Thermally Aged Tonewood

by Pertti Nieminen and Rauno Nieminen

English translation by Juha Ruokangas

MES - The Finnish Music Foundation
Finnish musical instruments made of Finnish wood

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INTRODUCTION

Wood seasoning - the traditional method to improve the acoustic and mechanical properties of wood - is a process that takes years, even decades. Acquiring seasoned wood has become increasingly hard; therefore, musical instrument makers are becoming more interested in various methods for simulating the effects of seasoning.

Fire Chief Osmo Savolainen developed a special thermal modification method for wood beginning in the 1990s in Finland. He wanted to find a substitute for chemical preservatives against decay, which led coincidentally into a successful experiment to simulate the effects of ageing tonewood by using the same equipment. Research conducted from 1996-1998 resulted in a new invention, thermally aged tonewood, marketed as Thermo Timber Tonewood®. This method was unveiled at the Frankfurt Musikmesse 1998, at the Finnish Guitar Network exhibition stand. [1] Unfortunately, however, the thermally aged tonewood was confused with the thermal treatment against decaying developed earlier by Osmo Savolainen, patented by VTT Technical Research Centre of Finland and sold under a different trademark, Thermo Wood®, by the International Thermo Wood Association.[2]

> *"Thermo Wood is a wood material produced by using natural methods, heat and steam. Thermal modification improves the wood's technical properties and Thermo Wood is non-toxic, dimensionally stable, resistant to decay and resin free. It can be used inside or outdoors, in any climate."*

The goals of these two methods differ. The method patented by VTT uses temperatures[3] in the range of 180-230°C. The goal of using such high temperatures is to improve wooden structures' resistance to decay in outdoors applications. The thermally aged tonewood, however, is always made in temperatures under 180°C and aims to achieve the same effects as the natural seasoning process of 10-50 years. The wood becomes more stable (by its decreased ability to absorb moisture), its weight lightens, its rigidity increases and its natural colour deepens. All this happens without compromising any of the wood's essential mechanical attributes.

The Tampere Technical University published an in-depth study of thermally aged tonewood in 2002 in the Finnish language only (*Raportti nr. 55, Lämpökäsittely ja Soitinpuu - Report 55, Thermal Treatment and Tonewood*). During this same time, Osmo Savolainen retired from his business and, sadly, the details of this unique process were nearly forgotten. Due to their positive experiences, many Finnish luthiers continued making musical instruments of thermally aged tonewood. They found a few thermal treatment facilities that agreed to treat wood at lower temperatures than the patented method they normally used - but since the details of thermally aged tonewood were never disclosed by the developer, the results were irregular, raising the costs and discouraging many luthiers from continuing its use.

The rumours about thermally aged tonewood, however, slowly spread out into the world. Many luthiers in different countries started experimenting with the method without the knowledge of exactly how or why the wood should be treated. Thermally aged tonewood was repeatedly mixed up with the patented thermal treatment to protect wood against decay, because the only existing information in the English language was about the patented method. Juha Ruokangas tried to educate people with correct information on the Ruokangas Guitars website and in two different, in-depth interviews by the *ToneQuest Report,* a U.S. magazine.[4]Juha Ruokangas and Rauno Nieminen have also lectured about thermally aged tonewood at the Holy Grail Guitar Show. Eventually, thermally aged tonewood became an international phenomenon. Large and small manufacturers throughout the world are now using the method in a vast variety of interpretations, with many builders having developed their own methods.

MES - The Finnish Music Foundation - initiated a three-year project in 2017 called "Finnish Musical Instruments Made of Finnish Wood". This venture's goal is to increase the use of domestic wood in musical instrument making. One key element of the project has been to purchase musical instruments from a wide variety of Finnish makers and to include this collection as a part of the MES Musical Instrument Bank, which maintains, borrows and leases valuable instruments for professional use in Finland. Another essential project goal has been to revive and update the essential results of the 2002 university research on thermally aged tonewood and to finally translate the study into the English language. Furthermore, the project has developed a prototype of a low-cost oven that will finally bring thermally aged tonewood within every musical instrument maker's reach.

In Ikaalinen 11.6.2020 Pertti Nieminen, Rauno Nieminen

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[1] Alatalo, Aulis. "Thermally modified guitar breakthrough in Frankfurt". *Aamulehti*, 19.3.1998

[2] https://www.thermowood.fi/1

[3] Nieminen, Oertti, Pietilä Taisto, Suhonen Pekka. Lämpökäsitelty puu ja soitinrakentaminen. Raportti 55 .Tampereen Teknillinen Korkeakolu.

[4] "The Mythology of Tone". *The ToneQuest Report,* August 2005 VOL. 6 NO. 10. (http://www.tonequest.com/august-2005-vol-6-number-10)

1 History of Thermally Aged Tonewood

Thermal treatment - with the goal of protecting wood from decay

Osmo Savolainen, the former fire chief of the Finnish town of Mänttä, started to develop a method to treat wood with heat in the late 1980s. He found a nonpoisonous way to protect wood against decay, and it was also safe to use on children's playgrounds. In this process, the wood was first heated to approximately 100°C and then to gradually hotter and lower temperatures, depending on the desired outcome. In the early stages of developing the process, the first test chamber (see cover photo) exploded as a result of the wood fumes igniting in the hot temperature. Savolainen solved the problem by spraying water vapor into the chamber. The water vapor also speeds up the chemical reactions in the wood. Nearly all variations of thermal treatment techniques around the world are based on these principles developed by Osmo Savolainen:

- *Air-tight chamber*
- *The wood to be treated*
- *Water vapor (some use other protective gases to replace water, but the result is not the same)*
- *A fan to rotate the air inside the chamber*
- *Sensors for monitoring the air and wood temperatures and the air humidity*
- *An operating program to adjust the heat and humidity during the process*
- *Cooling down the wood (with water vapor)*
- *Restoring the equilibrium moisture content*

Osmo Savolainen conducted market research on the basis of his idea in 1990, building the first test chamber the following year and the first production plant in 1992. Savolainen received an Innosuomi Award in 1993 and a Tuottava Idea award in 1998 for his invention. He also bought research -- a water absorbency analysis -- from the VTT Technical Research Centre of Finland. Savolainen named his company Suomen Ekopuu Oy and sold thermal treatment plants to Finland, Estonia and Canada. He talks about the early days in Kauppalehti: [5]

In Finland heat treatment of wood started in early 90's when the first treatment plant was built to Mänttä.

Osmo Savolainen conducted market research on the basis of his idea in 1990, building the first test chamber the following year and the first production plant in 1992. Savolainen received an Innosuomi Award in 1993 and a Tuottava Idea award in 1998 for his invention. He also bought research -- a water absorbency analysis -- from the VTT Technical Research Centre of Finland. Savolainen named his company Suomen Ekopuu Oy and sold thermal treatment plants to Finland, Estonia and Canada. He talks about the early days in Kauppalehti: [6]

"I got the original idea from Canada" he recalls. "But there was no detailed plans available and the present system is the result of my own development efforts."

Osmo Savolainen's 1st and 2nd thermal modification ovens in Mänttä. Photo by Rauno Nieminen.

[5] A. O. Rapp (2001) *Review on Heat Threatmants of Wood*. Page 9. (http://projects.bre.co.uk/ecotan/pdf/Heat_treatment_processes_Andreas_Rapp%20.pdf)

[6] Nevalainen, Petri (1999) "Thermowood Takes of the Heat". *Blue Wings*, December 1998–January 1999.

The thermal treatment business, with its goal to protect wood against decay, gained popularity in Finland. Many companies had started treating construction wood with the new method by the turn of the millennium. *The International ThermoWood Association* was founded in 2000 as an umbrella organisation for the companies doing thermal treatment. The association's website also mentioned these thermal treatment applications: "musical instrument making, boat making and other wooden objects". This must be one of the reasons for the misunderstanding between *'thermally treated decay resistant wood'* and *'thermally aged tonewood'*.

Thermo Timber Tonewood 1996–1998

Puutietokeskus (Wood Information Centre) was founded in 1995 in Pirkanmaa, and two of its Acoustic Committee members were Docent Pertti Nieminen (from Tampere University of Technology, TTKK) and guitar-making teacher Rauno Nieminen (Ikaalinen College of Arts and Crafts, IKATA).

Pertti visited the guitar-making school in 1996 and showed Rauno some electron microscope photos of thermally treated wood. The photos reminded Rauno of an article published in the Strad violin magazine with similar photos taken of 17th century violins. An electron microscope photo of an old violin top made of spruce looked the same as the photo of thermally treated spruce. The question arose of whether thermal treatment could speed up the changes that happen to wood in the course of natural ageing over decades. The first step was to find out what exactly happens to wood when it ages, so they collected wood samples from old schools, churches and musical instruments during the summer of 1996.

Coniferous tree from St Olaf's Church in Tyrvää from year 1510 and Aitoo from year 1830.

The tests to treat the first pieces of tonewood began in 1997. The goal was to find the optimal thermal treatment for musical instrument wood. This research was funded by the *Finnish Guitar Network* (an IKATA project), *TTKK* and *TEKES*.

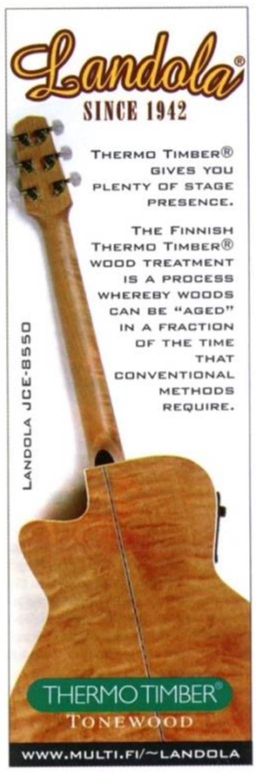
Osmo Savolainen treated test pieces made of spruce, alder and birch sized 20x50x500mm. Rauno and Pertti studied the effect. It became clear very early on that the high temperatures used in thermal treatment designed for construction wood destroyed the most crucial features of tonewood. Tonewood needed a treatment of its own. The tests continued using lower temperatures, seeking the optimal way to treat tonewood. The pieces of wood were inspected before and after treatments.

Musical instruments were made at the IKATA guitar-making school, using the test pieces treated in practise. Dozens of variations of thermal treatment were carried out both in the lab and in practical use. It turned out that every tree species and every plank size had to be treated differently. The treated wood was also provided to about 20 different musical instrument manufacturers and luthiers, for example, to *Landola Guitars, Liikanen Musical Instruments, Bass Makers Finland, Juha Lottonen, Veikko Virtasen Urkutehdas, Ruokangas Guitars*, etc.

Thermo Timber Tonewood®, the method to age tonewood with heat and developed by Osmo Savolainen, Pertti Nieminen and Rauno Nieminen, was trademarked in 1997. Savolainen founded a company, *Thermotimber, Ltd.*, in 1999. The business continued for a few years, then slowed down and finally ended in 2005. The *Thermo Timber Tonewood* process was never patented due to the earlier, confusingly similar *Thermo Timber* patent by VTT. It is noteworthy, however, that the thermal ageing of tonewood is done in temperatures lower than 180°C; that process never infringed the VTT patent in this regard.

Landola Guitars was the first company to use thermally aged tonewood on an industrial scale. They made thousands of guitars out of these materials. Their production with thermally aged materials began in June 1997, and they made approximately 1000 such guitars during the first year. The method gained a generous amount of attention from both the national and international press. The Finnish Guitar Network organised a seminar about thermally aged tonewood for luthiers on April 22, 1998. The use of aged tonewood increased among Finnish luthiers. They could now use species that had been problematic before, for example, flamed birch. Pertti and Rauno Nieminen received the Annual Wood Award from Pirkanmaan Puutietokeskus for developing the thermal ageing method for tonewood:[7]

> *Finnish manufacturers of musical instruments have found great potential in thermowood. One of them is the Landola Guitar factory in Pietarsaari, whose instruments have attracted a lot of attention aboard.*
>
> *Erkki Noromies says the new material has played a big role in changing companys strategy. "I spend a lot of time thinking ways that we could stand out from other guitar makers, and thermowood was the answer. It givers us three undeniable avantages: excellent resonance, very little deformation due to changes in moisture levels, and a beautiful colour"*
>
> *Noromies belives that within a year his company will using thermowood in about half the guitars it makes. That will be five thousand or so acoustic and electro-acoustic instruments made of the new material. Landola is now marketing its Thermotimber range of guitars in 11 countries.*



Landola JCE850 prototype, designed and made by Rauno Nieminen in 1998. Birch back, sides and neck, spruce top, rosewood fingerboard and bridge. All materials thermally treated by Suomen Ekopuu, Osmo Savolainen.

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[7] Nevalainen, Petri (1999) "Thermowood Takes of the Heat". *Blue Wing*s, December 1998–January 1999.


PIKA PALAT

Kuvat Pekka Väänänen, laitevalmistajat

Mikroskooppikuvista näkyy selkeästi tuoreen ja 100 vuotta kuivatun kuusen solukon ero. Kolmannessa kuvassa oleva lämpökäsitelty puu muistuttaa huomattavasti viime vuosisadalta talteen pantua puuta.

Tässä vaiheessa jo hymyilyttää. Dosentti Pertti Nieminen Tampreen teknisillisestä korkeakoulusta, soitinrakennus-koulun johtaja Rauno Nieminen sekä lämpöpuuhankkeen pellepeloton, palopäällikkö Osmo Savolainen esittelemässä vanhennetusta materiaalista valmistettua kitaraa.

Lämpöpuu tekee tuloaan soitinrakennukseen

Thermo Timber Tonewood -seminar in Mänttä, April 22, 1998. From left: Pertti Nieminen, Rauno Nieminen, Osmo Savolainen (Riffi Magazine, 1/1998).

Matti Nevalainen, Finnish Guitarworks, made the first electric guitar (Flying Finn) from Thermo Aged Wood in year 1998. Foto Rauno Nieminen.

Thermo Timber Tonewood at Frankfurt Musikmesse 1998

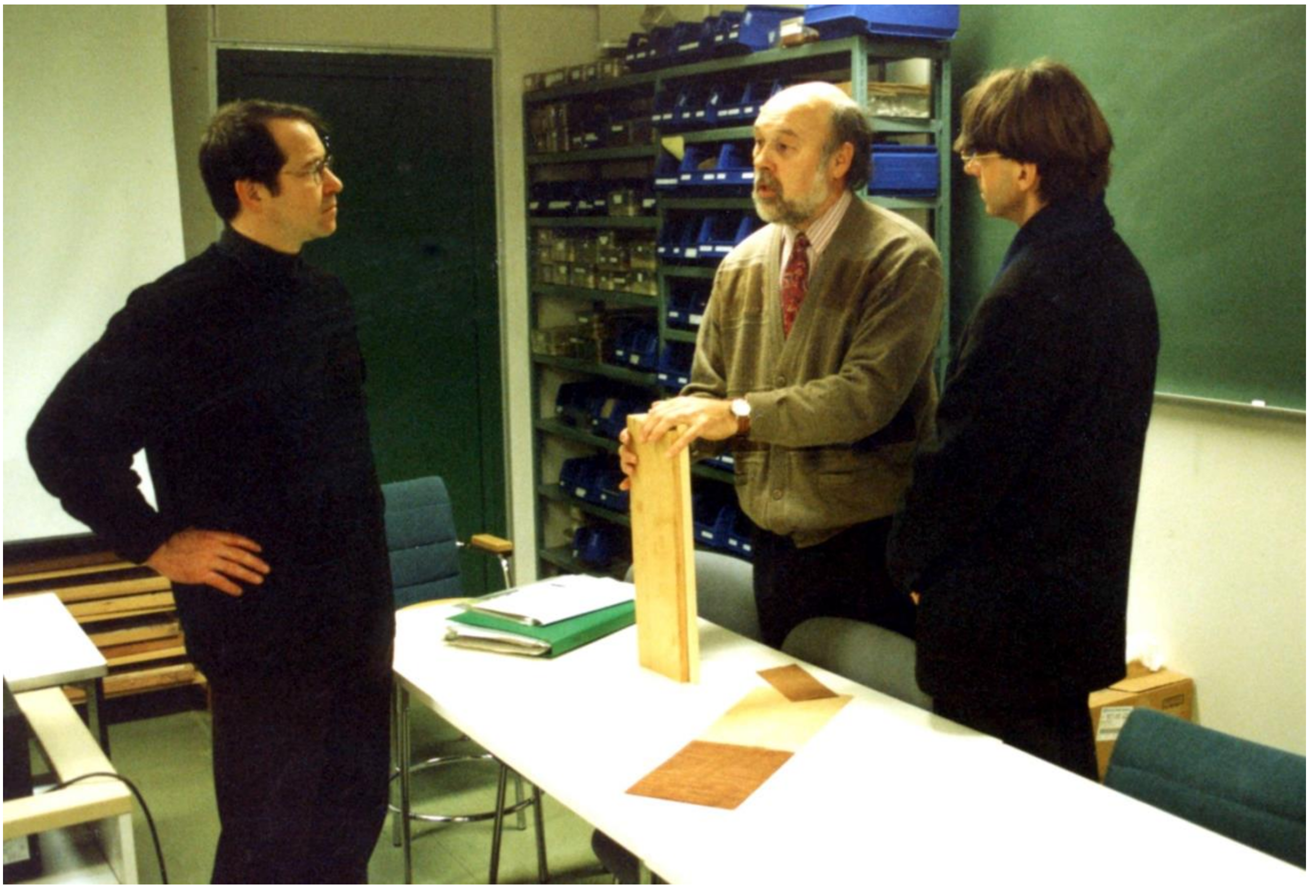
1998 Thermo Timber Tonewood was presented internationally for the first time at Frankfurt Musikmesse 1998, at the Finnish Guitar Network booth. Pertti and Rauno Nieminen were both present at the event. Landola Guitars exhibited their instruments made of thermally aged tonewood. The top, back, sides and neck were all made of thermally aged materials. The process gained much interest at the show. Many guitar makers came by to see what this was about. Chris Martin IV, the owner of C.F. Martin, visited the booth, tapped and bent the sample materials, and said, “I believe you. Wonderful!”, Pertti Nieminen recalls. Jerry Uwins wrote in an article for Music Business in August:[8]

Following prototype showing at Frankfurt of acoustic employing heat-treated timbers for "instant" ageing of colour darkening. Landola is now offering Thermo prosess back/sides options on its Ragtime LR, jumbo JCE and gutaway electro ACE series instruments, tought Westside Distribution hasn’t yet annouched price premiums. Landola is extending the project to include thermo treatment for tops and necks, and Docklands showed an LR20 with a treated solid spruce top that bore a marked resemblance to aged cedar.

Cedar itself is next on the list for experimention, as is alder for backs and sides and figured biech for necks. The Finnish company also says it has undertaken successful experiments with nondescript fingerboard woods that can be made to look like rosewood after treatment, and after wizardry of futher heating under high pressure, to resemble ebony. Intiguring stuff.

Finnish maker Landola, in collaboration with university and art and craft research centers and a specialist wood-handling operation, is experimenting with an innovative Thermo Timber process that aims to endow the properties of long-aged woods, virtually in overnight. It involves heating timbers in a temperature and moisture controlled oven for 24 hours or so, during witch time their cellular structure changes, becoming very similar – so micro photography comparisons show – to tonewoods of, say, 100 years old.

Fools' gold? Not from what I shaw: changes in appearance can be dramatic; and based on playing similar Landolas in Frankfurt made from treated and untreated woods, there do indeed seem to be tonal changes- in board there's a stronger high and low end, and a more audible sweetness. Mahogany and rosewood are next on the list for experimentation.



Gunther Reinhardt and Jan Tomsky visited Pertti Nieminen’s laboratory at Tampere Technical University in 1999. Photo by Rauno Nieminen.

[8]Uwins, Jerry (1998) "Doclands Guitars, Amps, FX". *Music Business*, August 1998.

Gunther Reinhardt exhibited at Frankfurt Musikmesse 2017, presenting guitars made of thermally modified wood. Reinhardt had researched the method in cooperation with Lothar Clauder and Dr. Alexander Pfriem.[9]

When the CITES endangered species convention restricted global trade with tropical timbers, hectic times broke out for instrument makers around the world. This is because these timbers, which grow slowly under specific climatic conditions, play an important role in the construction of guitars, violins and woodwind instruments due to their special sound characteristics. Within the scope of a research project with Eberswalde University of Sustainable Development, Best Acoustics Reinhardt has succeeded in developing a process for making a complete guitar from thermo-optimised indigenous timber. For this, the wood is heated for a short time to over 180 °C – a method originally developed for use in building façades and terraces. The resulting sound is every bit as good as in instruments made from tropical wood.

It looked like some interest had begun brewing. Osmo Savolainen sold a thermal treatment facility to Canada, which relocated later to Texas, USA; yet, it still took another ten years until the process became popular among the guitar industry outside Finland.

Eventually the international field of guitar manufacturers, both large and small, started to wake up. *Music Man* was the first major factory to take on thermally modified wood, along with many smaller makers in the USA. Today the technology has spread throughout the world. *Adam Perlmutter* wrote in an article for *Acoustic Guitar* magazine in September 2014:[10]

In Finland, torrefaction is known as "thermo-treatment" and has been used by various wood producers since it was patented in 1990. The Tampere University of Technology, together with a handful of Finnish instrument makers, initiated a study of thermo-treated tonewoods in 1996, culminating in a 2002 paper reporting the musical benefits of the process. This was a revelation for many builders in that country.

"Juha Ruokangas started torrefying everything in his instruments", says Bourgeois, referring to the luthier who specializes in electric guitars and basses. "Even organ builders found it was great for church instruments, whose cabinets were prone to swelling in those large halls."

Thermally Aged Tonewood and Guitar Making, 2000-2002

The development of Thermo Timber tonewood continued slowly after the 1998 premiere, funded privately by Osmo Savolainen and the Finnish Guitar Network.Then, a new endeavour emerged in 2000. The *Tampere University of Technology* (Pertti Nieminen), the *IKATA Guitar Making Department* (Rauno Nieminen) and *Thermo Timber Oy* (Osmo Savolainen) received a two-year funding grant to continue researching thermally aged tonewood.

A number of Finnish musical instrument companies joined the project: Lottonen Guitars, Taisto Pietilä, Soitinrakentajat Amf, Koistinen Kantele, Landola Guitars, Ruokangas Guitars, Liikanen Musical Instruments, Martti Porthan Organs and Veikko Virtanen Organs.

The research now focused completely on studying the lower temperature (140-180°C) treatment. Higher temperatures had already been proven unusable for tonewood. The two-year research project was carried out despite challenges that nearly ended it early. Rauno Nieminen had to pull out from the project due to health problems, and Osmo Savolainen's business was going through very hard times. The final research report was completed in 2002. Plentiful research data on the optimal processes for thermal ageing of tonewood were finally available, but no company had the skills or interest anymore to invest in bringing thermally aged and commercially available tonewood into common use. The final report existed only in the Finnish language, and only on paper. The report never became available online.

[9] Messe Frankfurt. Annual Report 2016: https://ru.messefrankfurt.com/content/dam/messefrankfurt-russia/corporaterussia/downloads/Annual-report-2016.pdf

[10] Perlmutter, Adam (2014) "Everything New is Old Again". *Acoustic Guitar,* September 2014. (https://bourgeoisguitars.net/our-news/dana-bourgeois-on-torrefaction-for-acoustic-guitar/)

Mick Box (Uriah Heep) fell in love with one of the early guitars made of Thermally Aged wood by Ruokangas Guitars in 1999. The guitar became a part of Mick Box's guitar collection. Photo taken at the Frankfurt Musikmesse 2000 by Markku Henneken.

Finnish Voodoo, 2006

Master Luthier Juha Ruokangas was among the first guitar makers to use thermally aged tonewood. The ToneQuest Report wrote an article, The Mythology of Tone, [11] about Juha's work in August, 2005. Ruokangas praised the qualities the thermal ageing process brings out in tonewood in his article. The outcome was that readers labeled the story as questionable "voodoo" without any factual basis to lean on. David Wilson, the ToneQuest Report's editor-in-chief, knew better than that and decided to write more, this time focusing solely on what Thermally Aged Tonewood is about. The article, Thermo-Treated Wood… Vintage Tone or Voodoo from Finland[12], came out in January 2006. Ruokangas was interviewed in it by David Wilson, and he talked about the thermal ageing process in detail, including hard data, charts and microscope photographs from the final Finnish research report from 2002. Ruokangas correctly explains the differences between the thermally aged tonewood and the VTT patented treatment to modify wood against decay. The article ends with these words by David Wilson: "Should Thermo-Treatment become available in United States (and we believe it will), you'll hear about it first, right here". Juha Ruokangas recalls, many years later:[13]

> *When luthiers buy wood, they examine carefully its properties. But when they buy thermally modified wood, it seems they just use it without much discernment. Thermal treatment has become like a quality label. When it's thermally modified, it's good. But that's not necessarily the case. Many builders around the world have started to notice this discrepancy. Some of them have begun developing their own methods, while others keep on using thermally modified wood protected against decay, even if its features as tonewood may be questionable. The correct information has existed for a long tie, but it's not widely known. There was the ToneQuest Report article, but that's about it in the English language. The Finnish luthiers and the developers of the technology had*

[11] Perlmutter, Adam (2014) "Everything New is Old Again". *Acoustic Guitar,* September 2014. (https://bourgeoisguitars.net/our-news/dana-bourgeois-on-torrefaction-for-acoustic-guitar/)

[12] Perlmutter, Adam (2014) "Everything New is Old Again". *Acoustic Guitar,* September 2014. (https://bourgeoisguitars.net/our-news/dana-bourgeois-on-torrefaction-for-acoustic-guitar/)

[13] Juha Ruokangas interview 15.10. 2019. By Rauno Nieminen.

the know-how, but as the availability of thermally aged tonewood has been (and still is!) so scarce, it was like a vicious circle. Why promote the technology to our international colleagues, when there's no reliable way to get the right kind of wood?

At the same time, there was the information available in the English language about the VTT patented higher temperature treatment - the kind used to protect wood from decay. And when the Thermo Wood association even mentions (in English language) on their website that the wood treated with their method is used also in musical instruments… there you have it. No wonder people are confused. So now we're in a situation where people around the world have different methods to treat wood with heat, named Torrefied, Roasted, Caramelized, Thermo Aged… There's not much information available about what these methods exactly are. There is one common factor to them, though. All claim they improve exactly the same features in tonewood that were brought out in the Finnish research back in the 1990's and on.

Roasted (Thermally modified)

http://www.americanspecialtyhardwoods.com/roasted-thermally-modified/

Artwood Vintage Thermo AgedTM

http://www.ibanez.com/products/u_ag_series18.php?series_id=99&year=2018&cat_id=3

Ibanez Introduces "Thermo Aged" Artwood Vintage Acoustics

https://www.youtube.com/watch?v=fyv2QAdkv6U

Taylor Guitars "Spruce Torrefaction Process"

https://www.youtube.com/watch?v=cv3cM0qQecY

Torrefaction Explained & Torrefied RP1-16C Demo

https://www.youtube.com/watch?v=27uKeLOIH_I

Martin Custom Shop 000-28 - Torrefied Adirondack Top

https://www.youtube.com/watch?v=d0arDcMO9Jo

30 years later

In 2017, the original developers of thermally aged tonewood and some of the first luthiers to use the wood in their guitars gathered together at Osmo Savolainen's home to discuss – in the sauna, of course – the past and present:[14]

Pertti Nieminen had continued his work at Tampere University of Technology during all these years. Rauno Nieminen, Juha Ruokangas and Juha Lottonen had continued to use thermally aged tonewood in their instruments for 20 years. The aforementioned trio of luthiers partcipated in the '*Suomi Soittimia Suomi Puusta*' (Finnish Instruments of Finnish Wood) project by The Finnish Music Foundation (MES) from 2016-2019. The goal of this project was to foster the use of Finnish wood in musical instruments and to resolve how to make a cost-effective, thermal ageing chamber for tonewood. The original university research from 2002 is also in the plans to be finally published online – also in the English language.

The Finnish Voodoomen in Mänttä. Visiting Osmo Savolainen in 2017. From left: Juha Lottonen, Osmo Savolainen, Pertti Nieminen, Rauno Nieminen and Juha Ruokangas.

This is what they remembered about the early days of thermal ageing:

Osmo Savolainen: "We had the production rolling long before that VTT patent came. I was supposed to get a royalty of every license the VTT sold. I still have that contract. We negotiated that I'll get a share, but then some new lawyer showed up and said I won't get a dime. Suomen Ekopuu spent 10 000 hours developing thermal treatment. I was never paid. Eventually I gave up. The fuck I care, as long as I get by somehow. I lost my nerve with those conmen and quit."

[14]Recording from the researchers meeting 11.4.2017, Mänttä. Recorded by Rauno Nieminen.

Juha Ruokangas: "I joined the university research in 1999. I was at that seminar in Mänttä, and then in March 2000 I exhibited at Frankfurt Musikmesse with the first guitar we had made out of thermally aged tonewoods. I sold the guitar to Mick Box of Uriah Heep. Mika Koskinen and Jiri Kaarmela were my business parthers. First we were supposed to make Flying Finn guitars with Matti Nevalainen. The necks were supposed to be made of thermally aged birch."

Pertti Nieminen: "Osmo applied for funding to his thermal treatment project. They asked if I could support Osmo in this, cause I had researched all kinds of materials. I gladly agreed. I had absolutely no knowledge of the particular topic. Osmo got the funding and I was directing the research part of it. I was along already when Osmo took the first pieces of wood to VTT (The Technical Research Centre of Finland). It was 1989 when we met. First we did mercury intrusion porosimetry measurements. Pentti Kuitunen was the professor of material sciences. I got discount of the electron microscope photos."

Rauno Nieminen: "I got interested when I saw those electron microscope pictures that reminded me of similar pictures taken of a Stradivari violin. Later I found out that Osmo was a neighbour to my sister in Mänttä. Finland is a small country. I took some wood to Osmo's place to be treated while I visited my sister. I had bought 20 logs of spruce to the guitar making school and I got the idea that what if we could speed up the seasoning. It's a long time to wait for 20-40 years."

Juha Ruokangas: "I was impressed by the stability of that wood. I had some birch tops for electric guitars, sanded to 5mm thickness. I left two tops laying on a table. One of them was thermally treated, the other one wasn't. The non-treated top twisted concave within days, and when I turned it, the same happened again the other way. The treated top stayed flat no matter what. I figured the treated top was better. Common sense. I started using the stuff. All alder bodies, maple necks, birch tops and fretboards have been treated since. Way less trouble with the necks. The colour and sound change too, and I thought it's nice - but the essential reason for me was the stability. Less problems. It just made sense to me, so I went through the effort of marketing, getting the customers used to the idea and all that."

Juha Lottonen: "In the very beginning, when we got the first treated pieces of wood, it was all twisted. The wood had swollen from the ends but not in the middle. Nobody had a clue how long it would take until the wood reaches its equilibrium moisture content. In those early days, when the testing started, we had a few violinmakers along, and they assumed the treatment would be like magic. They gathered all the worst pieces of wood to be thermally aged - and then they were disappointed when those violins didn't turn out good. They had gotten it a bit wrong. If the wood is bad, the thermal ageing doesn't change it into good. That made me thinking. It's a bit like a new material. It doesn't act like a normal non-treated wood. It chips like really old wood. I don't like to sand it, cause it has that sourness in it, like old wood has. It smells bad and tastes bad. I like to use cutting tools whenever I can. And you have to use a respirator with that stuff. Bending sides is a bit more challenging. Yeah, you could think of it as working with old wood."

Juha Ruokangas: "When you make a telecaster style electric guitar out of good thermally aged materials, the sound is balanced. It has that right kind of ring to it. It's just my subjective observation. A gut feeling. We didn't measure them. Now we've made guitars entirely out of thermally aged materials for nearly 20 years. All parts thermally aged. The feedback is unanimous from magazines, professional musicians. They say the guitar has an old guitar feel to it. The mids sound great, they say. Guitarists tend to gravitate towards those vintage classics, and many times it's because the mids are well pronounced. You need mids in an electric guitar, cause that's what cuts through in the mix when you play in a band. Without healthy mids, the player often feels that the sound is not good - the guitar is no good. And if the guitar doesn't produce those mids, you can't put them there by changing pickups or tampering with EQ. If it's not there, it's not there.

Nowadays we don't need to explain anymore. Or prove ourselves. Now it's a trend. Or, well, it's that burned stuff that the Americans have spread around. Roasted, torrefied or whatever. The fact that at least some of the builders have started looking for the right kind, the thermally aged tonewood - Rauno and I have worked for that a lot. The ToneQuest Report articles, lectures at The Holy Grail Guitar Show and elsewhere. Now everybody uses it - Martin, Taylor, Ibanez, Yamaha - and a lot of the smaller companies. Dana Bourgeois was one of the first luthiers who was interested in the milder treatment, cause he couldn't get it in the North America. I just got a letter from a large German wood supplier, advertising they have now milder treated wood available. There were photos of what they had earlier, and they were all black. Burned. It's great that the education starts to stick. Took a long time though."

Rauno Nieminen, electroacoustic bass, "Strandberg" from year 1999 . Thermally aged birch and spruce.

Ruokangas Guitars. Made of thermally aged tonewoods.

2 Thermally Modified Wood in Musical Instrument Making - Research 2000-2002

This study's goal was to analyze how the thermally aged wood differs from nontreated wood. We already knew - based on the research done in the 1990s - which attributes of wood could be altered by thermal modification: the sound velocity, acoustic and mechanical properties, water adsorption and the wood colour. The new study was comparative by nature: We wanted to find out the differences between treated and nontreated wood.

Thermal ageing does not change bad wood into good. The starting point is that the material to be modified needs to be of good quality and correctly sawn. The goal is to replicate the effects of natural ageing. In the early stages of the study, we aimed to find rough parameters for the modification by treating a number of identically sized wood samples in varying temperatures between 140°C - 230°C. The wood samples were split in half and examined before and after the treatment. One of the halves was untreated. This way we could study treated and nontreated wood samples even decades after the original study.

The temperature is raised and lowered according to a certain pattern, after which the wood is cooled down and the moisture balance restored. The result depends not only on the flow of the process or the raising, holding and lowering of the temperature, but also on the basic properties of the samples and the samples' humidity before treatment. Different wood species and size varieties need their own parameters to achieve the desired result.

The luthiers and manufacturers built musical instruments out of thermally aged materials and gave us feedback. The Landola guitar factory was crucially important to the study, because they made thousands of acoustic guitars usingboth thermally aged materials and nontreated materials. This streamlined the study tremendously, as we could analyze a large number of guitars made of a variety of grades (different temperatures) of thermally modified wood. The participating luthiers also built a large variety of musical instruments out of thermally aged wood: electric and acoustic guitars, electric basses, violins, mandolins, kanteles, cembalos, church organs, etc.[15]

About the research methods

We analyzed in the laboratory all the attributes that the earlier study had proven to be useful as rating parameters. Suitable research methods for both nontreated and thermally aged wood materials include:

Pore size distribution measurement	*(mercury intrusion porosimetry)*
Sound velocity measurement	*(ultrasonic speedometer)*
Water adsorption measurement	*(measuring dish with a variety of salts)*
Water absorption / swelling measurement	*(pressure tanks)*
Colour measurement	*(colorimeter)*
Flexural strength measurement	*(hydraulic press)*

For the **sound velocity measurement**, we used The Lucchi elasticity meter designed by Giovanni Lucchi. The metallic sensors are pressed lightly into the ends of the specimen, and the reading can be observed on the screen.[16]

The **water adsorption measurement** was performed in three different relative humidities that can be achieved with water and saturated salines. The relative humidities and the salts to achieve them were:

MgCI2• 6H20	*(33 %)*
NaCI	*(75 %)*
K2S04	*(96 %)*

The desired relative humidity was created in a hermetic measuring dish. Saturated saline was poured on the bottom of the dish, and the samples were placed on a grid above the saline surface. Samples sized 20x20x20mm were used to measure the relative humidity. The samples were first dried (24 hours in 105°C), weighed and placed into the hermetic

[15] Nieminen Pertti, Pietilä Taisto, Suhonen Pekka (2002) Lämpökäsitelty puu ja soitinrakentaminen. Raportti 55 .TTKK. Page 29
[16] LucchiMeter. (http://www.lucchicremona.com/portal/en/technology/lucchimeter/)

measuring dish. The samples were left in the aforementioned relative humidities until they reached the equilibrium (the weight no longer changed). The equilibrium moisture content percentage was calculated by comparing the dry weight and equilibrium weights of the samples.[17]

The **water absorption** was measured using two different pressure tanks. First, the samples (820x20x20mm) were weighed dry (24 hours in 105°C); then they were placed into a pressure tank in 75kPA under pressure for 30 minutes. After this, the samples were weighed and moved into another pressure tank in 600kPA excess pressure for 120 minutes and then weighed again.

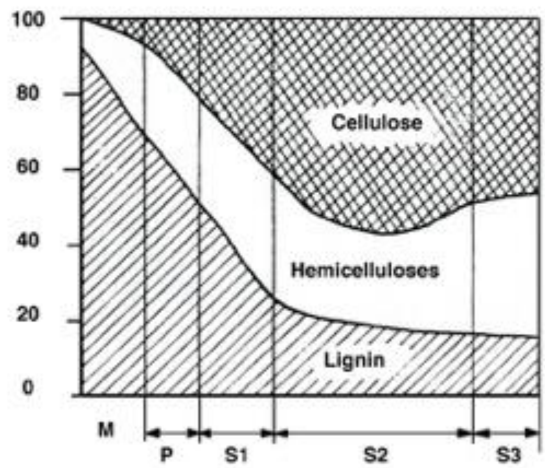
The **colour measurement** was done with the *Minolta Chroma CR-310* (CIELAB system) colorimeter from the samples' planed surface. The colour was measured from three determined points from every sample before and after the thermal ageing process.

The **pore size distribution measurement** was done with the *Micrometrics Pore Sizer 9300* mercury intrusion porosimeter. The sample was placed into a penetrometer that was then standardized. The penetrometer is filled with mercury at minimum pressure. When air is allowed into the device, the mercury pressure rises and will penetrate into the sample's pores. The volume of the sample pores can be read from the penetrometer mercury level capillary tube.

The **flexural strength measurement** was performed in a hydraulic press. Each sample was flexed with identical force before and after thermal ageing. The sample was placed on the hydraulic press between two supports. The support span was 600mm. The sample was stressed from a single point with approximately 1/4 force of the flexural strength value (MPa) found from the literature. Maintaining low flexing power, we wanted to ensure that we didn't fracture or break the wood's cell structure. The flexural strength measurement was performed to analyse the effect of thermal ageing on the wood's stiffness (bend strength).

The structure of the wood cell

All trees share a similar cell structure. The cells of coniferous and deciduous trees differ regarding their shape and sequence, for example. The cell walls are built of cellulose (40-50%) and hemicellulose (20-25%); both affect the wood's strength, while lignin (20-30%) is the adhesive keeping it all together. Wood has two kinds of cells. In coniferous trees most of the cells are tracheids, i.e., so-called water cells, that transport the water in the tree. These cells contribute significantly to the mechanical features of the wood. All tree species have ring-like pore formations. These radial pores run perpendicular to the longitudinal axis of the tree. Approximately 6% of all cells in spruce or pine are ring-like pores.[18]



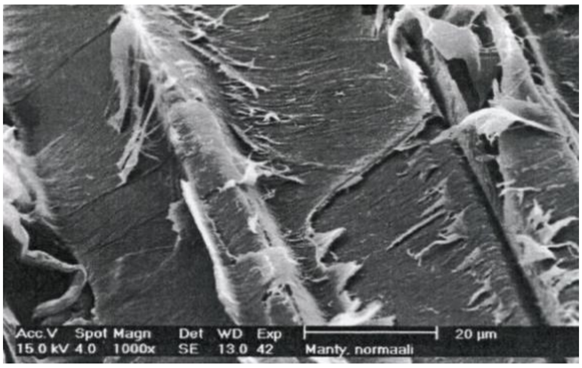
Pic 1. The chemical structure of wood cell.

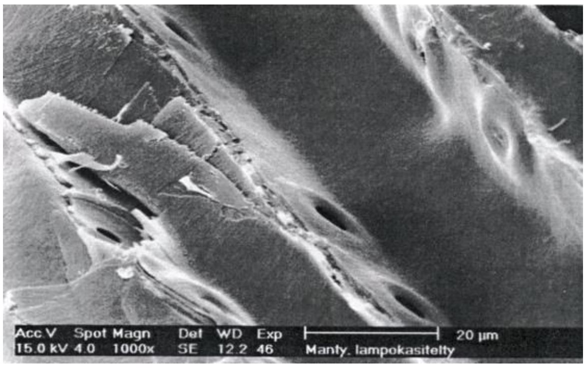
[17] Nieminen Pertti, Pietilä Taisto, Suhonen Pekka (2002) Lämpökäsitelty puu ja soitinrakentaminen. Raportti 55 .TTKK. Page 22.
[18] Nieminen Pertti, Pietilä Taisto, Suhonen Pekka (2002) Lämpökäsitelty puu ja soitinrakentaminen. Raportti 55 .TTKK. Page 15.

The cell wall's main components are cellulose, hemicellulose and lignin. Approximately 45% of a wood cell consists of cellulose. The majority of cellulose is located in the secondary wall S2 (pic 1). Usually about 25% of the dry mass of wood is hemicellulose. In coniferous trees, their share of lignin is 26-34%; it is 22-30% in deciduous trees. Measured from dry mass, the lignin portion in spruce is 30%, in pine 28%, and in birch or aspen 17%. In addition, trees consist of water, various excretions such as resin, polyphenols, fatty acids, silica and various salts. The amount of those in coniferous trees is under 5% and under 10% in deciduous trees. [19]

The effects of thermal ageing on the cell structure

The cell wall around the lumen changes during the thermal ageing process. The inner layer S3 and the middle layer S2 structures are altered due to the degrading cellulose and hemicellulose. See pic 2, the surface of a pine cell's structure before thermal ageing. The lamellar texture can be clearly seen. The cell structure's surface has clearly changed (pic 3), as if the surface has melted or crystallized due to the heat. The tests also showed that the hydrophilicity of the wood had decreased significantly. This explains the lower equilibrium moisture content of thermally aged wood.





Pic 2. The cellular structure of non-treated pine, 1000x magnification

Pic 3. The cell structure of thermally aged pine, 1000x magnification

Analysing the pore size distribution before and after treatment showed that the thermal ageing process increases the number of large (over 1µm) pores and decreases the number of small (under 1µm) water absorption cells. Another alteration caused by thermal ageing to a coniferous tree cell structure is related to the ring-like pores. See pic 4, the typical surface of dried spruce. The ring-like pores have closed due to the drying process. The thermal ageing process re-opens the ring-like pores (pic 5), just like the seasoning process does over decades (pic 6).

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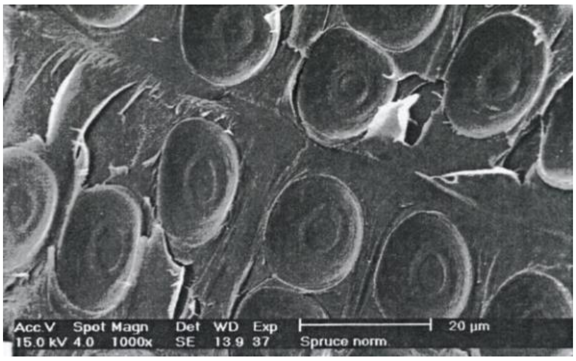
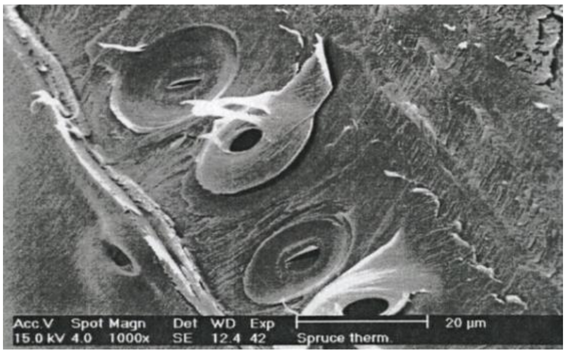
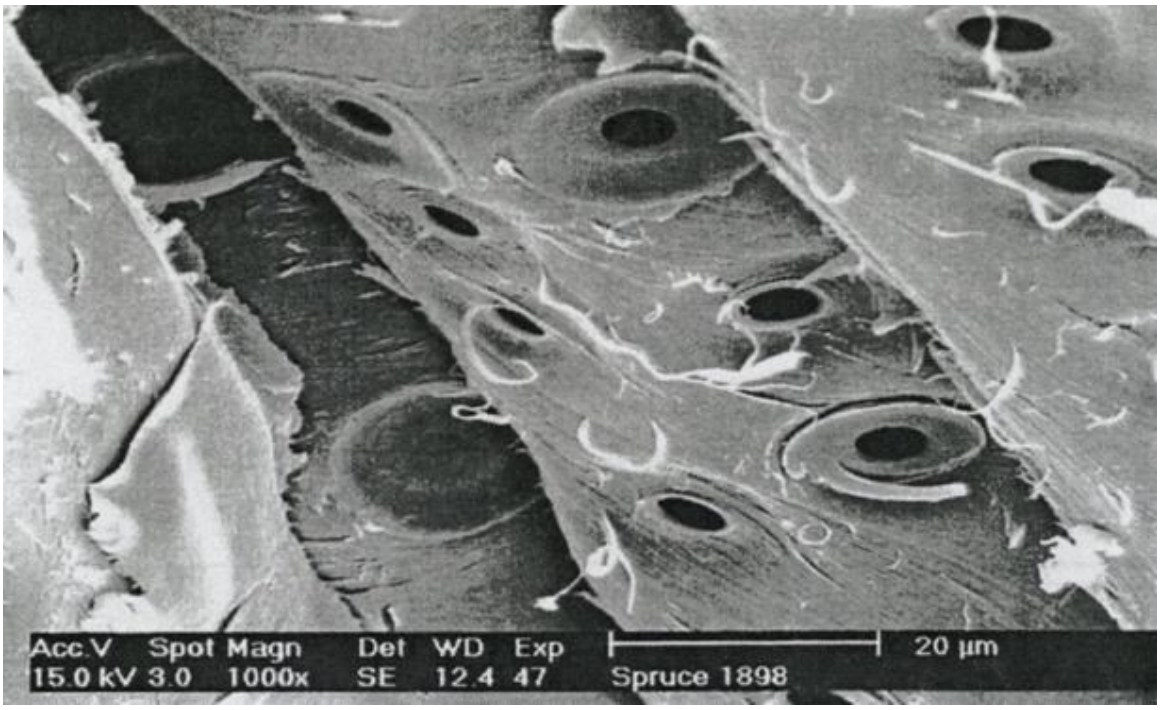
[19] Nieminen Pertti, Pietilä Taisto, Suhonen Pekka (2002) Lämpökäsitelty puu ja soitinrakentaminen. Raportti 55 .TTKK. Page 17.



Kuva 4. surface of non-treated spruce.



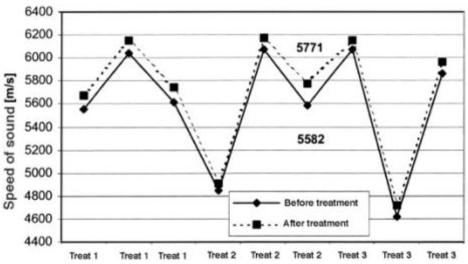
Kuva 5. The surface of thermally aged spruce.



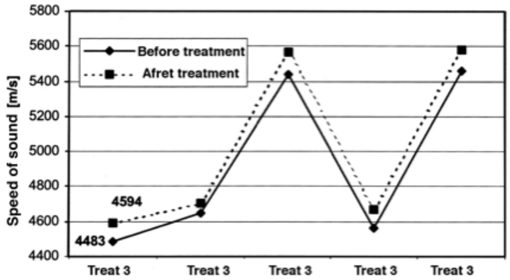
Pic 6. The surface of pine, seasoned for 100 years

The effects of thermal ageing on the sound velocity

The sound velocity measurements showed clearly that the treatment temperature affects the level of the achieved sound velocity. The sound velocity of wood was raised 0 - 1 000 m/s in lower (under 200°C) temperatures. Higher temperatures (over 200°C) are unfit for tonewood; the sound velocity decreases rather than increases. The density and moisture content also seemed to affect the achieved sound velocity.[20]



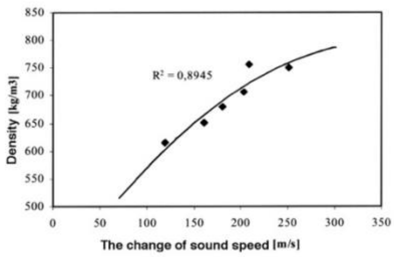
Pic 7. Sound velocity of spruce, before and after thermal ageing.



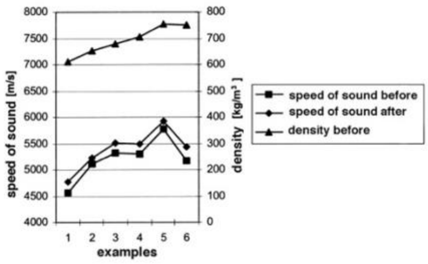
Pic 8. Sound velocity of maple, before and after thermal ageing.

The effects on wood density on the raising of sound velocity

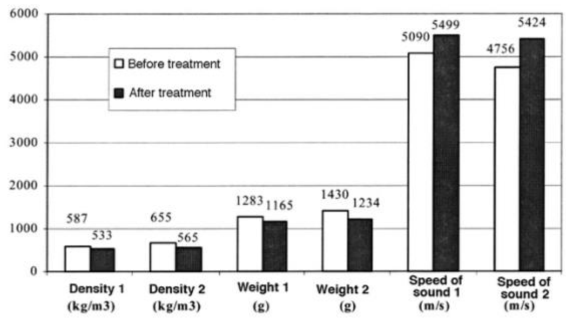
The birch wood samples showed that wood density affects how the sound velocity changes with thermal ageing. Sound velocity increased approx. 120-180 m/s (3,4%) with density samples in the range of 600-700 kg/m3. Sound velocity grew approx. 200-250 m/s (3,8%) with density samples over 700 kg/m3. The results are shown in images 17-20.[21]



Pic 9. The effects of thermal ageing to longitudinal sound velocity in birch wood.



Pic 10. The sound velocity of birch samples (1 - 6/ 1 K - 6K) before and after thermal ageing, and the densities of the thermally aged samples.



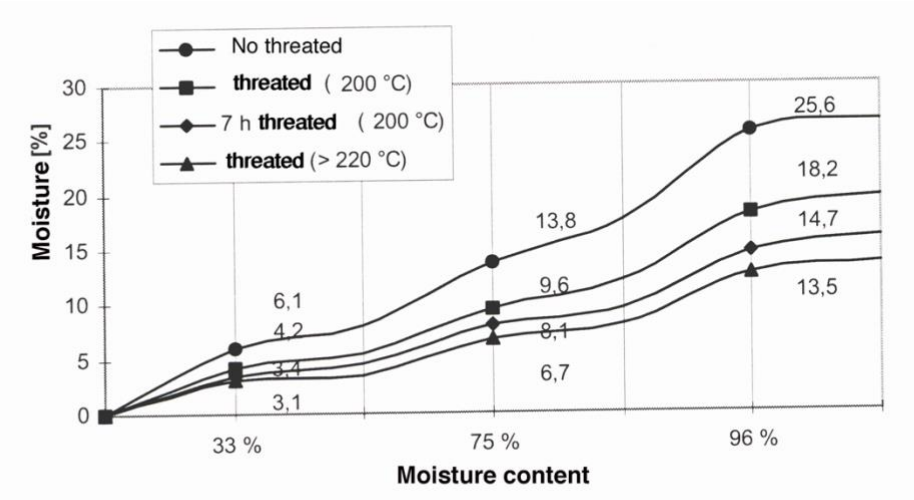
Pic 11. The effects of thermal ageing to samples of varying density (density 1 < 600 kg/m3, density 2: > 650 kg/m3.

20 Nieminen, Pertti, Pietilä Taisto, Suhonen Pekka. (2002) Lämpökäsitelty puu ja soitinrakentaminen. Raportti 55 .TTKK. Page 26.

21 Nieminen Pertti, Pietilä Taisto, Suhonen Pekka (2002) Lämpökäsitelty puu ja soitinrakentaminen. Raportti 55 .TTKK Page 29.

The effects of thermal ageing on water adsorption capability

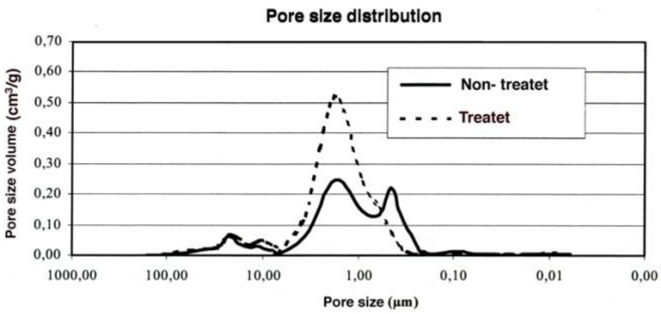
The adsorption measurements showed clearly the effect of thermal ageing temperature on the water adsorption capacity of the wood samples. The moisture content level of spruce samples treated in high (over 200°C) temperatures is approximately 12-13% in the equilibrium of 96% air relative humidity, whereas the moisture content level of nontreated spruce is at approximately a 26% level. The level is at about 18% in samples treated in slightly under 200°C.



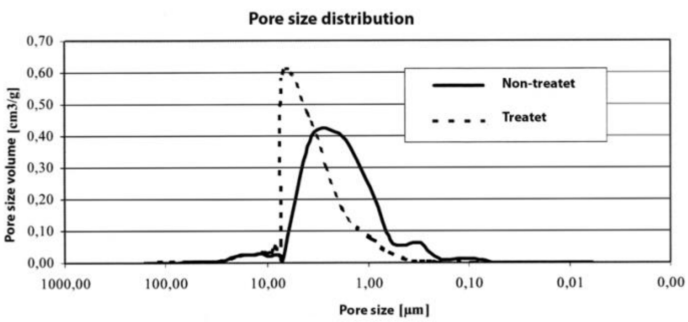
Pic 12. The effects of various treatment temperatures

The effects of thermal ageing on wood porosity

The wood porosity tests showed that thermal ageing changes the wood's porosity. The number of large (over 1µm) pores increases, whereas the number of smaller (under 1µm) water absorption pores decreases.



Pic 13. Thermal ageing changes the wood's porocity. (spruce)

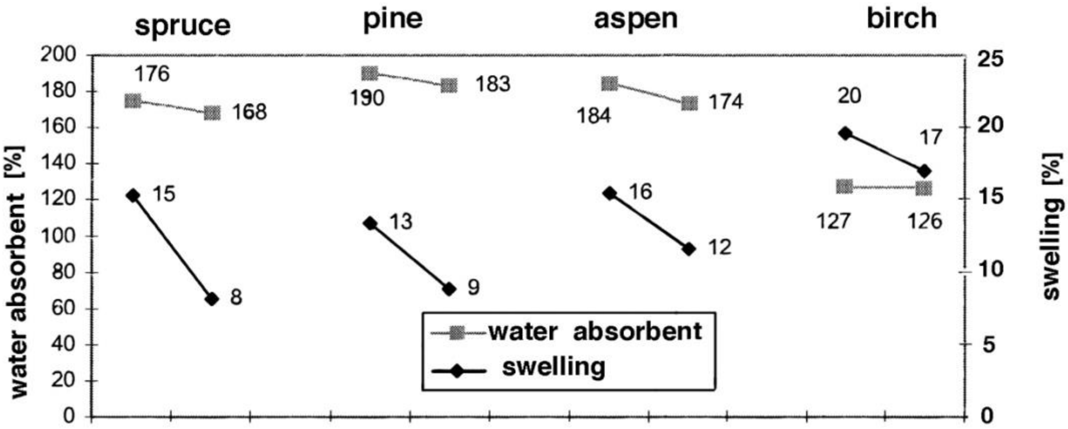


Pic 14. Thermal ageing changes the wood's porocity. (pine)

The tests showed that the water absorption capacity of samples (spruce, pine, aspen, birch) treated in temperatures slightly under 180°C is slightly lower than nontreated samples (pic 15). Aspen, spruce and pine behaved in a similar manner in swelling measurements.

The growth of the wood volume

wood species	*non-treated*	*treated*	*the decrease of swelling*
Spruce	*15%*	*8%*	*7%*
Pine	*13%*	*9%*	*4%*
Aspen	*16%*	*12%*	*4%*
Birch	*20%*	*17%*	*3%*

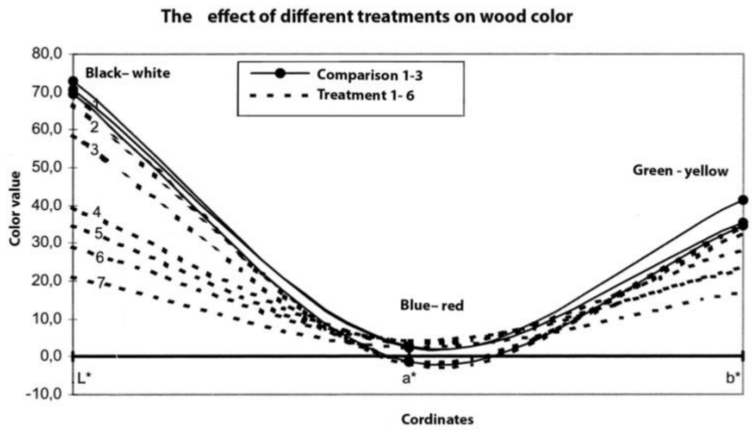


Pic 15. Water absorption capacity and swelling.

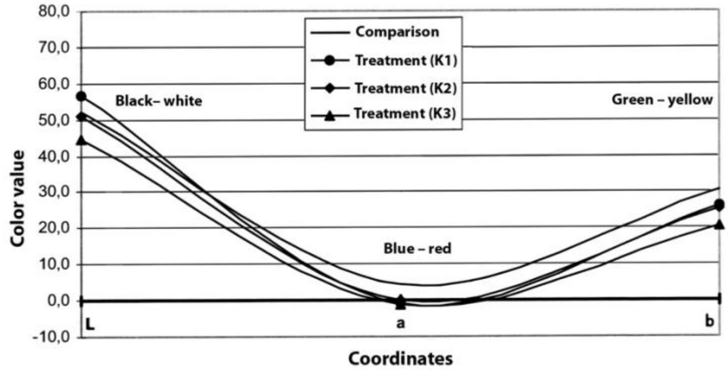
The colour changes

The colour measurements showed that the density of the wood samples affect the degree of the colour change after thermal ageing. The treatment temperature significantly affects the amount of colour change, as well. Thermal ageing can alter light coloured wood (for example, spruce) to a darker colour, and in figured (flamed) wood, the figuring shows better after the treatment.

Pic 16. Thermal ageing changes the wood colour.



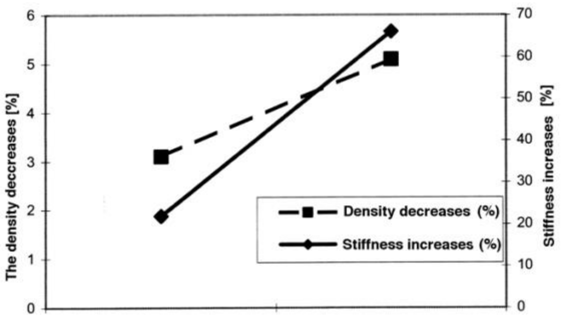
Pic 17. The treatment change the colour of the spruce samples.



*Pic 18. The treatments K1- K2 change the colour of the alder samples only slightly darker. The treatment K3 changes the colour more clearly (coordinate L *). The colour values of the coordinates a* ja b* are nearly identical in all treatments (K1 -K3). The colour value of the coordinate b* shows how the amount of yellow colour decreases in treatment K3 much more than in treatments K1- K2.*

Flexural strength

The flexural strength of spruce increased 20-81% after thermal ageing. The average increase was 53%. Pic 19 shows this result.

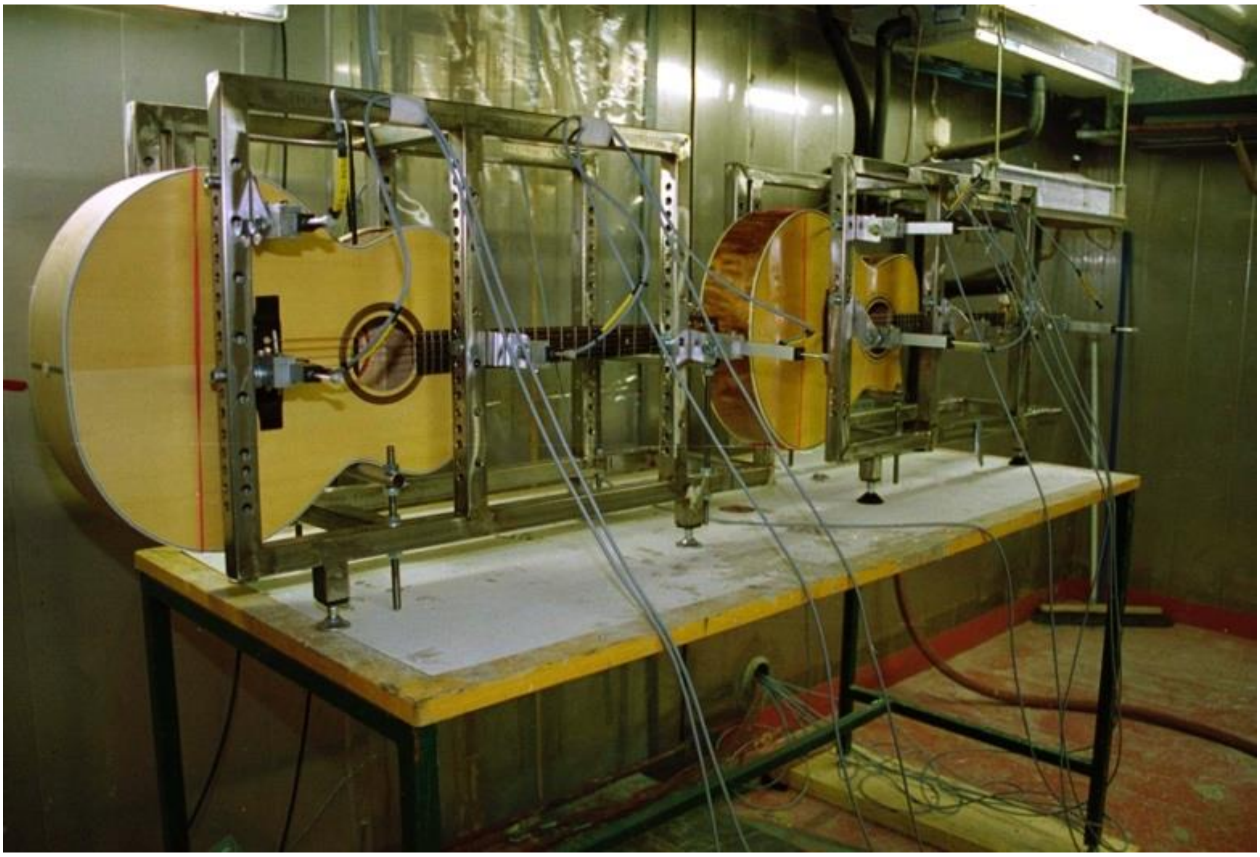


Pic 19. The increase of flexural strength correlates with the increase in density. The spruce samples that only grew 3% in density also changed less regarding flexural strength (22%). The density of other samples grew 5% - and the flexural strength as much as 66%.

The changes of form in finished musical instruments

We tested two Landola guitars. One was made of nontreated materials, and the other was made of thermally aged materials. The guitars were placed into a so-called artificial climate chamber with a constant temperature of +20°C. The air's relative humidity changed between 18-85% in a cycle of 96 hours. The guitars had been kept under controlled humidity before the testing, and the moisture content of the guitars was relatively low to begin with. The testing began with a drying process (RH 15%), and after that the relative humidity was raised up to 85%.

The guitars were placed into special sturdy stands, mimicking the playing position. They were attached from the body waist and from the strap button location. With these fixed points, we could eliminate the guitars' movement in their stands and still allow the possible changes of form due to the altering air relative humidity. Both guitars had dial gauges in five different positions that can be seen in pic 21. [22]

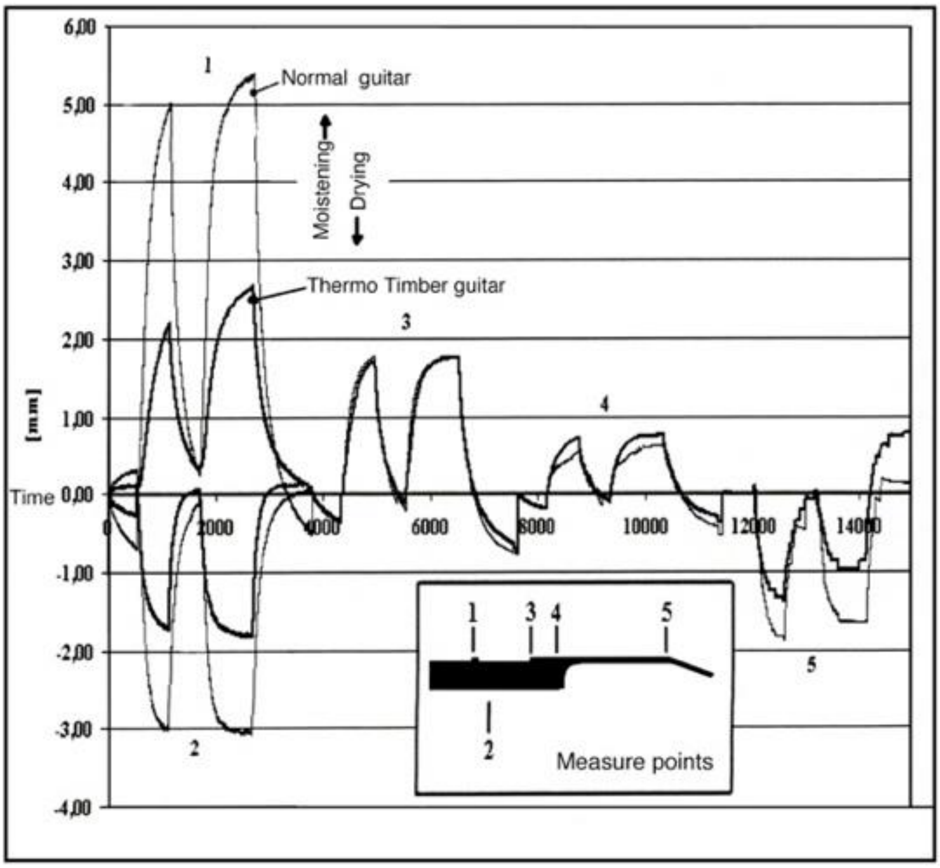


Pic 20. When comparing the formal changes of guitars when placed into an artificial climate chamber, we learned that thermally aged guitars are much more stable – the changes in the guitar forms dropped to half those of guitars made of nontreated wood materials.

The dimensions of the guitar made of nontreated materials changed during the humidity testing process as follows: The top raised over 5mm, and the back raised approximately 3mm. In other words, the top and back swell significantly when stressed with high relative humidity. The movement of the neck and fretboard at the neck joint area were only 0,5 – 1,0mm. The dimensions changed slightly under 2mm at the end of the fretboard (measure point 5).

The dimensions of the guitar made of thermally aged wood changed significantly less. The top raised 2,1 – 2,5mm (less than half of the nontreated guitar). The back raised 1,6 - 1,8mm. Measure point 5 at the end of the fretboard gave a reading 1,0 –1,3mm. The conclusion of this test was that thermal ageing decreases the guitar's movement / changes in dimensions to half those of a nontreated guitar. Pic 20 shows this.

[22] Nieminen Pertti, Pietilä Taisto, Suhonen Pekka (2002) Lämpökäsitelty puu ja soitinrakentaminen. Raportti 55 .TTKK. Page 29.



Summary

The results of this study are approximations that can point us in the right direction. We have discovered the following, among other things: The duration and temperature of the treatment sequence greatly affect the results. We also found out that the inner features of the wood, such as density and moisture content, affect the degree of the changes that occur in the thermal ageing process.

We learned that the thermal ageing temperature affects the sound velocity changes. Treating the wood in too low temperatures is equivalent to a regular drying process. Low temperatures (110 – 140°C), therefore, do not offer a significant benefit for tonewood qualities. For example, the too low temperatures showed that the sound velocity did not change at all. However, the wood becomes fragile if treated in too high temperatures (over 200°C), which affects the wood's workability, i.e., thin wood plates break easily, and screws don't hold as well in the fragile wood.

The benefits of correct thermal ageing temperatures (> 140°C – < 180°C) are that the moisture movement decreases, the density increases, the weight drops, the sound velocity increases, the wood colour deepens and the wood resonates better.

Thermal ageing differs in coniferous and deciduous species, in that deciduous trees (such as birch) can "take" the higher temperatures better. A birch blank still has rather decent workability after being thermally aged in 200°C. The high temperatures change the structure of deciduous species so much that they are not applicable for making musical instruments anymore. The wood becomes so brittle that it cannot be worked with a planer, because they don't chip naturally anymore. Brittle, crumbling chips are a sign that the wood has lost its natural elasticity, which is not good for making musical instruments. The wood chips normally maintain their natural elasticity after a milder thermal ageing process. These are signs that the treatment has succeeded and the wood can be used for making musical instruments.

Above pine and spruce treated in too high temperature for musical instrument making. Below thermally aged birch and spruce. Luthiers have many methods to test the wood they use. Common sense takes you a long way.

Tutkimustulosten perusteella todettiin selvä yhteys soitinrakentajien vanhentamiskäsitellystä puusta saamiin kokemuksiin. Korrelaatio mittaustulosten ja kokemusperäisten havaintojen kesken on merkittävä, kun tarkastellaan esimerkiksi kuusen muuttumista prosessissa ja loppulaatua, äänen nopeutta ja koputusääniä sekä työstettävyyttä. Mittaustulosten ja koerakentamisen kautta tutkimus päättyy tulokseen, että kysymys ei ole tavanomaisesta lämpökäsittelystä vaan todellakin puun vanhentamisesta, jonka myötä puun tietyt ominaisuudet paranevat mutta puu säilyttää kuitenkin työstettävyytensä ja lujuutensa. Näin tapahtuu sitä selvemmin, mitä paremmat lähtökohdat valitun puuaineksen laatu tarjoaa.

The results of our study correlate clearly with the luthiers' subjective experiences of using thermally aged materials. The measured facts match well with the practical experiences and observations when comparing, for example, the top plates of acoustic guitars: the original quality (grain pattern, when the tree was cut, etc.) with the changes that occur in thermal ageing regarding, for example, the final quality, sound velocity, tap tone and workability.

Both the measurements and the subjective experimenting support the conclusion that our thermal ageing process of tonewood is a whole different method from the ordinary thermal treatment. Thermal ageing succeeds, indeed, in improving many qualities of the wood while maintaining its workability and strength; and the better the raw material, the better the results become.

3. How to make thermally aged tonewood on a budget

One of the original goals of the project, *Finnish Musical Instruments Made of Finnish Wood,* was to purchase a thermal ageing oven/chamber and repeat the experiments done at the turn of the millennium. Finland has many manufacturers of thermal treatment ovens, and making a small oven suitable for our purpose would have been possible. The price, however, would have been approximately 150 000 euros. This was unreasonable. As the next step, we considered the possibilities of using an industrial kitchen oven. This type of oven fulfills all the technical requirements needed for thermal ageing - the temperature, steam content and the cycle phases are fully programmable, and one can use sensors to observe the temperature both inside the wood and within the oven space. The problem in this scenario was the small chamber size and large fuse size. The price of a used oven would have been in the range of 1500 euros.

By coincidence, Rauno Nieminen received a phone call from the Finnish pro, audio design guru *Jonte Knif,* in May 2018. Jonte had heard a rumour that Rauno might know something about thermal ageing of wood. A Finnish harpsichord maker, *Jukka Ollikka*, who lived in Prague, needed thermally aged wood in his instruments but could not find it anywhere. Nieminen told Knif and Ollikka all he knew about the requirements of the wood and the thermal ageing process.

Surprisingly enough, in June 2018 Ollikka built a thermal ageing test chamber and all the electronics needed for it - in three days! Knif and Ollikka did a few test runs during June and also made a "Do It Yourself"sound velocity meter. The background to Knif's interest in harpsichords and thermal ageing was due to the fact that he and *Arno Pelto* had also built harpsichords in the early 2000s . They had received some thermally aged wood materials from Osmo Savolainen, and Knif had also participated in research concerning the sound analysis and synthesis of a harpsichord. This study occurred in 2000, and the instrument observed was made of thermally aged wood by Knif and Pelto.[23]

Jukka Ollikka's thermal ageing chamber, in Prague, 16.10.2019. From left: Jukka Ollikka, Juha Ruokangas, Hannu Saha, Pertti Nieminen, Rauno Nieminen and Juha Lottonen.

[23] Välimäki V, Penttinen H, Knif J, Laursin M, Erkut C (2003) *The analysis and synthesis of Cembalo sound*. *http://www.akustinenseura.fi/wp-content/uploads/2013/08/aku03_129-134.pdf*

Jukka Ollikka's thermal ageing chamber

It took three days for Jukka Ollikka to build his first thermal ageing chamber. He used a piece of standard air conditioning tube as the oven chassis. Rauno Nieminen began building his own version of the oven, based on Jukka Ollikka's instructions. Here is the build process for Ollikka/ Nieminen's oven.

The chassis was built of 1,25mm thick stainless steel. The 100mm thick heat isolation of this oven is sturdier than in Ollikka's 1st generation oven. Ollikka built Nieminen a next generation control unit. The chamber measures 500x500x2500mm. The chassis was welded closed from one end. The heat isolation was capped with fiber cement board. The door was also made of stainless steel and isolated in a manner similar to the chassis. A 3kW sauna heat element was used for heating. For those of us located in Finland, this is the most cost-effective and convenient method. A PID (proportional-integral-derivative) controller with thermal sensor was used to control the heat element.

A regular steamer meant for wallpaper removal was used to generate steam. The steam generator is controlled with a solid state relay and a pulse-width modulator, which allows the amount of steam to be adjusted. The oven door has a connector for the steam generator, and the outlet for air/steam/water is located in the other end of the chassis. A heat-resistant silicone tube was used for the steam generator and outlet hoses.

An MMotors JSC FE-T300 hot air extractor was chosen for ventilation. This fan model can be easily disassembled and and installed partly into the hot chamber, while mounting the motor outside the chamber to keep it cooler. The following chart shows the material costs. Notice that working hours are not included in this calculation.

Stainless steel: 1,5mm, 3 boards	660,00
Heat isolation: Fireproof Paroc 2x50mm	60,00
Fan: MMotors JSC firmzn FE-T 300	98,00
Steamer: Cocraft HW2000 40-7022	37,95
Heat element: Harvia ZSB-229 3000W/230V	56,90
Control unit: Ollikka, Mark II 1	100,00
Fiber cement board 9 mm	300,00
Heat sensors	10,00
Silicone seal for the door	6,00
	1328,85€

Jukka Ollikka's 1st oven brand new, in 2018. Photo: Jukka Ollikka

Preparations and measuring tools

Thermal ageing of tonewood is similar to the process Osmo Savolainen developed in the early 1990s to improve resistance against decay of wooden structures. The main difference of thermal ageing is that the treatment is done at a lower temperature. Only a few basic elements are needed in thermal modification: 1) Wood, 2) Air tight chamber, 3) Heat and 4) Water vapour. The wood is heated to a certain temperature according to the desired effect, and eventually the wood is cooled down. A variety of gases are evaporating from the wood when it is being heated, so the wood might catch fire, which is why water vapour is injected into the chamber. The water vapour also affects the result of the wood modification. It is good to have a fan inside the chamber that rotates the air and steam, resulting in a more even temperature throughout the whole chamber.

The moisture content of the wood to be thermally aged should be 8-10%, and all the wood in a single treatment cycle should have the same moisture content. It is good practise to measure the properties of the wood before the process, because only then can one know what exactly happens in the process. If you don’t know the premises, how can you determine the effect?

A luthier does not typically have access to the expensive measuring equipment introduced in the previous chapter, but a few basic measuring tools will go far. Precision scales are a standard tool for a luthier, who can can easily calculate the density of wood from its size and weight. A moisture content meter is a very useful tool to have, and a sound velocity meter is one of the best tools for studying wood. It is not a cheap tool, but it is well worth the cost. A sound velocity meter is used to measure wood pieces of virtually any size, as well as finished instruments.

Knowing how to finalize thermal ageing is as important as the preparations for it. It is especially important that the wood regain its equilibrium moisture content before using it. This does not happen within a few hours. Depending on the wood species and the plank size, it may take even months to regain its equilibrium. It is easy to measure this. Take 2-3 planks out of the freshly treated batch of wood and weigh the planks with your precision scales. Repeat the procedure weekly - and once the weight no longer increases, it has regained its equilibrium moisture content. It is impossible to predict exactly how long this will take, but thin pieces of soft wood regain the equilibrium much faster than large pieces of a dense wood species. It took three months for the birch planks (55x80mm) shown in the next image to regain the equilibrium.

Measuring the equilibrium moisture content with precision scales. The relative humidity of the room is observed with a hygrometer. Photo: Rauno Nieminen

Thermal ageing step by step

The thermal ageing process is explained next on a general level. The process has seven steps or phases: the first one is to heat up the oven, and the last one is to regain the equilibrium moisture content of the wood.

It is good to remember at this point how thermal aged tonewood was developed in the 1990s: Osmo Savolainen treated wood using various temperatures and cycles. Pertti Nieminen used a variety of lab equipment to study what happened inside the wood. Rauno Nieminen studied on a practical level which one of the various treatments was best suited to musical instrument making, how the treatment affected the gluing and finishing properties of the wood, and so on. The correct parameters were found through trial and error. It was a slow and expensive process, partly because the oven was so big (10m3). The extremes were also found through trial and error. If the wood looked and smelled burned, it was burned. If there were no changes at all, the temperatures had been too low. The correct parameters were somewhere in between. Common sense.

Jukka Ollikka and Jonte Knif went through a similar process in June 2018. They performed a series of treatments at different temperatures for beech, spruce and basswood. Their oven was small, so they found the correct parameters rather easy. Ollikka has already built three harpsichords out of wood he has treated, and he is very happy with the results. He tells the following:[24]

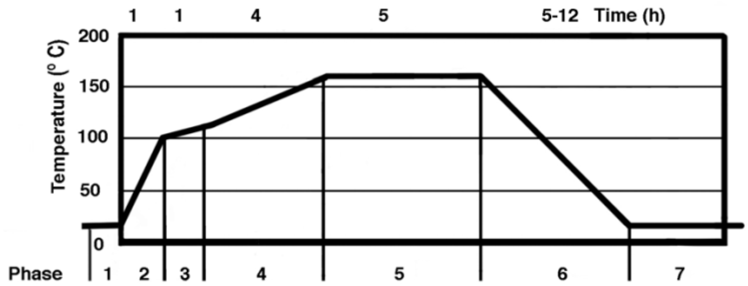
> *It took three days to build the oven, including the electronics. The total cost was about 600 euros. It was all a lot easier than I had expected. The fan works very well and the temperature is even everywhere inside the chamber. All the joints must be welded. I've treated max. 25mm thick wood, and the temperature has been 140°C. I can hear the difference in the sound of the instruments, and the tuning stability has improved. The lower keylevers are tall, and even the slightest instability of the wood material causes problems. With thermally aged wood, the keylevers have lined up well after sawing them to shape. Earlier there's been a lot of bending with heat after sawing. The result is at least ten times better with thermally aged basswood than it was before.*

Jukka Ollikka's thermal ageing oven. Photo: Rauno Nieminen

[24] Jukka Ollikka interview 15.10.2019, by Rauno Nieminen.

The basic formula of thermal ageing

After Osmo Savolainen retired, thermally aged tonewood has been hard to get, and the parameters have been more or less a lottery. Thermal ageing has been outsourced from companies specializing in thermal treatment of construction wood. There have been no confirmed programs for lower temperatures, and the results have been somewhat arbitrary. The programs used by Savolainen have never been disclosed to others. Now, as we have the knowledge to a build small and fully functional thermal ageing oven optimized for luthier use, the next step is to develop the appropriate programs (again)[25]. Jukka Ollikka has used the following basic formula:



phase	time	function	temperature	time
1	7:30 – 8:00	steam on	20 –	0,5 h
2	8:00 – 9:00	raising the temperature 1	20 – 100 ºC	1 h
3	9:00 – 10:00	raising the temperature 2	100 – 115 ºC	1 h
4	10:00 – 14:00	raising the temperature 3	115 – 160 ºC	4 h
5	14:00 – 19:00	holding the temperature	160 – 160 ºC	5 h
6	19:00 – 23:00	lowering the temperature	160 – 20 ºC	5h
7	23:00 –	regaining the equilibrium moisture content	20 ºC	2 weeks – 4 months

Phase 1, the beginning, 7:30am
The moisture content of the wood is optimally in the range of 6-10% prior to the treatment. All wood treated in a single cycle should be of similar moisture content. If the moisture level is over 10%, phase 2 will take longer. You can begin the heating with steam about half an hour before switching the heating element on. Switch the fan on simultaneously with the steam.

Phase 2, raising the temperature 1, 8:00-9:00am
The temperature is raised within one hour up to about 100-105°C. Depending on the moisture level of the wood, this might take a longer time, too.

Phase 3, raising the temperature 2, 9:00-10:00am
The temperature is raised up to 115°C. It is slow to get past the water boiling point, but then it speeds up quickly.

Phase 4, raising the temperature 3, 10:00am-2:00pm
The temperature is raised, depending on the wood species, plank thickness and the desired effect, up to 140-160°C. Hardwood species, such as maple or birch, can take even 180°C without serious damage.

Phase 5, holding the temperature, 2:00-7:00pm
Once we have reached the actual thermal ageing temperature, we keep it even for some hours.

Phase 6, lowering the temperature, 7:00-12:00pm
The temperature is lowered slowly with the aid of water vapour.

Phase 7, regaining the equilibrium moisture content

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[25] *Prezemyslaw Mania, Waldemar Molinski, Edward Roszyk, and Maria Gorska. Optimization of Spruce (Picea Abies L.) Wood Thermal Treatment Temperature to Improve Its Acoustic Properties. https://ojs.cnr.ncsu.edu/index.php/BioRes/article/view/BioRes_*

This will take at least some weeks, or up to some months, depending on the species and plank sizes. Great precision and patience is needed to observe and confirm when this process is ready and the wood can be used.

Test runs by Jukka Ollikka and Jonte Knif in June 2018.

Conclusion

One of our project's goals was to clarify the history of thermal ageing of tonewood and to study the possibilities of how to make such wood easily available for luthiers and small guitar-making companies. First, it appeared that our goal for the future was beyond reach, but Jukka Ollikka's successful research and development of his own thermal ageing chamber proved to be the turning point that suddenly gave our project a clear objective: To instruct luthiers how to make their own, fully functional thermal ageing ovens.

The people who have participated in our project have given their know-how free of charge for common use. That is why we are publishing this report with all the data we have collected for public use. To our best knowledge, publishing this report cannot violate anybody's patents, as this information has already been publicly available in Finland for 20 years, and the thermal treatment at higher temperatures has already been publicly available for 30 years. New patents should not be possible, either, for a method that has been commonly in use in our country for decades.

Notice that if you plan to make yourself a thermal ageing oven, you must follow the law, and test / audit your oven according to the electrical safety legislation of your country. We do not hold any liability for the electrical safety of your oven.

Thank you to everyone who has participated the project. We are especially grateful to MES (The Finnish Music Foundation) and Suomen Kulttuurirahasto (The Finnish Cultural Foundation).

Cembalo made of Thermally Aged Tonewood by Jukka Ollikka. Photo by Jukka Ollikka.

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The reunion of wood researchers 11.4.2017, Mänttä. Recorded by Rauno Nieminen.

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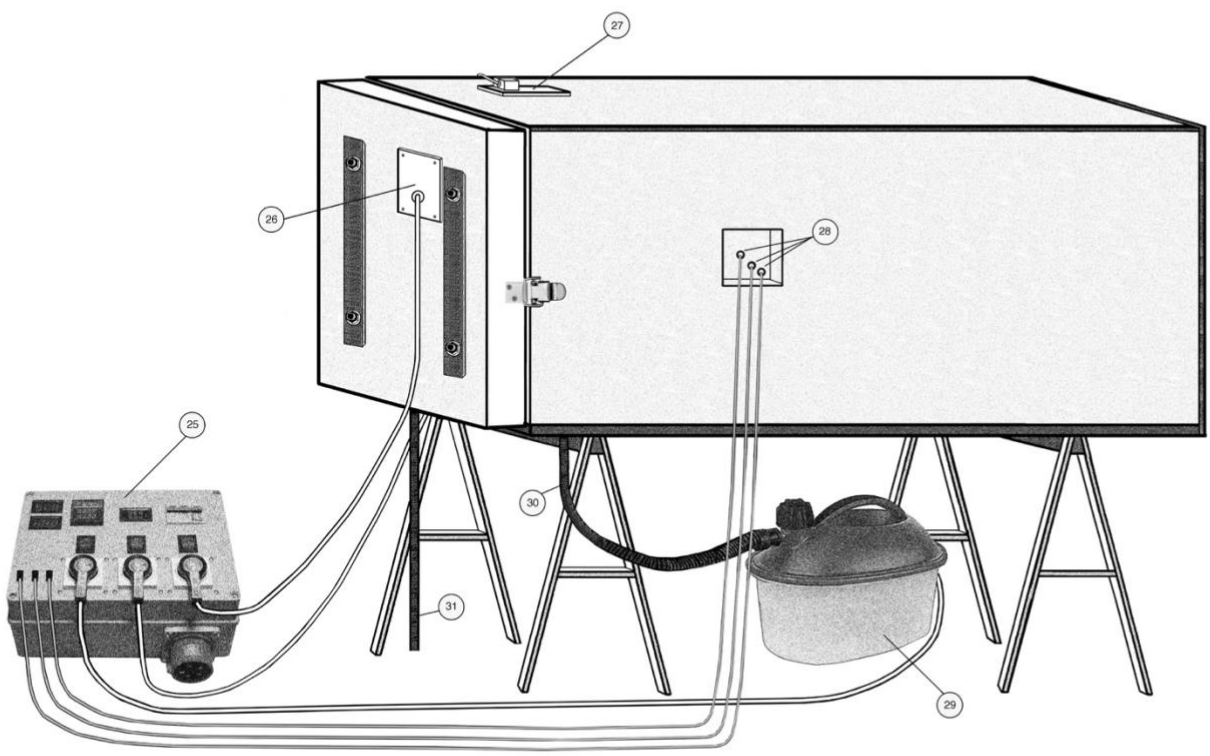
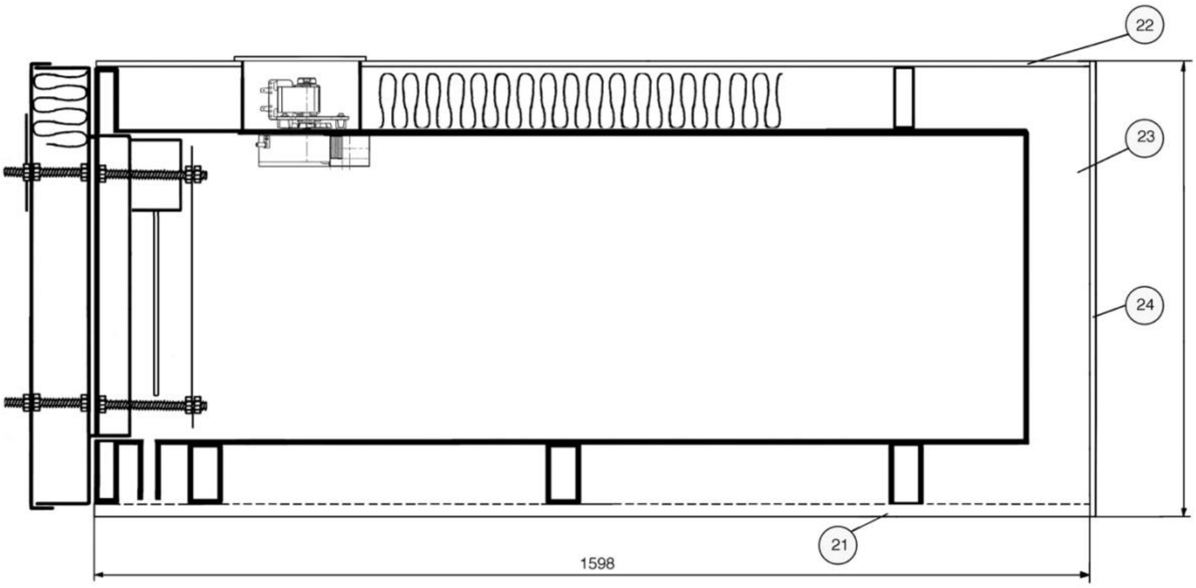
Attachments

Thermal ageing chamber

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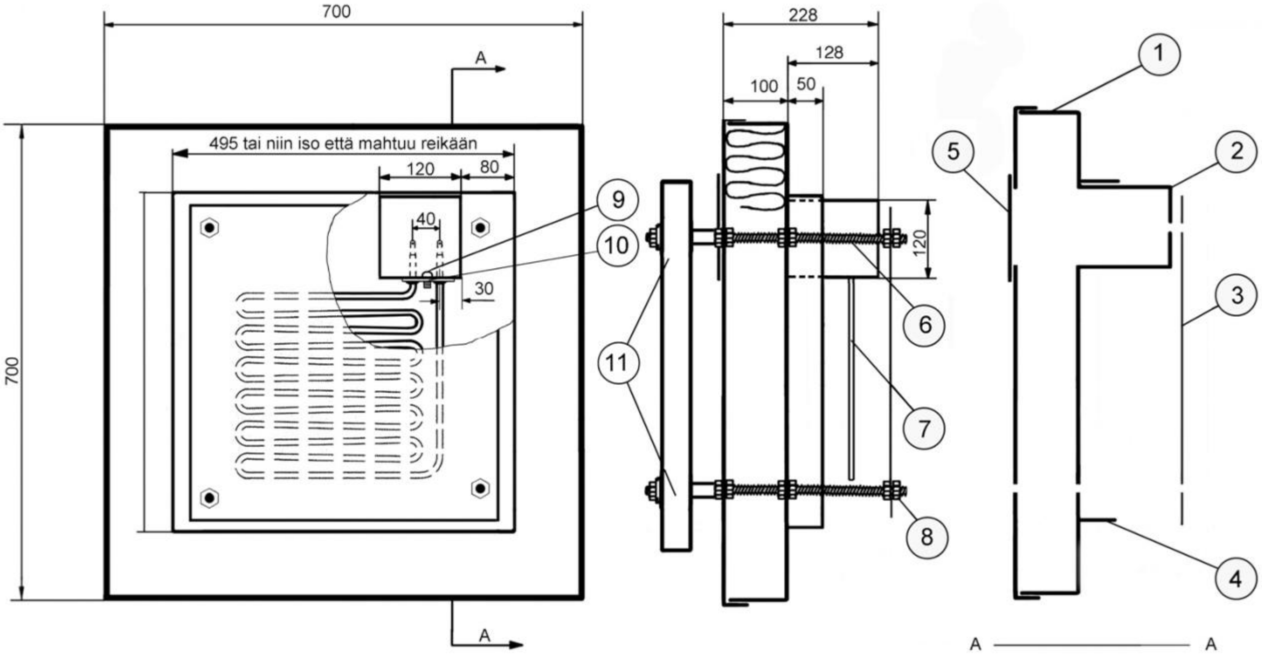
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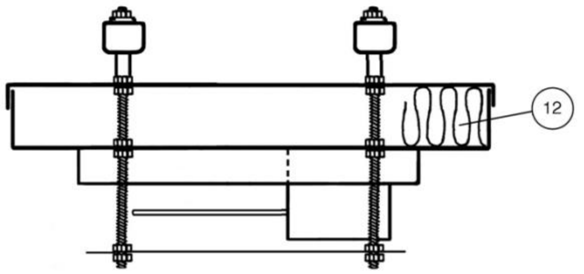
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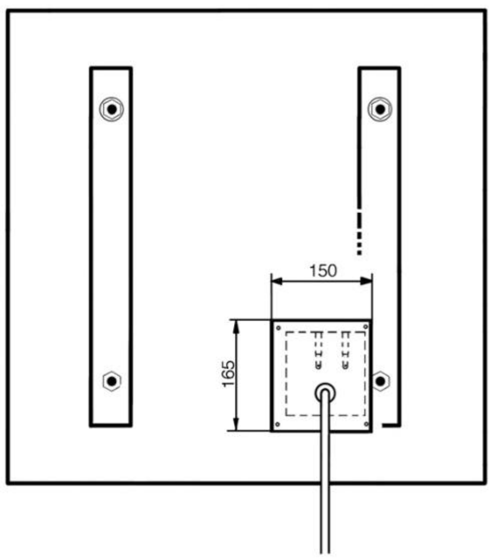
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Part nr / Osanro	Part / Osa	Pcs / Kpl	Material / Materiaali	Measurements / Mitat
1	Door / Ovi	1	1,5mm stainless steel sheet / RST-levy	700 x 700 x 228
2	Heat element housing / Vastuksen kiinnityskotelo	1	1,5mm stainless steel sheet / RST-levy	128 x 120 x 120
3	Heat shield / Suojapelti	1	1,5mm stainless steel sheet / RST-levy	450 x 450 x 1,5
4	Collar / Kaulus	1	2,0mm stainless steel sheet / RST-levy	495 x 495 x 50
5	Shield for heat element mounting housing / Vastuskotelon suoja	1	2,0mm stainless steel sheet / RST-levy	145 x 60
6	Threaded rod / Kierretanko	4	M10 Stainless steel / RST	M10 x 400
7	Heating element / Lämpövastus	1	Harvia ZSB-229 3000W / 230V	
8	Nut / Mutteri	28	Stainless steel / RST	M10
9	Screw to mount the heating element / Vastuksen kiinnitysruuvi	1	Stainless steel / RST	
10	Heat element seal / Vastuksen tiiviste	2	Silicone / Silikoni	
11	Door handle / Oven kahva	1	Birch / Koivu	510 x 50 x 50
12	Thermal isolation / Lämpöeriste	1	Fireproof mineral wool / Paroc tulivilla	2 x 50mm
13	Oven / Uuni	1	1,5mm stainless steel sheet / RST-levy	1500 x 500 x 500
14	Door hinges / Oven karmit	1	1,5mm stainless steel sheet / RST-levy	2100 x 100 x 40
15	Base beam / Pohjapalkki	3	2,0mm stainless steel sheet / RST-levy	700 x 100 x 50
16	Top beam / Kansipalkki	1	2,0mm stainless steel sheet / RST-levy	700 x 100 x 50
17	Fan housing / Tuulettimen kotelo	1	1,5mm stainless steel sheet / RST-levy	190 x 190 x 100
18	Fan / Tuuletin	1	MMotors JSC FE-T 300	
19	Steam inlet / Höyryn sisäänmeno	1	Stainless steel pipe / RST-putki	⌀ 35
20	Steam outlet / Höyryn ulostulo	1	Stainless steel pipe / RST-putki	⌀ 35
21	Base plate / Pohjalevy	1	Waterproof plywood / Filmivaneri	1600 x 700 x 25
22	Top plate	1	Fiber cement board / Kuitusementtilevy	1600 x 700 x 25
23	Side plate	2	Fiber cement board / Kuitusementtilevy	1600 x 700 x 9
24	End plate	1	Fiber cement board / Kuitusementtilevy	1600 x 735 x 9
25	Control unit	1	Ollikka, Mark II	
26	Heat element housing	1		
27	Fan housing / Tuulettimen kotelo	1		
28	Heat sensor outlets	1	1,5mm stainless steel sheet / RST-levy	140 x 140 x 100
29	Steamer / Höyrystin	1	Cocraft HW2000	
30	Steam inlet hose / Höyryn sisäänmenon letku	1	Silicone hose / Silikoniletku	
31	Steam outlet hose / Höyryn ulostuloletku	1	Silicone hose / Silikoniletku	

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Date: 3.12.2019

Design: Jukka Ollikka
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Thermal ageing chamber