



Samuli Heikkonen • Katri Luostarinen • Kimmo Piispa

KILN DRYING OF SIBERIAN LARCH *(Larix sibirica)* TIMBER

Mikkelin ammattikorkeakoulu
A: Tutkimuksia ja raportteja - Research Reports

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<p>Tekijät Samuli Heikkinen, Katri Luostarinen, Kimmo Piispa</p>		
<p>Nimeke Kiln drying of Siberian Larch (<i>Larix sibirica</i>) timber</p>		
<p>Tiivistelmä</p> <p>SIBLARCH-projektissa verrattiin neljää eri kuivausmenetelmää Siperianlehtikuusen kuivauksessa. Käytetyt menetelmät olivat lämminilma-, alipaine-, kuuma- ja suurtaajuuskuivaus. Tavoitteena oli saavuttaa sahatavaran hyvä kuivauslaatu mahdollisimman nopeasti. Aineistona käytettiin dimensioiltaan 50 mm x 150 mm sahatavaraa sekä Suomesta että Siperiasta; tavoitekosteussuhde oli 10 %.</p> <p>Tavoitekosteussuhde saavutettiin parhaiten lämminilma- ja alipainekuivauksissa. Vaihtelu oli melko pientä, mikä on tyypillistä näille hitaille kuivausmenetelmille tasaannutusta käytettäessä.</p> <p>Nopeimmat menetelmät olivat kuuma- ja suurtaajuuskuivaus. Kuumakuivauksessa sahatavaran muodonmuutokset olivat vähäiset, kun taas tavoitekosteussuhdetta ei saavutettu; lisäksi hajonta oli suuri. Kuumakuivatun sahatavaran värinmuutokset olivat lisäksi huomattavat. Suurtaajuuskuivauksessa tavoitekosteussuhde saavutettiin hieman paremmin kuin kuumakuivauksessa, mutta hajonta oli liian suuri puusepänteollisuuteen. Kuumakuivausta voitaisiin käyttää ulkotiloissa käytettävälle lehtikuusisahatavarakkeelle, sillä silloin kosteussuhdevaihtelut voidaan sallia. Suurtaajuuskuivauksella taas voitaneen saavuttaa selvä ajansäästö alle 10 % kosteussuhteeseen kuivattaessa.</p> <p>Tulevaisuudessa kaikille kuivausmenetelmille pitäisi optimoida parhaat kuivauskaavat. Etenkin alipainekuivaus korkeilla lämpötiloilla voisi tuottaa hyviä kuivaustuloksia kuten myös alipaine-, suurtaajuus- ja kuumakuivausmenetelmien yhdistäminen.</p> <p>Siperialainen, selvästi tiheämpi ja hitaammin kasvanut puuainekkuus kuivui selvästi hitaammin kuin suomalainen Siperianlehtikuusisahatavara. Niiden kuivaus olisi siten suoritettava omissa erissä.</p> <p>Säteensuuntaisesti sahatun sahatavaran muodonmuutokset olivat kuivauksen jälkeen pienemmät kuin X-log –menetelmällä sahatun sahatavaran. X-log –menetelmällä ytimen sisältävät tai läheltä ydintä sahatut kappaleet kieroutuivat selvästi enemmän kuin kauempaa ydintä sahatut kappaleet.</p> <p>Siperianlehtikuusisahatavaran kuivauksessa voidaan saavuttaa laadullisesti hyviä tuloksia. Kuitenkin tasaisen tavoitekosteussuhteen saavuttaminen on haastavaa nopeilla kuivausmenetelmillä.</p>		
<p>Avainsanat (asiasanat)</p> <p>siperianlehtikuusi, sahatavara, kuivaus, menetelmät, fysikaaliset ominaisuudet, tiheys, lujuus, kutistuminen, muoto - muutos</p>		<p>ISBN</p> <p>978-951-588-210-3 (nid.)</p> <p>978-951-588-211-0 (PDF)</p> <p>ISSN</p> <p>1795-9438</p>
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<p>Name of the work Kiln drying of Siberian larch (<i>Larix sibirica</i>) timber</p>		
<p>Abstract</p> <p>Four different methods for drying Siberian larch were investigated in the SIBLARCH-project. The methods were conventional kiln drying, vacuum kiln drying, high temperature drying and high frequency vacuum drying. The aims of the study for each method were to reach good drying quality and reduce drying time. The material was originated from Siberia and Finland. Planks of dimensions of 50mm x 150 mm were dried to a target moisture content of 10%.</p> <p>Target moisture content was reached best with the lowest variation by conventional kiln drying and vacuum kiln drying. Low variation is common with slow drying methods especially when stabilising the moisture correctly at the end of the process.</p> <p>High temperature drying and high frequency vacuum drying resulted in the fastest drying times. Deformations were low in high temperature drying. Reaching the target moisture content was difficult and the variation in the final moisture content was significant. Also, the colour changes in high temperature drying were clear. In high frequency drying the target moisture content was reached with better success, but still the variation was clearly too high for the joinery industry. High temperature dried larch timber could be useful for outdoor use when a greater moisture variation is allowed. High frequency drying would offer a significant reduction in drying time when drying to low moisture contents below 10%.</p> <p>Optimisation of all drying methods should take place in future studies. Especially vacuum kiln drying at high temperatures could offer some benefits in drying time as well as a combination of vacuum, high frequency and high temperatures.</p> <p>Test material originating from Siberia is clearly slower to dry than material from southern Finland because of the higher density and slower growth rate. Thus the origins should be dried separately.</p> <p>Radial sawing led to better deformation results when compared to X-log sawing. X-log sawn planks from close to the pith or including the pith twisted significantly more than the planks from the larger distance from the pith.</p> <p>According to this research the drying of Siberian larch timber can result in good drying quality. Reaching even final moisture content is especially challenging with fast drying methods.</p>		
<p>Keywords</p> <p>Siberian larch, timber, drying, methods, physical properties, density, strength, shrinkage</p>		<p>ISBN 978-951-588-210-3 (nid.) 978-951-588-211-0 (PDF)</p> <p>ISSN 1795-9438</p>
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FOREWORD

This publication has been written to publish the results of the SIBLARCH project: “Decay resistant timber – Siberian Larch compared to Scots Pine in forestry and products”. The project was carried out by several public organizations and private companies in Finland, Iceland, Norway, Russia and Sweden.

The research into kiln drying of Siberian Larch was done at the YTI Research Centre in the Mikkeli University of Applied Sciences and at Faculty of Forest Sciences, University of Joensuu. This Research was financed by the European Union Northern Periphery Programme, the Finnish Ministry of Agriculture and Forestry and the Mikkeli University of Applied Sciences.

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Mikkeli 14.11.2007

Authors

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LIST OF ABBREVIATIONS

Aver. – average

Br – Brinell

C – conventional kiln drying (C1 - C8)

Cop. – copious

Det. – detectable

DF – drying force (MC/EMC)

EL – setting value for power

EDG – European Drying Group

EMC – equilibrium moisture content, %

END IP – electric current (A) at the end of the drying process

Grad – gradient

HT – high temperature drying (H1 - H6)

HF – high frequency drying (R1 - R6)

IP – electric current (A), setting value during the drying process

Ja – Janka

ju – juvenile

ma – mature

MC – moisture content, %

MOE – modulus of elasticity (kN/mm²)

NT – Nordic Timber

Obv. – obvious

R – high frequency drying

RAD – radial

Ref – reference

RF – radio frequency 13,58 Mhz

RH – relative humidity of the air (%)

SD – standard deviation

T – temperature, °C

T_A – air temperature, °C

T_W – wood temperature, °C

T_{WOOD} – wood temperature, °C

TAP – voltage (V), setting value

V – vacuum kiln drying (V1 – V6)

Ventil. – ventilation

VOC – volatile organic compound

1 INTRODUCTION

The sapwood of Fenno-Scandinavian wood species such as Norway Spruce (*Picea abies*) and Scots Pine (*Pinus sylvestris*) need to be protected against decay when aiming for outdoor use. In Fenno-Scandinavia outdoor timber constructions are usually protected by chemical treatment. During the past few years environmental protection has become increasingly important. For this reason the chemical treatment of wood is undergoing changes and new chemicals and alternative solutions for wood preservation are being developed.

It is believed that the wood of Siberian Larch (*Larix sibirica* Ledeb.) is resistant against decaying fungi, which is the main reason why it is recommended to be increasingly used particularly outdoors. The wood of Siberian Larch is a good raw material particularly in the mechanical wood industry. From the point of view of this industry, the admirable properties of larch wood are e.g. its good decay resistance, lively and beautiful patterning of annual rings, and its strength, but its drying has often been difficult as defects may exist in larch wood after drying.

Kiln drying is used in order to minimise production time as well as the capital needed for industrial timber production. Drying can take months depending on the wood species, dimensions of the planks, air temperature and air humidity. For the purposes of the joinery industry, wood needs to be dried to an even moisture content below 10% to minimise dimensional changes. This is also required for successful gluing, finishing and planing. Low moisture contents can be achieved only by using different kinds of kiln drying methods. The common defects occurring after the drying of larch timber are deformations, cracking and a varying moisture content. Yet studies concerning the properties and drying of larch wood are still scarce.

The purpose of this research was to examine the suitability of different drying methods (conventional kiln drying, vacuum kiln drying, high temperature kiln drying and high frequency vacuum kiln drying) for Siberian Larch timber aimed at the joinery industry. At the same time, several drying schedules for each drying method were compared to determine the conditions of each method and their impacts on the drying quality of larch timber. The differences in the drying and drying quality of Siberian Larch originating from Finland and Russia (Siberia) were also examined. Density, annual growth, strength and the amount of heartwood were compared between origins to find the differences. The second aim was to collect information on the properties, especially to bring together the knowledge about drying properties of larch, and use of larch. Thus the research was carried out as a literature briefing and experimental research.

2 PROPERTIES, USES, PROCESSING AND AVAILABILITY OF SIBERIAN LARCH TIMBER

2.1 Decay resistance and amount of heartwood

The timber of Siberian Larch is known for its decay resisting properties. This reputation is the main reason why it is recommended to be increasingly used particularly outdoors. The present day environmental consciousness emphasises this recommendation. Effective traditional preservatives are banned requiring that new solutions be found. Naturally durable species are one possibility for use in less demanding and quite easily repairable outdoor constructions. Over the last few decades larch has been used in demanding ground contact environments. However, in the European standards the heartwood of Siberian Larch is ranked to be slightly durable – moderately durable (classes 3 to 4) (e.g. Finnforest Thermowood 2003). These durability classes are aimed for outdoor use above ground. The variation in decay resistance properties of larch wood are known to be significant.

An advantage of Siberian Larch in decay resistance is its large proportion of heartwood, which is the part of the secondary xylem including the extractives which make the resistance properties. The proportion of heartwood has been observed to be larger the older the tree is, around 50% (Hakkila et al. 1972, Hakkila & Winter 1973) or 67% (Juvonen et al. 1986) at the age of 50 years, and even 85% at an age of over 160 years (Use of larch... 1971). The proportion of heartwood has also been observed to be larger the faster the Siberian Larch tree had grown (Hakkila & Winter 1973). In Scots Pine (*Pinus sylvestris*) the proportion of heartwood is usually under 40% (e.g. Björklund 1999).

Genetic determination for decay resistance has been observed to exist, but growth characteristics and decay resistance do not correlate in Siberian Larch wood (Venäläinen et al. 2001). Instead, the older the Siberian Larch tree is, the more durable its wood; no difference in the decay durability of wood between Siberian and Finnish grown Siberian Larch was observed. However, durability has been noted to vary within the same plank (Viitanen et al. 1997).

Studies have been made to differentiate resistant individuals from susceptible ones: taxifolin (a flavonoid) and the total phenol concentrations in Siberian Larch heartwood correlate positively with decay resistance while density and water adsorbing properties did not correlate with it (Venäläinen et al. 2006). In other *Larix* species similar correlations have been found between the concentration of total phenols and decay resistance (Gierlinger et al. 2004b), and the reddish colour of heartwood correlates positively with phenols and decay resistance (Gierlinger et al. 2004a). Non-destructive near-infrared (FT-NIR) spectroscopy has proved to be an accurate and fast method for determining decay resistance of *L. sibirica*, *L. decidua* and *L. kaempferi* (Gierlinger et al. 2003, Sykacek et al. 2006).

2.2 Density and mechanical properties

When comparing the mechanical properties of Siberian Larch wood with those of other tree species, particularly conifers, the wood of Siberian Larch is of high density, medium hardness and its strength is relatively high. Density has the main effect on the mechanical properties of Siberian Larch wood, the wood being the stronger the denser it is (Koizumi et al. 2003). Some mechanical properties of Siberian larch wood are presented in Table 1, comparing to the same wood properties of some other tree species.

TABLE 1. Some mechanical properties of wood of Siberian Larch, Scots Pine, Norway Spruce and Silver Birch. Some values of larch are for juvenile and mature wood, hardness values are either Janka (Ja) or Brinell (Br) values. (References: 1) Cudinov 1965b according to Sairanen 1982, 2) Juvonen et al. 1986, 3) Grekin 2006, 4) Jalava 1945, 5) Heräjärvi 2004, 6) Wagenführ 1996)

Species	Basic density (kg/m ³)	MOE (GPa) (ma-ju)	Bending strength (MPa) (ma-ju)	Compression strength (MPa)	Hardness (MPa) (ju-ma)	Shear strength (MPa) (ju-ma)
Larch	490-560 ¹⁾	12.7-13.1 ²⁾	96-101 ¹⁾ 84-91 ²⁾	47-61 ¹⁾	26.4-34.5 ²⁾ (Ja)	10-12 ²⁾
Pine ³⁾	401-438	12.7	86	48	24.4 (Br)	11
Spruce ³⁾	354-417	13.7	86	45	20.9 (Br)	5.3
Birch	480 ⁴⁾	15.1 ⁴⁾	114 ⁵⁾	54 ⁴⁾	23.4 ⁵⁾ (Br)	13 ⁶⁾

There is significant variability in the density of the wood of Siberian Larch, especially between earlywood and latewood and between origins (Koizumi et al. 2003). In addition, according to Kärkkäinen (1978), basic density is connected to age; being at its largest around annual rings 40-60 from the pith. Hakkila and Winter (1973) also found that age is the best parameter to explain the changes in basic density between trunks – the older the tree is, the larger is the density. The basic density of Siberian Larch wood has been observed to be 476 kg/m³ at 60 years and 539 kg/m³ at 100 years in the trees of Punkaharju, Finland (Tuimala 1993). Also values around 490 kg/m³ of Siberian Larch grown in Finland have been measured for basic density (Hakkila et al. 1972, Hakkila & Winter 1973, Juvonen et al. 1986). In larch

heartwood there exists arabinogalactan, an extractive (e.g. Venäläinen et al. 2006), the concentration of which increasing along with the age of the trees (Viitanen et al. 1997) and affecting the density of larch wood. Arabinogalactan is located in tracheids near the rays forming filled tracheid rows. These filled tracheid rows have been measured as clearly improving the transversal compression strength and Young's modulus of larch wood (Grabner et al. 2005).

According to Kärkkäinen (1978), basic density is connected also with the width of annual rings; the higher the density the narrower the rings. Late seasonal snow melt and a low temperature in early summer have been observed to decrease the annual ring width in Siberian Larch trees (Kirilyanov et al. 2003) and thus it should affect the density. In addition, poor growing conditions make basic density lower, and at the same time, the compression strength becomes weaker (Lvov & Klimov 1971 according to Sairanen 1982). Shear strength as well as the slope of the grain can be predicted by density (Müller et al. 2004). Contrary to density, microfibril angle and tracheid length do not affect the mechanical properties in Siberian Larch wood (Koizumi et al. 2003).

2.3 Proportion of bark

An important and often measured property, particularly in the pulp industry, is the proportion of bark, which has been observed to be different in South (14.1%) and North (18.7%) Finland (Hakkila et al. 1972) grown Siberian Larches, the average being 15.5% (Hakkila & Winter 1973) or 16% (Juvonen et al. 1986) at the age of 50 years. Verkasalo (1993), instead, measured a higher value, 20.9%, for the bark proportion of ca 60-year-old Siberian Larch trees. The proportion of bark is somewhat higher in Siberian Larch than in pine and spruce trees grown in Finland (Hakkila & Winter 1973).

2.4 Uses and problems in use of larch timber

The wood of Siberian Larch is beautiful and especially suitable for decorative uses (Verkasalo 2001). Traditional uses for larch timber were boats, window frames, doors and stairs (Pro Puu ry 2007). At present in Finland, the main uses of the wood of Siberian Larch are for outdoor purposes: garden furniture and plaques on the ground as well as bridges and piers (Pro Puu ry 2007), but stairs and comparable constructions are less common because of the high density of the larch wood.

In the former Soviet Union the wood of Siberian Larch was used for wooden houses, packaging and casks, furniture, parquet, plywood, fibreboard (Černenko & Fadejev 1982 according to Sairanen 1982), railway sleepers, power transmission line supports, bridges, piers (Bukštynov 1981 according to Sairanen 1982), as mining timber (Byvših 1977 according to Sairanen 1982), in cement and chip blendings (Akodus & Buharkin 1980 according to Sairanen 1982), pulp and paper industry (Šapiro et al. 1971 according to Sairanen 1982, Bukštynov 1981 according to Sairanen 1982), turpentine and resin industries (Bukštynov 1981 according to Sairanen 1982) and gas and charcoal industries (Tverdohlebova & Levin 1975 according to Sairanen 1982).

It is hypothesised that larch wood could substitute pine wood in interiors because of its smaller amounts of VOCs. The amount of terpenes is especially low, however, the amount of acetic acid is rather high (Viitanen et al. 2001). The amount of VOCs depend on the drying method, but at room temperature, in spite of the drying method used, it was always very low. Instead, the amount of highly inflammable extractives is high, which impairs the fire resistance (Viitanen et al. 2001).

In Finland larch wood users have mentioned the following problems in the use of larch timber: 1) cracks emerging during drying, because they increase the amount of waste wood, 2) uneven final moisture content because it causes marked deformations in the billets and a need to let the billets dry after the

first processing before final processing, 3) knots that always crack during drying and cause bends in the timber, 4) large resin content, 5) splinters, 6) loosening of growth rings, 7) the very tightly attached bark, and 8) large difference in density between earlywood and latewood (Saimovaara 2001). According to Pelz et al. (1999, according to Verkasalo & Viitanen 2001), the main factor limiting the primary processing and thus the use of larch timber in Central Europe is the availability of the larch timber, but very important factors were also resin flows and cracks, sticking of tools and blades, deformations – especially twisting, crooked logs, difficult drying, price, reaction wood, pith not located at the center of the log, and spiral grain, all of them impairing the processing possibilities.

2.5 Processing of larch timber

Although studies concerning the properties of Siberian Larch timber are scarce, it is known that the good properties of the wood show especially in the fields with a low degree of processing, while further processing emphasises its poor properties (Sairanen 1982). In addition, arabinogalactan makes the sawing of larch wood difficult as it sticks in the saw blades (e.g. Viitanen et al. 1997). Especially the cracking of larch timber when using screws and nails, due to the poor shear strength in relation to its hardness (Verkasalo 2001), is mentioned and their use is not recommended: drilling guide holes should be employed if it is necessary to use screws (Tjurikov 1965 according to Sairanen 1982). The poor shear strength in relation to the hardness can be observed also as splinters loosen when larch timber is sawn and planed; this is commonly known among users. In sawing as well as in cutting veneer, radial processing is recommended because the wood is most stable and strongest in this direction, thus cracking least radially (Zuban 1965b according to Sairanen 1982, Minejev 1975 according to Sairanen 1982).

Of further processing, gluing properties are much alike those of e.g. pine but large shrinkage and swelling when moisture content is changing may cause problems for the durability of the glue line. Thus when gluing larch wood,

the orientation of the annual rings should be taken into account and a long pressing time is recommended (Suomi-Lindberg & Viitanen 2001). Also finishing properties are comparable to those of pine. When several different finishes were tested, the only one sparing larch timber from cracking in seasoning of six months was water-dilutable covering wood protective liquid (Ahola 2001).

2.5.1 Drying

There is little information available on the drying of Siberian Larch timber but generally it is thought that the drying is quite difficult, more difficult than e.g. the drying of Scots Pine timber (Tarvainen et al. 1999). For example, the drying of larch timber takes significantly longer than the drying of pine timber of similar dimensions (Sipi 1988, Rantala & Anttila 2004). To reduce the drying time higher temperatures should be used for larch timber than for pine (Sipi 1988).

There are contradictory results concerning the cracking of Siberian Larch wood during drying. According to Russian references (Ponomarev 1934 according to Sairanen 1982, Čudinov 1965b according to Sairanen 1982, Byvših 1977 according to Sairanen 1982) and results of the research of Pelz et al. (1999; according to Verkasalo & Viitanen 2001) cracking is the most serious problem in the drying of larch but Finnish scientific references claim that the most serious problems are a large moisture gradient and difficulties in reaching the target moisture content (Sipi 1988, Tarvainen et al. 1999). Finnish users of larch timber, instead, claim that cracking of larch timber is the main problem in processing it after drying (Saimovaara 2001).

The large tangential shrinkage of larch wood and the significant difference between tangential and radial shrinkage (Table 2) as well as the low longitudinal ability of fibres to conduct moisture causes cracking, both on the surfaces and at the ends of timber pieces (Čudinov 1965a according to Sairanen 1982). Also the difference in shrinkage between earlywood and

latewood increases cracking in the tangential direction (Čudinov 1965a according to Sairanen 1982) while inner cracking is rare in larch wood in drying (Zuban 1965a according to Sairanen 1982). Juvonen et al. (1986), Sipi (1988), and Tarvainen et al. (1999) found that larch wood cracks only a little more than pine during drying: cracking occurs most often in the pieces containing the pith and juvenile wood.

Sawn larch timber pre-dried in cold outdoor storage for one year has been clearly observed to crack more than artificially dried timber immediately after sawing (Asikainen 2001). To reduce cracking, high temperature drying with steaming and a high relative humidity of air at the beginning of conventional drying has been recommended (Zuban 1965a according to Sairanen 1982). The conditions of the latter recommendation enhance the movement of moisture from inside the timber pieces to their surface.

TABLE 2. Shrinkage and swelling (%) of Siberian Larch and shrinkage (%) of Scots Pine wood from green to absolutely dry (Tjurikov 1965 according to Sairanen 1982)

Species	Property	Tangential	Radial	Volume
Larch	Swelling	11.7	6.0	18.3
Larch	Shrinkage	12.0	5.4	19.8
Pine	Shrinkage	8.4	5.1	13.2

Twisting is another problem in the wood of Siberian Larch timber during drying (Sipi 1988, Rantala & Anttila 2004). Angled support sections fitted to the kiln wagon to twist the timber in the opposite direction to the natural twist (Tarvainen 2005) and top-loading of the timber (Tarvainen 2005, Frühwald 2006) have been found to be effective ways to diminish distortion especially in high temperature drying (Tarvainen 2005) while deflection in the opposite direction to the natural warp during cooling down reduced warping only for a short period (Taylor & Mitchell 1990). However, drying in high temperatures may decrease the decay resistance of larch wood, probably caused by chemical changes in the hemicellulose (Doi et al. 2005).

A simulation model for the drying of Siberian Larch timber has been developed (Tarvainen et al. 1999). In this model, it has been possible to accurately predict the drying of Siberian Larch timber if the initial moisture content and density are known, and cracking has been possible to be minimised, however, it has proven difficult to predict the moisture gradient.

2.6 Availability of larch logs and sawn timber

The availability of Siberian Larch timber is limited in Finland. In Finland larch is a cultivated species, though the amount of cultivation is limited. The cultivation of larch started in Finland in the 18th century and it has been estimated that there is ca 20 000 hectares of larch cultivations at present in Finland (Verkasalo 2001). However, the commercial significance of the timber available from the cultivations is minor although it is estimated to increase in the future when the trees reach the size of large logs (Verkasalo 2001).

At present the larch wood commercially available in Finland is mainly imported from Russia as sawn timber. There are significant amounts of larch growing in Siberia, there is enough larch wood for decades for much more extensive use than nowadays, but the problems are the transport of the timber from forests to sawmills as well as from Russia to Finland. For example in this research, in spite of agreements, the chosen timber lot did not come from Russia to Mikkeli at the right time. Furthermore, the introduction of, during spring 2007, increased custom duties for round timber exports from Russia limit the possibilities of buyers to purchase timber from there. In addition, larch logs are not allowed to be imported into Finland because of the possibility of an insect invasion. Also sawn larch timber imported in Finland is allowed to contain bark because of the insects.

3 MATERIALS

For this study the Siberian Larch timber from a Finnish source came from Punkaharju, Eastern Finland (61°81'N, 29°32'E) from the plantations of the Finnish Forest Research Institute. The forest was planted in 1924 with four year old seedlings. The trees were harvested in December 2005 and two logs, a butt log and a middle log, of length of 4.3 m were taken. Samples for diameter, heartwood and bark proportion as well as for annual growth measurements were taken from the height of 4.5 m, i.e. from above the butt log.

Logs from Punkaharju were sawn with a small portable circular saw into planks of dimensions of 50 mm x 150 mm (Figure 1). Most of these logs were sawn using the X-log method. Few logs were sawn using the radial sawing method (Figure 2). The latter method resulted in various dimensions of the planks, while the waste material was minimised. Radial sawing required special arrangements when handling the timber halves and quarters while the saw took care of that for X-log sawing. In an industrial scale radial sawing would require specialised production.



FIGURE 1. Sawing the Finnish test material in Punkaharju

In the sawing process special attention was paid to the inner tensions of the wood (Figure 3). It was noticed that planks and strips of some logs had a significant crook or bow immediately after sawing. Tensions caused problems especially in radial sawing. The saw blade became easily stuck when sawing

through the log. Large resin pockets (Figure 3) were also detected especially near the pith. These resin pockets looked like cracking over the full length of the planks. Thus the pith contained a remarkable amount of resin, which may cause problems in the sawing process as well as in other processing of larch timber.

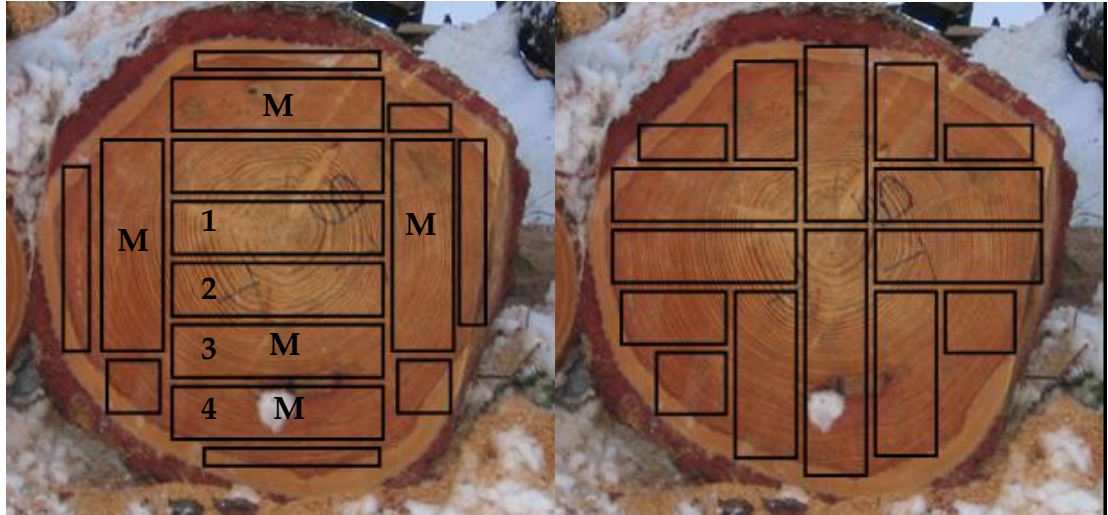


FIGURE 2. X-log sawing method (left) and radial sawing method (right) used when sawing the test material in Punkaharju Research Station. Letters M in the left figure indicate the planks for which the drying quality measurements were performed (see paragraph 4.5). Numbers indicate the distance of the sample from the pith (see paragraph 4.2)



FIGURE 3. Relieved growth tensions in the strips and planks after sawing (left and middle). Large resin pockets in the planks from near the pith (right)

The Siberian Larch timber from the Siberian source came from Ust Ilmsk in the Irkutsk area (58°15' N, 102°75' E) (Figure 4). The trees were harvested in October – December 2005 and the logs were sawn in Siberia in November – December 2005 – 2006 into planks of the dimensions of 50 mm x 150 mm. The planks were purchased from Pariwood Oy from Parikkala, Finland, and thus more precise information could not be found.



FIGURE 4. The origin of the Finnish and the Siberian test material (map from Commonwealth 2006)

For the drying tests, the planks were cut into suitable lengths for the kilns used in this study (see details in paragraphs of each method). In cutting the sample planks, attention was paid to take as similar as possible planks from each log for drying in different methods to make the comparison of the drying results between methods and lots possible. The dried material was mainly from the butt logs. The total amount of the test material was ca 22 m³ (~11 m³ of Finnish, ~11 m³ of Siberian), which makes 780 planks.

Similar samples were taken for Scots Pine originating in Northern Finland (Pello, Lapland), and Southern Finland (Rantasalmi, South-Savolax) and

they were compared with larch. The number of Scots Pine samples was 50 from both sites.

4 METHODS

4.1 Age of trees, diameter of logs and amount of heartwood and bark

The age (a) of the larch trees was calculated from the annual rings from the stump. The diameters (mm) of the trunks, heartwood and secondary xylem were measured. The amount of heartwood (%) and bark (%) were also calculated from discs of the Finnish material (n=20) taken from the logs before sawing from 4.5 metres in height from the stump.

The age, diameter of logs and amount of heartwood and bark were determined similarly for pine than for larch and the results of pines were compared to those of larch.

4.2 Annual growth of trees and initial moisture content, basic density and strength of timber

The amount of annual growth (mm) was measured according to the INSTA 142 (Nordic visual strength ... 1997) not closer than 24 mm from the pith from the samples taken from the height of 4.5 m.

Density and initial moisture content measurements were done for all the planks (N=780) used in the drying tests. Samples of 20 mm in length were taken from the 4.3 m long planks when cutting them to a suitable length for each kiln. The exact dimensions of the samples were measured and they were weighed immediately after cutting from green planks. After this the samples were dried at a temperature of $103 \pm 2^\circ\text{C}$ and weighed. The basic density (kg/m^3) and the initial moisture content (% in dry weight basis) were then calculated. In the measurement the distance of the sample from the pith was taken into account; in Siberian material, purchased as sawn timber, the distance was determined from the curve of annual rings, and the existence of

the pith, sapwood and bark. The scale used was 1) planks including the pith, 2) planks from the innermost heartwood, 3) planks from the middle of the heartwood, and 4) planks containing both heartwood and sapwood (Figure 2).

After analysing the drying results some of the planks were cut up into 20 mm x 20 mm x 400 mm samples without any defects. These specimens were stabilised ($T = 20^{\circ}\text{C}$, $\text{RH} = 65\%$) and tested in a four point bending test measuring the bending from the middle of the sample. Bending strength and modulus of elasticity (MOE) were tested according to the standard EN 408 part 10: "Determination of global modulus of elasticity in bending". The test was done with a Shimadzu AG-100 kNE, serial number 28092778 using the Trapezium2 PC-program.

4.3 Drying methods and schedules

Usually both the Siberian and Finnish material were included in the same process, but several tests were carried out using timber only from one origin at a time. The process control was done according to the Finnish test material when both materials were dried in the same process.

4.3.1 High temperature kiln drying

A high temperature drying kiln manufactured by Nardi, Italy, was used for the high temperature dryings (Figure 5). The device can be used for high temperature drying, conventional kiln drying and thermal modification. The process control program used was Wintek by Tekmawood Oy. In the drying process it is possible to adjust wood temperature, dry bulb temperature, wet bulb temperature, pressure value (overpressure) and ventilation. The control of the process is based on the wood temperature. The capacity of the kiln is ca 1 m³. The maximum length of timber possible to dry in this kiln is 1.85 m but the length of 1.7 m was used. Weights of 134 kg/m² were used on top of the load.



FIGURE 5. High temperature drying kiln at YTI Research Centre

All high temperature drying processes included heating, drying, cooling, conditioning and final cooling stages. Heating was done in very humid conditions with steam to prevent surface cracking. Additional steam was also used in the early stages of drying before steam was generated from the wood itself. After the drying stage the wood was cooled to 70 – 80°C. Conditioning was carried out by steaming the surface of the wood up to 90 – 95°C. Finally the wood was cooled to 40°C.

In total six high temperature drying tests were done at temperatures between 108 – 120°C. The research was started at a temperature of 108°C. The aim was to start with a gentle drying test, proceeding to more efficient ones.

Temperature differences between the wood and the air as well as temperature levels were raised in the more efficient processes to shorten the drying time.

Temperature information of the drying schedules is presented in Table 3.

TABLE 3. Wood and air temperatures (°C) in different stages of the high temperature drying processes. H5 and H6 were optimising tests

H1		H2		H3		H4		H5 and H6	
T _w	T _A	T _w	T _A	T _w	T _A	T _w	T _A	T _w	T _A
Pre-heating stage									
60	65	20	10	5	15	5	15	5	15
Heating / Drying stage									
59	64	20	30	5	30	5	30	5	25
90	95	60	70	60	85	60	85	60	80
99	103	90	100	90	100	90	110	90	105
103	106	99	106	95	113	95	113	95	108
105	108	101	107	99	114	99	114	99	109
	108	105	110	101	109	101	109	101	109
		111	115	105	111	108	117	105	112
			108	110	116	112	120	108	113
					105		106	111	115
								113	115
									110
Cooling / Conditioning / Cooling stage									
108	105	100	98	105	102	106	103	110	108
80	77	80	77	80	77	80	77	70	67
80	82	80	76	80	85	80	85	70	74
95	97	95	91	95	100	95	100	90	94
95	93	95	93	95	89	95	89	90	83
40	38	40	38	40	34	40	34	40	30

4.3.2 Vacuum kiln drying

The laboratory scale vacuum kiln used, HIGH VAC-BL 13 (Figure 6), is manufactured by Brunner-Hildebrand GmbH, Germany, and the process is controlled by the manufacturer's own program. The capacity of the kiln is 0.6 m³. The kiln is heated electrically. The drying processes are controlled by the wood moisture content which is measured from 12 points within the wood. In addition the temperature of the wood (two sensors) and the climate in the kiln (air pressure, air temperature, relative moisture content of the air) are measured and the equilibrium moisture content of the wood is calculated. Weights of 154 kg/m² were used on top of the load.



FIGURE 6. Vacuum kiln drying at YTI Research Centre

In total six vacuum drying tests were performed at temperature levels between 55 – 85°C. The research was started with temperature level tests at 55°C, 65°C, 75°C and 85°C. Drying forces were chosen to be similar to the best ones in the drying tests in the project 'Larch as a raw material for joinery industry' (Asikainen 2001). The same heating stage was carried out in each drying test using a high relative humidity of the air to prevent surface cracking. After the drying stage the wood was conditioned for 24 hours to a equilibrium moisture content of 6.2%. In the last stage of the process the wood was cooled to 40°C before the kiln was opened (Table 4). After the temperature level tests, a drying schedule for optimising drying tests V5 and V6 was planned. In V5, only Finnish, and in V6, only Siberian material was dried.

TABLE 4. Air temperatures and drying intensities in different stages of the vacuum kiln drying processes. V5 and V6 were optimising tests

Stage of drying	EMC (%)	DF	Drying temperature (°C)				
			V1	V2	V3	V4	V5 and V6
Heating up	20		55	65	75	85	70
Drying, > 70%		2.8	55	65	75	85	70
60-70%		2.9	55	65	75	85	75
50-60%		3.0	55	65	75	85	75
40-50%		3.1	55	65	75	85	75
30-40%		3.1	55	65	75	85	75
25-30%		3.2	55	65	75	85	78
20-25%		3.3	55	65	75	85	81
15-20%		3.4	55	65	75	85	83
10-15%		1.8	55	65	75	85	85
<10%		1.4	55	65	75	85	85
Conditioning 24 h	6.2		49	59	59	59	76
Cooling 4h	8		40	40	40	40	40
Correction factor for moisture measurement			25				
Target moisture content (%)			10				
Target moisture gradient (%)			1				

4.3.3 High frequency kiln drying

The high frequency kiln used is manufactured by Yasujima Co., Japan (Figure 7). This kiln can be used for both high frequency drying, high frequency vacuum drying and ordinary vacuum drying. The kiln allows temperatures of up to 120°C. The operation of the kiln is based on high frequency energy, which heats up the wood from the inside. The capacity of the kiln is ca 3 – 4 m³. The process control is based on electric values, evaporated water and wood temperature. Wood temperature was measured with one temperature sensor. A hydraulic cylinder pressed the load from the top with the lightest possible weight of 550 kg/m².

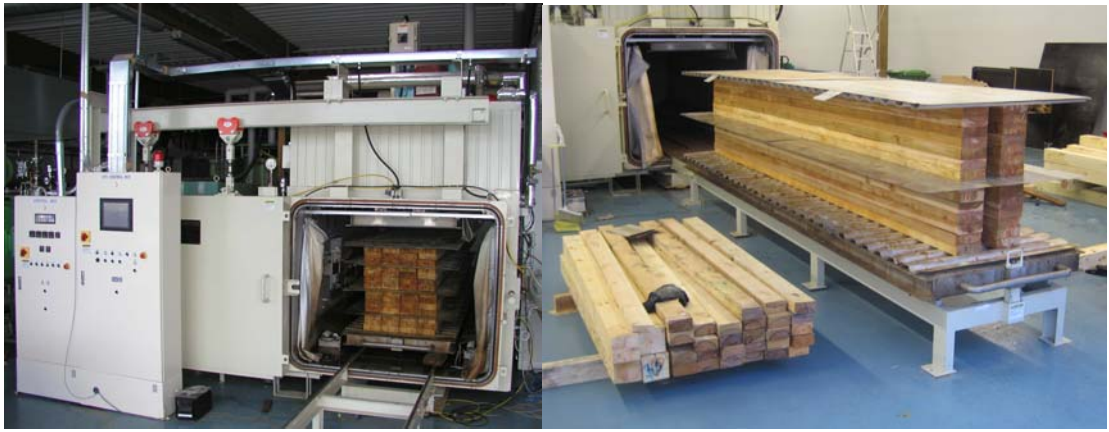


FIGURE 7. High frequency drying kiln at YTI Research Centre

In total six high frequency vacuum drying tests were performed using electric power between 1.0 – 6.1 kW/m³. The research was started with the process using the highest possible high frequency power allowing the wood temperature to rise up to 95°C. Based on the results from the first drying test (marked internal cracking and colour darkening) the power and highest temperature levels were lowered for the other tests. The last test was done with extra electric metal plates between timber layers and a much stronger press than the five earlier tests (approximately 2000 kg/m²).

TABLE 5. Wood temperatures and high frequency information of R1

Stage of the process	Heat	Step1	Step2	Steam	Step3	Step4	Steam	Step5
	1.5 h		4.5 h	18.5 h	20 h	29.5 h	42 h	44 h
Vacuum (Torr)	100	100	100	1	300	300	0	300
RF on (min)	4	4	4	2	4	4	2	4
RF off (min)	2	2	2	2	2	2	2	2
IP	0.55	0.55	0.75	1.05	1.45	1.45	1.05	1.45
EL	1.45	1.45	1.45	1.45	1.45	3	3.7	3.7
END IP	0.4	0.4	0.4	4	1.2	1.2	4	1.2
Power (kWh/m ³)	2	2	3	2	7	7	2	7
T _{WOOD}	85	85	85	85	95	95	85	95

TABLE 6. Wood temperatures and high frequency information in high frequency drying processes R2-R6

Stage of drying	Parameter	R2	R3	R4	R5 and R6
	Volume (m ³)	1.67	1.67	1.67	1.67
Prevacuum	Vacuum (Torr)	200	200	80	-
Heating	Steaming time (h)	8	8	8	8
	Steaming T (°C)	85	85	85	85
	RF with steaming	Yes	Yes	Yes	No/Yes
	IP	1.4	1.4	1.4	-
	EL	-	-	-	-
	TAP	7	7	7	7
	Wood T setting (°C)	85	85	85	85
	RF on (min)	4	4	4	-
	RF off (min)	2	2	2	-
	Power (kWh/m ³)	2.95	2.95	2.95	-
Drying Step 1	Vacuum (Torr)	100	100	300	100
	RF on (min)	4	4	4	4
	RF off (min)	2	2	2	2
	IP	1.4	1.4	1.4	1
	EL	3.2	1.65	2.5	2.5
	END IP	0.1	0.1	0.1	0.1
	Power (kWh/m ³)	2.95	2.95	2	2.11
	Wood T setting (°C)	70	52	76	52
		Finish	Finish	Continue	Continue
Step 2				After 119 h	After 138 h
	Vacuum (Torr)			120	100
	RF on (min)			1	2
	RF off (min)			2	4
	IP			1.4	1
	EL			2.5	2.5
	END IP			0.1	0.1
	Power (kWh/m ³)			2	1.05

Heating was always done in very humid conditions with steaming for 1.5 – 8 hours to prevent surface cracking. Usually the high frequency was combined with steam to heat the wood from the inside. In the drying stage high frequency was applied in cycles according to Tables 5 and 6. Power level, power cycle time and the highest temperature were changed for each drying test. Usually there were one or two steps in the drying stage. There was no conditioning stage in the high frequency drying.

4.3.4 Conventional kiln drying

The laboratory scale conventional kiln used was a B 9400 COMP (Figure 8), manufactured by Brunner Hildebrand GmbH. The processes are controlled by the manufacturer's own program. The capacity of the kiln is 0.5 – 0.7 m³. The kiln is heated electrically (max. 15 kW) and air humidity is adjusted by cold water spraying. Both the temperature and the relative humidity of the air are measured at two points. The drying processes are controlled by the moisture content of the wood. The moisture gradient is also taken into account to ensure sufficient control. This is necessary when the differences between the inner and surface moisture content are high. The moisture content is measured from twelve points, six from a depth of 1/3 of the plank thickness and six from the core of the planks. The moisture content measurements are based on changes in electrical conductivity caused by the drying of the wood. The moisture content of the surface of the planks is assumed to be 1 – 2% more than the equilibrium moisture content of the kiln. The velocity of the air can be controlled by regulating the rotating velocity of the electric motor with a frequency converter, and the air flow can be directed by a manual flap. A change in the direction of air flow can be regulated to an accuracy of one hour.

Drying schedules for the Brunner conventional laboratory kiln are made by determining the temperature and the drying force for ten moisture content intervals for the drying stage, while the climates for heating up, conditioning and cooling down are determined by temperature and equilibrium moisture content. The programmed drying schedules are presented in Table 7. Weights of 154 kg/m² were used on the load to minimise the deformations.



FIGURE 8. Conventional drying kiln at the Faculty of Forest Sciences, University of Joensuu

TABLE 7. Programmed drying schedules for conventional drying

Stage of drying	C1	C2	C3	C4	C1 – 4		C5 – 8		
	T (°C)				EMC (%)	DF	T(°C)	EMC (%)	DF
Heating up	80	70	60	50	18		70	18	
Drying, >70%	80	70	60	50		2.6	70		2.6
60-70%	80	70	60	50		2.6	70		2.6
50-60%	80	70	60	50		2.6	70		2.6
40-50%	80	70	60	50		2.6	70		2.6
30-40%	80	70	60	50		2.4	70		2.6
25-30%	80	70	60	50		2.3	75		2.7
20-25%	80	70	60	50		2.3	80		2.7
15-20%	80	70	60	50		2.6	80		2.7
10-15%	80	70	60	50		2.7	80		3
<10%	80	70	60	50		1.4	80		3
Conditioning	70	60	50	50	9.8		65	8.6	
Cooling	40	40	40	40	9.8		40	8	
Stopping of ventil. (°C)	40	40	40	40			40		
Correction factor for moisture measurement						25	25 in C5-7 20 in C8		
Target moisture content (%)						10	10 in C5-6 8 in C7-8		
Target moisture gradient (%)						1	1 in C5 0.1 in C6-C8		

4.4 Drying shrinkage

Drying shrinkage measurements were done for five different drying processes: two vacuum dryings, two high frequency dryings and one high temperature drying. Shrinkage was calculated from the difference in dimensions before and after drying and it was compared to the moisture content of each plank. Dimensions and moisture content of each plank were measured both before and after drying.

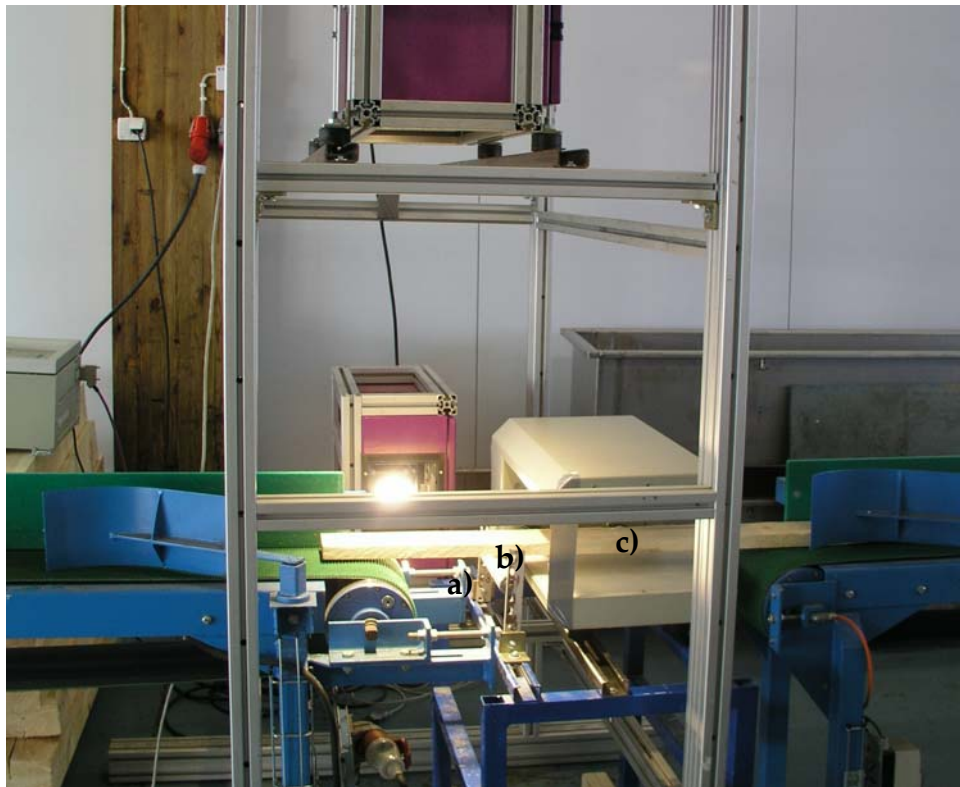


FIGURE 9. Dimension and moisture content measuring systems for drying shrinkage measurements. a) Thickness, b) width, and c) moisture content measurement

Dimensional measurements were carried out with two Inx System Seecon CCD line-scan measuring systems and moisture content measurements with a FMI capacitive in-line moisture meter (Brookhuis 2007) (Figure 9). Planks were moved through a measuring unit using a conveyor system in a longitudinal direction. The system measures the intensity of reflected light from the plank and calculates plank dimensions from this data. Hundreds of individual exposures are taken of a single plank as it moves through the

camera's field of view. Thickness was always measured from the same edge and width from the inner flat of plank.

In the measurement of dry timber, the deformations caused wobbling of planks on the conveyor during measurement. Also the discolouration and ice on the surface of green planks caused some problems in the measurement. Because of these factors, some results had to be filtered out.

4.5 Drying quality of timber

After the processes, measurements were done for the chosen planks which were placed randomly in the drying load. Some measurements were taken for the samples sawn from the inner parts of the logs, too, but a comparison of the methods was only done for the specimens sawn from the outer section of the logs (Figure 2). In the results of each process only the result of these planks are presented.

When performing the measurements, the surface cracks were determined first. Subsequently the deformations were measured and resin flows were determined, i.e. when the measurements for whole planks were made, they were cut into pieces to determine the final average moisture content and gradient, inner cracks, casehardening, and spectra.

4.5.1 Moisture content, casehardening and deformations

The drying quality of larch planks was evaluated according to the guidelines of the European Drying Group (EDG) (see e.g. Sipi 2002) and Nordic Timber (Pohjoismainen sahatavara 1994) which follow the SFS-EN standards mentioned in Table 8. The target quality class was Q (E = Exclusive, Q = Quality, S = Standard) according to EDG; these recommendations were applied for moisture content, moisture gradient and casehardening. For deformations the target was class A according to Nordic Timber (NT) (Pohjoismainen sahatavara 1994). The classification also includes lower

qualities B, C and D. When the drying processes were finished, deformations of the planks were measured (Table 8), after which moisture content and casehardening samples were taken.

When analysing the deformations it is important to note that the length between the supports in the measurements was 1.7 m in high temperature kiln drying and 1.2 m in conventional kiln drying. In other drying methods the distance was 2.0 metres. Thus the measured deformation results of high temperature drying and conventional drying are most probably smaller than they would be if measured for 2.0 metres length.

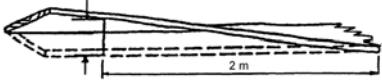
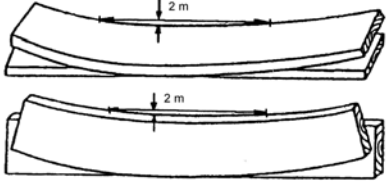
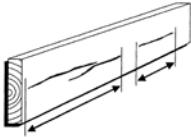
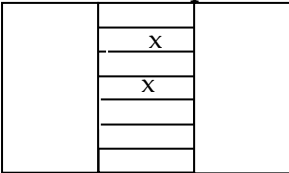

4.5.2 Resin flows and cracking

Before the drying processes, already existing surface cracks were marked on the surfaces of the planks. These marked cracks were not analysed after drying. After the drying processes, new surface cracks of the planks were measured (Table 8).

Resin flows were estimated from the surfaces of the planks with a three-step scale before cutting the moisture content samples (Table 8).

Inner cracking was inspected from the fresh crosscuts when the planks were cut into smaller specimens for moisture and casehardening measurements. In addition to the method described in Table 8, inner cracking was also determined as number of planks containing inner cracking. The former method was used only for the points system, and the results of it are not shown here (results of this method can be find in Lehto 2006). Instead, the results of the latter method are shown in this publication.

TABLE 8. Methods used for measuring the quality of dried larch planks

Measurement	Unit	Method
Twisting	% of the width of timber	SFS-EN 1310:1997 
Bow Crook	mm in two metre distance	SFS-EN 1310:1997 
Cup	% of the width of the plank	Chord of the convex surface
Surface cracking	% of the length on the most cracked surface	SFS-EN 1310:1997 
Inner cracking	none, 1 – 2 cracks, more than 2 cracks	
Resin flows	none, detectable, obvious, copious	
Moisture content	% of dry weight	Oven-dry method EN 13183-1 and electrical resistance method.
Moisture gradient	% of dry weight Moisture difference between the sample taken from the second piece from the surface and from the middle of the planks crosscut	7 different depths 
Casehardening	mm The gap between 20 mm thick split crosscut sections of the plank	SFS-ENV 14464:2002 EDG 
Colour	E^*_{ab} (colour change)	Converting reflectance spectra into $L^*a^*b^*$ coordinates

4.5.3 Colour

After taking moisture and casehardening samples, halves of the planks were ripped and then planed from the surface and from the ripped flat to measure the reflectance spectra of surface and inner wood of planks, respectively. The reflectance spectra show how different wavelengths in the visible region (400-700 nm) reflect from the surface. A 100% reflection in the whole visible range corresponds to white, and 0% reflection corresponds to black. Thus a change in the level of the spectrum corresponds to the change in brightness, and the form of a spectrum corresponds to the hue and saturation of the colour.

L*a*b* colour coordinates were determined from the measured spectra (e.g. Precise color ... 1994). These coordinates present the colour as numerical values so that the ambient light and the differing colour senses of individual human beings are eliminated. L*a*b* coordinates indicate the "location" of the colour in a three-dimensional colour coordinate system. The L* coordinate is scaled so that zero corresponds to black and one hundred to white. Large negative values of a* indicate green and positive values indicate red (a* is positive in the case of larch), large negative values of b* indicate blue and positive values indicate yellow (b* is positive in the case of larch). A colour difference value E^*_{ab} can be calculated with L*a*b* coordinates to represent the colour difference between two measurements.

$$\Delta E = \sqrt{(L^*_{mit} - L^*_{vert})^2 + (a^*_{mit} - a^*_{vert})^2 + (b^*_{mit} - b^*_{vert})^2} \quad (1)$$

L^*_{mit} measured lightness

L^*_{vert} reference value for lightness

a^*_{mit} measured red colour

a^*_{vert} reference value for red colour

b^*_{mit} measured yellow colour

b^*_{vert} reference value for yellow colour

The reference colour in this research was the inner colour of vacuum kiln dried Siberian Larch timber in V2 at 65°C. The Siberian material was the reference for the Siberian test material and the Finnish material was the reference for the Finnish test material. Spectral measurements were carried out with portable spectrophotometers Minolta CM-2002 and Minolta CR-210.

4.5.4 Comparison of drying methods and processes

Drying methods and processes were compared with the help of a points system developed for this research (Table 9). The system was created on the basis of the quality needs for wood for the joinery industry. To classify each measured property, classes were formed on the basis of EDG (Sipi 2002) and Nordic Timber (Pohjoismainen sahatavara 1994), and classes for inner cracking, colour change, drying time and resin flow were decided according to previous experience. The amount of points to be given for each class was determined, and various importance factors were given for each property on the basis of the joinery industry.

Based on the measured result and importance factor each plank got a certain amount of points. The points from each plank in the same process were calculated together and divided by the number of planks. In the comparison of the methods these average points were compared.

NOTE: Equipment and energy costs are not included in the points system.

TABLE 9. Points system for classifying the drying lots and methods. Length of drying time consists of heating, drying, conditioning and cooling down

Quality factor	Importance factor	Points					
		0	1	2	3	4	5
Moisture content	12		S		Q		E
Moisture gradient	11		S		Q		E
Surface cracking	10		90	35	25	15	0
Inner cracking	9	>2	1-2				None
Casehardening	8		S		Q		E
Colour change	7		10	8	6	4	2
Length of drying time	6		30	16	12	8	4
Twist	5		10		6		4
Crook	4		8		4		3
Bow	3		20		10		5
Cup	2		4				2
Resin flows	1	Cop.		Obv.		Det.	None

5 RESULTS

5.1 Age of trees, diameter of logs and amount of heartwood and bark

The age of the Siberian Larch trees grown in Finland was 85 years, which is close to the age of the Scots Pine trees grown in Southern Finland (82 ± 8.1 years) and used for comparison here. The Scots Pines harvested for comparison in Northern Finland were clearly older (133 ± 26.0 years).

The diameter of the sample log, including larch and pine, was the larger the younger the tree. The Siberian Larch from Finland had clearly the biggest diameter (371 mm), which differs especially from the Scots Pine grown in Northern Finland (Figure 10). Also, the volume of the Siberian Larch was 42.3% more than that of the Scots Pine grown in Southern Finland. When comparing the Siberian Larch to the Scots Pine from Northern Finland the difference was 190%, the size of the Siberian Larches being almost triple when compared to that of the Scots Pine in Northern Finland, and reaching this volume took about 50 years less time.

The diameters of the heartwood were as following: Siberian Larch 306 mm, Scots Pine South 181 mm and Scots Pine North 140 mm. This means that the volume of the heartwood in the Siberian Larch was 186% and 375% more than the Scots Pine grown in Southern and Northern Finland, respectively. Thus the Siberian Larch had produced almost five times more heartwood than the Scots Pine in Northern Finland.

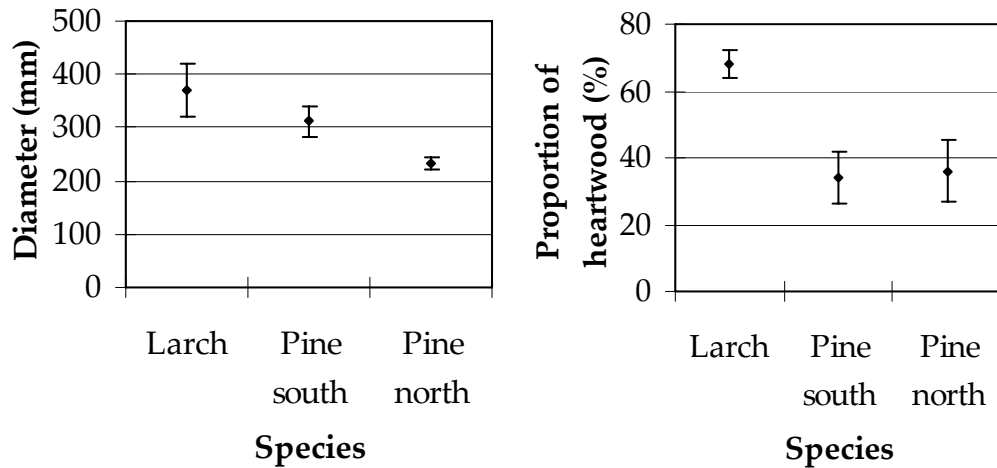


FIGURE 10. Diameter (mm) ± SD of the Siberian Larch and Scots Pine trees at 4.5 metres height (left). Amount of heartwood (%) ± SD of the Siberian Larch and Scots Pine trees at a height of 4.5 metres (right)

The heartwood proportion was largest in the Siberian Larch (68%). As a percentage, the amount of heartwood of Scots Pines grown in Northern Finland and Southern Finland were clearly lower, 34 – 36% (Figure 10). The amount of bark in the Siberian Larch was 11.8%. Thus the amount of sapwood was only about 20%.

5.2 Annual growth of trees and initial moisture content, basic density and strength of timber

Initial moisture content was larger in Siberian test material particularly near the surface of the trunks while the difference was small in the wood sawn from near the pith (Table 10).

TABLE 10. Initial moisture content (% in dry weight basis) of used wood material by radial location in the trunk

Radial location of wood	Initial moisture content (%)			
	Finland		Siberia	
	Aver.	SD	Aver.	SD
Total	49.6	8.5	53.4	10
1) planks including the pith	52.3	7.7	53.4	10.8
2) planks from the innermost heartwood	51.2	7.9	50.9	7.6
3) planks from the middle of the heartwood	45.9	6.1	54.3	10.7
4) planks containing both heartwood and sapwood	51.4	10.0	54.8	10.1

The average annual growth of the Siberian larch material was 1.4 mm/year while the growth in the Finnish larch material was 3.1 mm/year. The Finnish material, especially the inner parts of the logs, had grown rapidly (Figure 11).

The basic density of the Finnish wood material decreased significantly towards the core of the log while that of the Siberian material did not (Figure 11). The planks from the Siberian test material sawn close to the core were denser when compared to the corresponding Finnish material. Annual growth had a clearly negative correlation with basic density in the Finnish test material (Figure 12).

In the Finnish test material the wood from near the surface of the logs had a clearly higher bending strength and modulus of elasticity (MOE) than the wood located near the pith (Figure 13). In the Siberian test material the differences in bending strength and MOE between wood from different locations in radial direction were very small. This correlates with the density and annual growth results.

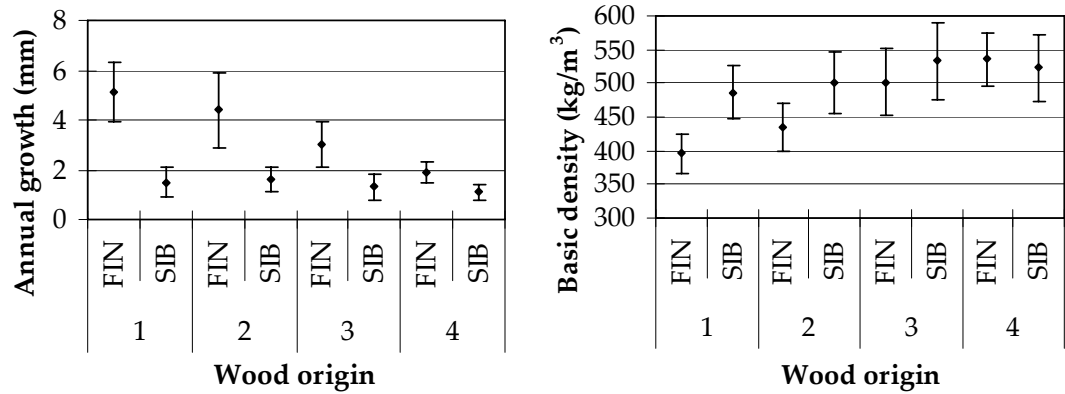


FIGURE 11. The average annual growth (mm) \pm SD and basic density (kg/m³) \pm SD of the Finnish (FIN) and Siberian (SIB) test material by the radial location of the wood in the trunk (1 – 4, see Table 5)

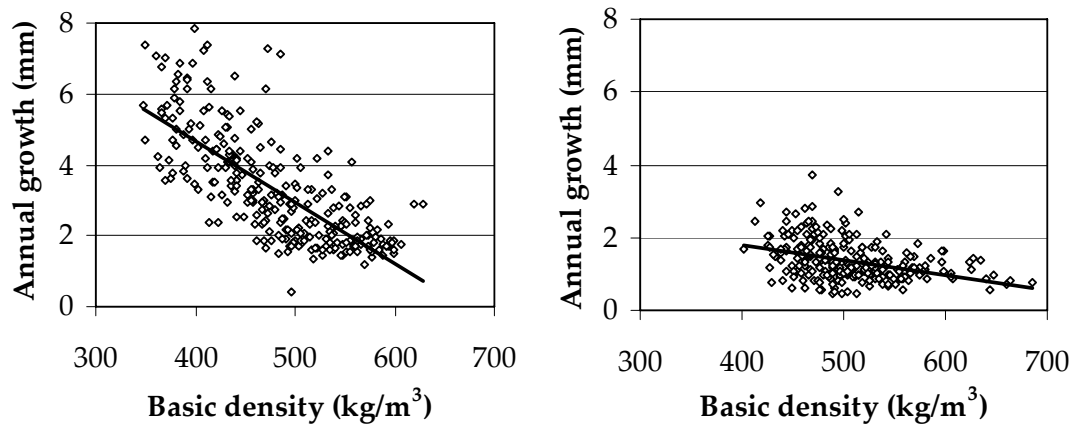


FIGURE 12. Correlation of annual growth and basic density in the Finnish (left) and the Siberian (right) wood material

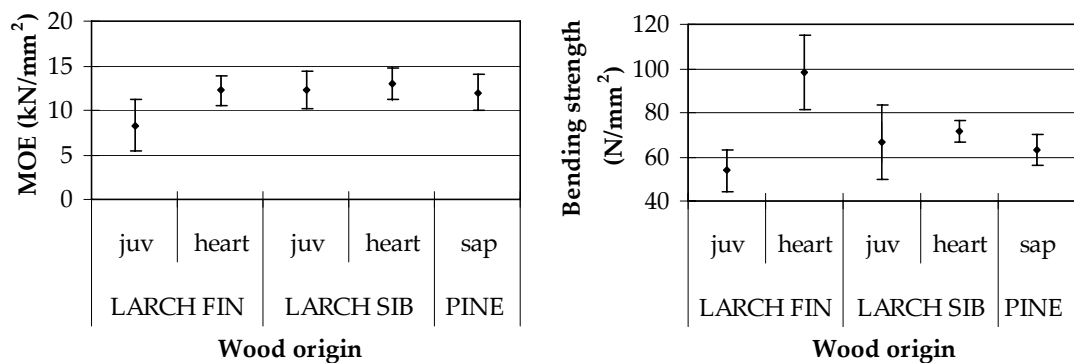


FIGURE 13. The average MOE (kN/mm²) \pm SD and bending strength (N/mm²) \pm SD in Finnish (FIN) and Siberian (SIB) larch wood (juv – juvenile wood, heart – youngest mature heartwood) and pine sapwood

5.3 Drying processes and quality of dried timber

5.3.1 High temperature kiln drying

The duration of the high temperature drying tests was between 78 and 145 hours (Table 11). The target moisture content could not be reached and the moisture gradient remained too large in high temperature drying especially with the Siberian material. Average moisture content was between 11.3 and 15.3% in the Finnish material and 14.6 – 23.3% in the Siberian material (Table 11). According to the EDG classification, 60 – 83% of the Finnish material, but only 11 – 38% of the Siberian material reached the standard drying quality with regard to moisture content.

The deformations were minor in the high temperature drying (Table 12). There was no clear difference between the high temperature drying tests in the amounts of deformations. When deformations were analysed according to

TABLE 11. Final moisture contents and moisture gradients in high temperature kiln drying

Parameter	Origin	H1	H2	H3	H4	H5	H6
Drying T (°C)		108	115	115	120	114	114
Drying time (h)		143	115	100	78	102	145
Final MC (%) -Target 10% +/- 2%	Finland SD	12.6 2.2	15.3 2.1	11.3 2.3	12.1 4.1	11.3 3.0	
	Siberia SD		23.3 5.3	17.8 4.8	21.5 5.2		14.6 3.3
Moisture gradient between depths 1/2 - 1/6 (%) -Target <3%	Finland SD	8.9 6.5	7.3 5.3	5.0 3.9	5.5 4.4	5.6 4.1	
	Siberia SD		22.7 11.4	16.3 8.6	20.9 11.0		10.1 6.4
Final MC in EDG classes (target 10 %)	E (Exclusive) Q (Quality dried) S (Standard)			MC 10% +/- 1% MC 10% +/- 2% MC 10% +/- 3%	Gradient < 2% Gradient < 3% Gradient < 4%		

TABLE 12. Deformations in high temperature kiln drying

Deformation	Origin	H1	H2	H3	H4	H5	H6
Twist (% of width/2m) -Target <6%	Finland	1.5	3.1	4.0	1.3	2.4	
	SD	0.9	2.4	2.4	0.9	2.1	
	Siberia		0.4	1.9	1.2		1.3
	SD		0.9	0.5	0.5		1.1
Bow (mm/2m) -Target <10 mm	Finland	1.3	2.7	2.5	2.8	2.0	
	SD	2.5	1.8	2.1	2.0	2.1	
	Siberia		0.9	0.8	1.8		0.6
	SD		1.8	1.1	1.7		0.8
Crook (mm/2m) -Target <4 mm	Finland	0.8	1.0	1.8	1.1	1.1	
	SD	1.6	1.2	3.6	0.9	1.2	
	Siberia		0.3	0.0	1.1		1.5
	SD		0.7	0.0	1.6		1.4
Cup (% of width) -Target <2%	Finland	0.4	0.7	0.7	0.6	0.7	
	SD	0.5	0.7	0.8	0.4	0.5	
	Siberia		0.0	0.4	0.1		0.7
	SD		0.0	0.4	0.2		0.4
Limits in quality classification (NT)		A1-A2		A3-A4		B	C
	Twist	0-4%		4-6%		4-6%	6-10%
	Bow	0-5 mm		5-10 mm		5-10 mm	10-20 mm
	Crook	0-3 mm		3-4 mm		3-4 mm	4-8 mm
	Cup	0-2%		0-2%		0-2%	2-4%

Nordic Timber (Pohjoismainen sahatavara 1994) the quality of the timber in most of the high temperature lots belonged to the classes A1 – A4. Only H6 dropped to class B because of one timber piece. The deformations in the Siberian material were clearly smaller than those of the Finnish material.

TABLE 13. Casehardening, cracking and colour changes in high temperature kiln drying

Parameter	Origin	H1	H2	H3	H4	H5	H6
Casehardening (mm) -Target <2 mm	Finland	2.8	0.7	2.0	1.1	2.6	
	SD	1.5	0.6	1.8	1.1	1.8	
	Siberia		0.9	1.8	1.4		4.5
	SD		0.8	0.4	0.7		4.7
Surface cracking (% of length on surface)	Finland	17.4	9.8	13.5	26.3	18.8	
	SD	31.3	26.3	24.6	24.3	36.8	
	Siberia		6.5	11.8	21.2		14.8
	SD		9.3	31.5	36.7		31.5
Inner cracking (no.)	Finland	0/10	0/10	0/10	3/10	0/12	
	SD						
	Siberia		0/10	0/10	3/7		1/8
	SD						
Colour changes (E*ab)	Finland	9.4	8.8	11.9	11.7	11.6	
	SD	2.4	2.2	2.7	1.9	2.5	
	Siberia		12.1	15.8	13.4		20.1
	SD		2.5	2.9	2.4		3.6
Difference in E*ab	0-2 = Slight difference 2-4 = Visible difference 4-6 = Clear difference 6-8 = Strong difference >10 = Very strong difference						

Casehardening was large in the Finnish material in lots H1 and H5 while it was large in lot H6 in the Siberian material (Table 13). Surface cracking of the planks was detected, but the width of the cracks was narrow (very often below one millimetre). Even if the cracking existed the planks looked fine when looking from a distance of 1 – 2 m. The variation in the surface cracking was significant: in the given drying lot some planks had very long cracks while in other planks cracks were not detected (Table 13). Inner cracking existed only in the planks of H4 dried at 120 °C. This result led on to the use of lower temperatures in H5 and H6.

The colour of the high temperature dried larch wood darkened significantly when compared to the colour of the reference lot (Table 13). The colour of the planks was light brown uniformly from the surface to the core. The colour of the Siberian material was even darker than that of the Finnish material.

Especially in H6 the colour darkened remarkably during drying.

Resin flows observed in high temperature dried timber belonged to classes none and detectable.

5.3.2 Vacuum kiln drying

The duration of the vacuum drying tests was between 185 and 523 hours (Table 14), and an average final moisture content of 9.1 – 12.7% was reached with the Finnish and 12.0 – 18.1% with the Siberian material. However, V4 and also V6 came to an end too early in relation to moisture content because the moisture measurement indicated much lower values than the real moisture content of the wood. According to the EDG classification, 80 – 100% of the Finnish material, except V4 with moisture measurement failure, but only 50 – 67% of the Siberian material reached the standard drying quality with regard to moisture content. The moisture gradient remained somewhat high especially with the Siberian material (Table 14).

Deformations in vacuum drying remained on an acceptable level except crook in V1 and V3 in the Finnish material (Table 15). According to Nordic Timber (Pohjoismainen sahatavara 1994), 70 – 100% of the sample planks reached the classes A1 – A4 with regard to deformations. Only some individual planks

TABLE 14. Final moisture contents and moisture gradients in vacuum kiln drying

Parameter	Origin	V1	V2	V3	V4	V5	V6
Drying T (°C)		55	65	75	85	75 - 85	75 - 85
Drying time (h)		407	523	371	185	348	293
Final MC (%) -Target 10% +/- 2%	Finland	11.8	10.3	9.1	12.7	9.9	
	SD	1.3	1.5	1.4	1.6	1.4	
	Siberia		13.1	12.2	18.1		12.0
	SD		3.8	2.4	3.8		2.3
Moisture gradient between depths 1/2 - 1/6bv(%) -Target <3%	Finland	4.0	3.0	2.8	6.8	3.1	
	SD	1.7	0.9	1.6	3.6	1.9	
	Siberia		5.0	5.8	14.3		5.3
	SD		2.9	2.8	6.7		3.5
Final MC in EDG classes (target 10%)	E (Exclusive)		MC 10% +/- 1%			Gradient <2%	
	Q (Quality dried)		MC 10% +/- 2%			Gradient <3%	
	S (Standard)		MC 10% +/- 3%			Gradient <4%	

TABLE 15. Deformations in vacuum kiln drying

Deformation	Origin	V1	V2	V3	V4	V5	V6
Twist (% of width/2m) -Target <6%	Finland	2.6	3.1	3.5	3.1	2.3	
	SD	1.6	1.6	3.2	1.8	1.6	
	Siberia		2.6	4.5	1.8		2.4
	SD		2.0	1.8	1.4		1.5
Bow (mm/2 m) -Target <10 mm	Finland	4.0	5.3	4.6	4.7	3.5	
	SD	1.4	2.4	1.9	2.6	1.7	
	Siberia		3.3	2.1	3.5		3.0
	SD		1.1	0.4	1.1		1.4
Crook (mm/2m) -Target <4 mm	Finland	4.2	2.7	4.9	2.3	1.6	
	SD	1.6	0.6	5.1	1.1	0.8	
	Siberia		3.2	2.8	2.7		2.3
	SD		1.0	0.7	1.0		1.6
Cup (% of width) -Target <2%	Finland	1.2	1.0	1.2	0.6	0.8	
	SD	0.3	0.4	0.5	0.5	0.6	
	Siberia		0.7	0.8	0.5		0.6
	SD		0.7	0.2	0.3		0.6
Limits in quality classification (NT)		A1-A2		A3-A4		B	C
	Twist	0-4%		4-6%		4-6%	6-10%
	Bow	0-5 mm		5-10 mm		5-10 mm	10-20 mm
	Crook	0-3 mm		3-4 mm		3-4 mm	4-8 mm
	Cup	0-2%		0-2%		0-2%	2-4%

dropped to class B or C. Slightly better results were reached with optimising drying tests V5 and V6 than with the other tests (Table 15). Twist, bow and cup were, in most cases, smaller in the Siberian than in the Finnish material, but crook was larger in V2 and V4 in the Siberian material; the last two differences were small. In conclusion, improvement could be achieved in twist, bow and crook in the Finnish material but only in crook in the Siberian material through optimising the schedules (V5, V6).

TABLE 16. Casehardening, cracking and colour changes in vacuum drying. V2 was the reference lot for colour comparisons

Parameter	Origin	V1	V2	V3	V4	V5	V6
Casehardening (mm) -Target <2 mm	Finland	2.6	1.9	2.1	2.8	2.3	
	SD	1.1	0.4	1.2	1.1	0.9	
	Siberia		2.1	3.4	3.1		1.9
	SD		1.0	1.7	0.9		0.7
Surface cracking (% of length on surface)	Finland	14.2	0.0	0.6	18.9	1.0	
	SD	27.7	0.0	1.7	25.0	3.0	
	Siberia		3.1	1.1	14.8		4.5
	SD		7.3	2.7	34.7		8.4
Inner cracking (no.)	Finland	1/10	0/9	0/8	0/10	0/9	
	SD						
	Siberia		0/9	0/6	0/8		0/9
	SD						
Colour changes (E*ab)	Finland	2.0	Ref.	1.6	1.9	1.1	
	SD	1.6	1.8	1.3	2.5	1.3	
	Siberia		Ref.	1.4	2.3		0.7
	SD		2.0	1.5	2.3		1.5
Difference in E*ab	0-2 = Slight difference 2-4 = Visible difference 4-6 = Clear difference 6-8 = Strong difference >10 = Very strong difference						

Casehardening was slightly high in vacuum dried timber except in lot V6 (Table 16). On average, it was somewhat larger in the Siberian than in the Finnish material. The surfaces of planks in lots V1 and V4 cracked markedly, but generally either surface cracking or inner cracking were not problems in vacuum drying. However, in a given drying lot some planks had long surface cracks while other planks had no cracks at all.

Colour changes were minor in vacuum kiln drying (Table 16) when compared to the reference (V2). The surface colour of the Finnish test material was slightly reddish while the inner colour changes were not visible. Resin flows observed in high temperature dried timber belonged to classes none and detectable, except in the lots V4 and V6 to classes detectable and obvious.

5.3.3 High frequency kiln drying

The duration of the high frequency drying tests was between 48 and 245 hours (Table 17). Failures in reaching the target moisture content occurred: some of the planks dried too much while some of them ended with clearly too high a moisture content. Average final moisture content was 6.3 – 13.9% with the Finnish and 8.4 – 20.3% with the Siberian material. The closest lot to the target moisture content was R6, which was comprised totally of Siberian material. According to the EDG classification, 40 – 60% of the Finnish material, but 14 – 67% of the Siberian material reached the standard drying quality with regard to moisture content. The moisture gradient was also the lowest in R6 (Table 17).

Deformations remained at an acceptable level in the high frequency drying except that the crook slightly exceeded the target value in R4 and R6 in the Finnish material (Table 18). According to Nordic Timber (Pohjoismainen sahatavara 1994), ca 80% of the sample planks reached the classes A1 – A4 with regard to deformations. Some individual planks dropped to class B or C.

TABLE 17. Final moisture contents and gradients in high frequency drying

Parameter	Origin	R1	R2	R3	R4	R5	R6
Power (kWh/m ³)		max	2.95	2.95	2.00	2.11/1.05	2.74
Wood T (°C)		95	70	52	76	52	52
Drying time (h)		48	113	112	209	234	190
Final MC (%) -Target 10% +/- 2%	Finland	13.9	6.3	13.8	6.9	11.7	
	SD	4.5	2.7	3.0	2.3	2.7	
	Siberia		11.1	20.3	12.7	16.0	8.4
	SD		11.2	7.2	8.0	8.4	2.8
Moisture gradient between depths 1/2 - 1/6 (%) -Target <3%	Finland	9.7	4.8	9.2	3.3	5.6	
	SD	5.7	2.6	4.7	1.9	2.3	
	Siberia		11.6	18.2	10.1	13.2	1.7
	SD		19.2	17.9	13.3	19.7	1.3
Final MC in EDG classes (target 10%)	E (Exclusive)			MC 10% +/- 1%		Gradient <2%	
	Q (Quality dried)			MC 10% +/- 2%		Gradient <3%	
	S (Standard)			MC 10% +/- 3%		Gradient <4%	

TABLE 18. Deformations in high frequency drying

Deformation	Origin	R1	R2	R3	R4	R5	R6		
Twist (% of width/2m) -Target <6%	Finland	3.6	4.8	4.2	3.8	3.2			
	SD	6.1	2.8	3.5	2.7	2.7			
	Siberia		3.0	2.2	2.8	2.9	2.7		
	SD		1.3	1.2	1.2	1.8	1.4		
Bow (mm/2 m) -Target <10 mm	Finland	3.9	5.3	5.7	6.0	3.1			
	SD	5.0	1.3	2.7	3.5	2.2			
	Siberia		2.9	3.2	3.3	3.2	3.1		
	SD		1.4	1.2	1.9	3.5	2.3		
Crook (mm/2 m) -Target <4 mm	Finland	2.1	4.1	3.9	5.2	2.5			
	SD	2.4	1.9	1.4	3.4	1.5			
	Siberia		3.8	3.0	3.9	2.5	2.8		
	SD		2.2	1.0	1.6	2.0	1.4		
Cup (% of width) -Target <2%	Finland	0.6	1.0	0.8	1.4	0.5			
	SD	0.6	0.7	0.6	0.9	0.5			
	Siberia		0.5	0.7	0.7	0.7	0.8		
	SD		0.7	0.5	0.3	0.6	0.3		
Limits in quality classification (NT)		A1-A2		A3-A4		B		C	
	Twist	0-4%		4-6%		4-6%		6-10%	
	Bow	0-5 mm		5-10 mm		5-10 mm		10-20 mm	
	Crook	0-3 mm		3-4 mm		3-4 mm		4-8 mm	
	Cup	0-2%		0-2%		0-2%		2-4%	

The best results were reached in R6, but there was no clear difference between the drying tests. The deformations in the Siberian material were generally smaller than those of the Finnish material.

Casehardening exceeded the target level in four high frequency lots (Table 19). Surface cracking of the planks was strong especially in R2 and R3, and the variation was large; inner cracking was largest in R1 and R2. In R1 and R2 the colour clearly darkened, but in other lots the darkening was hardly visible (Table 19).

Resin flows observed in high frequency dried timber belonged to classes none and detectable, except in the lot R6 to classes detectable and obvious.

TABLE 19. Casehardening, cracking and colour changes in high frequency drying

Parameter	Origin	R1	R2	R3	R4	R5	R6
Casehardening (mm) -Target <2 mm	Finland	6.7	1.4	3.1	1.8	2.9	
	SD	2.0	1.4	0.8	0.7	1.1	
	Siberia		1.7	2.1	2.5	2.5	1.7
	SD		1.6	1.1	0.9	1.2	0.6
Surface cracking (% of length on surface)	Finland	6.8	32.9	31.0	2.3	12.9	
	SD	10.3	33.8	30.3	5.5	23.1	
	Siberia		64.7	31.0	12.6	5.9	10.6
	SD		27.9	33.0	24.8	4.4	21.3
Inner cracking (no.)	Finland	Very	7/9	0/10	0/10	0/9	
	SD	much					
	Siberia		5/7	1/10	1/9	0/6	1/6
	SD						
Colour changes (E*ab)	Finland	Very	6.7	1.3	1.1	1.1	
	SD	dark	5.3	1.7	1.3	1.8	
	Siberia		5.3	1.3	3.9	1.8	1.8
	SD		4.5	1.9	2.1	4.7	4.7
Difference in E*ab	0-2 = Slight difference 2-4 = Visible difference 4-6 = Clear difference 6-8 = Strong difference >10 = Very strong difference						

5.3.4 Conventional kiln drying

In results of conventional drying the planks from near the pith/including pith were included as well as the planks from near the trunk surface although the proportion of the former was small. This increases the deviation in the results of conventional drying.

The duration of the conventional kiln drying tests was between 324 and 634 hours (Table 20). The programmed drying schedules of the C1 and C2 were realised quite well, but during the drying of these lots, the wood moisture content increased during the conditioning and cooling down (Appendix 1). The kiln automation did not perform conditioning for every lot although it was programmed; this could not be seen in the level of the final moisture content, in the moisture gradient or in the deviation between them.

Conditioning was performed in C2, C3, C6, C7 and C8. In C3, C6, C7 and C8 the kiln could not maintain the programmed schedule well at the end of the

drying process. In these lots the drying force raised to too high a level and the kiln tried to correct this by lowering the temperature and raising the equilibrium moisture content. However, it seemed that the drying of the wood stopped when this happened, and to go on drying, the drying force was raised again.

The final moisture content was too low especially in C1 and C8 containing the Finnish material only (Table 20). Also, in other lots in which the sensors were mounted in the Finnish material, they showed the target moisture content but real moisture content of the Finnish material was lower than that. The final moisture content of the Siberian material was close to the target moisture content or higher. However, the deviation of moisture content was smaller in the Finnish than in the Siberian material. In C6 and C7 containing only the Siberian material the moisture sensors ended up with a lower moisture content than the programmed target, but still the real moisture content was even lower than that. According to the EDG classification, 19 – 100% of the Finnish material, and 19 – 92% of the Siberian material reached the standard drying quality with regard to moisture content.

The moisture gradient differed after conventional drying between origins within the same lots and between lots (Table 20). The gradient was always larger in the Siberian than in the Finnish wood material. According to the gradient, the Siberian material was not acceptable in most cases; there was one case in which the material belonged to class S of EDG. Instead, the gradient of the Finnish material varied from Q to unacceptable according to the EDG classes. Deviation was in most cases larger in the Siberian than in the Finnish material.

TABLE 20. Final moisture contents and moisture gradients in conventional drying. Target final moisture content was 10% in the lots 1 – 6, 8% in the lots 7 and 8. The gradient of lot C7 is not shown because the process was interrupted for one week because of broken bearing

Parameter	Origin	C1	C2	C3	C4	C5	C6	C7	C8
Drying T (°C)		80	70	60	50	70 – 80			
Drying time (h)		396	407	357	696	278	585	528	428
Final MC (%)	Finland	8.0	9.5	9.4	9.4	8.4			6.3
-Target 10% +/- 2%	SD	0.9	0.9	1.6	1.0	1.6			0.7
-Target 8% +/- 1.6%	Siberia		10.3	13.7	13.0	10.7	7.5	7.2	
	SD		0.9	1.9	6.2	4.3	1.9	1.4	
Moisture gradient between depths 1/2 - 1/6 (%)	Finland	3.1	2.9	2.9	3.3	1.9			1.1
-Target <3% in 10%, <2.4% in 8%	SD	1.3	1.2	0.6	1.0	0.9			1.0
	Siberia		3.7	5.7	5.8	5.8	1.8		
	SD		0.9	1.2	3.1	5.6	1.8		
Final MC in EDG classes	E (Exclusive)					MC 10% +/- 1%	Gradient <2%		
-target 10%	Q (Quality dried)					MC 10% +/- 2%	Gradient <3%		
Final MC in EDG classes	S (Standard)					MC 10% +/- 3%	Gradient <4%		
-target 8%	E (Exclusive)					MC 8% +/- 0.8%	Gradient <1.6%		
	Q (Quality dried)					MC 8% +/- 2.4%	Gradient <2.4%		
	S (Standard)					MC 8% +/- 3.2%	Gradient <3.2%		

According to Nordic Timber (Pohjoismainen sahatavara 1994) 69 – 100% of the sample planks reached the classes A1 – A4 with regard to deformations. The deformations were slightly smaller in the Siberian than in the Finnish wood material (Table 21).

The moisture gradient and the final moisture content correlated with the deformations: the larger they were, the larger the casehardening but twist, bow, crook and cup were lower. These correlations were clearer in the Finnish than in the Siberian material, in which bow and crook did not correlate with moisture content or with gradient. Also basic density correlated with deformations: the larger the basic density was the smaller the twist, bow, crook and casehardening.

TABLE 21. Deformations in conventional drying

Deformation	Origin	C1	C2	C3	C4	C5	C6	C7	C8
Twist (% of width/2m) -Target <6%	Finland	8.4	2.1	3.3	4.0	3.8			4.4
	SD	5.3	2.1	3.0	3.7	4.1			3.6
	Siberia		2.4	0.9	1.5	2.6	2.7	3.2	
	SD		1.7	1.0	1.2	1.8	1.9	3.4	
Bow (mm/2m) -Target <10 mm	Finland	2.8	1.8	2.3	1.7	2.5			3.0
	SD	2.4	2.7	2.0	0.9	1.9			2.1
	Siberia		2.0	2.4	1.7	1.2	1.6	2.0	
	SD		1.0	0.8	0.5	0.4	1.0	1.0	
Crook (mm/2m) -Target <4 mm	Finland	1.4	0.3	1.7	1.5	1.4			1.2
	SD	0.6	0.7	1.1	0.5	1.0			0.7
	Siberia		0.2	1.8	1.8	1.4	1.7	1.8	
	SD		0.6	0.5	1.1	0.7	0.9	1.0	
Cup (% of width) -Target <2%	Finland	1.0	0.6	1.0	0.8	1.0			1.1
	SD	0.6	0.5	0.5	0.6	0.5			0.5
	Siberia		0.6	0.8	0.5	0.7	1.0	1.1	
	SD		0.5	0.5	0.2	0.4	0.6	0.5	
Limits in quality classification (NT)		A1-A2		A3-A4		B		C	
	Twist	0-4%		4-6%		4-6%		6-10%	
	Bow	0-5 mm		5-10 mm		5-10 mm		10-20 mm	
	Crook	0-3 mm		3-4 mm		3-4 mm		4-8 mm	
	Cup	0-2%		0-2%		0-2%		2-4%	

Casehardening was around 2 mm in most of the lots in both origins (Table 22). In C2 and C3 the Siberian material showed larger casehardening, in C3 it was over 3 mm. Thus generally the planks belonged to EDG class Q according to casehardening.

The amount of surface cracking varied significantly between planks within a drying lot and between origins (Table 22). Those planks that contained the pith or were sawn from near the pith cracked most. Inner cracking was seldom observed in the test material: most of it occurred in lots C1, C3 and C4 (Table 22). Inner cracks were always small.

TABLE 22. Casehardening, cracking and colour changes in conventional drying

Parameter	Origin	C1	C2	C3	C4	C5	C6	C7	C8
Casehardening (mm) -Target <2 mm	Finland	4.1	1.8	2.1	1.6	1.6			1.3
	SD	1.9	0.9	0.5	1.0	1.1			0.8
	Siberia		2.5	3.7	2.1	2.1	1.3	1.0	
	SD		0.8	1.0	0.9	0.8	1.1	0.6	
Surface cracking (% of length on surface)	Finland	8.7	3.1	13.6	31.7	4.4			0.9
	SD	17.9	8.1	30.8	27.3	7.7			2.8
	Siberia		13.0	20.2	9.6	2.1	0.0	17.4	
	SD		23.1	26.7	17.5	4.5	0.0	30.3	
Inner cracking (no.)	Finland	6/15	0/8	4/8	5/10	2/10			1/10
	SD								
	Siberia		2/7	3/8	2/10	1/10	1/10	2/10	
	SD								
Colour changes (E*ab)	Finland	3.3	2.3	2.7	2.8	3.5			2.2
	SD	1.5	2.2	1.4	1.6	1.3			1.3
	Siberia		2.5	3.3	3.3	2.2	2.8	2.5	
	SD		1.5	1.6	2.6	1.0	1.0	1.5	
Difference in E*ab	0-2 = Slight difference 2-4 = Visible difference 4-6 = Clear difference 6-8 = Strong difference >10 = Very strong difference								

When comparing the colour of conventionally dried larch wood with the reference colour of vacuum dried larch wood, the E^*_{ab} values were between 2.2 and 3.5 in Finnish material and between 2.2 and 3.3 in the Siberian material (Table 22). Thus the colour difference between the conventionally dried and the reference colour was determined to be “visible”.

Conventionally dried larch wood was always lighter in colour than the vacuum dried reference timber. Differences in colour coordinates between origins or drying lots were observed in most cases in the surface layer. The L^* , lightness, and a^* , redness, differed between origins in the surface, as well as the a^* coordinate of the inner wood: the Siberian material was lighter and less red than the Finnish material. In the Finnish material, both the inner and the surface b^* , yellowness, were larger in lot C1 than those of most of the other lots. Instead, in the Siberian material, all three colour coordinates had differences in the surface: in lot C7, L^* was lowest and a^* highest, while in lot C4, b^* of the surface was lowest. The colours of the plank surfaces were

darker and redder than the colour of the inner wood and the inner colour more yellow than the surface colour in all lots and both origins.

The colour coordinates correlated with the basic density: the higher the basic density, the lower the lightness and the higher the redness and yellowness. This correlation was observed when all the material was considered together as well as when the material was divided into Finnish and Siberian parts; instead, by lots, this correlation did not exist in all the lots.

Resin flows were observed in all lots and origins. They were classed as detectable.

5.4 Effects of radial location of plank and sawing method on the drying quality

The radial location of the plank in the trunk affected the deformations. When all the material was considered together, twist, crook and cup were larger in the planks from near the pith/containing the pith while casehardening and moisture gradient were larger in the planks from near the surface of the logs. Thus deformations were smallest in the planks sawn from the outer circumference of the trunk (Figure 14).

Twist and crook were similar in the radially and X-log sawn planks originating from the outer circumference of the log. Cup and bow were slightly smaller in the radially than X-log sawn samples.

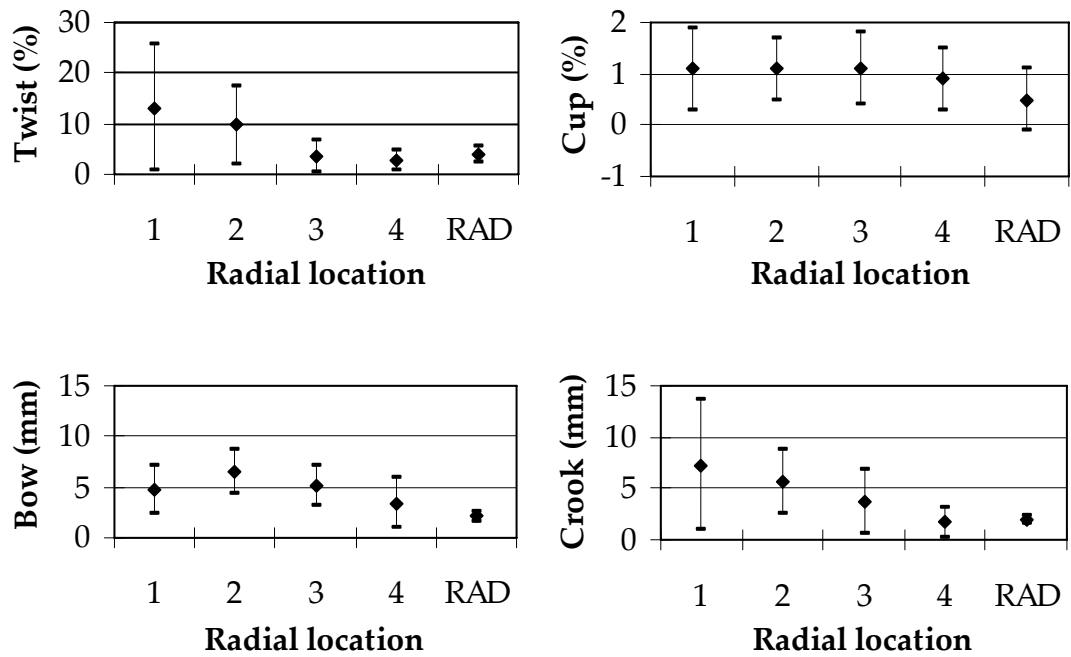


FIGURE 14. Twist (%) \pm SD, cup (%) \pm SD, bow (mm) \pm SD and crook (mm) \pm SD by the radial location of planks in trunk as well as in the planks sawn with the radial method

Differences in deformations between radial locations of planks were observed in the Finnish material, but not in the Siberian material. In the Finnish material bow and crook were largest in the timber originating from near the pith, and final moisture content and moisture gradient were lower in planks sawn from near the pith than in those sawn from the outer circumference. These results concern the conventionally, vacuum and high frequency dried planks.

Moisture content remained the highest in the radially sawn planks (Figure 15). In the radially sawn planks cracking was lower than in the planks sawn with the X-log –method. Cracking that emerged during drying was greater in the samples from the outer circumference of the log with large deviation when compared to the inner circumference (Figure 15).

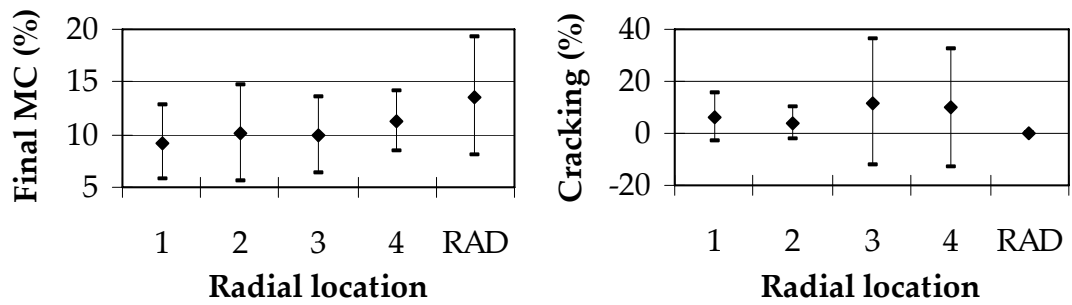


FIGURE 15. Final moisture content (%) \pm SD and cracking (%) \pm SD emerging during drying by radial locations of planks in the trunk as well as with the radial method sawn planks

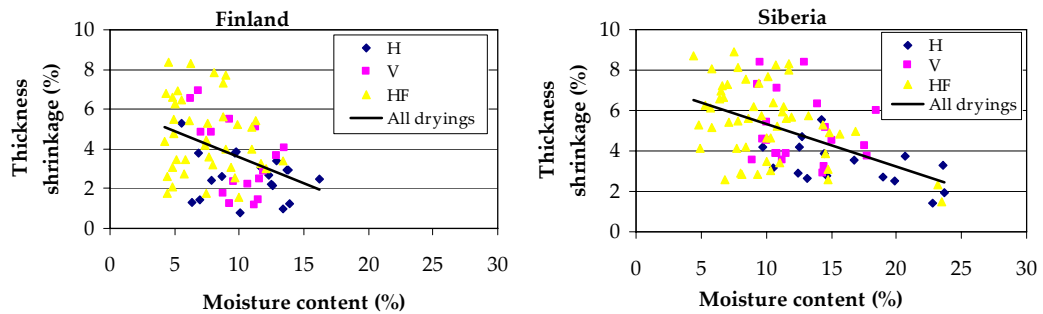
5.5 Drying shrinkage

The variation of the thickness and width of the measured planks increased significantly during drying. The standard deviation of the dimensions increased on average by 50.4% with a maximum of 119.6%. Average values of drying shrinkage are presented in Table 23.

The thickness shrinkage of the planks from Siberia was significantly greater than that of the planks from Finland (Figure 16). On the other hand, the width shrinkage of the planks from Finland was greater than that of the Siberian planks (Figure 17). The thickness shrinkage of the high temperature dried planks seemed to be slightly smaller than that of the planks dried with the other methods. There was no difference in the width shrinkage percentage between the different drying methods.

TABLE 23. Shrinkage (%) during high temperature drying (H), vacuum kiln drying (V) and high frequency drying (R)

Drying	Origin	Moisture content (%)	Basic density (kg/m ³)	Shrinkage (%)	
				Width	Thickness
H3	Finland	11.3	505.47	4.12	2.60
	SD	2.3	60.51	0.85	1.16
	Siberia	17.8	542.44	2.66	3.32
	SD	4.8	37.50	1.10	1.04
V2	Finland	10.3	544.59	4.95	2.34
	SD	1.5	43.06	0.81	1.32
	Siberia	13.1	525.62	3.73	5.64
	SD	3.8	67.88	1.04	1.91
V3	Finland	9.1	542.70	3.84	5.17
	SD	1.4	56.18	1.76	1.13
	Siberia	12.2	518.88	3.66	4.29
	SD	2.4	66.32	0.81	1.49
R2	Finland	6.3	536.74	4.75	4.47
	SD	2.7	50.80	1.35	1.80
	Siberia	11.1	520.22	3.63	4.84
	SD	11.2	53.34	1.12	1.40
R4	Finland	6.9	519.03	4.94	4.82
	SD	2.3	40.21	0.94	2.10
	Siberia	12.7	546.81	3.32	6.00
	SD	8.0	84.54	1.22	2.07

**FIGURE 16. Thickness shrinkage of the larch planks by origin. H – high temperature, V – vacuum, and HF – high frequency dried planks**

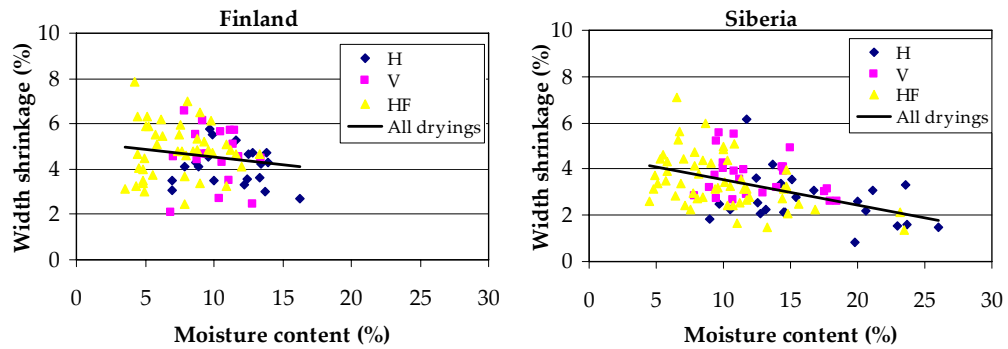


FIGURE 17. Width shrinkage of the larch planks by origin. H – high temperature, V – vacuum, and HF – high frequency dried planks

5.6 Comparison of the drying methods and schedules

High temperature and high frequency drying were clearly faster than vacuum and conventional kiln drying methods (Figure 18). Drying times of the optimising tests were generally lower than drying times of most other lots within the given method. With the Siberian test material the drying times were longer than with the Finnish test material; the exception was high frequency drying with opposite result. However, the drying of the conventional lot C7 (Siberian material) took less time than lot C6 (Siberian material) to attain a larger target moisture content; the difference between C5 and C8 (Finnish material) was opposite, as expected. As a comparison, the drying of Scots Pine to the same moisture content of 10% takes 200 – 230 hours with conventional kiln drying.

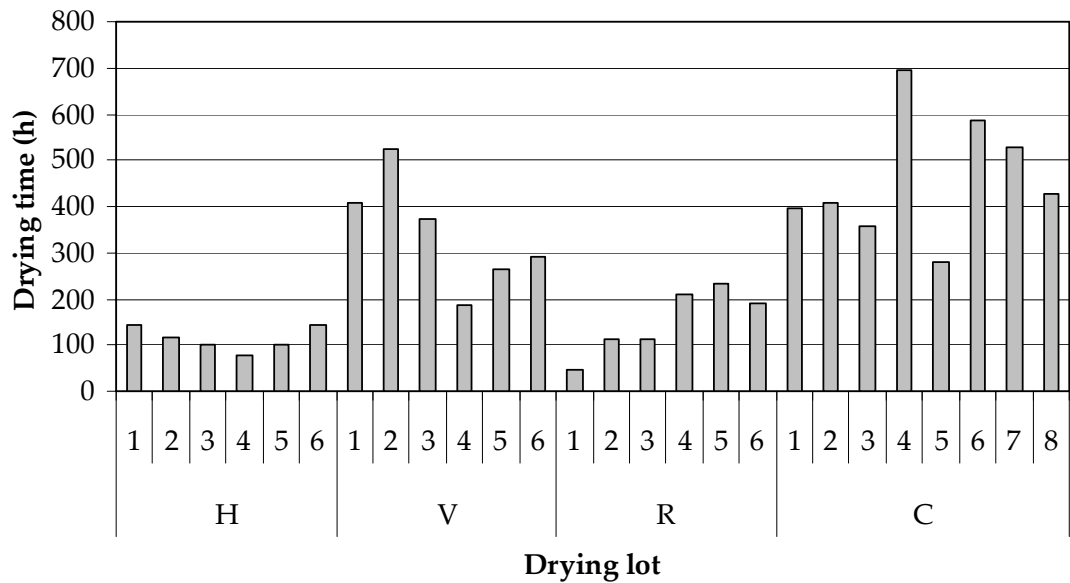


FIGURE 18. Process times of the drying tests for Siberian Larch. Optimising tests for Finnish material with the target MC of 10% MC were: H5, V5, R5 and C5 and for Siberian material: H6, V6, R6 and C6. In lots C7 and C8 the target MC was 8% with the same programmed schedule than C5 and C6

The target moisture content was best reached with the conventional drying, particularly for the Finnish material. Also in vacuum drying the target moisture content was almost reached, better with the Finnish than the Siberian material. With the fast methods (high temperature and high frequency drying) there is a larger difference in the final moisture content between the origins. In conventional drying the difference in the final moisture content between the Siberian and Finnish material was the smallest. The final moisture content of Siberian Larch originating from Siberia was higher than that of larch originating from Finland in spite of the drying method (Figure 19).

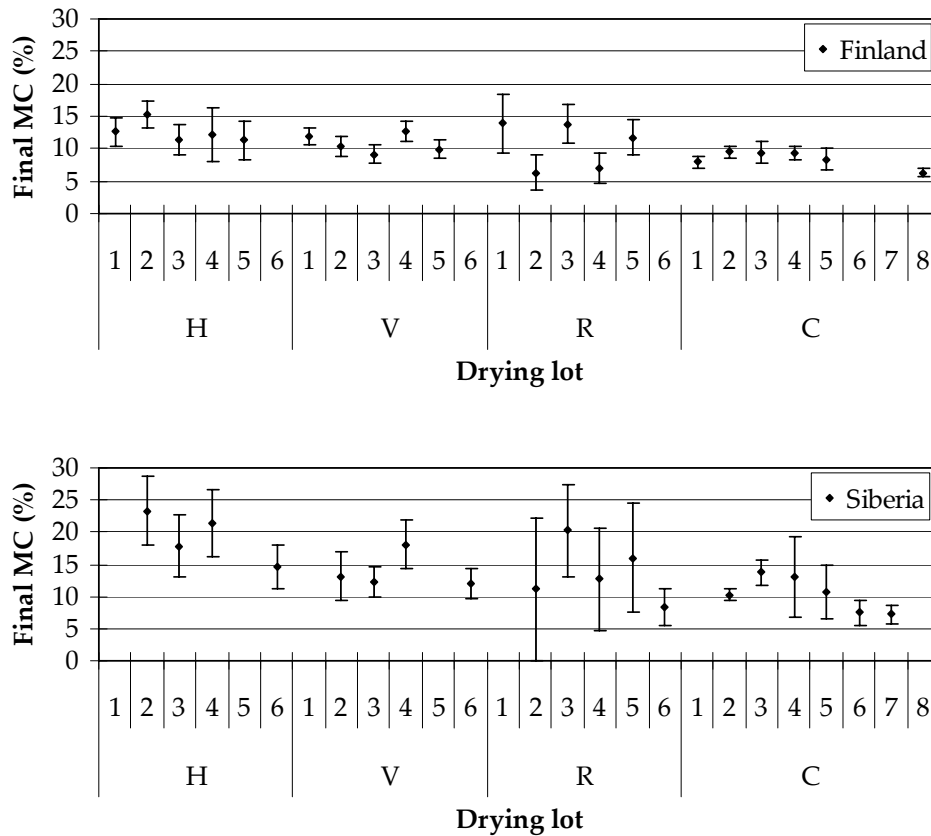


FIGURE 19. Moisture content (%) \pm SD of the Finnish and Siberian test material. Target moisture content was 10% \pm 2%

As well as the final moisture content, moisture gradient between the surface and middle part of the planks was smallest with the conventional and vacuum drying (Figure 20). With the high temperature and high frequency drying the variation was clearly higher and often too high if the material was for use in the joinery industry soon after the process; with the exception being R6. The moisture gradient was too high particularly in the Siberian test material when drying the Finnish and Siberian test material in the same process.

Casehardening was detected with all drying methods and there was no clear difference among them. However, in conventional kiln drying the casehardening was the most even and closest to the target of maximum of 2 mm. There was no clear difference between the Finnish and the Siberian test material in any of the methods (Figure 21).

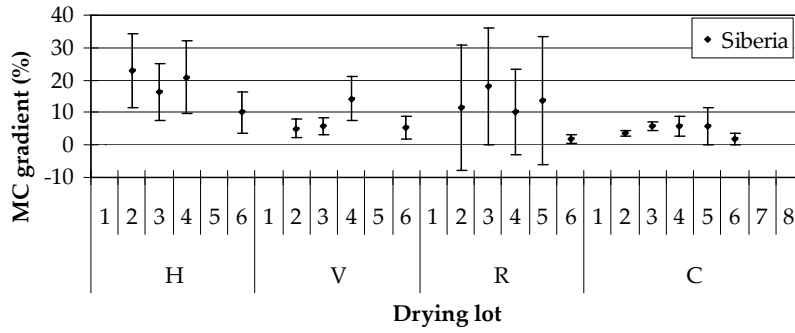
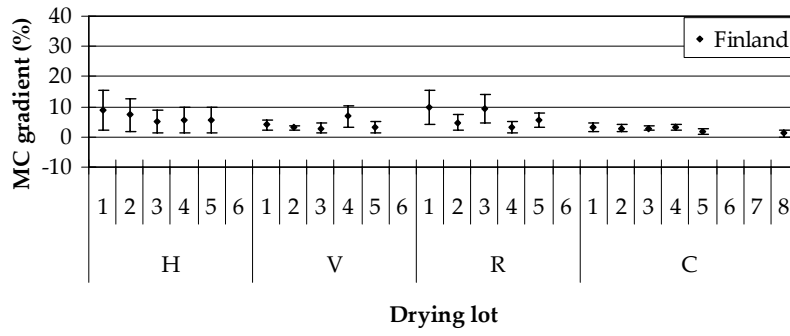


FIGURE 20. Moisture gradient (%) ± SD of the Finnish and Siberian test material. Target moisture gradient was <3%

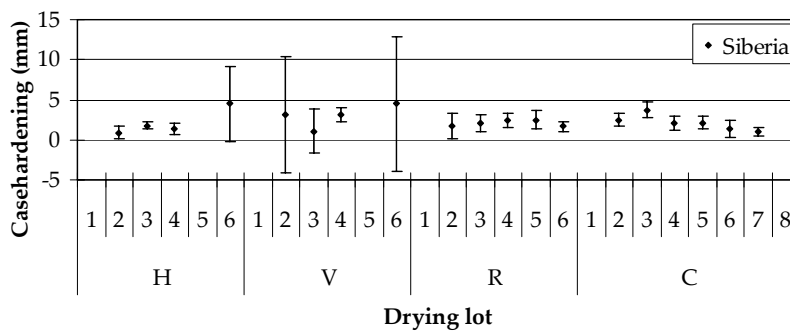
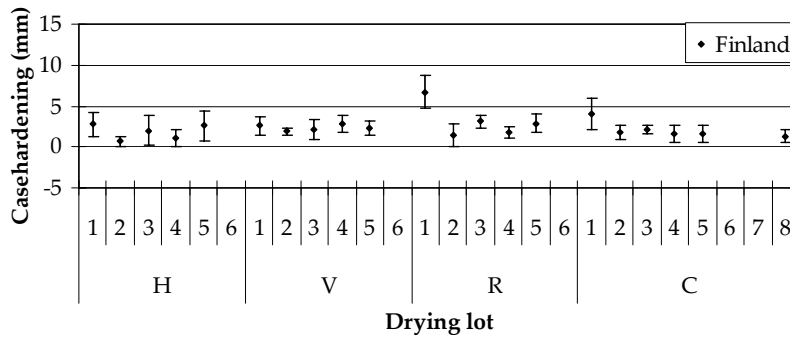


FIGURE 21. Casehardening (mm) ± SD in the Finnish and Siberian test material. Target casehardening was <2 mm

Twisting was lowest in the high temperature drying, but the difference compared to the other drying methods was not clear (Figure 22). As a whole, the target (<6%) was achieved in most lots with regard to twisting. Twisting, as well as other deformations, was, in most cases, smaller in the Siberian than in the Finnish material. However, exceptionally large twist was observed in conventionally dried larch timber originating from Finland. It is important to note that the conventionally dried samples were only 1.2 m long. This fact makes the result even worse.

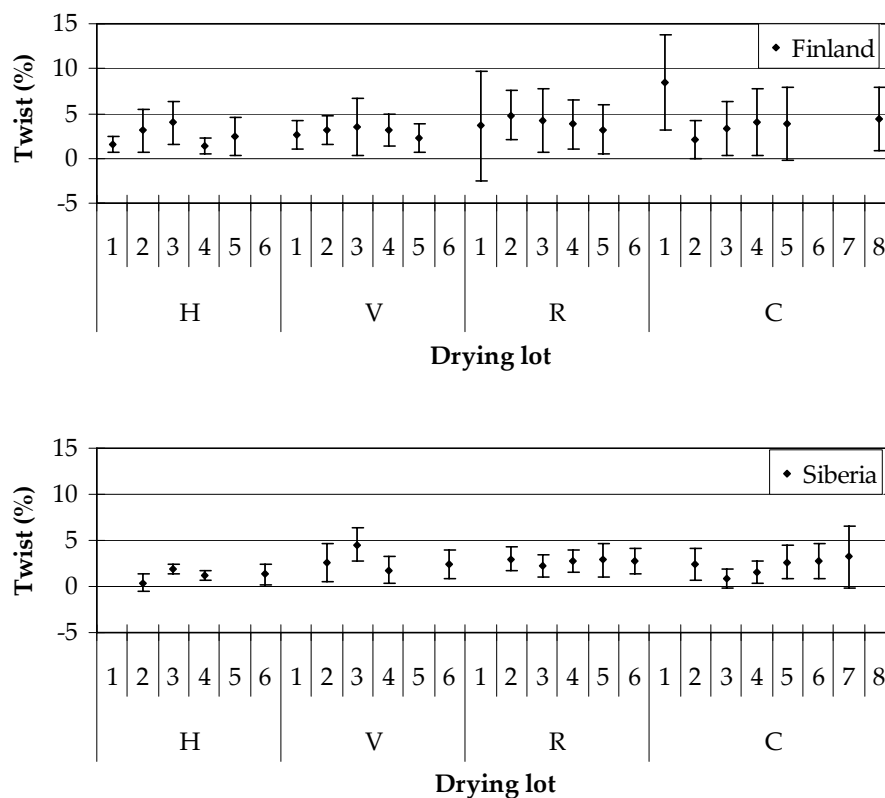


FIGURE 22. Twist (%) ± SD of the Finnish and Siberian test material. Target twist was <6%

There were clear differences regarding the cracking of the planks in the different drying processes. In some processes almost no cracks were detected in the analysed planks. Very often in the same process there were intact samples and ones with long cracks. This caused a large deviation in the results of some lots (Figure 23). When considering the length of the cracked surface the best results were reached with an optimising test of conventional and vacuum kiln drying. Good results were reached also with some high

frequency lots. Instead, in high temperature drying marked cracking was observed in each process. However, the benefit of this method was that the cracks were very narrow and could be detected only from a short distance. With other methods the cracking was more visible.

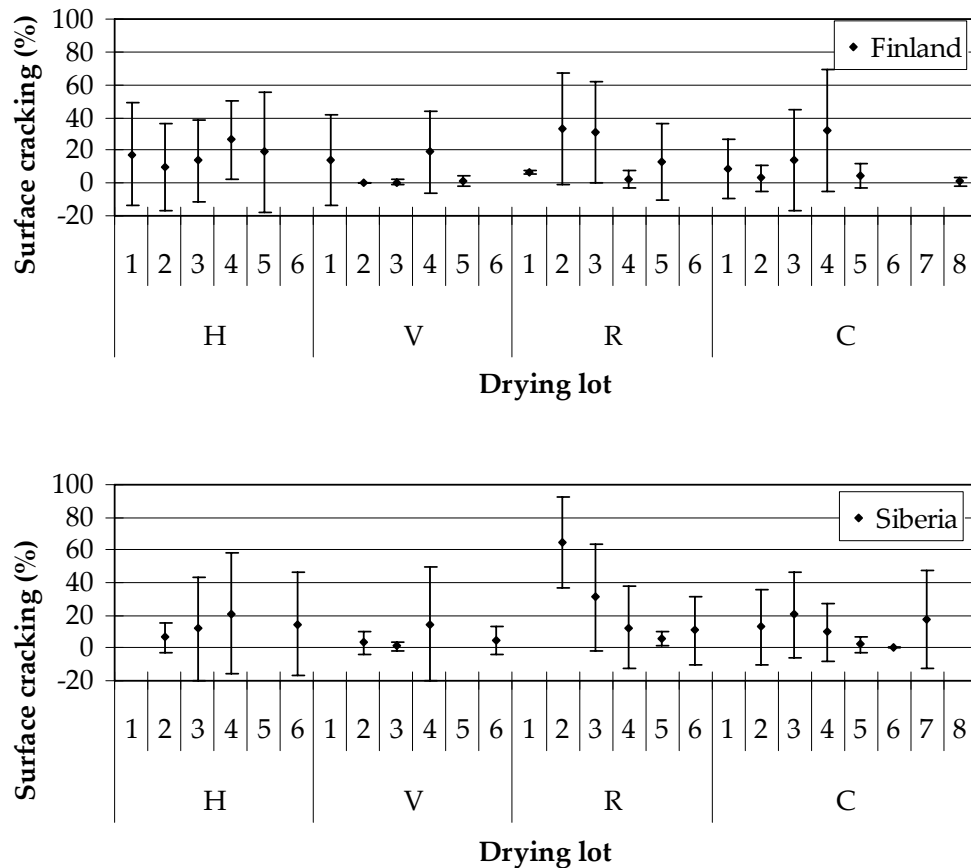


FIGURE 23. Cracking (%) \pm SD of the Finnish and Siberian test material

The colour change was smallest with conventional and vacuum drying and with high frequency drying lots R3 – R6 which after two learning lots showed very small colour darkening. The high temperatures in high temperature drying caused clear colour darkening (Figure 24). Conventionally dried larch timber remained always lighter than the vacuum dried reference lot, which was lightest in colour among the vacuum dried lots. Usually there was no difference in the colour darkening between the Siberian and Finnish material but with high temperature drying the Siberian timber darkened somewhat more than the Finnish material and in conventional drying the situation was opposite.

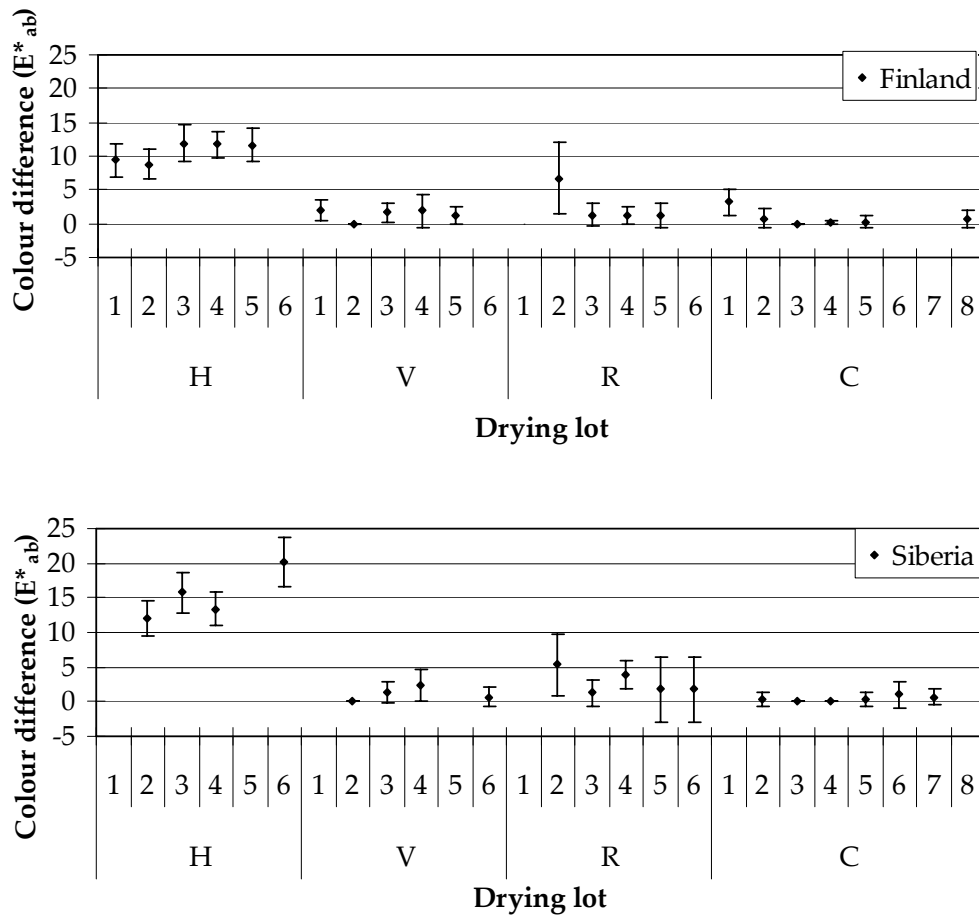


FIGURE 24. Colour difference as ΔE^*_{ab} to reference lot V2 \pm SD in the Finnish and Siberian test material

According to the points system conventional and vacuum drying have shown to be the most suitable for drying of Siberian Larch timber when aiming at the joinery industry (Figure 25). The third method in the ranking was high temperature drying, lots of which achieved a level almost equal in points except H6 which was carried out only for the Siberian test material; H6 was placed the last. The lowest ranking was high frequency drying. This method improved significantly during the research and the last test (R6) gave results close to the level of conventional and vacuum kiln drying.

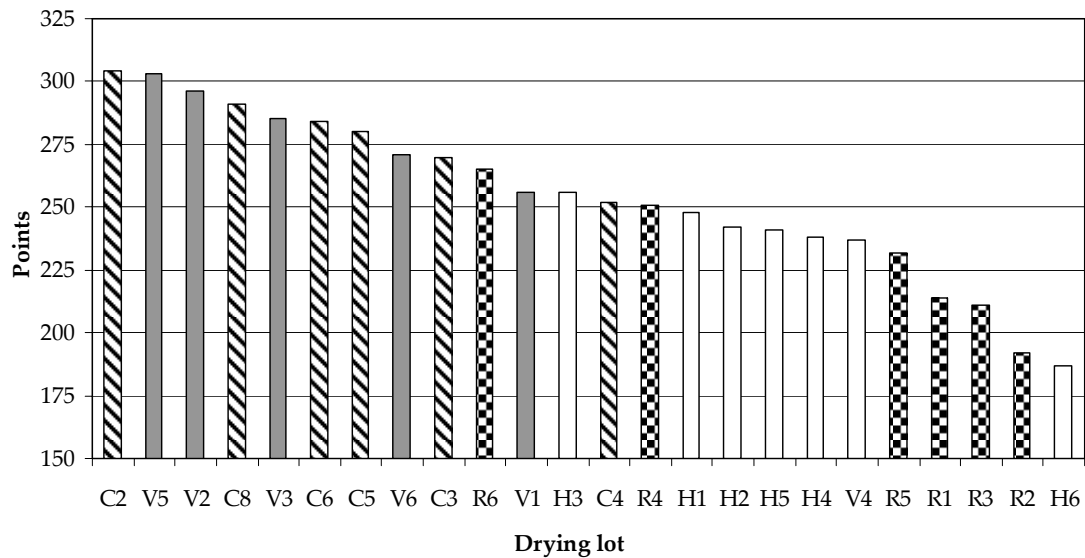


FIGURE 25. Ranking of the drying methods according to the points system

6 DISCUSSION

6.1 Log and wood properties

In this study the amounts of heartwood as well as bark were similar to the results of earlier studies (Use of larch... 1971, Hakkila et al. 1972, Hakkila & Winter 1973, Juvonen et al. 1986, Verkasalo 1993). Earlier results concerning the development of wood density along age, instead, differ partly from the results of this study. Kärkkäinen (1978) and Koizumi et al. (2003) observed that the density is at its highest in the outer parts of the heartwood and they claimed that it is caused by the accumulation of arabinogalactan there (see Côté et al. 1989). In this study in 85-year-old Siberian Larch grown in Finland the density of wood increased from the pith to the outermost radial location; no lowering of the density was observed in the outermost location which is probably due to both sampling intervals and the fact that due to the shape of the samples, pieces of planks, the proportion of the less dense sapwood in them was very small. In the Siberian material the increase in density from the pith to near the trunk surface was much lower and the density decreased slightly in the outermost planks containing sapwood.

The trees that were sources for the Finnish test material grew very fast as young trees, which caused low densities and the fastest drying particularly for the wood located near the pith. Sakki (2000) has found that the density correlates positively with the final moisture content. In the Siberian material the small increase in density along the radius correlated with the concurrent very small decrease in the ring width. Ring width may have an effect on the intensity of water movement within the planks. The differences in both the ring width and wood density between the Finnish and Siberian material may be caused by the genetic differences between the origins or the differences between the growing sites (see Lvov & Klimov 1971 according to Sairanen 1982) and its effects on e.g. extractive concentration. In a species of wood that is known to be difficult to dry, e.g. Siberian Larch, the significance of the density, ring width and initial moisture content of the wood may be emphasised and all possible effort should be done to sort the timber lot accordingly for drying. In practice this means that different sawing/purchasing lots should not be combined, the width of the annual rings should be taken into account and juvenile wood should be separated from the mature wood for drying in different lots.

MOE of the samples measured here corresponded with the values of Udinov (1965b according to Sairanen 1982) but were lower than the values of Koizumi et al. (2003). Bending strength of the Siberian material here was clearly lower than presented in older literature (Udinov 1965b according to Sairanen 1982). MOE and bending strength correlated with the density and the amount of annual growth. Thus the variation in the strength can not be explained simply by the juvenility/maturity of the wood: also juvenile wood can be strong if it has grown slowly. However, the bending strength of the Siberian slowly grown material was somewhat lower than that of the Finnish material, which may refer to the quality of the growing site, poor sites producing weaker larch wood than fertile sites (see Lvov & Klimov 1971 according to Sairanen 1982). In European Larch (*Larix decidua*) it has been observed that the high lignin concentration affects the strength positively (Gindl & Teischinger 2003, Müller et al. 2004). Thus there may have been chemical differences in the used

timbers as they were grown on different sites. However, most probably the weaker bending strength is not as a result of the growth rate changing proportions of earlywood and latewood, as Zhu et al. (1998) has observed that in the mature wood of Japanese Larch (*Larix kaempferi*) both wood types increased if the ring width increased.

6.2 Final moisture content and gradient

The results of this study support the conclusion of Juvonen et al. (1986) regarding the slow drying of Siberian Larch timber. The target moisture content was difficult to reach and it took longer with larch timber than with pine timber for all the methods according to our earlier experiences with the same kilns. Thus the main quality degrading factors here were the wrong final moisture content, uneven moisture content between timber pieces and the large moisture gradient within a timber piece for each of the tested methods. A large and unpredictable moisture gradient in larch timber was also the most serious problem in the study of Tarvainen et al. (1999). In the study of Sakki (2000) the moisture gradient of dried Siberian Larch timber was large, despite the drying schedule, both cross-sectionally and longitudinally in the timber pieces after conventional drying.

High temperature and high frequency drying methods were clearly faster than vacuum and conventional dryings due to higher temperatures and different heating principles used. Drying times varied markedly between high frequency drying tests because very different high frequency powers and the highest temperatures were used. As a consequence, marked failures in reaching the target moisture content and gradient occurred: some of the planks dried too much while some of them ended with clearly too high a moisture content. The results concerning moisture content were even worse with high temperature drying, which was due to the shortest drying times. Instead, the target moisture content (10%) was reached best with conventional drying and moisture gradient with conventional and vacuum drying. V4 and also V6 came to an end too early in relation to moisture

content because the moisture sensors showed much lower values than was the real moisture content of the wood. Instead, in conventional drying the kiln sensors measured higher values than was the real moisture content, which caused an even longer drying time than was really needed regarding the origin of the material, Finland, in which the sensors were mounted.

The Finnish test material had typically a clearly lower moisture content in the planks sawn close to the pith than from the outer circumference and in particular the denser, slower grown and initially wetter Siberian material remained too wet in the drying processes or at least wetter than the Finnish material. Also the moisture gradient was larger in the Siberian than in the Finnish material. The correction factors of 25 and 20 in conventional drying and 25 in vacuum drying for the moisture measurement were not good – adjusting the factor might have shortened the drying time and simultaneously led to a better final moisture content. However, in spite of performing the process control according to the Finnish material, in conventional drying the Siberian material attained clearly more points than the Finnish material according to the developed points system.

Here the conventional kiln did not perform the conditioning for each lot, which was caused by the acceptable moisture content gradient measured by the sensors at the end of the drying stage. However, the kiln was forced to try to perform it by changing the target gradient to 0.1%. Besides the long drying time this probably caused the small moisture gradient observed in the conventionally dried timber of the Finnish origin; the Siberian material still had too large a moisture gradient. In conventional drying the observed rise in moisture content, which did not equalise the gradient, during the conditioning and cooling down of C1 and C2 is probably due to a damaged valve in the water spraying system. Also, the long drying times in these lots with temperatures of 80 and 70°C, compared to the time of C3 with 60°C, refer to the damaged valve. The equalising of the moisture differences in larch timber pieces during the drying process in raised temperatures is important because it has been observed to be slow after that: even after 6

weeks conditioning at room temperature and air humidity the moisture contents have varied between 9.25% and 10.88% (Juvonen et al. 1986). In vacuum drying better results concerning the moisture gradient would have been reached with a longer conditioning stage. The large gradient also caused large casehardening, which was observed particularly in the vacuum drying.

6.3 Deformations, cracking and resin flows

Twisting and cracking have been mentioned as significant problems in the drying of Siberian Larch timber (e.g. Rantala & Anttila 2004), but according to the drying tests performed here both twisting and cracking (both surface and inner) occurring during drying had little importance. The idea about the marked cracking and twisting is probably caused by the timber pieces which contain the pith or are sawn from near the pith containing a large amount of juvenile wood: pith and juvenile wood have been observed to emphasise cracking (Juvonen et al. 1986) and twisting (e.g. Sipi 1988, Ormarsson et al. 2000, Sakki 2000, Sandberg 2005, Frühwald 2006). According to this study the specimens sawn from near the pith had already large cracked resin pockets before drying; they were not included in the drying cracks here. In Siberian Larch timber, increasing density has been observed to decrease the amount of heart checks; also, the cracking of timber pieces sawn from different tree individuals proved to be different (Sakki 2000).

Here twisting and cracking were not pronounced in the denser Siberian material, although pine and spruce wood of high density tends to crack more than wood of low density (Siimes 1967). Probably the higher final moisture content of the Siberian over the Finnish material here decreased the deformations of the Siberian material. Particularly in high temperature drying the difference in the final moisture content was significant between Siberian and Finnish material, which might have been the reason for the very low twisting of the wetter Siberian material. Thus here, as well as in the study of Tarvainen et al. (1999), the benefits of high temperature drying were minor deformations and short drying time; instead, according to Juvonen et al.

(1986) deformations, except twist, were clearly larger in high temperature dried than in conventionally dried larch timber. The most significant factor affecting deformations of the larch timber has been observed to be the large occurrence of spiral grain (Juvonen et al. 1986).

Although twist was at its largest in the Siberian Larch timber pieces sawn from near the pith, bow and crook were at their largest in timber pieces sawn from nearest the log surface (Juvonen et al. 1986). Regarding twist and crook, this study gave similar results with whole the material when dried conventionally, but other deformations did not differ significantly in planks sawn from different distances from the pith. In the Finnish material alone, the result of twist and crook was opposite to that of Juvonen et al. (1986).

Here, according to the points system, the best conventional schedules were those which started with 70°C and ended at 80°C (i.e. the optimising schedules); the worst schedule, causing marked surface and inner cracking among others, was C4 with the lowest temperature. Also the vacuum schedule with the lowest temperature proved to be defective: cracking was obvious. In the lowest used temperatures the wood might not have been elastic enough to allow shrinkage without cracking. In V4 the cracking was probably caused by too fast a drying process due to a failure in the moisture measurements. Sakki (2000) achieved the least cracked and deformed larch timber having the best final moisture content with the conventional schedule with the lowest drying force and the highest dry temperature; however, the same schedule caused the strongest colour darkening.

Resin flows were not a marked problem in this study although in the questionnaires made for Finnish (Saimovaara 2001) and especially for Central European (Pelz et al. 1999 according to Verkasalo & Viitanen 2001) larch timber users claim otherwise. The main larch species used in Central Europe is European Larch while in Finland it is Siberian Larch, in which the resin problems may not be as pronounced as in European Larch.

6.4 Colour

The colour change depended on the drying method and on the temperature used for the given test. Timber dried with the high temperature method darkened more than the timber dried in vacuum and conventional kilns, the last method producing the lightest timber of all. Usually vacuum drying has produced lighter dried timber of any species than conventional drying in same temperature but for particularly species difficult to dry, e.g. Siberian Larch, lowered boiling temperature in vacuum together with slow longitudinal moisture movements (see Juvonen et al. 1986) may enhance darkening.

In high temperature drying, especially in the last lot H6, the colour darkened remarkably which may have been caused by the longer drying time than that used in lot H5 with a similar temperature. Instead, in high frequency lots R3 – R6 a lower electricity power and a lower setting value for the maximum wood temperature were used successfully to minimise the colour darkening during drying.

The surface was darker and redder than the inner wood in conventionally and vacuum dried planks. However, the dark surface layer was so thin that it can be planed away and thus it does not cause harm in further processing. The slower grown Siberian material proved to be lighter than the Finnish material in colour after conventional drying although it was expected that the darker latewood would be emphasised in the material originating from Siberia. In Japanese Larch it has been observed that when ring width increases in mature wood, both earlywood and latewood width increase (Zhu et al. 1998) which equalises the effect of the wood types on colour.

6.5 Drying shrinkage

In this study, the average thickness shrinkage was lower when compared to the tangential values from the earlier literature (Tjurikov 1965 according to

Sairanen 1982). Instead, the width shrinkage values of each drying test were quite near the theoretical radial shrinkage values. In practice the width and thickness shrinkages of the planks are usually between the tangential and radial shrinkage values. In this study, a big variation in density, annual growth, moisture content and grain directions as well as the small number of samples also caused a large variation in shrinkage. Furthermore, the difference in the thickness shrinkage here is partly explained by the radial origin of the plank. The thickness shrinkage of planks sawn from near the pith is larger than that of planks sawn from a greater distance from the pith. The direction of the thickness is close to the direction of the tangent in planks sawn from near the pith, while the direction of the thickness in the planks that are sawn from a greater distance from the pith is close to radial. The difference in the shrinkage between the origins may be affected by the fact that the number of planks sawn from near the pith was slightly higher for the Siberian than for the Finnish material.

The different drying temperatures can also explain some of the differences in shrinkage observed here as the thickness shrinkage of high temperature dried planks seemed to be slightly smaller than that of the other planks. Similarly, shrinkage of Southern Pine timber has been observed to be the smaller the higher is the drying temperature (Price & Koch 1980). In deciduous trees contradictory results have been found: shrinkage has been observed to be larger in diffuse porous Silver Birch timber dried in room conditions than in that dried conventionally (Paukkonen et al. 1999) and in ring porous Red Oak timber dried at high temperature than at low temperature (McMillen 1955). In addition, Stöhr (1988) observed that the wider the tangentially sawn (corresponds to the X-log method) boards are the less they shrink during drying; this may also be due to the changing direction of the annual rings. However, the difference between drying methods in thickness shrinkage observed here needs to be studied more because of the small number of samples and varying ring orientations.

The shrinkage measurements from the full size planks gave a good overview about how drying shrinkage affects plank dimensions in a practical sawmill situation. Variations and differences in shrinkage are important also because anisotropic shrinkage of wood is the main reason for the deformations in timber. Thus the increase in the variation in dimensions of sawn timber pieces during drying has to be taken into consideration when deciding and optimising the green target size for sawing.

6.6 Drying and sawing methods

The relatively small difference in drying times between best vacuum and conventional tests was surprising. It is probably caused by the poor ability of larch wood to conduct water longitudinally (70 – 80% of that of spruce and pine) (Juvonen et al. 1986): longitudinal travel through open fibres and pores is the main direction for steam to move away from sawn timber when air pressure is strongly lowered (Chen & Lamb 2004). In the conventional dryings, the observed large increase in the drying force at the end of the drying stage was similar to that Sakki (2000) observed with larch timber dryings with the same conventional kiln used in this study. He claimed that the rise is caused by the fact that the wood moisture content sensors were located in the middle of the timber pieces with the highest moisture content of the moment while the surfaces of the timber pieces were much drier causing them not to conduct moisture into the air. This was measured as a strong decrease in the equilibrium moisture content of the surfaces (Sakki 2000). Also Shmulsky et al. (2002) found that a high air velocity may reduce the equilibrium moisture content of the wood surface below the setting value of the kiln. The poor longitudinal ability of larch wood to conduct water enhances the failure in the measuring of the equilibrium moisture content as it shows particularly as a raised moisture gradient in timber. Thus the uncontrollable rise in the drying force also emphasises the need for slow drying in which care has to be taken to keep the moisture gradient at a low level throughout the whole process. However, in this research the drying

quality of conventionally dried wood was reasonably good in spite of a too high a drying force at the end of the drying stage.

High frequency drying would require more tests to gather information on its suitability for drying larch wood to low moisture contents, because only in the last test did the results show improvement. There would be numerous possibilities for high frequency drying with the Yasujima device and by improving the schedules this method could rise to the level of conventional and vacuum kiln drying. In recent studies for the drying of Western Hemlock (*Tsuga heterophylla*) in a radio frequency vacuum kiln several sorting strategies performed before drying have been tested and some of them, concerning sorting by initial moisture content, were found to improve the average moisture content of dried wood (Elustondo & Avramidis 2003).

In this study high temperature drying caused discolouration and the wrong final moisture content as well as a high moisture gradient in the larch timber. Previously, Juvonen et al. (1986) observed internal cracking in addition to colour darkening in through sawn Siberian Larch timber in high temperature drying. Here the material was mainly flat sawn (X-log method), and the orientation of the annual rings produced by this sawing method has been observed to cause a larger moisture gradient than that produced by quarter sawing (radial sawing) when drying Norway Spruce in high temperature kilns (McCurdy & Keeey 2002). The quarter sawing method has been observed to also reduce the deformations and cracking of larch timber in drying (Minejev 1975 according to Sairanen 1982). Results in this study support this information. In fact, because of its poor longitudinal ability to conduct water (Juvonen et al. 1986) as well as the large tangential and radial shrinkage differences causing cracking (Zuban 1965b according to Sairanen 1982, Minejev 1975 according to Sairanen 1982), the sawing method might be exceptionally important regarding the drying quality of larch timber. However, the drying time has been observed to be 10 – 15% longer for quarter than flat sawn Radiata Pine timber in conventional drying (Pang 2002); also here the final moisture content remained on a higher level in the

radially sawn planks than in the planks sawn with X-log method. This emphasises the need for also sorting timber by annual ring orientation for drying in addition to ring width, density and initial moisture content to minimise the final moisture content and gradient differences and to optimise the drying time and quality for each lot.

7 CONCLUSIONS

The most significant factor, which reduces the drying quality of Siberian Larch timber is the imbalance of the final moisture content. This was seen as both wrong final moisture content, large moisture content differences between timber pieces and as a large moisture gradient within a timber piece. These problems can be reduced by ensuring a sufficient drying time, even longer than the drying times in this study, and a sufficient conditioning stage in the drying process. The best results would be reached by sorting the timber according to annual ring orientation and width, density and initial moisture content, but this is likely to be problematic in industrial production especially in medium or small scale production. Sorting by origin, which affects particularly the density, could be possible because each purchased lot consists commonly of one origin. Here, when considering mechanical strength, density and annual growth, the Siberian wood material was clearly more homogenous than the Finnish material, and the wood of these two origins should be dried in different lots.

Also, using highest possible temperatures among each drying method, taking drying time, deformations, darkening and other quality factors into account, seems reasonable according to the results of this study. In these tests a slight increase in drying temperatures led to internal cracking and darkening which could probably be avoided by low drying forces. Thus using the higher temperatures would need more tests. Temperature clearly accelerates the drying process and its significance rises when drying to low moisture contents.

The location of the plank in the log in a radial direction is also a significant factor regarding drying quality: pith causes cracking (even before drying) and twisting. Twisting and other deformations might possibly be reduced by strongly pressing the timber pile during drying, conditioning and cooling down.

The ranking of the drying methods and processes based on the points system indicates that the most suitable methods for Siberian Larch timber were conventional and vacuum kiln dryings. The results were quite similar concerning the drying quality, but vacuum kiln drying was somewhat faster. When compared with the other methods the most significant benefits of conventional and vacuum methods were the most even final moisture content and the smallest moisture gradient. However, vacuum kiln drying should offer a clear benefit in drying time while the investment costs of a conventional kiln are clearly lower. It could be possible to shorten the vacuum drying time without a significant increase in defects by raising the temperature while keeping the drying force quite low.

High frequency kiln drying was not successful in this research because of the large differences in the final moisture content and gradient as well as surface cracks. However, high frequency drying showed potential in other measured quality properties as well as in drying time, and by focusing on the developing the schedules for this method it might be possible to achieve good results. In fact in the last test, using high pressure and more electrical metal plates in the load, clearly improved results were reached. A combination of vacuum kiln drying and high frequency drying would be essential to try to help reach an even moisture content and minimise the drying time.

The advantage of high temperature drying was minor deformations and quite a short drying time. However, conventional and vacuum kiln drying were clearly better in the comparison of the methods by the points system. The major weakness of high temperature drying was in reaching an even and low enough final moisture content. When developing this method the drying time

needs to be extended. Tests with slightly higher temperatures would be needed to ensure fast drying. The remarkable difference of this method compared to others was significant colour darkening, which can be an advantage or a disadvantage depending of the end use.

Differences between the drying methods could be clarified on the basis of this study. However, to develop each method and the drying schedules for Siberian Larch timber, more tests should be performed within each method. Especially the high frequency and high temperature drying methods need more test runs. These drying tests, however, give a good basis to continue developing the drying schedules and methods.

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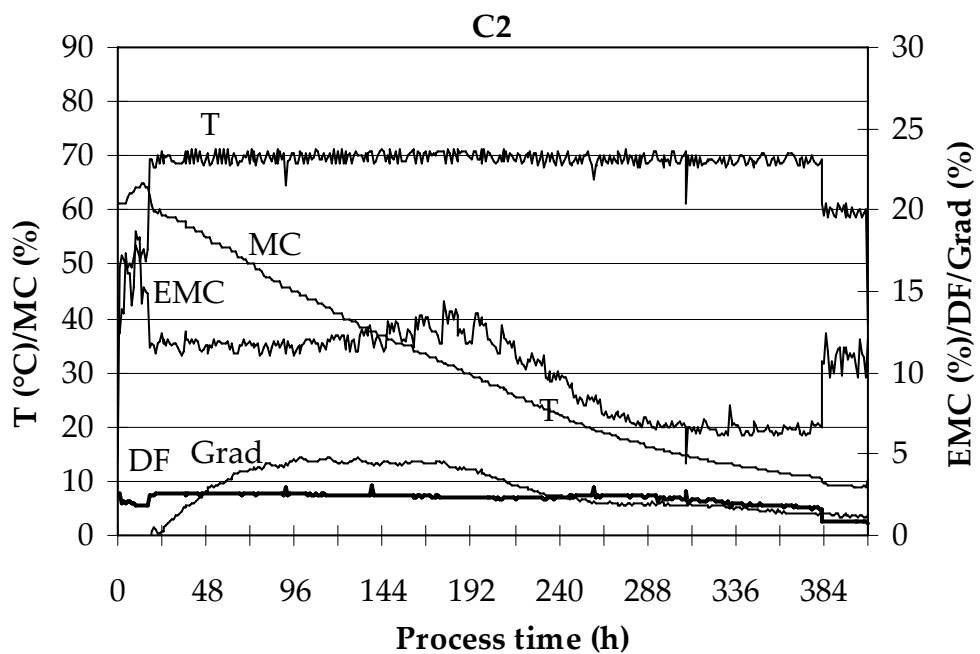
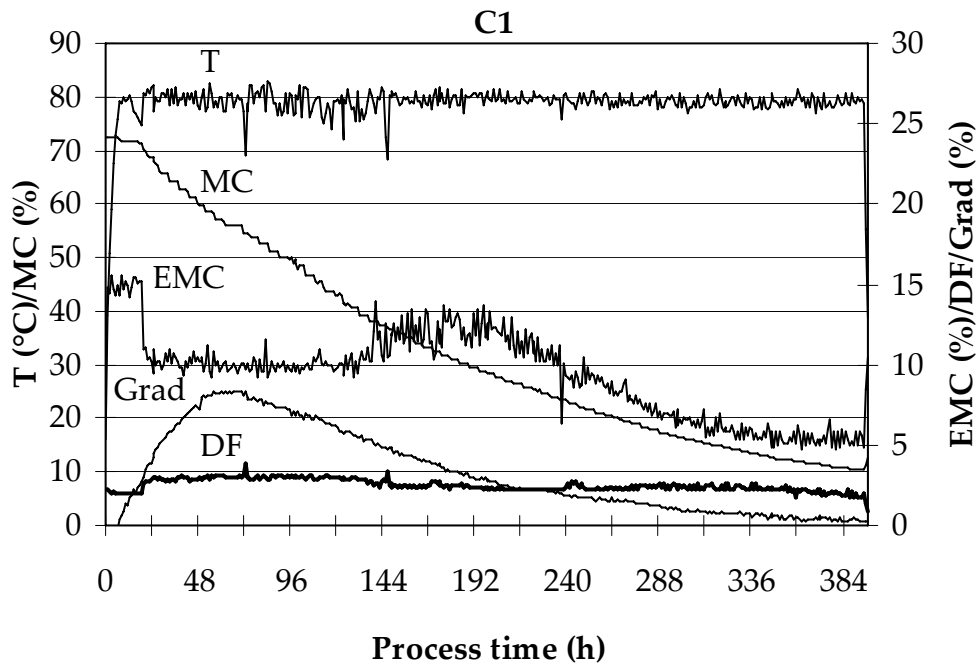
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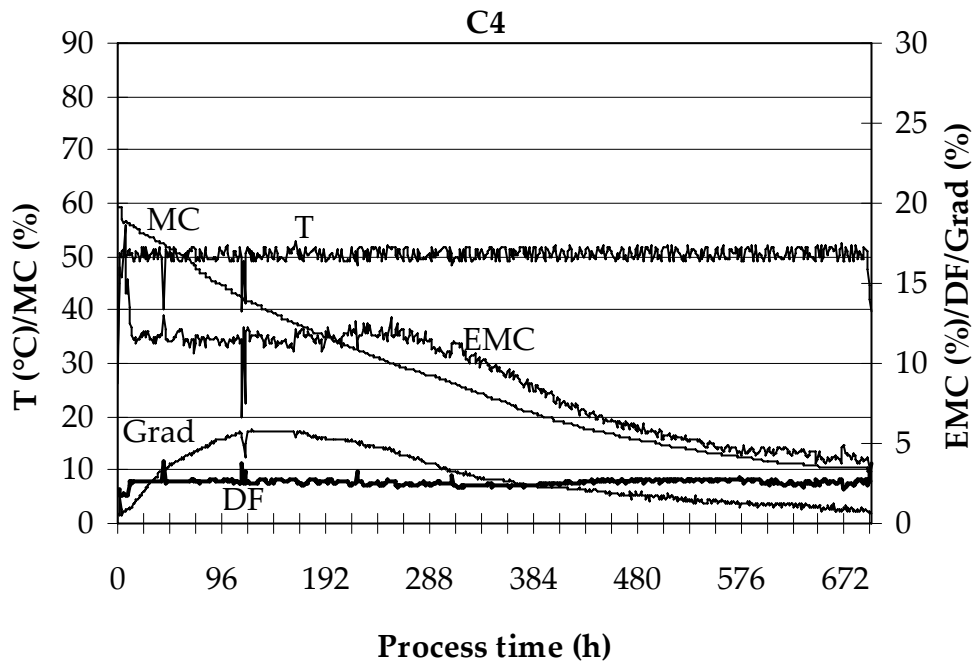
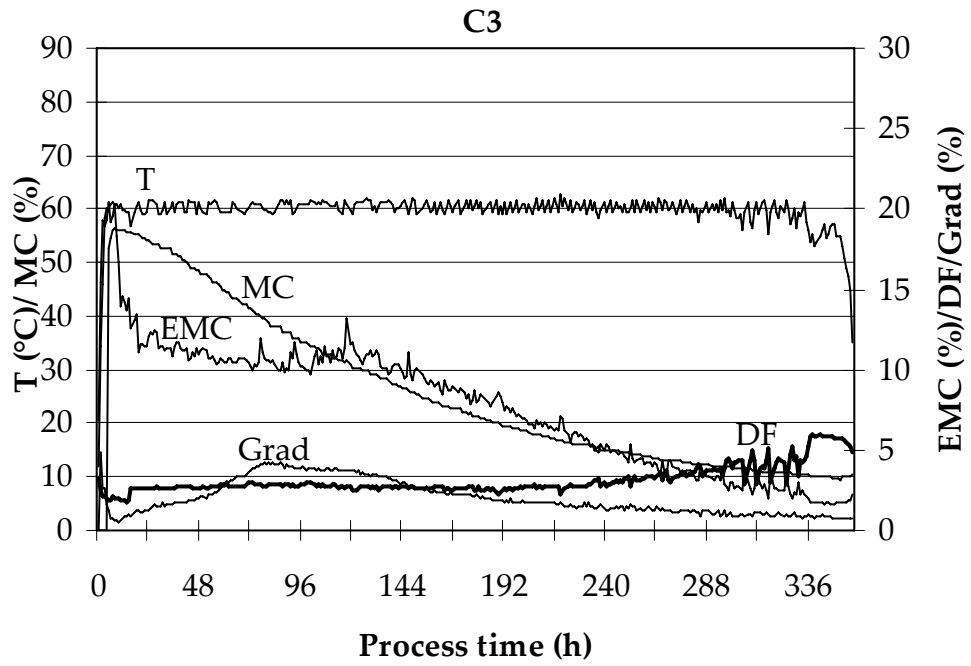
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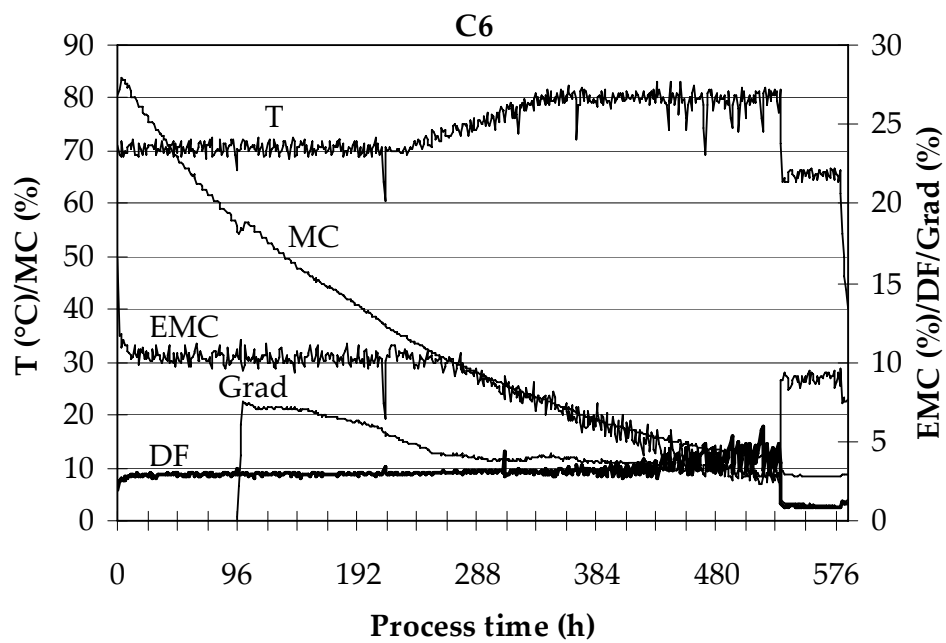
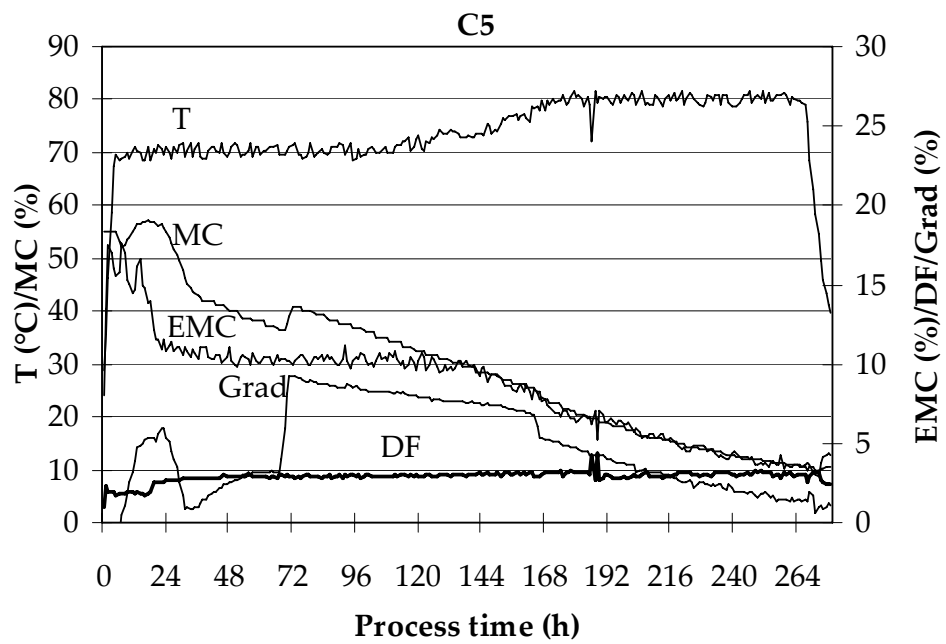
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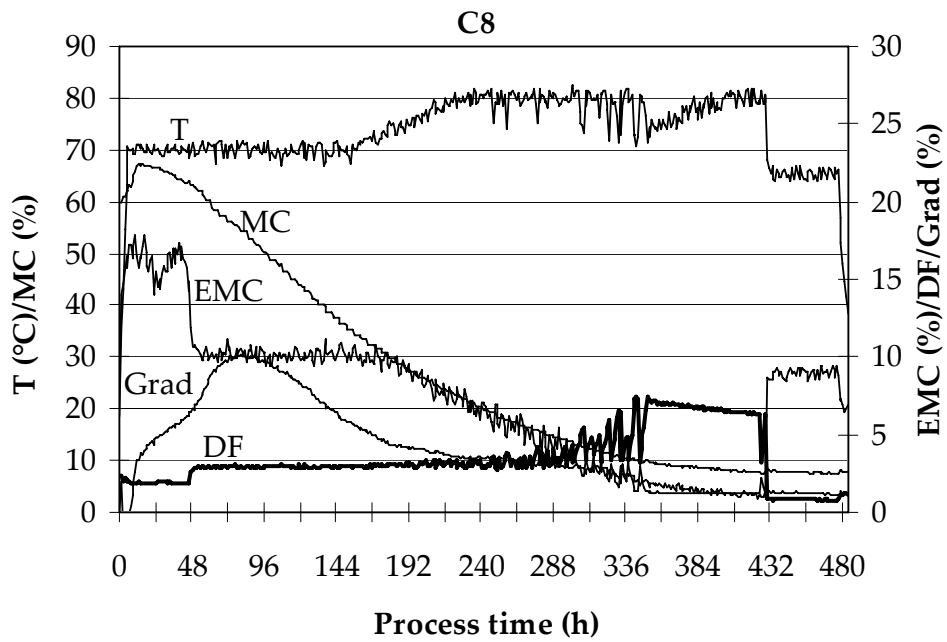
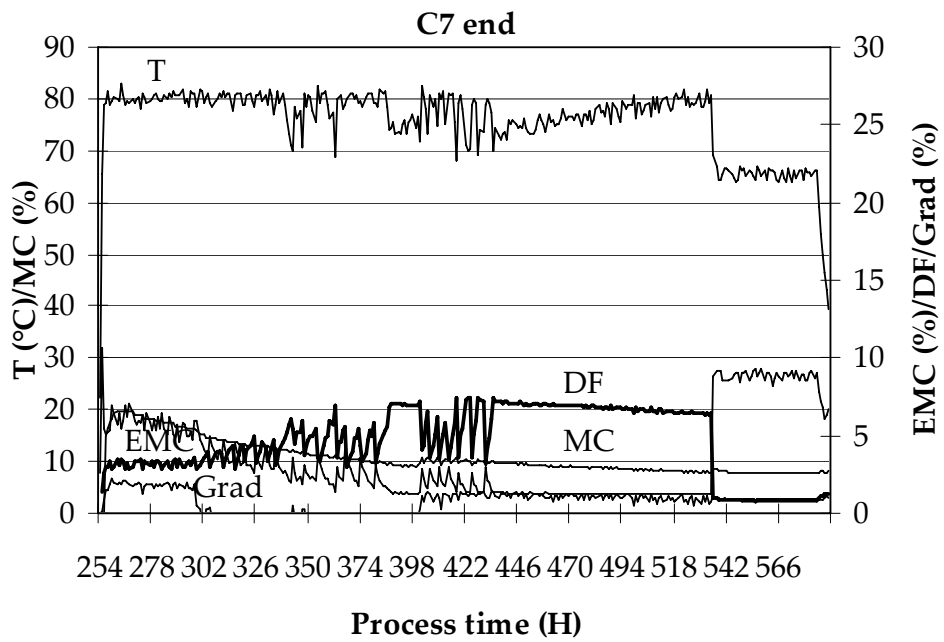
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Measured conventional drying schedules. In C1, C5 and C6 the clearly seen irregularity in the moisture content curve means that one sensor pair has been removed from the controlling because it clearly showed anomalous moisture content values when compared to the average









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