THERMAL MODIFICATION OF SITKA SPRUCE

LAHTI UNIVERSITY OF APPLIED SCIENCES
Faculty of Technology
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ALKUSANAT

Tämä opinnäytetyön tekeminen aloitettiin keväällä 2009 ja saatiin päätökseen huhtikuussa 2010. Opinnäytetyö on tehty Jartek Oy:n toimeksiannosta. Ohjaavana opettajana toimi Mikko Salmi ja yrityksen ohjaavina henkilöinä Timo Tetri ja Lasse Stylman.

Haluaisin kiittää Jartek Oy:n Timo Tetriä ja Lasse Stylmania kallisarvoisista tiedoista ja hyvistä neuvoista. Tahdon kiittää myös ohjaavaa opettajaani Mikko Salmea tärkeistä neuvoista.

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TORVINEN, PENTTI: Sitkakuusen lämpökäsittely

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TIIVISTELMÄ

Tämän opinnäytetyön tarkoituksena on tutkia sitkakuusen soveltumista lämpökäsiteltäväksi. Lämpökäsittelyt on tehty Lahden ammattikorkeakoulun puulaboraation kamarikuivaamossa. Lämpökäsittelyt on tehty thermowood prosessin mukaisesti.

Tutkimuksessa käytetty sitkakuusi kasvaa luonnonvaraisena Pohjois-Amerikan länsirannikolla. Sitkakuusi on tuotu Eurooppaan, eikä se täten ole luonnollisesti levinnyt. Tässä tutkimuksessa on käytetty englantilaista sitkakuusta.

Tutkimuksen edetessä sitkakuusen oksat osoittautuivat ongelmallisiksi, koska oksien halkeilu ja irtoaminen oli systemaattista. Kuivausohjelmien muuttaminen ei parantanut lopputulosta. Oksien halkeilua tapahtui kaikilla dimensioilla, ja halkeilun aiheutti suuri kosteusero oksan ja puuaineksen välillä. Sitkakuusen oksien ja puuaineksen tiheysero on myös huomattava, mikä omalta osaltaan edesauttaa oksien irtoilua. Sitkakuusen lämpökäsittely antaa tasaisen ja kauniin värin. Lämpökäsitellyn sitkakuusen oksien irtoaminen ja halkeilu rajaa huomattavasti sitkakuusen käyttöä kaupallisessa mielessä.

Avainsanat: sitkakuusi, lämpökäsittely, oksa, thermowood

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TORVINEN, PENTTI: Thermal modification of Sitka spruce

Bachelor’s thesis in wood technology, 45 pages, 5 appendices

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ABSTRACT

The objective of this thesis was to make thermal modification for Sitka spruce and find out its suitability for the Thermo Wood process. The thermal modification process was done using the standards of the Thermo Wood process. At the end of the thermal modification and drying sessions, quality inspections were based on the Thermo Wood standards.

The thesis was done for a company called Jartek Oy, which supplies wood processing equipment and mills. Jartek Oy ordered the study from the Lahti University of Applied Sciences. The skope of this thesis was to conduct practical tests and to report the results to Jartek Oy.

During the thermal modification process the wood material will be heated to at least 180 degree Celsius. Steam is used as a safe gas, which protects the wood material from risks of fire. The steam also affects the chemical changes to the wood material during the process. As a result of the thermal modification Thermo Wood is created and the wood material is more stable than normal wood and resistance against wood decay is better. The thermal modification darkens the wood color and it is suitable for different applications in interior and exterior use.

Green sawn Sitka spruce timber was shipped to Finland from the United Kingdom. The timber was sawn to dimension 25 x 150 x 2200 mm. Green Sitka spruce stacks contained approximately 50 % of heartwood and 50 % of sapwood.
After the thermal modification process Sitka spruce samples were tested in several different ways.

It seems that the moisture difference of knots is the main factor that contributed to the knots cracking and dropping off. Knot cracking is a major problem, which prevents commercial use. The main factor causing knot cracking is the difference of moisture content between wood material and knot. The Sitka wood material itself looks good and it is suitable for thermal modification. More testing must be done to find a way to avoid knot cracking. Without knot cracking thermally modified Sitka spruce would have great commercial value.

Key words: Sitka spruce, thermal modification, thermo wood, knot

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1 INTRODUCTION

This Bachelor’s thesis is an examination of the thermal modification process of the Sitka spruce (*Picea Sitchensis)*. The thesis is done for a company called Jartek Oy, which supplies wood processing equipment and mills. Jartek Oy ordered this study from the Lahti University of Applied Sciences. My tasks are to conduct practical tests and to report results to Jartek Oy.

Green Sitka spruce timber is shipped from the United Kingdom for this research. Sitka spruce is a non-native conifer in England and its native range is in Northern America. Sitka spruce can grow up to 50 meters and its diameter can be 2 meters. Sitka spruce has a fast growth ratio and it achieves its maximum timber potential in 40-60 years.

The most common methods to modify wood are thermal modification and chemical modification. All the different modification methods have the same goal – to improve the properties of wood.

2 RESEARCH OBJECTIVE

The objective of this research is to find out whether Sitka spruce timber is suitable for the Thermo Wood process. The thermal modification process is done using the standards of the Thermo Wood process. At the end of the thermal modification and drying sessions, quality inspections are based on the Thermo Wood standards.

3 DRYING WOOD

3.1 High temperature drying

The thermal modification process generally starts with high temperature drying where the temperature is more than 100 °C. High temperature drying is also called fast drying. Fast drying is used if the moisture content of timber before the process is 10 % or more. After high temperature drying the process continues with the thermal modification process without cooling the timber between the processes. These two processes are conducted in the same kiln. High temperature drying is an important phase in the wood thermal modification process.

In the late 1960s high temperature drying was a common drying method. At that time the poor quality of drying kilns and wrong drying formulas caused poor timber quality. Because of the quality problems, the wood industry stopped using high temperature drying. After a couple of decades there was vast improvement in information technology, materials, machines and energy efficiency which allows the use high temperature drying again. (Möller, Otranen 1999, 15)

3.1.1 Principles of high temperature drying of wood

In conventional drying the temperature is usually not more than 80 °C. Warm and dry air is led through timber stacks, removing moisture from the timber. Conventional wood drying consumes lots of energy and drying time is relatively long. (Möller, Otranen 1999, 15)

The high temperature drying process uses higher temperatures than the conventional process. The process temperature is between 100 °C and 130 °C. Different wood species and drying formulas need different drying times. Generally the drying time is 12 to 48 hours. (www.puuproffa.fi)

There is no air intake from the outside of the kiln so the air is not ventilated in high temperature drying, but the boiling water develops water vapor and it is ventilated out from the kiln because of excess pressure. The process is simple because the only factor that is monitored is the air temperature in the kiln. (www.puuproffa.fi)

Benefits of high temperature drying

- Very short drying time
- Few drying defects, if correctly performed
- Short delivery times → small warehouse → flexibility in business

Disadvantages of high temperature drying

- Color change is quite strong, especially in green wood drying
- Softwood has strong pitch bleeding
- Strength and workability deteriorate slightly
- Thick pieces have internal cracks
- Sound knots cracking; loosening and color change in dark knots (especially spruce)
- Sticking of surface treatment materials deteriorates

(www.puuproffa.fi)

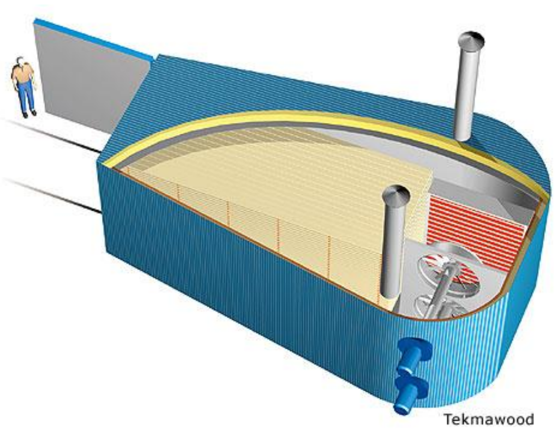

FIGURE 1. High temperature drying kiln (batch kiln). (www.puuproffa.fi)

4 THERMAL MODIFICATION OF WOOD

4.1 Development of the thermal modification process

The first thermal modifications were done during the 1930s – 1950s in Germany and the United States. In the research it was noticed that high temperature has effects on the durability and color of wood. There was not enough knowledge of thermal modification to enable industrial use. In the 1980s in France and Canada research of thermal modification of wood led to industrial use and patents. (Jokelainen 2008, 6)

In Finland the first thermal modification kiln was built in the city of Mänttä in 1991. At the same time VTT (Technical Research Centre of Finland) started their research of thermal modification of wood. The University Of Applied Sciences Of Mikkeli started research on thermal modification of wood in 1993. During the last few years wood thermal modification has developed enormously and its use is more common nowadays. (Jokelainen 2008, 6)

4.2 Thermal modification process

In thermal modification the wood’s physical and chemical properties will be changed using temperatures of over 180 °C. In the thermal modification process 180 – 245 °C temperatures are used. (The Proceedings of the Third Conference on Wood Modification 2007, 183)

Thermal modification has four main phases:

1. high temperature drying
2. raising the temperature
3. thermal modification at 180 – 245 °C
4. cooling and conditioning

The thermal modification process starts with high temperature drying. It has been noticed that if the wood moisture content is too high before the heat treatment phase it will have effects on the quality. Generally it causes cracking and color faults in the wood. Usually the duration of first and second phase together is 4 to 15 hours. High temperature drying time is dependent on how high wood moisture content is in the beginning of the process. (Möller, Otranen 1999, 17)

In the thermal modification phase the temperature is constant but between 180 – 245 °C. The longer the time of thermal modification phase is, the more effects it has on the wood. The duration of the thermal modification phase is usually 0. 5 – 4 hours. (Möller, Otranen 1999, 17)

FIGURE 2. Effects of the thermal modification temperature on the final result. (Lämpökäsitellyn puun ominaisuudet ja lujuus, 2002)

Phase four is cooling and conditioning. In the fourth phase the temperature of wood is decreased to such a level that it can be taken out from the kiln. In the fourth phase moisture content of wood will be restored to the end use level. The duration of phase four is 5 to 15 hours. (Möller, Otranen 1999, 17)

None of the four phases has a standard duration. The duration depends on the wood species and how dark the wood color has to be. The right parameters for the thermal modification process are generally found out by testing.

4.3 Thermally modified wood species in Finland

In principle thermal modification is a suitable modification process for all the wood species. Wood species have different features like annual growth, wood cells, wood pores and different fiber length, etc. In Finland the most commonly used species are pine (*Pinus sylvestris*), spruce (*Picea abies*), birch (*Betula pendula*), and aspen (*Populus tremula*). (Thermo Wood handbook 2003, 1-2)

4.3.1 Spruce *(Picea abies)*

Among softwoods, spruce is not so good material for thermal modification as pine. In thermally modified spruce there are problems especially in the knots. Spruce knots start cracking in low temperatures. Dry knots are stuck to the wood material with pitch and they fall off during the thermal modification process. On the other hand, the durability of spruce against wood decay can be improved to a much better level in the thermal modification process.
(Möller, Otranen 1999, 97)

4.3.2 Pine *(Pinus sylvestris)*

Pine is suitable for the thermal modification process and the quality of thermally modified pine is good. The most common end use applications are in exterior use. After the process pine knots have usually survived very well and knots are in one piece. Knots with a long diameter can crack in the process, so quality control before the process is important. It is recommended to thermally modify only the best quality of sawn timber.
(Möller, Otranen 1999, 96)

4.3.3 Birch *(Betula pendula)*

Birch has a big role in the Finnish carpentry industry and thermal modification has brought more opportunities. In birch the thermal modification process is not important to improve durability against decay. The most important is other features of thermal modification, and especially the color. For thermal modification the best sawn timber must be used so that the quality of treated wood is good. Faults to the birch wood material happen in the drying phase and thermal modification phase does not have so much influence on these.
(Möller, Otranen 1999, 97)

4.3.4 Aspen *(Populus tremula)*

During the last decade aspen has not been much used in industry. Nowadays the use of aspen is increasing and it is especially very commonly used in saunas. The thermal modification process of aspen is challenging because the result can be multicolored. The main reason for the multicolor is decay. Decay is hard to spot from the greenwood and that is why after the thermal modification a lot of aspen timber is not suitable for commercial use.
(Möller, Otranen 1999, 98)

4.4 End use applications of thermally modified wood

Thermally modified wood has several end use applications. It is suitable for interior and exterior use. In interior use it is most commonly used for furniture, flooring and sauna/bathroom furnishing. In exterior use its most common uses are for garden furniture, doors and cladding.
(www.wikipedia.org)

4.5 Environmental issues

Environmental issues are getting more and more important all the time. Some people prefer chemical-free timber preservation methods. Wood modification using thermal modification is chemical-free. The process uses only water vapors and heat and this makes thermal modification safe to the environment. Making heat and vapor consumes energy and the generation of energy releases carbon oxide to the atmosphere. When the life cycle of the end use application reaches the end, thermally modified wood is disposed of along with normal wood “waste”. Thermally modified wood can be exploited in generating energy because it can be burnt like normal unmodified wood.

5 SITKA SPRUCE

5.1 Properties

The name Sitka spruce comes after a place called Sitka. The natural range of Sitka spruce natural range is on the west coast of North America. Sitka spruce is a maritime species. Sitka spruce can grow up to 50 meters and its diameter can be up to 2 meters. Sitka spruce has a fast growth ratio and it achieves its maximum timber potential in 40-60 years. The biggest known Sitka spruce is 99. 6 meters tall and its volume is 337 m^3. Sitka spruce grows straight and the trunk shape is conical. Sitka spruce has a good weight-to-strength ratio and its typical density is 400 kg/m^3 for seasoned timber.
(www.forestry.gov.uk)

5.2 Commercial aspects

Sitka spruce was introduced to the United Kingdom in 1813 and therefore it is not a native conifer. In the UK Sitka spruce has accounts for 30. 2 % of the national forest resources and softwood in general accounts for 61 % of the national resources. Sitka spruce has spread and planted quickly to the biggest conifer in the UK. Planting Sitka spruce became popular in the 1930s and 1950s as it was the most popular species in the UK. In the UK are readily available large quantities of Sitka spruce. Sitka spruce has a great commercial importance to the United Kingdom because Sitka spruce provides over half of the total volume of timber produced. (Adding value to home-grown timber, 2007)

5.3 High temperature drying of Sitka spruce

The EU funded a project called STRAIGHT, which investigated drying techniques of wood. The goal was to reduce distortion and shorten drying times. The most promising method of drying was high temperature drying. UK grown Sitka spruce was finally dried to moisture content of 18 % in approximately 63 hours with a similar quality or better than achieved using conventional drying. (High Temperature Drying, 2005)

TABLE 1. Effect of high temperature drying times of Sitka spruce on moisture content. (High Temperature Drying, 2005)

Drying time	High temperature	Deviation
Hours	Average MC%	
76	15.6	2.4
60	17.1	2.5
56	18.0	3.7
58	17.9	2

Sitka spruce was conventionally dried and high temperature dried during STRAIGHT project. Below is a figure 3 where it's shown how each drying methods are causing faults in the wood.

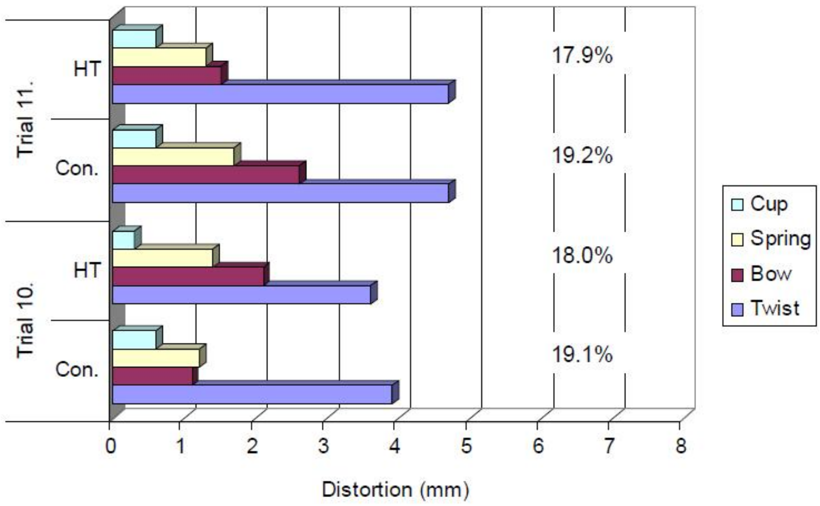

FIGURE 3. Average distortion & M/C values. Drying effects on the wood material. (High Temperature Drying, 2005)

In the STRAIGHT project four loads were dried using the high temperature drying method and twist values were lower than in conventional dried material. In comparison, bow and spring values tended to vary slightly, although in all instances they were well within acceptable limits. Strength and stiffness reduced by approximately 22-28 % compared to conventionally dried values. High temperature drying darkens the wood color. Clear color variation may cause problems to producers. (High Temperature Drying, 2005)

5.4 End use applications

Sitka spruce is very popular in construction and the main reason is relatively low price compared to quality. Sitka is popular in the marine industry such as masts, spars and deck beams. Sitka spruce is very popular in industrial equipments where a high strength-to-weight ratio is desired. In history Sitka spruce had a big role in airplane construction.
(www.naturallywood.com)

6 THERMO WOOD PROCESS

6.1 The Thermo Wood process

The Thermo Wood process has three main phases. The first phase is high-temperature drying using heat and steam. The temperature in the kiln is raised rapidly to 100 °C and then more steadily to 130 °C. After the high-temperature drying process, the wood moisture is near zero.

When the high-temperature drying is finished, it is time for the second phase; the thermal modification. The temperature will be raised to between 185 °C and 215 °C. The target temperature will be constant for two to three hours. The target temperature is in proportion to the wood color darkness and therefore the darker the wood is desired, the higher the temperature should be.

Phase three is cooling the wood using a water spray system in the kiln. When the temperature is between 80 °C to 90 °C, then re-moisturizing will take place and the wood moisture content will increase to the usual level of 4-7 °C.

The thermal modification process has to be optimized for different kinds of wood species. The Thermo Wood method is suitable for softwood and hardwood. Thermo Wood has standards for different species and how it has to be modified for different end-use applications. (Thermo Wood handbook, 2003)

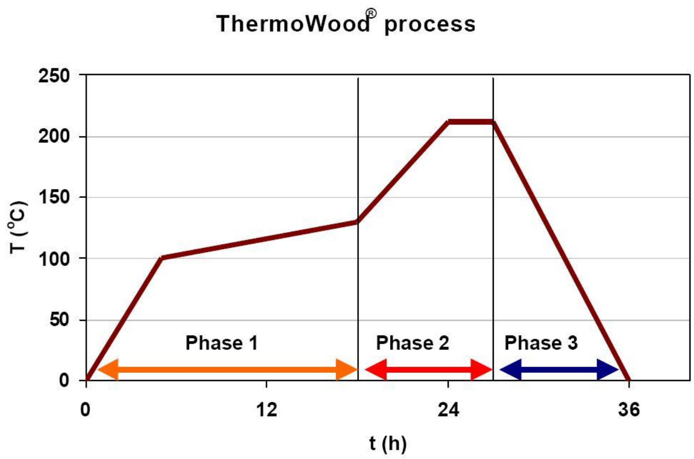

FIGURE 4. Phases of the Thermo Wood process.
(Thermo Wood handbook, 2003, 2-1)

6.2 Standard Thermo Wood classification in Finland

Softwood and hardwood species differ and that is why they have their own classification. Thermally modified wood is divided into two classes. Using more classes could cause confusion between classes. (Thermo Wood handbook, 2003, 4-1.)

Thermo Wood standards and classification have similarities with standard EN113.

Definition of standard EN113:

Wood preservatives. Test method for determining the protective effectiveness against wood destroying Basidiomycetes. Determination of the toxic values.

(Thermo Wood handbook 2003, 6-1)

6.2.1 Thermo-S class

Letter S in Thermo-S class S comes from the word **Stability**. The main factor of-Thermo-S is stability and appearance in end use applications. The tangential moisture swelling and shrinkage of Thermo-S modifies wood is 6-8 %. The resistance to decay of Thermo-S class is the same as class 3 requirements according to standard EN113. (Thermo Wood handbook 2003, 4-1)

Thermo-S Softwood	Thermo-S Hardwood
- building components - furnishing in dry conditions - fixtures in dry conditions - furniture - garden furniture - sauna benches - door and window components	- furnishing - fixtures - furniture - flooring - sauna structures - garden furniture

FIGURE 5. End use applications of Thermo-S class.
(Thermo Wood handbook 2003, 4-1)

6.2.2 Thermo-D class

Letter D Thermo-D class comes from the word **Durability**. As the name suggests, the key factor of this class is durability. The tangential moisture swelling and shrinkage of Thermo-D modified wood is 5-6 %. The resistance to decay of Thermo-D class is the same as class 3 requirements according to standard EN113. (Thermo Wood handbook 2003, 4-1)

Thermo-D Softwood	Thermo-D Hardwood
- cladding - outer doors - shutters - environmental constructions - sauna and bathroom furnishing - flooring - garden furniture	End use applications as in Thermo-S. If a darker colour is desired, Thermo-D should be used.

FIGURE 6. End use applications of Thermo-D class.
(Thermo Wood handbook 2003, 4-1)

Thermo Wood process effects to the wood by thermal modification class.

Softwoods (pine and spruce)

	Thermo-S	Thermo- D
Treatment temperature	190 °C	212 °C
Weather resistance	+	++
Dimensional stability	+	++
Bending strength	no change	-
Colour darkness	+	+ +

FIGURE 7. Effects of Thermo Wood on softwoods.
(Thermo Wood handbook 2003, 5-1)

Hardwoods (birch and aspen)

	Thermo-S	Thermo- D
Treatment temperature	185 °C	200 °C
Weather resistance	no change	+
Dimensional stability	+	+
Bending strength	no change	-
Colour darkness	+	+ +

FIGURE 8. Effects of Thermo Wood process on hardwoods.
(Thermo Wood handbook 2003, 5-1)

7 THERMAL MODIFICATION AND TESTS BACKROUND

7.1 Wood material

Green sawn Sitka spruce timber was shipped from the United Kingdom to the Finland. It was sawn to dimensions 25 x 150 x 2200 mm. Green Sitka spruce stacks contained approximately 50 % of heartwood and 50 % of sapwood. After the thermal modification process each test was conducted with suitable sample sizes. In the knot cracking test Sitka spruce samples were cut approximately to 25 cm long pieces. In the seasoning chamber test samples were cut and planed to size 17. 6 x 135. 5 x 50 mm.

7.2 Thermal modification loads

During the first trial of testing the thermal modification process on Sitka spruce, the plan was to make four to five thermal modification loads for Sitka spruce. After the first load the plan had to be changed because of the results after the first load. Before the first load ten pieces of sawn timber of heartwood and ten pieces of sawn timber of sapwood were taken aside, to provide reference material.

7.3 Tests for sample pieces

Before all the thermal modification loads major faults were marked to the sawn timber. The most important test for sample pieces is the seasoning test. The test consists of three phases and each phase lasts fourteen days. In the test the temperature is stable at 20 ^{o}C and relative humidity is in the first phase 35 %, in the second phase 60 %, and in the third phase it is 90 %. Into the chamber 40 sample pieces were placed. The sample pieces were identical in dimension: 17. 6 x 135. 5 x 50 mm.

Sitka spruce knots are a major problem in thermally modified sawn timber. The cracking of knots in Sitka spruce was tested in the oven which was preheated to 102 ^{o}C. Sitka spruce samples were cut approximately to 25 cm long pieces. Sample pieces were taken out of the oven seven times. Each time the samples were taken out of the oven the knots were photographed. The samples were weighed in all stages of the test so that moisture content could be calculated. In the knot cracking test it is essential to mark what the moisture content is when knots start cracking powerfully.

In all tests the moisture content of Sitka spruce was calculated from the dry weight.

$$\frac{(\text{wood initial weight / wood dry weigth})}{\text{wood dry weight}} \times 100 = \text{MC\%}$$

8 THERMAL MODIFICATION TEST

Test treatments were done in the wood laboratory of the Lahti University of Applied Sciences. The manufacturer of the kiln is Tekma Wood / Jartek Oy. The maximum dimensions of the load are 2 m x 1 m x 1 m and volume is approximately 2 m^3. In the kiln there are moisture and temperature sensors, which are supplying data to the PC and the process is controlled by *Wintek* program.

FIGURE 9. Heat treatment kiln by Tekma Wood. (Batch kiln)

8.1 Thermo Wood process using high temperature drying

The first load is called A. Timber were checked and faults were paid attention to. Dark knots were marked and knots divided to categories according to the knot type. Categories are bark knot, unsound knot and bark ringed/cracked knot. Information sheet on marked knots is Appendix 1. Cracks in the knots had partly been formed in storage drying. The most common were knots cracking/bark ringed knots and unsound knots.

The Thermo Wood process started with high temperature drying. In thermal modification the temperature was 215 ^{o}C. After the process the wood was very dry and to the next loads more steam had to be used in drying and in conditioning. The timber did not need marking and closer examination because all the dark knots dropped off from the timber and sound knots cracked. The diameter of most of the sound knots was between 20 to 30 mm and cracked completely. Dark knot dimension did not have any influence on the knot getting loose from the wood material.

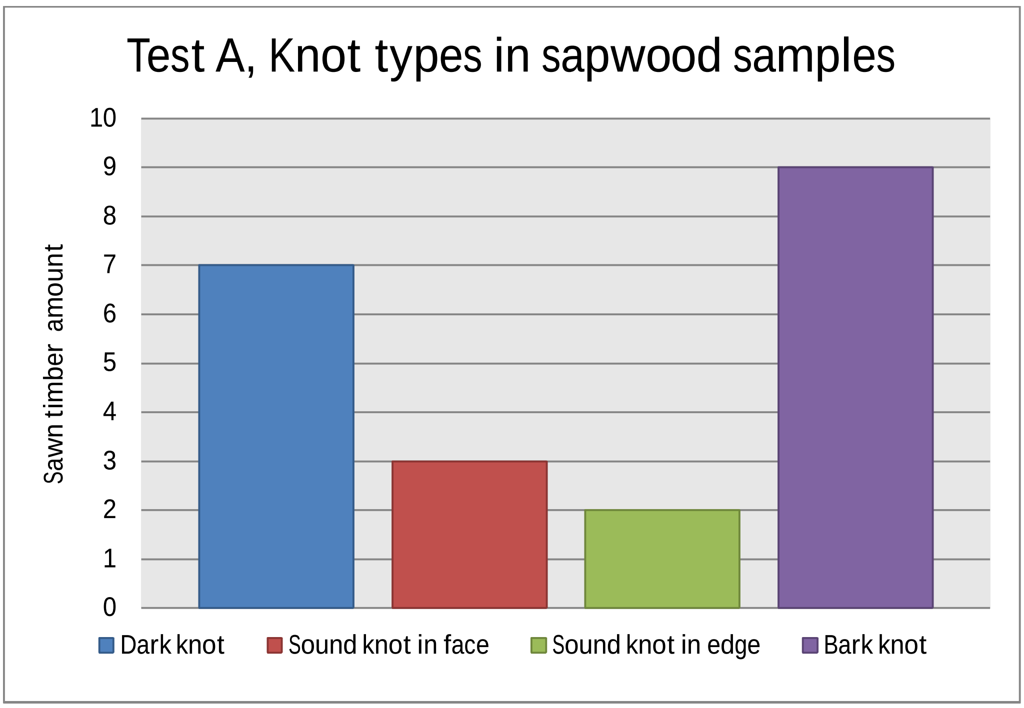

FIGURE 10. Knot types in the sapwood of sawn timber

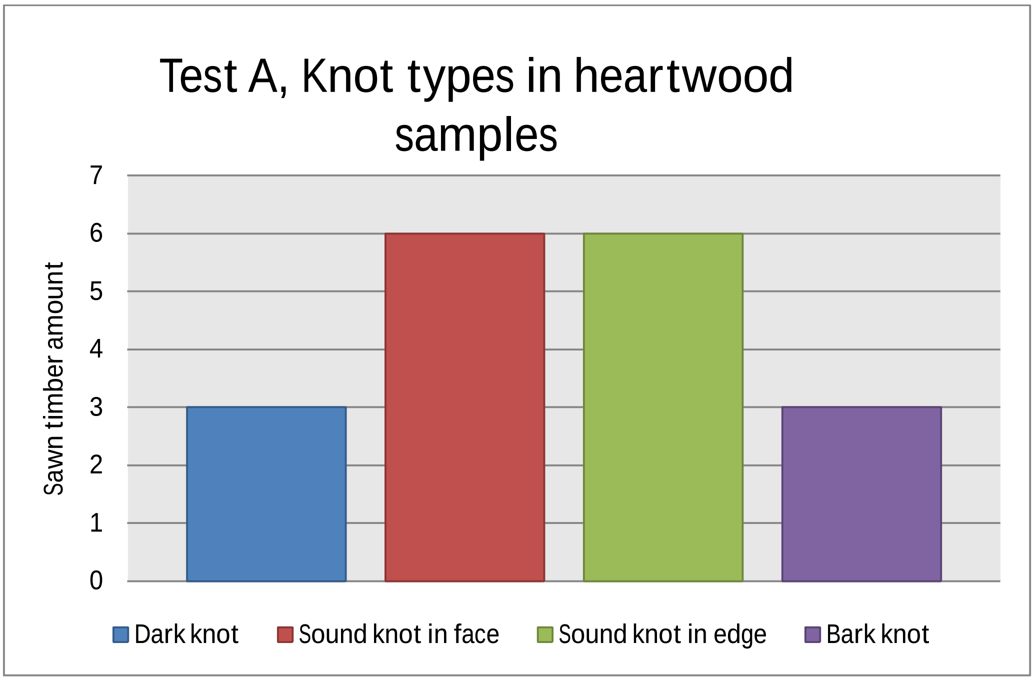

FIGURE 11. Knot types in the heartwood of sawn timber

8.2 Thermo Wood process using conventional temperature drying

High temperature drying was changed to conventional temperature drying. Warm temperature drying is gentler for the wood. In the visual check there were no cracks found from the sound knots because the moisture content of sapwood was 130 % and heartwood 110 %. Before the Thermo Wood process ten sapwood and ten heartwood pieces of sawn timber were taken aside, to provide reference material.

The closer visual check reveals no difference in knots cracking from high temperature drying. Knots cracking are similar even though the drying process is gentler for the wood.

9 KNOT CRACKING TEST

The problem of the thermal modification process on Sitka spruce was knot cracking. Knot cracks are not dependent on the knot's dimensions. Knots in all dimensions can crack or drop off completely.

9.1 Green wood drying in oven

During the experiment green Sitka spruce samples were cut approximately into 25 cm long pieces. The test was conducted on heartwood and sapwood. At the beginning of the test the oven was preheated to 102 ^{o}C. Knots from samples were photographed before and after all seven stages of the test. Samples were weighed at all stages so that moisture could be calculated. Samples were taken randomly from the stack which came from the sawnmill. The test consisted of six sample pieces from heartwood and sapwood.

9.2 Sapwood samples

FIGURE 12. Green sapwood knots

Figure 12 shows green sapwood with a sound knot and a bark-knot. The sample number is P2. The knots are not cracked or cracked off the wood material. The moisture content of the wood is 100 %.

FIGURE 13. Sapwood knots after two and a half hours in the oven

In Figure 13 the moisture content of sample P2 is 69 %. The knots have formed small cracks. In the bark-knot joint to the wood material it has cracked approximately 70 % of its knot circular. Resinous dark knots started to come loose from wood material because the pitch was boiling. The pitch was boiling and therefore it was evaporating and the dark knots joint became very weak or the knots dropped off completely.

FIGURE 14. Sapwood knots after three and a half hours in the oven

In Figure 14, the moisture content of sample P2 is 57 %. The knot cracks are constant and there are no remarkable changes.

FIGURE 15. Sapwood knots after six hours in the oven

In Figure 15, the moisture content of sample P2 is 34 %. The number of crack has not increased but the former cracks have enlarged. The bark-knot joint to the wood material is weak because the crack covers 70 % of the circle. In the bark-knot joint decomposable bark has vanished.

FIGURE 16. Sapwood knots after seven hours in the oven

In Figure 16, the moisture content of sample P2 is 12 %. Bark has vanished from the bark-knot and the healthy part of the knot stays joined to the wood material. The sound knot has broken down entirely and it does not meet standards anymore.

FIGURE 17. Sapwood knots in absolute degree of dryness

In Figure 17, sample P2 wood has dried to the absolute degree of dryness. The knots show no remarkable changes compared to the moisture content of 12 %.

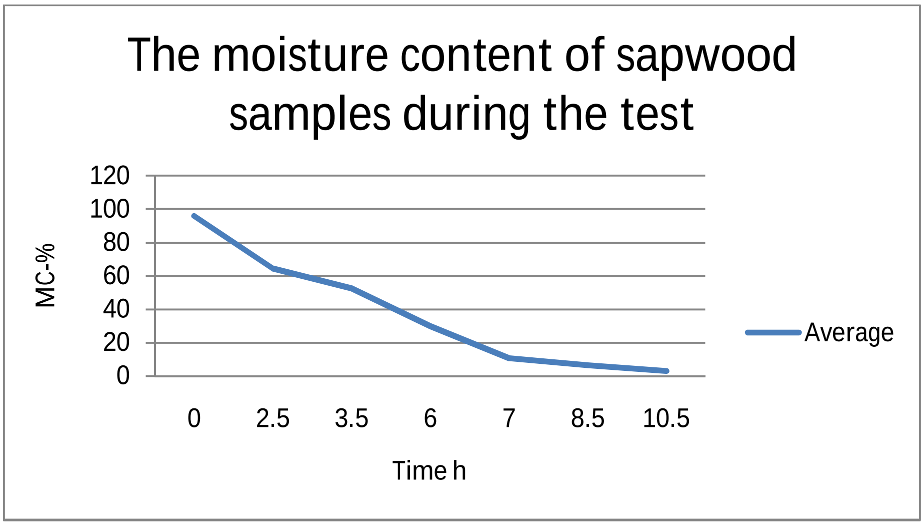

FIGURE 18. Sapwood samples moisture content is decreasing during the time in oven.

In Figure 18, the blue line represents moisture content change by time. The sample's moisture content is decreasing steadily and there are no rapid or lasting stages during the test.

9.3 Heartwood samples

Knots from samples were photographed before and after all seven stages of the test. Samples were weighed at all stages so that moisture could be calculated. The test for heartwood samples was identical to the sapwood sample test. In the test, the samples were marked S1 to S6.

FIGURE 19. Green heartwood knots

In Figure 19, sample S1 has two sound knots. The moisture content of sample S1 greenwood is 80 %. In Figure 19 two similar sound knots illustrate how similar knot cracking is.

FIGURE 20. Heartwood knots after two and a half hours in the oven

In Figure 20, the moisture content of sample S1 is 50 %. Fast drying has caused small cracks to the surface of both knots. Cracks have not damaged wood quality remarkably in this degree of moisture.

FIGURE 21. Heartwood knots after three and a half hours in the oven

In Figure 21, the moisture content of sample S1 is 40 %. Cracks have not enlarged and new cracks have not formed. Knot joint to the wood material is strong and there are no cracks.

FIGURE 22. Heartwood knots after six hours in the oven

In Figure 22, the moisture content of sample S1 is 23 %. Cracking of heartwood sound knots follows the same pattern as cracking of sapwood sound knots. The number of small cracks does not increase when the wood is drying. Cracks which are formed to the surfaces of knots are enlarging when the moisture content of wood is decreasing.

FIGURE 23. Heartwood knots after seven hours in the oven

In Figure 23, the moisture content of sample S1 is 9 %. Knot cracks have enlarged so much that the wood working as an example planing will erase the knots from wood material.

FIGURE 24. Heartwood knots in absolute degree of dryness

In Figure 24, sample S1 wood is in absolute degree of dryness. Knots have broken down completely. The durability of Sitka spruce knots in the heartwood and sapwood is not as good as in Norway spruce.

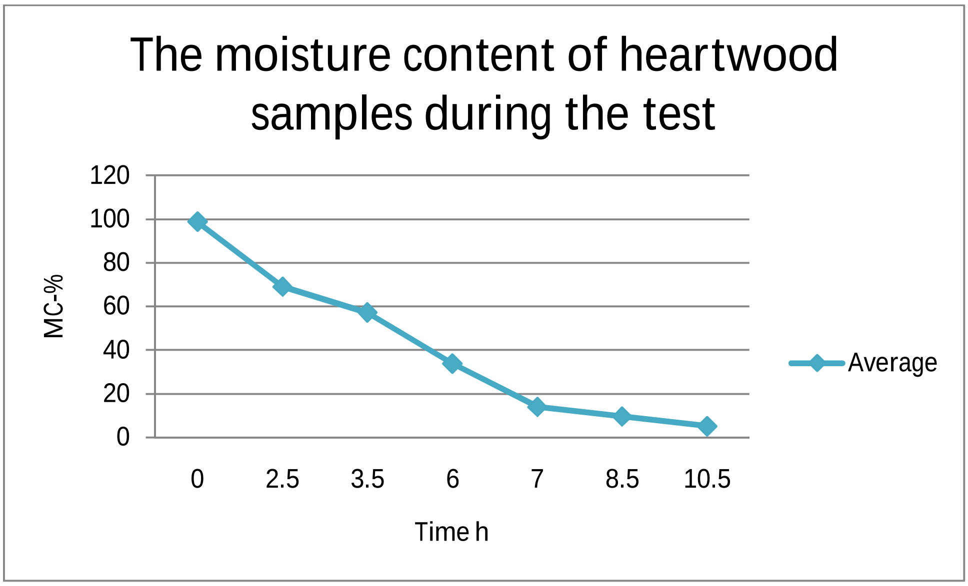

FIGURE 25. The moisture content of heartwood samples is decreasing during the time in the oven.

In Figure 25, the moisture content of heartwood samples is decreasing steadily. The moisture content of heartwood and sapwood is decreasing, forming the same pattern by time. Quality of wood material is good without cracking. Knots cannot stand fast drying and will break down or drop off completely.

10 SEASONING CHAMBER TEST

10.1 Backround of seasoning test

The Lahti University of Applied Sciences has a cabin where it is possible to simulate real weather conditions. The test consisted of three phases and each phase lasted fourteen days. In the test the temperature was stable at 20 ^{o}C and relative humidity was in the first phase at 35 %, in the second phase 60 %, and in the third phase it was 90 %. 40 sample pieces were placed into the chamber. Sample pieces were identical in dimension so that dimensional stability can be identified.

FIGURE 26 . Seasoning chamber where it is possible to simulate real weather conditions.

10.2 Seasoning test

In the chamber there were ten sample pieces from four different treatments. In each sample group there were five sapwood and five heartwood samples. The sample pieces had no faults or knots. Before the test the samples pieces were in the laboratory for 2 weeks and the weight was measured at the beginning of the test.

Samples were divided into groups following a certain pattern. Groups were marked with two letters. The first letter was the group sign and the second was **H** for heartwood or **S** for sapwood.

The groups are shown below:

– **AH** and **AS** group is high temperature dried and thermo wood
– **CH** and **CS** group is conventional dried and thermo wood

Only dried are

- **2AH** and **2AS** are high temperature dried
- **2CH** and **2CS** are conventional dried

TABLE 2. Moisture content is not so high in thermo wood samples. Wood water resistance is better when it is thermally modified.

Samples MC- % average after certain phase					
Thermo Wood	Absolutely dry	Start/Phase 1	Phase 2	Phase 3	Phase 4
AS+CS	0	3.5	4.4	7.1	14.0
AH+CH	0	3.3	4.4	7.2	13.7
Dried					
2AS+2CS	0	7.0	7.1	11.5	20.7
2AH+2CH	0	7.1	7.1	11.5	20.8

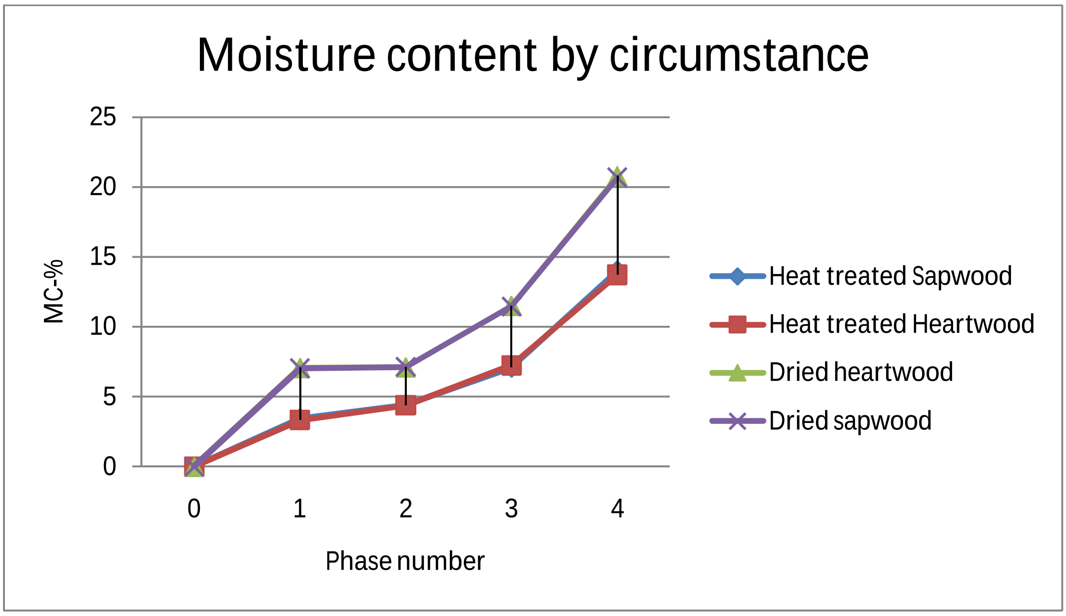

FIGURE 27. Moisture content change after different seasoning chamber phases

In Figure 27, the moisture content of thermally modified sapwood and heartwood is increasing equally. The moisture content of dried sapwood and heartwood is equal in all phases. In Figure 27, the moisture conten of thermally modified samples is lower than that of dried wood.

The **Scottish Forest Industries Cluster** has made the same kind of test. Figure 28, below show the results. The test results are very near the results of this thesis.

	Moisture content in 90% humidity	Moisture content in 60% humidity	Corresponding tangential movement	Corresponding radial movement
Sitka spruce	19%	12.5%	1.3%	0.9%

FIGURE 28. Results of the tests made by Scottish Forest Industries Cluster. (Adding value to home-grown timber, 2007.)

11 CONCLUSIONS

Sitka spruce timbers were planed to wooden cladding with tongue and groove. The wood material itself looked good and it was suitable to planning but even before planing it was clear that the knots are not suitable for planing. There are a few photographs of wooden cladding made of thermally modified Sitka spruce.

FIGURE 29. Thermally modified Sitka sprucee cladding with tongue and groove

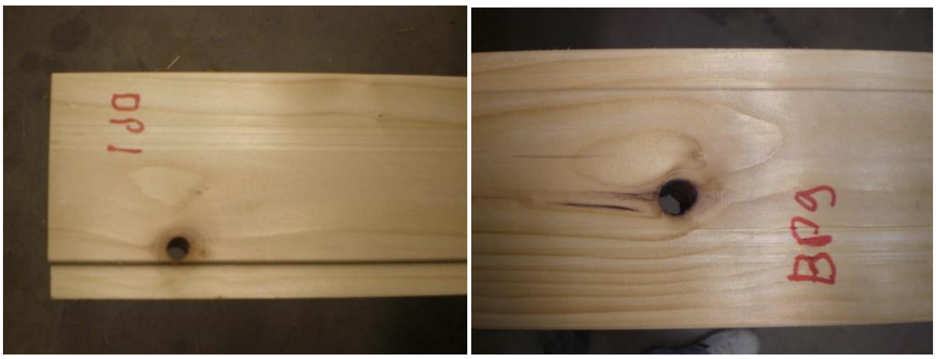

FIGURE 30. Dried Sitka spruce cladding with tongue and groove

In Figures 29, and 30, shown the results after planing. The color of heat treated Sitka spruce is even. Main factor causing knots cracking is moisture content difference between wood material and knots. When moisture content is decreasing under wood fiber saturation point, knots are shrinking remarkably. More testing must be done to find a way to avoid knot cracking. A solution for the problem is better quality control when picking the wood for the thermal modification process. Further developments to this research can be done to find out whether the Sitka spruce trunk is more suitable for the thermal modification process from the bottom or from the top of the trunk. The main objective of further research would be to find out if there is better quality and knot free Sitka spruce available.

12 SUMMARY

This Bachelor’s thesis is an examination of thermal modification process of the Sitka spruce (*Picea Sitchensis)*. The thesis is done for a company called Jartek Oy. Jartek Oy supplies wood processing equipment and mills. Jartek Oy ordered this research from the Lahti University of Applied Sciences. The objective was to make thermal modification for Sitka spruce and try to find out its suitability for the Thermo Wood process. The thermal modification process is done using Thermo Wood process standards. At the end of the thermal modification and drying sessions, quality inspections are based on the Thermo Wood standards.

The theoretical part of this thesis is a review of high temperature drying of wood and the thermal modification process. The theoretical part includes introduction of the suitability of different wood species to the thermal modification. The quality standards of the Thermo Wood process are introduced and there is a description of the properties and end use applications of Sitka spruce.

Green sawn Sitka spruce timber was shipped to Finland from the United Kingdom. The timber was sawn to dimension 25 x 150 x 2200 mm. Green Sitka spruce stacks contained approximately 50 % of heartwood and 50 % of sapwood.
In the thermal modification process, conventional and high temperature drying

was used. During the first trial of testing the thermal modification process on Sitka spruce, the plan was to make four to five thermal modification loads for Sitka spruce. After the first load the plan had to be changed because of the results after the first load. Conventional drying was used bein order to try to reduce faults and cracking that happened when using high temperature drying. Conventional drying is gentle for the wood but it did not cause any improvement to the quality of thermally modified Sitka spruce.

The test consisted of three phases and each phase lasted fourteen days. In the test the temperature was stable at 20 ^{o}C and relative humidity was in the first phase at 35 %, in the second phase 60 %, and in the third phase it was 90 %. 40 sample pieces were placed into the chamber. Sample pieces were identical in dimension 17, 6 x 135, 5 x 50 mm. In the chamber there were ten sample pieces from four different treatments. In each sample group there were five sapwood and five heartwood samples. The sample pieces had no faults or knots.

The seasoning chamber test confirmed that the water resistance of wood is better when it is thermally modified. The moisture content of dried sapwood and heartwood is equal in all phases of the test. In all phases of the test thermally modified samples moisture content is lower than dried wood.

The problem of the thermal modification process on Sitka spruce was knot cracking. Knot cracks are not dependent on the knot's dimensions. Knots in all dimensions can crack or drop off completely. Sitka spruce samples were cut approximately into 25 cm long pieces. The test was conducted on heartwood and sapwood. At the beginning of the test the oven was preheated to 102 ^{o}C. The test consisted of six sample pieces from heart- and sapwood. In the knot cracking test it is essential to mark what the moisture content is when knots start cracking powerfully.

After the knot cracking test is remarked that cracking of heartwood sound knots follows the same pattern as cracking of sapwood sound knots. Cracks which are formed to the surfaces of knots are enlarging when the moisture content of wood is decreasing. When sample pieces moisture content is around 20 % cracks starts enlarging. When moisture content is below 10 % wood working as an example planing will erase the knots from wood material.

The result of this research is that Sitka spruce is not suitable for thermal modification. Knot cracking is a major problem, which prevents commercial use. The main factor causing knot cracking is the difference of moisture content between wood material and knot. The wood material itself looks good and it is suitable for thermal modification. More testing must be done to find a way to avoid knot cracking. Without knot cracking thermally modified Sitka spruce would have great commercial value.

REFERENCES

Literature:

Möller, K., Otranen, L. 1999. Puun Lämpökäsittely, Ympäristötekniikan Instituutin julkaisuja 4 1999.

Hill, C.A.S, Militz, H. & Ormondroyd, G.A. 2007. Proceedings of the Third Conference on Wood Modification 2007. 3rd European Conference on Wood Modification, The Angel Hotel, Cardiff, UK 15th – 16th October 2007.

Riekkinen M. & Kärki T. (toim.) 2001. Koivun kuivausmenetelmät 2000- vuosituhannella. Seminaaripäivän esitelmät. Joensuun tutkimuskeskus, Joensuu.

Antti Jokelainen. 2008 Kuivausmenetelmän vaikutus lämpökäsitellyn koivun ominaisuuksiin. Opinnäytetyö Lahden ammattikorkeakoulu.

Electronic:

Puuproffa. [web]. [cited 9.12.2009] Available: http://www.puuproffa.fi/

Lämpökäsitellyn puun ominaisuudet ja lujuus 2002, [web]. [cited 10.12.2009] Available:
http://raklab.kyamk.fi/seminaari/2002/juha_elolinja/index.htm

[cited 17.12.2009]. Available:
http://fi.wikipedia.org/wiki/L%C3%A4mp%C3%B6puu

[cited 15.12.2009]. Available:
http://www.naturallywood.com/uploadedFiles/General/Wood_Products/Tree-Species-Sitka-Spruce.pdf

High Temperature Drying. 2005 [web]. [cited 13.12.2009]. Available: http://www.forestry.gov.uk/pdf/cr_HighTemperatureDrying.pdf/$file/cr_HighTemperatureDrying.pdf

Adding value to home-grown timber. 2007 [web]. [cited 17.12.2009]. Available http://www.forestry.gov.uk/pdf/cr_AddingValueManual.pdf/$FILE/cr_AddingValueManual.pdf

[cited 11.12.2009]. Available: http://www.forestry.gov.uk/forestry/INFD-5NLEJ6

Thermo Wood handbook 2003. [web]. [cited 7.1.2010]. Available: http://www.thermowood.fi/data.php/200312/795460200312311156_tw_handbook.pdf

Appendix 1. Moisture content in seasoning chamber

Seasoning chamber

Heat treated	Weight	Moisture content Start	Phase 1	Phase 2	Phase 3
AP1	46,7	3,6	4,7	7,5	14,1
AP2	45,7	3,9	4,8	7,4	14,2
AP3	46,8	3,4	4,7	7,5	14,5
AP4	48,3	3,1	4,6	7,0	13,7
AP5	42,1	3,6	4,3	6,7	13,8
Average	45,92	3,5	4,6	7,2	14,1
AS1	45,5	3,7	4,4	7,7	13,4
AS2	48	3,7	4,4	7,5	13,3
AS3	41,8	3,3	4,5	7,7	13,9
AS4	38,5	3,4	4,2	7,0	13,2
AS5	56,8	3,2	4,4	7,6	14,4
Average	46,12	3,5	4,4	7,5	13,7
CP1	41,3	3,4	4,4	7,3	13,8
CP2	46,9	3,2	4,3	7,0	13,9
CP3	42,9	3,7	4,2	6,8	14,0
CP4	47	3,2	4,0	6,8	13,6
CP5	41,1	3,4	4,4	6,8	14,4
Average	43,84	3,4	4,2	6,9	13,9
CS1	46,3	3,0	4,3	7,1	13,6
CS2	46	3,0	4,3	7,2	13,7
CS3	51,4	3,1	4,3	7,0	13,6
CS4	41,4	3,6	4,6	7,0	14,3
CS5	45,1	3,1	4,4	6,7	13,7
Average	46,04	3,2	4,4	7,0	13,8

Appendix 2. Moisture content in knot cracking test

Sample	MC% at the beginning	MC 1	MC 2	MC 3	MC 4	MC 5	MC 6	MC 7	Abs. Dry	Weight before test
P 1	145	112	95	61	22	17	11	5	288,2	706,5
P 2	100	69	57	34	20	12	7	4	286,8	572,4
P 3	75	49	37	16	11	6	4	2	252,5	442,7
P 4	81	50	40	24	15	11	7	3	340,6	615,1
P 5	91	56	45	24	15	10	6	3	260,9	497,6
P 6	85	52	41	21	14	9	5	3	251	464
S 1	80	50	40	23	18	14	9	5	310,2	557,5
S 2	74	46	38	22	16	11	8	4	221,8	385,5
S 3	125	93	80	48	19	15	10	5	257,7	579,1
S 4	129	99	82	52	22	17	12	7	311,5	713,9
S 5	115	86	70	35	19	14	9	5	226,1	486,6
S 6	70	40	33	22	16	12	8	5	212,7	361,5
S 7	79	47	38	23	18	13	9	5	216,9	387,2
S 8	80	50	41	25	18	14	10	6	229,2	413,6

Appendix 3. Knot types relevance in load A

	sample	Lots of knots	Dry knot	Sound knot on side	Sound knot on edge	Bark knot
	AP1		x			x
	AP2		x	x	x	
	AP3					x
	AP4			x		x
	AP5		x			x
	AP6		x			x
	AP7			x	x	x
	AP8		x			x
	AP9		x			x
	AP10		x			x
Amount			7	3	2	9
Amount %		0	70	30	20	90

	KPL	Lots of knots	Dry knot	Sound knot on side	Sound knot on edge	Bark knot
	AS1			x	x	
	AS2			x	x	x
	AS3			x		
	AS4		x	x	x	
	AS5	x		x	x	
	AS6			x	x	
	AS7				x	
	AS8		x			x
	AS9					
	AS10		x			x
Amount		1	3	6	6	3
Amount %		10	30	60	60	30

Appendix 4. Knots relevance average in loads A,B,C and D.

Sapwoo	Dry knot	Sound knot on side	Sound knot on edge	Bark knot
A	7	3	2	9
B	4	1	2	8
C	2	2	3	7
D	4	5	5	7
Average	**4**	**3**	**3**	**8**
Heartwood	Dry knot	Sound knot on side	Sound knot on edge	Bark knot
A	3	6	6	3
B	1	9	8	
C	1	10	10	2
D	3	7	2	2
Average	**2**	**8**	**7**	**2**

Appendix 5

Comparison of different drying techniques in figures
(High Temperature Drying, 2005.)

Scots Pine 50 mm	batch kiln 8 %	HTD -kiln 8 %	contin.kiln 18 %	HTD -kiln 18 %
Initial data				
drying capasity, m^3 / a	7200	7000	14000	14000
kiln acquisition price, million euros	0,3	0,21	0,35	0,21
repayment period, a	12	12	12	12
interest rate, %	6	6	6	6
price of heat, €kWh	0,02	0,02	0,02	0,02
price of electricity, €kWh	0,04	0,04	0,04	0,04
timber value, €m^3	200	200	170	170
drying time, h	200	50	100	25
heat consumption, kWh/m^3	450	360	300	300
electricity consumption, kWh/m^3	40	50	25	35
labour and maintanace costs, €m^3	2	2	2	2
value loss due drying defects, %	5	5	5	5
Costs, €m^3				
capital costs, kiln	4,97	3,58	2,98	1,79
interest payable, timber during drying	0,27	0,07	0,12	0,03
energy	10,60	9,20	7,00	7,40
labour and maintenance	2,00	2,00	2,00	2,00
value loss due drying defects	10,00	10,00	8,50	8,50
Total	*27,84*	*24,85*	*20,60*	*19,72*
change LTD > HTD, %		-10,8		-4,3