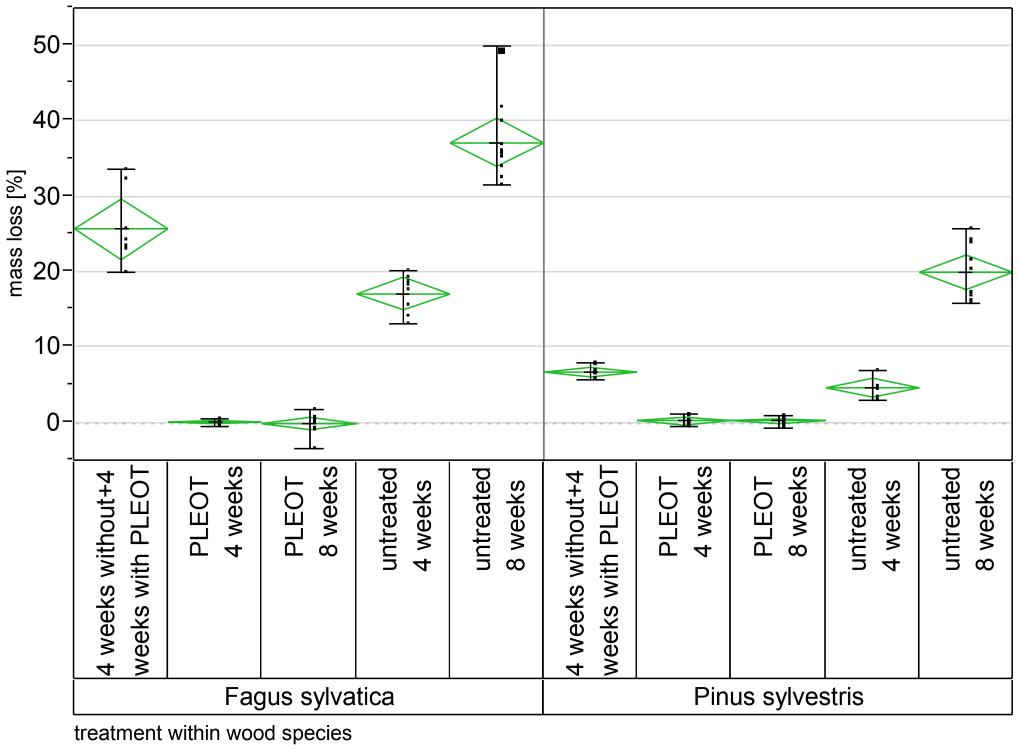

Figure 2 – Mass loss of PLEOT protected and untreated beech and Scots pine sapwood samples after 4 and 8 weeks of exposure to *Trametes versicolor*.

The wood moisture content was generally lowered with PLEOT protection (table 2). This can be due to less fungal activity in the samples or due to transport of water out of the samples by using PLEOT. It is still unclear how the wood moisture content after 4 and 8 weeks of PLEOT protection is distributed within the wood sample.

Table 2 – Wood moisture content of PLEOT protected and untreated beech and Scots pine sapwood samples after 4 and 8 weeks of exposure to *Coniophora puteana* and *Trametes versicolor*.

wood species	treatment	fungi species	average wood moisture content [%] (STDV)
Pinus sylvestris	PLEOT 4 weeks	*Coniophora puteana*	42,54 (19,07)
		Trametes versicolor	54,69 (32,83)
		No fungi	30,42 (0,82)
	untreated 4 weeks	*Coniophora puteana*	110,13 (11,21)
		Trametes versicolor	96,99 (22,22)
	PLEOT 8 weeks	*Coniophora puteana*	50,39 (39,48)
		Trametes versicolor	44,20 (21,34)
		No fungi	29,79 (0,42)
	untreated 8 weeks	*Coniophora puteana*	113,14 (19,13)
		Trametes versicolor	130,03 (32,77)
	4 weeks without+4 weeks with PLEOT	*Coniophora puteana*	53,08 (13,02)
		Trametes versicolor	58,38 (55,03)
		No fungi	28,88 (1,57)
Fagus sylvatica	PLEOT 4 weeks	*Coniophora puteana*	33,20 (1,46)
		Trametes versicolor	46,63 (17,21)
		No fungi	33,15 (1,61)
	untreated 4 weeks	*Coniophora puteana*	75,38 (8,48)
		Trametes versicolor	70,92 (18,09)
	PLEOT 8 weeks	*Coniophora puteana*	53,83 (24,07)
		Trametes versicolor	63,66 (31,64)
		No fungi	30,65 (0,66)
	untreated 8 weeks	*Coniophora puteana*	95,85 (9,93)
		Trametes versicolor	67,91 (8,94)
	4 weeks without+4 weeks with PLEOT	*Coniophora puteana*	45,48 (5,65)
		Trametes versicolor	86,74 (39,17)
		No fungi	29,56 (2,73)

3.2. Exposure to subterranean termites

For the purpose of this paper, results are only summarized (full results in Treu *et al.* 2010). Termite survival was over 50 % for the untreated samples with low initial moisture content. Wood samples with high initial moisture content were covered with mould fungi after 4 weeks which results in a lower termite survival. According to EN 117 (2005) the test would not be valid for wood samples with high initial moisture content due to this very low termite survival.

Wood mass loss caused by termite attack in a non-choice test is 4.5 % after 4 weeks for untreated Scots pine samples with low initial wood moisture content and 15.5 % after 8 weeks. Studies on an accelerated termite test reports 13.3 % mass loss after 4 weeks using untreated Scots pine sapwood samples (Feci et al. 2009). The wood mass loss is lower in a non-choice test after 4 weeks and slightly lower after 8 weeks using PLEOT protected samples.

The attack degree was higher in controls, where 75.0% of the samples were classified with the highest level of attack; in non-choice tests 50.0% of the samples were classified with the highest level of attack. In two-choice tests, the level of attack was lower, comparing with control and non-choice tests, since only 12.5% of the samples reached the highest attack level. Accordingly to these results for attack degree, the mass loss associated with the tests was lower for two-choice tests (average 0.9% ± 0.8%), comparing with non-choice (2.0% ± 1.7%) and control tests (3.6% ± 1.4%).

Particularly relevant was the effect of the treatment on the wood moisture content and the superficial development of moulds that can happen at higher moisture levels (figure 3). The moisture content was higher in control tests (average 93.8% ± 48.5%), compared to non-choice (59.5% ± 28.4%) and two-choice tests (51.7 ± 31.0%) and the development of moulds was significantly lower on PLEOT treated samples.

Figure 3: Scots pine sapwood samples after 8 weeks of exposure to subterranean termites, (left) PLEOT protected, (right) unprotected

3.3. Drying of concrete

The relative humidity [%] in the 7 areas of measurement is reduced significantly during 6 years of installation of electro osmotic pulsing. The moisture reduction is starting rapidly after installation. The relative humidity [%] is reduced by 10- 15 % after the first year of installation.

The drying of concrete of outside wall areas is comparable to the drying of inside wall measurements (figure 4). It is therefore concluded that the drying on the surface of the walls is starting at the same time as the drying inside the walls. A drying due to natural room drying is therefore not likely. In addition, due to the situation of the cellar under groundwater level, it is not believed that moisture variations due to climate variations had an influence on the measurements. This reduction in the first year of installation is therefore attributed to the electro osmotic pulsing.

After one year of installation, the outer parts of the walls approximate 75% rel. humidity in the pores.

During 5 years of installation, the measurements deep inside the walls show smallest amount of changes in moisture. It is assumed that access of moisture from outside cannot be compensated by electro osmotic pulsing under 75 %.

It could be shown that variations in moisture of concrete are correlating to the changes in relative humidity during the year. High peaks are correlating to weather conditions in September and October, whereas lows are correlating to January-March (measurement area C and G).

For inside walls the concrete became dryer during 6 years of installation with reduced cyclic variations due to different weather periods. This means that moisture access to the inner part of the walls was reduced to great extend.

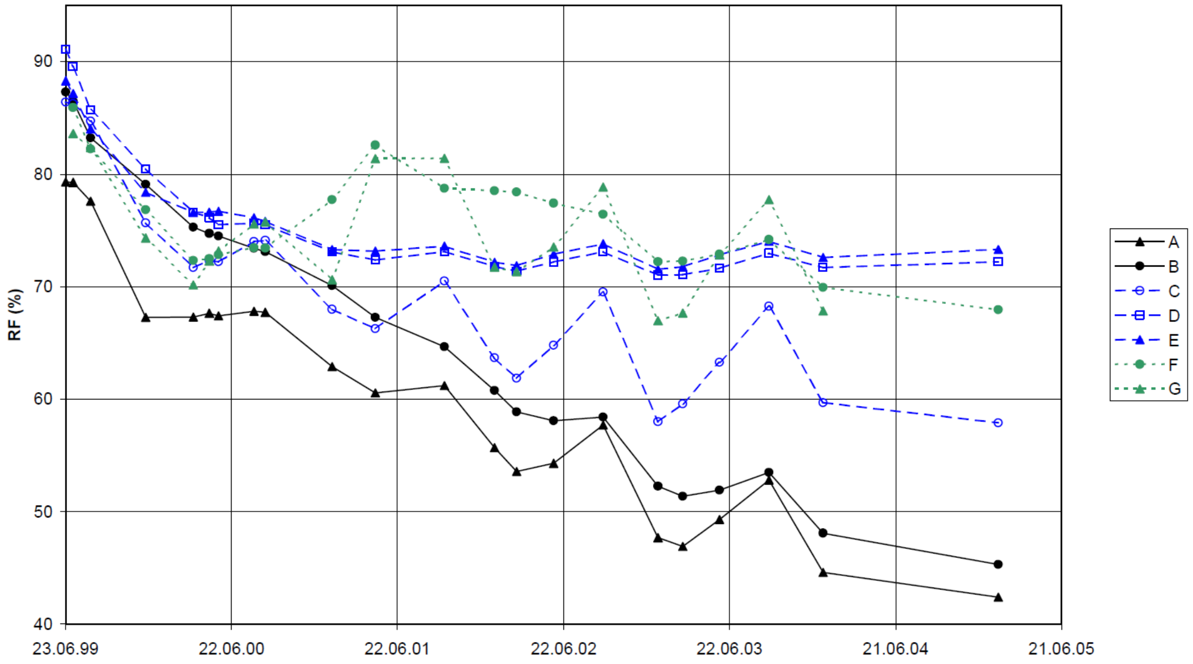

Figure 4 – Development of relative humidity (RF) [%] at 7 different measurement areas in the cellar of a building during 6 years of installation of electro osmotic pulsing technology, data logger A and B is installed in the inner part of the wall, C-G in the outer part

4. CONCLUSIONS

The electro osmotic pulsing technology (PLEOT) protects Scots pine sapwood and beech samples against fungal decay when exposed to brown- and white rot. The wood moisture content of protected samples is lower compared to untreated samples. PLEOT could stop degradation of unprotected wood samples exposed to white rot when protection was installed after 4 weeks. Unprotected brown rot exposed samples had already high mass loss after 4 weeks and showed therefore no significantly different mass loss after 8 weeks. The wood moisture content was generally lowered by the PLEOT protection.

For termite testing, it was observed that, when moisture content was higher (control tests), the termites attack degree also increased, on the other hand, when moisture content was lower (other tests, with PLEOT) the attack degree decreased. Subterranean termites need a high moisture content of wood to perform their attack (Nobre and Nunes, 2007). PLEOT can play an important role in an integrated strategy to control subterranean termites attack to wood in service, since it is a low invasive method of intervention which favors the maintenance of lower wood moisture contents and therefore reduces the probability of attack by the insects.

The electro osmotic pulsing drastically reduces the moisture level of concrete walls in the cellar of the tested building. In inner walls the concrete is dried to ca. 45 % after 6 years. The outer parts of the walls have larger access to water, but rel. H. < 75 %. The de-installation of the technology will lead to the moisture conditions of the initial state.

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