

## Final report for SNS research projects

Submit the report to [sns@slu.se](mailto:sns@slu.se) by 24:00 CET, 1<sup>st</sup> of September, 2022, at the latest.  
The report should not exceed 3500 words (including words in the template).

Please adjust the size of the box according to the length of your answer.

|                    |                                                                                                                                                        |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Project title:  | Where is the water in acetylated wood? Studies of amount, location and state of water in acetylated wood for development of more durable wood products |
| 2. Reporting year: | 2022                                                                                                                                                   |

|                         |                                                                               |
|-------------------------|-------------------------------------------------------------------------------|
| 3. Project coordinator: | Maria Fredriksson                                                             |
| Email:                  | maria.fredriksson@byggtek.lth.se                                              |
| Address:                | Lund University, Division of Building Materials, Box 118, 221 00 Lund, Sweden |

### Activity report

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| 4. Provide a project summary, including:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <p><b>a) The purpose of the project/main problems /hypothesis addressed</b></p> <p>A transition to a bio-based economy requires increased use of bio-based construction materials. One of the main factors that presently limits the use of wood and bio-based materials is their susceptibility to fungal degradation. Thus, the use of wood and wood-based products in environments with high moisture levels (e.g. outdoors) requires that the resistance against fungal degradation is improved. Traditionally, this has been done by treatments with biocides, e.g. creosote or chromated copper arsenate (CCA), but due to environmental and health issues, the use of such substances is now restricted. Alternatively, the resistance to degradation can be improved by chemical modification that functions without a toxic mode of action. The exact mechanisms behind the increased durability are not known, but the lowered moisture content plays an important role. In wood, water is present both as bound water in cell walls and as capillary water in cell lumina. The lowered cell wall moisture content obtained by chemical modification has been suggested as a possible mechanism behind the enhanced durability, but wood-degrading fungi also need capillary water and there are indications that modifications such as acetylation also changes the amount of this water. How different modifications affect not only the total amount of water, but also the location and state of water is, however, much less explored.</p> <p>The purpose of this project was to study the influence of modification on the amount, location and state of water in wood in order to understand the mechanisms behind the increased durability. We mainly focused on the modification called acetylation. The hypothesis of the present project was that acetylation affects not only the amount of water, but also the location and state of water and that this is an important key to understanding the enhanced durability of acetylated wood. We used different protocols to control the amount, state and location of water in a systematic way, and obtained knowledge on how to control the moisture content in different parts of the wood structure by targeted modification. This will in turn enable systematic studies on how the location of water influences the fungi's ability to degrade wood, knowledge which can be used to optimize wood modification techniques to produce more durable wood products from sustainable forestry. In the present project, the following research questions were addressed:</p> <ul style="list-style-type: none"> <li>• How does different degrees of acetylation affect the amount of water?</li> <li>• How does different degrees of acetylation affect the location of water?</li> <li>• How does different degrees of acetylation affect the state of water?</li> <li>• Can the amount of capillary water be reduced by only modifying the surfaces of the cell lumina?</li> </ul> <p><b>b) A short description of the main activities of the project</b></p> <p>During the first part of the project, protocols for targeted modification using acetic anhydride were developed and wood material (<i>Picea abies</i> L. Karst.) was modified using these procedures. Two types of modification approaches</p> |

were used:

- 1) uniform modification that acetylated the cell wall uniformly
- 2) interface modification that acetylated the lumen-cell wall interface

In order to establish if the modifications acted as intended, wood samples were characterized by Raman micro spectroscopy, which gives spatial information of the wood chemistry at cell wall level. These results showed that the chemical changes from modification were localized as intended. The amount, state and location of water was then studied using several methods. We used Low Field Nuclear Magnetic Resonance (LFNMR) to separate cell wall water and capillary water as well as to differentiate between different populations of capillary water. These measurements were made for both water saturated samples and samples conditioned to several high moisture states using the pressure plate technique. Sorption calorimetry was performed to study enthalpy of sorption (state of water). Initial measurements were performed by a master student, and since the results were interesting we continued with further measurements. We also measured hydroxyl accessibility, i.e. the hydroxyl groups available for water molecules, and sorption isotherms, i.e. the amount of water as a function of relative humidity and temperature. Apart from using Raman micro spectroscopy for characterization of the distribution of the wood modification, we also used this technique to study the location of water within cell walls. For this purpose, a custom-built micro-humidity cell was developed for moisture conditioning wood specimens and measurements were made at different humidity levels.

The results from the studies of the wood-water interactions showed that the two types of modifications affected water in different locations within the wood structure differently. The cell wall-lumen interface modification altered the interaction between the wood and the capillary water without affecting the interaction with water in cell walls while the uniform modification affected both. Additionally, the results from the Raman micro spectroscopy showed that for the interface modified wood less water was present in the modified layer than in the other parts of the cell wall, while in the uniformly modified wood the water molecules were more evenly distributed. In summary, the results showed that it is possible to control the location of water within the wood structure by using this targeted modification approach.

Since the results from the measurements of wood-water interactions were promising and showed differences between the uniformly modified samples and the samples with interface modifications we decided to take the project one step further and investigate how/if this affected the ability of fungi to degrade the wood. We therefore applied for and received additional funding from other sources to perform fungal degradation experiments and chitin analyses for quantification of fungal biomass.

During the project time we have published four papers in peer-reviewed scientific papers (see 5) and presented results at several conferences (see 5 and 6). In addition, we have collaborated around other manuscripts and written several project applications together (see 6). Furthermore, work with manuscripts is ongoing and papers from the project will also be published after the project time has ended.

### **c) Achieved targets and to what extent the research plan was fulfilled**

We have addressed all our research questions and performed all experimental work in the research plan. In addition. The Covid-19 pandemic has made travelling and meetings more challenging, but we have managed to perform the work despite of this and have made travels during periods when restrictions allowed it. We have also participated at several conferences, but many of these were converted to online conferences because of the pandemic. For the same reason, project meetings and communication during the latter part of the project have been through digital platforms and e-mail instead of physical meetings. The project has resulted in 4 publications in peer-review scientific journals (1-2 was in the plan) and 9 conference contributions. We have also written several research applications together and have received funding from the Swedish Research Council FORMAS (4 000 000 SEK) and Aase og Ejnar Danielsens Fond (ca 300.000 DKK) to continue on this research topic.

5. Published outputs achieved as a consequence of the project (peer-reviewed articles, other publications)

**Papers in peer-reviewed scientific journals:**

Thygesen LG, Beck G, Nagy NE, Alfredsen G (2021) Cell wall changes during brown rot degradation of furfurylated and acetylated wood. *International Biodeterioration and Biodegradation* 162:105257

Digaitis R, Thybring EE, Thygesen LG, Fredriksson M (2021) Targeted acetylation of wood: a tool for tuning wood-water interactions. *Cellulose* 28:8009-8025

Thybring EE, Fredriksson M (2021) Wood Modification as a Tool to Understand Moisture in Wood. *Forests* 12:372

Yang T, Thybring EE, Fredriksson M, Ma E, Cao J, Digaitis R, Thygesen LG (2020) Effects of Changes in Biopolymer Composition on Moisture in Acetylated Wood. *Forests* 11:719

**Conference papers and abstracts:**

Ponzecchi A, Piqueras SS, Thybring EE, Fredriksson M, Digaitis R, Thygesen LG, 2021, Raman microspectroscopy of native and acetylated wood at different relative humidities using a tailored moisture chamber, presented WSE2021 - the 17<sup>th</sup> Annual Meeting of the Northern European Network for Wood Science and Engineering, 14-15 October 2021, Kaunas, Lithuania.

Digaitis R, Thybring EE, Thygesen LG, Fredriksson M, 2021, Targeted acetylation of wood: a tool for tuning wood-water interactions, presented WSE2021 - the 17<sup>th</sup> Annual Meeting of the Northern European Network for Wood Science and Engineering, 14-15 October 2021, Kaunas, Lithuania.

Digaitis R, Fredriksson M, Thybring EE, Thygesen LG, 2021, Mapping targeted acetylation of Norway spruce wood by use of Raman microscopy, presented at the 259th American Chemical Society (ACS) National Meeting, 5-16 April 2021, held online.

Fredriksson M, Digaitis R, Thybring EE, Thygesen LG, 2020, Tuning wood-water interactions by targeted wood modification, presented at *Treesearch Progress*, 23-24 September 2020, held online.

Fredriksson M, Digaitis R, Thybring EE, 2020, Moisture in wood near or at saturation. Part 2. How much, where is it and what state is it in, presented at WSE2020 - 16th Annual Meeting of the Northern European Network of Wood Science and Engineering, 1-2 December 2020, held online.

Fredriksson M, Thybring EE, Digaitis R, 2020, Studying amount, location and state of water in modified wood at moisture levels relevant for fungal degradation, IRG51 - Annual Meeting of the International Research Group on Wood Protection, 10-11 June, 2020, held online.

Digaitis R, Thygesen LG, Thybring EE, Fredriksson M, 2019, Targeted acetylation of Norway spruce tissue and its effect on moisture states in wood, presented at WSE2019 – the 15th Meeting of the Northern European Network of Wood Science and Engineering 9-10 October, Lund Sweden.

Thygesen LG, Beck G, Nagy NE, Alfredsen G, 2019, Cell wall changes during brown rot degradation of furfurylated wood as compared to acetylated wood, presented at WSE2019 – the 15th Meeting of the Northern European Network of Wood Science and Engineering 9-10 October, Lund Sweden.

Yang T, Thybring EE, Fredriksson M, Ma E, Cao J, Digaitis R, Thygesen LG, 2019, Effects of acetylation on moisture in wood, presented at WSE2019 – the 15th Meeting of the Northern European Network of Wood Science and Engineering 9-10 October, Lund Sweden.

6. Other practical outputs of the project (websites, policy recommendations, conferences, scientific meetings, large-scale project applications, research training etc.)

**Scientific meetings and research visits:**

17-21 February 2020: Maria Fredriksson visited NIBIO, Ås to do LFNMR measurements.

27-29 January 2020: Maria Fredriksson and Emil E. Thybring visited Georg-August-Universität Göttingen, Germany.

May-July 2020: PhD student Tiantian Yang, Beijing Forestry University and University of Copenhagen visited Lund University for a period of 10 weeks to do measurements.

17-18 June 2019: Project meeting in Lund with participants from all project partners.

In addition, online project meetings have been held during the project period. Furthermore, many travels between Denmark and Sweden have been made during the whole project period to transport samples and perform measurements. During the last two years, these travels have been made during periods when the Covid-19 restrictions allowed it.

**Participation at conferences:**

During the project, we have participated at the following conferences:

- WSE2021 – the 17th Annual Meeting of the Northern European Network for Wood Science and Engineering, 14-15 October 2021, Kaunas, Lithuania.
- International Building Physics Conference (IBPC2021), 25-27 August 2021, held online
- Nordisk Bygningsfysikdag Aalborg University, BUILD, 5 May 2021, held online.
- The 259th American Chemical Society (ACS) National Meeting, 5-16 April 2021, held online.
- WSE2020 – the 16th Meeting of the Northern European Network of Wood Science and Engineering 1-2 December, 2020, held online.
- IRG51 - Annual Meeting of the International Research Group on Wood Protection, 10-11 June, 2020, held online.
- IRG52 - Annual Meeting of the International Research Group on Wood Protection, 1-2 November, 2021, held online.
- Forest Operations for the Future 22-24 September 2020, Helsingør og online.
- Tresearch Progress, 23-24 September, 2020, held online.
- WSE2019 – the 15th Meeting of the Northern European Network of Wood Science and Engineering 9-10 October, Lund Sweden.

**Project applications:**

- 2022: We submitted an application to The Research Council of Norway (8.4 million NOK). We are still waiting for the decision if granted or not.
- 2021: We submitted an application to Aase og Ejnar Danielsens Fond, which was granted (c:a 300 000 DKK).
- 2021: We submitted an application to the Swedish Research Council FORMAS, which was granted (4 000 000 SEK).
- 2020: We submitted an application to the Swedish Research Council VR. Unfortunately, this application was not granted.
- 2020: Together with Chalmers, we worked with and sent in an application (60 million DKK) to Novo Nordisk Fonden, Denmark. The application was selected for the second (i.e. final) round, but was unfortunately not granted.
- 2019: Together with other institutions in Europe we sent in an application to BBI (Biobased Industries Joint Undertaking, Horizon 2020). Unfortunately, this application was not granted.

7. How and within which areas was the project beneficial for the Nordic countries?

The project has strengthened the collaboration within wood science in the Nordic region. During the project time, we have collaborated around experimental work and researchers have travelled between the three institutions involved to do measurements. These combined laboratory resources have been necessary in order to fulfil the

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aims of the project. We have also worked with mutual research applications and was granted a project from the Swedish Research Council FORMAS (4 000 000 SEK, 2022-2025). The collaboration between Lund University, University of Copenhagen and NIBIO will thus continue also after this project.

8. Write a short (maximum 800 words) popular science piece for dissemination in SNS' various channels with *emphasis on application of results and benefits for the Nordic society*.

Provide pictures (size at least 500x500 pixels and resolution at least 72 pixels) as separate files (.jpg). Include caption to each picture and the name of the photographer.

A transition to a bio-based economy requires increased use of bio-based construction materials. The construction sector stands for a significant part of both Nordic and global carbon dioxide emission and a decrease in carbon dioxide emissions from the construction sector is pivotal to meet both national and international climate goals. An increased use of wood as a construction material instead of materials with higher climate impact has the potential to decrease carbon dioxide emissions. This requires a long service life of wooden structures to prolong the sequestration of carbon. Use of wood in environments with high moisture levels (e.g. outdoors) generally requires that the resistance against fungal degradation is improved. Traditionally, this has been done by treatments with biocides, e.g. creosote or chromated copper arsenate (CCA), but due to environmental and health issues, the use of such substances is now restricted. Alternatively, the resistance to degradation can be improved by chemical modification, which functions without a toxic mode of action. The exact mechanisms behind the increased durability are not known, but that the modifications lower the moisture content is considered to play an important role. However, recent research has shown that not only the amount of water, but also where the water is located and how it interacts with the wood can be affected by modification.

The purpose of this project was to study how wood modification affects not only how much water is present, but also where the water is and how it interacts with the chemically modified wood structure. This knowledge is needed in order to understand the mechanisms behind the increased durability. We focused mainly on a modification type called acetylation and found that it was possible to control the distribution of the modification within the cell walls of wood, and in turn control the location and interaction with water. This type of modification approach can contribute to a better understanding of the underlying mechanism of decay protection by non-toxic wood protection methods. Wood species grown in the Nordic countries for construction purposes generally have non-durable wood and understanding how the durability of these species can be increased using sustainable methods is consequently important to meet demands on long service life for wood from sustainably managed forests. Additionally, this project has strengthened the collaboration within wood science in the Nordic region and we have used the combined resources available at the participating institutions Lund University, University of Copenhagen and NIBIO. We have also written several papers, conference contributions and research applications for future projects together.

### Participation

#### 9. Number of participants

| Country | Young researchers / PhD students | Senior researchers | Stakeholders | Others (specify) | Gender |     |       | Total |
|---------|----------------------------------|--------------------|--------------|------------------|--------|-----|-------|-------|
|         |                                  |                    |              |                  | Women  | Men | Other |       |
| Denmark | 2                                | 3                  |              |                  | 3      | 2   |       |       |
| Finland |                                  |                    |              |                  |        |     |       |       |
| Iceland |                                  |                    |              |                  |        |     |       |       |
| Norway  | 1                                | 2                  |              |                  | 1      | 2   |       |       |
| Sweden  | 2                                | 2                  |              |                  | 2      | 2   |       |       |
| ...     |                                  |                    |              |                  |        |     |       |       |
| ...     |                                  |                    |              |                  |        |     |       |       |

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|       |   |   |  |  |   |   |  |  |
|-------|---|---|--|--|---|---|--|--|
| ...   |   |   |  |  |   |   |  |  |
| Total | 4 | 7 |  |  | 6 | 6 |  |  |

### 10. List the participating institutes/sectors

Lund University, Sweden  
University of Copenhagen, Denmark  
NIBIO, Norway

## Economic report

### 11. Received grant from SNS in total (SEK):

1 050 000 SEK

### 12. Transfer of SNS funds to project partners

| Country                   | Partner organization     | Sum (SEK)      |
|---------------------------|--------------------------|----------------|
| Denmark                   | University of Copenhagen | 300000         |
| Finland                   | -                        | 0              |
| Sweden                    | Lund University          | 600000         |
| Norway                    | NIBIO                    | 150000         |
| Iceland                   | -                        | 0              |
| Other countries (specify) | -                        | 0              |
| <b>Total SUM</b>          |                          | <b>1050000</b> |

### 13. Costs

|                        | SNS funding      | External funds*  | Sum              |
|------------------------|------------------|------------------|------------------|
| Travel and hotel       | 46 418           | 6 368            | <b>52 786</b>    |
| Meeting costs          | 3 046            | 0                | <b>3 046</b>     |
| Consumables            | 23 751           | 0                | <b>23 751</b>    |
| Salary                 | 940 858          | 2 093 870        | <b>3 034 728</b> |
| Communication          | 0                | 0                | <b>0</b>         |
| Other costs (specify)  | 34 101           | 0                | <b>34 101</b>    |
| <b>Total SUM (SEK)</b> | <b>1 048 174</b> | <b>2 100 238</b> | <b>3 148 412</b> |

\* If possible, provide details otherwise summarize the total sum for external funds and total.

### 14. Economic result (deficit or surplus):

The project has a small surplus of 1 826 SEK.

### Optional: Comments to the economic reporting:

Compared to the original budget, less money has been spent on travel and hotel costs and meeting costs. This can be attributed to the Covid-10 pandemic which has inhibited travelling during a large part of the project period.

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Instead, we have had online meetings and several conferences have also been held online. We have thus participated in meeting and conferences, but without travelling and hotel costs.

Through new university agreements on open access publishing, we have been able to publish open access without fee. Therefore, we have not spent money on communication costs.

The savings made on travel and hotel and communication costs have instead been spent on salary costs. The salary costs are therefore higher than in the budget in the application.

**15. Submit a policy brief as a separate document.** Provide pictures (size at least 500x500 pixels and resolution at least 72 pixels) in the policy brief as well as separate files (.jpg). Include caption to each picture, and the name of photographer.

I hereby declare that the above statements are true to the best of my knowledge

Signature of the project coordinator



Lund University

2022-08-31

Signature

Institution

Date

Maria Fredriksson

Printed name

Signature of the department head at the department of the project coordinator



Lund University

2022-09-01

Signature

Institution

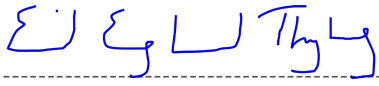
Date

Peter Johansson

Printed name

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### Second applicant's signature, place and date



University of Copenhagen

August 31, 2022

Signature

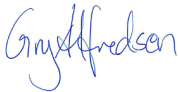
Institution

Date

Emil Engelund Thybring

Printed name

### Third applicant's signature, place and date



Norwegian Institute of Bioeconomy Research

August 31, 2022

Signature

Institution

Date

Gry Alfredsen

Printed name