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Section 4 **Processes and Properties**

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Wood protection by means of electro osmotic pulsing technology (PLEOT)

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ABSTRACT

Wood protection is mainly based on chemical protection of wood. The disposal of wood preservative treated material causes restrictions in its later use or recirculation into the eco-cycle. A new protective system, electro-osmotic pulsing technology on wood, called PLEOT, is tested in a fungi test and in soil contact. Mass loss and moisture content of Scots pine sapwood samples was calculated after testing and an element analysis was performed on the sample powder.
The results show that PLEOT- protected samples have nearly no mass loss after 4, 8 and 12 weeks of exposure to *Coniophora puteana* in laboratory trials. The samples protected with PLEOT showed lower moisture content but trace elements of metals in the samples after basidiomycete test compared to untreated samples. It is concluded, that neither the resulted wood moisture content nor the transferred metal ions in the PLEOT samples contribute to large amounts to the wood protection effect. Furthermore, the PLEOT system might give a protection for wood in soil contact.
Further research on the mode of action as well as further tests including field tests are under planning.

Keywords: electro osmotic pulsing, fungi test, PLEOT, wood protection

1. INTRODUCTION

The most commonly-used timber for products in outside applications (e.g. house claddings, fences, floorings, windows, garden furniture, noise barriers etc.) in Europe has little resistance to decay compared to the some more durable wood species from tropical forests. An increase in durability is therefore required if such wood products are to be used for above-ground or in ground applications. Wood is 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).
The wood preservation industry uses mainly copper- based and metal- free products. 415.035 m^3 copper- and 3.700 m^3 metal-free impregnated wood has been produced in Norway in 2006. The Western European wood preserving industry supplies around 6.5 million m^3 of pressure treated wood per year for woodworking, construction, landscaping, leisure wood, agriculture, marine, railway, telecommunication, electricity generation and distribution applications. This wood is treated with waterborne products, solvent based products or creosote.
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.

1.1 Dielectric properties of wood

Wood has a low specific conductivity and is considered as a dielectric material (Torgovnikov 1993). Wood interacts with an electromagnetic field. The two components, electric and magnetic field, have different influence on wood. The magnetic field is a negligible factor whereas the electric field has a very strong influence on wooden materials which results in the creation of electric current (Torgovnikov 1993). Water plays a major role in the dielectric properties of wood. Dry wood has specific resistance ranging from 10^{13} to 10^{15} Ohm m. Electrical conduction in wood is described by the percolation theory and the existence of a continuous path of loosely bound or capillary water in wood which is below the traditional fiber saturation n point (Zelinka *et al.* 2008).
Applying a D.C. electric field through a natural material, such as wood, leads to electrical transport of water and ions. The ionic transference and the electro osmotic water flow was measured showing the independence of these two processes (Simons *et al.* 1998b). The electrical transport of endogenous and exogenous mineral ions in green sapwood of Scots pine revealed that potassium and calcium ions were the main endogenous current carriers followed by magnesium, sodium and chloride ions. This was underlined for potassium by the results from trials with exogenous mineral ions. It was also found that copper ions possess a higher conductance within the wood than calcium or magnesium (Simons *et al.* 1998a; Simons *et al.* 1998c).

1.2 Electro osmotic pulsing technology

Electro osmosis is the motion of polar liquid through a membrane or a porous material, such as wood, when an electric field is applied. The material can be dehydrated by the electro osmotic pulsing technology. Therefore, electrodes are placed across the porous material and a direct current is applied. Water is transported to the cathodically charged electrode by electro osmosis. The transport of water due to electro osmosis is a result of diffuse double layer cations in the pores of the material which are attracted to a negatively charged electrode or cathode. The cations are moving through the material towards the cathode, bringing with them water molecules that clump around the cations. Additionally, the friction between the molecules drags more water molecules to the cathode. As a result, water is reduced at the anode and increased at the cathode side.
The electro osmotic pulsing technology is used in buildings in order to remove water from wet parts of concrete or other porous material. 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.

1.3 Wood and electro-osmotic pulsing technology

There has not been published any research on the field of wood protection in combination with electro-osmotic pulsing technology (EOP). This technology can not be compared to microwave and high frequency technologies since the frequency used in microwave treatments of wood is by far higher than the frequency used in electro-osmotic pulsing. There is literature available on the topic of EOP, however the main focus is moisture reduction of materials and wood protection is neither mentioned nor has there been performed scientific research that focuses on the effect that EOP has on biotic factors such as fungi, bacteria and insects on wood. It is here important to emphasis that the antifungal effect of this system is not due to reduced moisture content in the wood, but the interaction between electro-osmotic pulsing and the fungus.

The electro-osmotic pulsing technology on wood, called PLEOT (from Norwegian abbreviation "pulserende likestrøms elektro-osmose teknologi"), combines two fields of research: wood technology and electrical engineering and combines thereby the knowledge of a research institute (Norwegian Forest and Landscape Institute, Section Wood Technology) with the expertise of an industry partner (Miljøteknologi AS, Porsgrunn, Norway) who is working in the field of electro-osmotic pulsing and is the holding company of the patent holder EPT AS (Porsgrunn Norway).

Preliminary trials at the Norwegian Forest and Landscape Institute show that PLEOT has a significant effect on the degradation of wood. Wood samples that are connected to PLEOT show no mass loss whereas untreated samples loose approximately 20 % of its mass due to fungal degradation. A patent on the topic has been submitted.
Wood protection by means of PLEOT can preserve wood in service without using any chemical protection at all. The system can easily be installed and is extremely low in maintenance costs.

2. EXPERIMENTAL METHODS

2.1 Material

For all trial were Scots pine (*Pinus sylvestris*) sapwood samples used. The samples were connected to PLEOT by drilling 5 mm deep and 2.1 mm holes in diameter in the center of each cross section of the samples. Acid-resistant and rust-free screws with 15 mm in length were used on both sides of the samples. Isolated copper cables (0.5 mm), connected to the screws, transferred the electro-osmotic pulsing to the samples.

2.2 Protection against basidiomycetes

The non-leached wood samples with dimensions of 0.5 x 10 x 30 mm^3 (miniblocks) were tested on *Coniophora puteana* for 8 weeks according to Bravery (Bravery 1978) using 40 V/1 kOhm, 40 V/10 kOhm, 10 V/1 kOhm as different parameters of PLEOT. Additionally, untreated samples and samples connected to cables but not to PLEOT were used as reference.
A low frequency pulsed electrical direct current (DC) voltage was used in all tests.
The samples were dried at 103°C after 8 weeks of exposure and mass loss was calculated. Two of the different treated samples respectively were ground, acid digested and analyzed using element analysis with ICP-AES. The determination of elements was performed by a simultaneous ICP-AES technique with axial or radial viewing of plasma (Skoog *et al.* 1998) on a Thermo Jarell Ash ICP-IRIS HR Duo. The following elements were determined in all leaching water samples: Al, As, B, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Se, Si and Zn.

The second half of the samples collective was used to repeat the fungal test without any applied treatment while testing. This was done in order to test the influence of a PLEOT pre-protection. The previously exposed samples (pre-protected by PLEOT) were compared to previously non-exposed and untreated Scots pine sapwood samples.

2.2.1 Different sources of electricity

Non-leached wood samples with dimensions of 0.5 x 10 x 30 mm^3 (miniblocks) were tested on *Coniophora puteana* for 4 and 12 weeks according to Bravery (Bravery 1978) using 13 V/1 kOhm of PLEOT treatment, 13 V/1 kOhm of DC from a battery and 13 V/1 kOhm of alternating current (AC) from a adjustable generator. Untreated Scots pine sapwood samples and samples connected to cables without connection to any electrical source were used as reference.

2.3 Protection in soil contact

Non-leached wood samples with dimensions of 0.5 x 10 x 100 mm^3 were tested in soil contact according to ENV 807 (1999) for 32 weeks. A brown rot decay type dominated soil from Simlångsdalen (Sweden) was used.

The samples were PLEOT-treated with 40 V/1 kOhm and CCA-treated and untreated samples were used as reference.

3. RESULTS AND DISCUSSION

3.1 Protection against basidiomycetes

As basidiomycetes are the major hazard for above ground applications, the basidiomycete fungus *Coniophora puteana* was used for these initial tests. Several additional tests have been performed to verify the results. The results presented here (fig. 1) are from a test to explore the influence of applied voltage and applied resistance. Initial trials which are not presented in this paper with normal Petri dishes gave not only no mass loss for the treated sample, but also very low mass loss for the untreated sample. It was assumed that the agar medium or the fungus itself conducted electricity. Petri dishes with a centre barrier were then provided. The samples did then not shear agar medium, but sheared atmosphere. The test setup has been optimized for the tests presented here.

The treated samples show nearly no mass loss and the untreated samples show higher mass loss (fig. 1). In figure 1 it is still apparent that the Petri dishes with two untreated samples (“untreated” bar) have higher mass loss than the untreated “neighbor” samples i.e. the “40V/1kOhm” bar. The bars labelled “cable connections” are untreated samples with cables connected, but no electricity was applied. The reason for the low mass loss in these samples is still unclear.

The moisture content of the PLEOT treated samples with different parameters is in general lower compared to untreated control samples. However, the wood moisture content of all PLEOT-treated samples is >40 % and should therefore still create a favorable environment for the fungus. Cardinal points on wood moisture content for *Coniophora puteana* of 30-70 % is given as optimum (Schmidt 2006). Wood held about 20 % moisture content can be considered as protected from basidiomycete decay (Dix and Webster 1995). The untreated control samples have higher moisture content than the treated samples (fig. 1).

By changing the applied resistance from 1 to 10 kOhm, the antifungal effect of the PLEOT system does not change, but the untreated samples show much higher mass loss in the 10 kOhm Petri dishes. By reducing the voltage to 10V, some mass loss (<1%) is detected for the treated samples. An interesting artifact here is the very low mass loss of the untreated control sample. The reason for this mass loss is at this point unclear. All the untreated samples show a high standard deviation, both the untreated control samples laying beside the treated ones and the untreated controls.

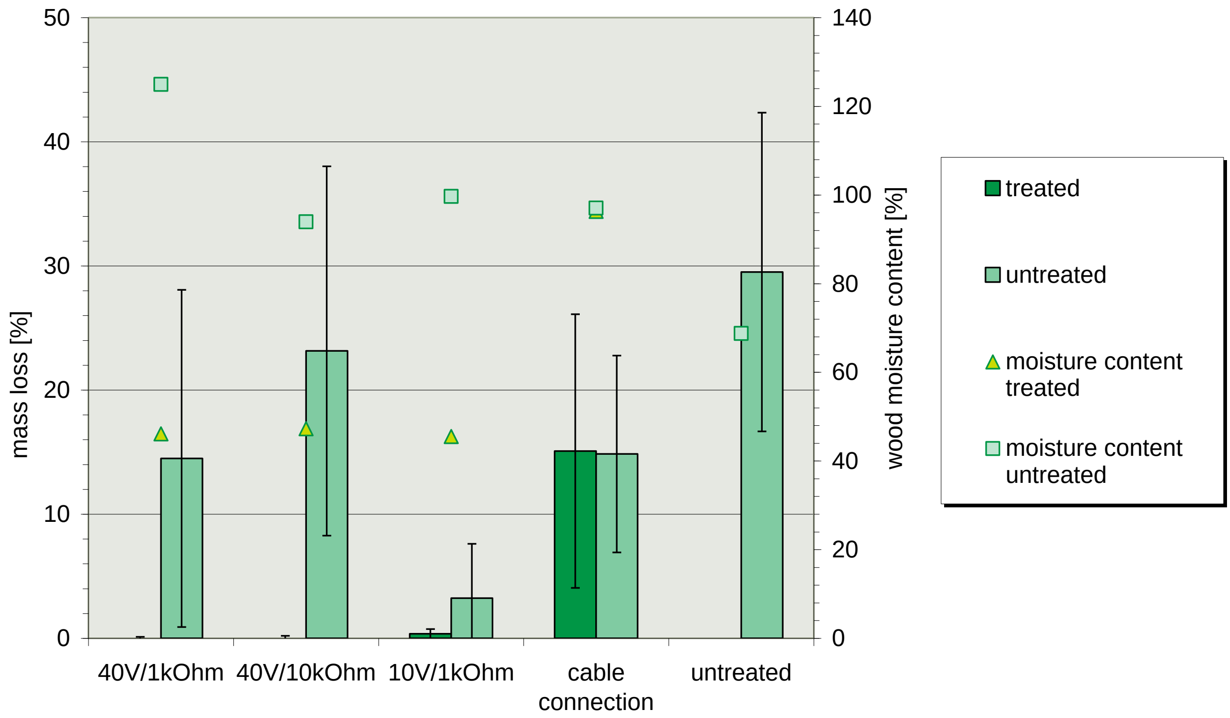

Figure 1: Average mass loss and wood moisture content of different PLEOT- treated and untreated Scots pine samples (*Pinus sylvestris*) after 8 weeks of exposure to *Coniophora puteana*.

Some of the samples protected by PLEOT showed some discoloration on the negative pole side. At this point the focus was drawn to the possibility that the effect of the treatment solely was an effect of transferred ions into the wooden matrix. Copper from the wires and nickel and chromium from the screws, was the main concern. After the ICP element analysis of wood powder from the treated samples, trace amounts of elements were found (tab. 1). The distribution of these metal ions within the wood samples is not evaluated.

Table 1: Average amount of elements in µg/g (with STDV) of two ground wood samples per treatment after 8 weeks of treatment with PLEOT and exposure to *Coniophora puteana* analyzed by using ICP

Treatment	***Cr***	***Cu***	***Fe***	***Ni***	***S***	***P***
40V/1kOhm	119 (9.4)	33 (23)	411 (78)	190 (33)	36 (9.2)	56 (5.7)
40V/10kOhm	149 (26)	51 (63)	516 (66)	324 (187)	28 (6.4)	37 (1.4)
10V/1kOhm	160 (162)	86 (95)	485 (517)	268 (311)	43 (26.9)	153 (154)
cable connection	2 (0.3)	3 (1.3)	13 (7.3)	1 (0)	224 (140)	1195 (830)
Untreated	1 (0)	1 (0.5)	6 (3.1)	1 (0)	226 (89)	1172 (427)

To verify if these elements had an influence on the protection of wood, the treated samples, which already had been exposed to the fungus *Coniophora puteana* for 8 weeks, were again exposed to a fungi test for 8 weeks, but now without PLEOT protection. The results from this trial are presented in figure 2.

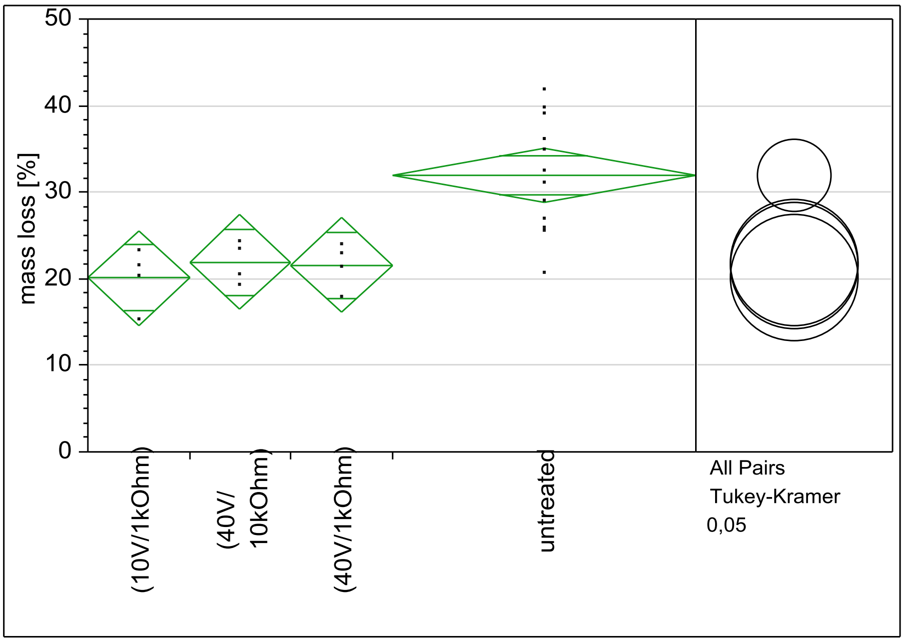

Figure 2: Mass loss of different previously protected (PLEOT) and untreated Scots pine samples (*Pinus sylvestris*) after 8 weeks of exposure to *Coniophora puteana*; the previously protected samples have been in a fungi test with PLEOT installation before this test was performed; none of the samples had any PLEOT installation during this test.

After 8 weeks of repeated exposure to *Coniophora puteana*, the mass loss of the previously protected samples is in average around 20%. This is a 10% lower mass loss than the mass loss of new untreated samples after the test. The difference of the untreated and previously protected samples compared to the untreated and not preciously protected samples is an additional autoclaving, additional drying at 103°C, a previous exposure to *Coniophora puteana* and a previous protection by PLEOT during the preliminary fungi test. The difference in mass loss might be explained by these differences. Additionally, the trace elements that were found in the wood samples can also contribute to the differences in mass loss. However, as the samples that were previously protected and exposed to the fungus achieved around 20% mass loss, it is assumed that the trace elements have only a minor effect. One must also consider that the amount of trace elements has built up over 8 weeks, and the amount tested in figure 2 was the maximum concentration over these 8 weeks.
The samples showed a wood moisture content after the test of 63 (16) % previously protected 10V/1kOhm, 58 (25) % previously protected 40V/10kOhm, 76 (18) % previously protected 40V/1kOhm and 82 (50) % untreated. A significant difference in moisture content can therefore not be seen.

3.1.1 Different sources of electricity

After testing of different parameters such as voltage and resistance which lead to nearly the same results, the source of electricity was investigated. To verify that the anti-fungal effect is caused by the distinct electric pulsing and not by the electricity itself, 3 different electric sources were tested. The results after 4 and 12 weeks that are shown in figure 3 clearly indicate that only the PLEOT system gives sufficient protection against *Coniophora puteana* both during 4 and 12 weeks.

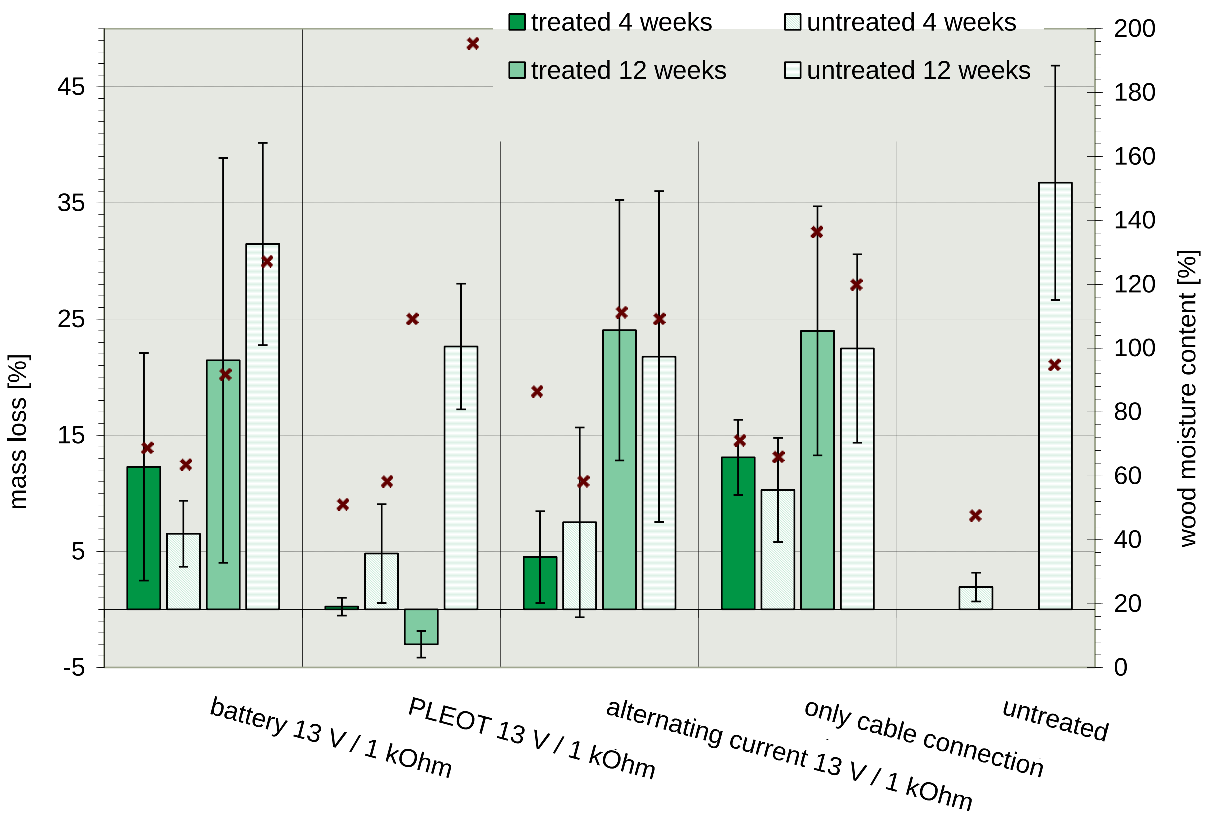

Figure 3: Average mass loss of different treated and untreated Scots pine samples (*Pinus sylvestris*) after 4 and 12 weeks of exposure to *Coniophora puteana.*

3.2 Protection in soil contact

After concluding that the PLEOT system is protecting against attack from *Coniophora puteana* in miniblock lab trials, it was important to test the PLEOT system on wood samples in soil contact. The test results, shown in figure 4, show mass loss of untreated samples around 6% after 32 weeks. The test is not valid according to ENV 807 (1999). However, the difference in mass loss between PLEOT-treated samples and the untreated control samples is significant.

The treated samples also showed severe degradation of the copper wire and were at several places broken.

It is likely to conclude that the PLEOT system was influencing not only the directly connected samples but also the untreated samples since the untreated samples were in the same soil and container as the treated ones. The PLEOT system could thereby lower the mass loss of the untreated samples. New test setup is necessary to verify these results.

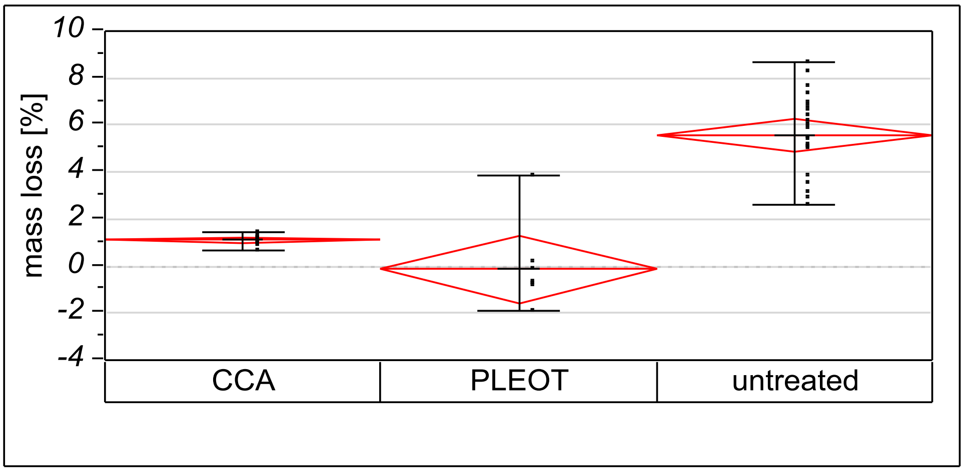

Figure 4: Average mass loss of CCA- and PLEOT- treated and untreated Scots pine samples (*Pinus sylvestris*) after 32 weeks in soil contact; the samples showed a wood moisture content after the test of 124 (11) % PLEOT, 100 (21) % and 165 (14) untreated.

3.3 Outlook

These initial tests have been performed over the last two years. Although questions arise as one works further with this system, the technology has definitively potential, and field tests should detect the limitations of the application of PLEOT. Further tests including also field tests are under planning.
The test setup has been optimized for the presented tests. However, further optimization needs to be done.

4. CONCLUSIONS

- The PLEOT system fully protects Scots pine sapwood samples from attack by *Coniophora puteana* in laboratory trials
- The samples treated with PLEOT showed lower wood moisture content after basidiomycete test compared to untreated samples
- The wood moisture content of samples treated with PLEOT is not below a unfavorable amount for the fungi to attack
- The PLEOT system transfers metal ions through the wood samples
- The transferred metal ions do not provide the wood protection effect
- The PLEOT system might give a protection for wood in soil contact

5. ACKNOWLEDGEMENTS

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