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Edited by Veikko Tarvainen

Measures for improving quality and shape stability of sawn softwood timber during drying and under service conditions

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Abstract

In the EU funded STRAIGHT project, different processing methods (drying, sorting, conditioning and re-engineering) were investigated in order to minimise the distortion of sawn softwood timber. This Best Practice Manual summarises the main outcome from the study and was primarily written for industry. This manual describes the methods studied, and the advantages and disadvantages they bring to the sawmilling process and end uses of sawn timber. The methods for improving straightness are ranked according to a distortion acceptance percentage measured over the central 2000 mm portion of structural batten, when straightness is the main criteria (twist 4 mm / 100 mm, bow 4 mm, spring 3 mm & cup 2 mm / 100 mm). Other important criteria included in each assessment is extra drying and handling costs, the impact of using different methods on other factors of quality and the improvement in the saleability of material from normal sawmill production.

The methods studied were a) pre-sorting of logs according to the angle of spiral grain, b) twisting small diameter logs during sawing to counteract natural direction of twist, c) re-engineering boxed-pith battens using green gluing (splitting battens along their length and re-engineering whilst “green”), d) twisting the drying load in the opposite direction to natural twist (the support sections on the kiln wagon were angled to counteract the normal direction of twist), e) top-loading of the kiln, f) oscillating drying schedules to introduce mechano-sorptive creep to reduce twist, g) high-temperature drying and finally, h) new conditioning techniques where dried, twisted timber was re-stacked and stickered on angled supports to promote opposite twisting during special conditioning.

It was found that the best straightening results were achieved by the re-engineering and green gluing of boxed-pith battens before drying. The most cost-effective method of improving straightness of timber was top-loading. How cost-effective the opposite twisting will be depends on the practical solutions to be developed. The main disadvantage of top-loading and counter-wise twisting during drying was the amount of “spring back” which occurs when timber is subjected to gradual changes in environmental conditions. These methods of drying are deemed suitable if the timber is kept under pressure or used soon after drying or re-engineered so that the spring-back effect is reduced.

Preface

STRAIGHT, "Measures for improving quality and shape stability of sawn softwood timber during drying and under service conditions", was part of the EU's 5th framework programme (QLRT-CT-2001-00276) and was completed at the end of 2004. Martin Greimel was the EU contact for this study. Project participants are listed below:

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This publication is a manual for practitioners wishing to improve the straightness of sawn softwood timber (primarily spruce). The quality improvement methods studied, results achieved, feasibility of different methods and recommendations are presented. This report was written by the editor, Veikko Tarvainen, with the co-operation of all participants.

Major contributions from the following persons are acknowledged:

Dr Robert Kliger and Ms Marie Johansson (CHA) for chapters 3.1 and 3.2, Dr Johannes Welling (BFH) for chapter 3.3, Mr Geoff Cooper (BRE) for chapter 3.4, Mr Sverre Tronstad (NTI) for chapter 3.5, Dr Jarl-Gunnar Salin and Mr Björn Esping (Trätek) for chapter 3.6, Mr Torsten Riehl (BFH) for chapter 3.7, and Mr Michel Riepen (TNO) for chapter 3.8.

More detailed results are published in the papers given in the references section.

I would like to express my sincere thanks to all persons involved for their continued commitment to this publication.

Espoo 2005

Veikko Tarvainen

Contents

1. Introduction

In the EU member states, approximately 81 million m^3 of sawn softwood timber (mainly Spruce and Pine) is produced annually, representing a total value of some 12–14.000 million euros. The major part of this material is used in the building sector as structural components, joinery, furniture, cladding and flooring and in temporary structures (including formwork). A high percentage of structural members (beams, roof-truss timber, purlins, studs, glulam timber) require kiln drying to approximately 18–20% moisture content, whilst other products require drying to lower moisture contents corresponding to their final in-service moisture content (approximately 10% for interior joinery and 16% for exterior joinery).

Despite the recent investments made in improved kilning technologies (over 200 million euro) by the European sawmill industry, there are still major problems that require addressing and improvements that can be made to improve the efficiency and competitiveness of commercial kiln drying. Two of the most significant areas which require improvement are

- achieve the target moisture content (MC) and minimise or limit MC gradients
- minimise or prevent distortion of pieces during drying and in service conditions.

The deformation which occurs in sawn timber during and after the drying process is the most important reason for down grading timber during primary processing. Consultation with sawmills across Europe (including member states with the highest quality resource) has demonstrated that between 10 and 12% of each kiln load is rejected due to excessive distortion occurring during drying. This represents a total loss of over 1000 million euro per year.

The deformations that occur during and after drying are related to the characteristics of the raw material (e.g. grain angle, density, juvenile wood content, compression wood, knots), kilning schedules and technologies, and post kilning conditioning treatments. There is a need for best practice guidance on how to optimally

- select and sort logs
- kiln dry timber economically with minimum of degrade
- treat and handle the timber post kilning so that distortion remains minimised.

This project has addressed these needs through the development and assessment of novel approaches to minimise distortional degrade during drying. These include

- high-temperature drying (above 100 ºC)
- novel top-loading methods
- pre-sorting of logs due to spiral grain angle
- pre-twisting during sawing
- oscillating schedules to induce mechano-sorptive response in the wood (an accelerated form of creep deformation to minimise internal stresses and resultant distortion levels)
- twisted pack drying to counter the most common form of distortion in spruce (twist)
- pre-sorting of battens based on wood characteristics or moisture content and density so that the most efficient drying schedules are used to combat the distortional characteristics of different wood types
- use of face green gluing technology to re-engineer boxed pith battens so that distortion during subsequent drying is minimised (the twist distortion in each piece counteracts each other)
- novel conditioning techniques that minimise distortion.

Also undertaken within the project were

- comprehensive assessment of the quality of the timber dried by each of the novel approaches described above to determine optimum approaches for different wood raw material
- post drying assessment to determine the stability of the dried pieces in end-use environments

- determination of the relationships between growth characteristics, drying approaches and quality.

The project has integrated the information, models and best practice identified by each of the above workpackages and produced a best practice guidance manual for take up and implementation of the methods by the European sawmilling industry. Information produced throughout the project has been continuously disseminated to the European wood chain, who is concerned with processing softwood timber.

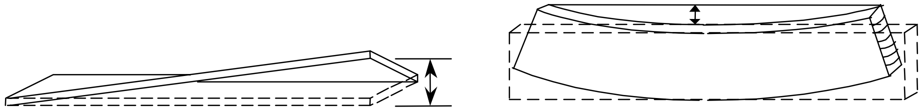
2. Quality of sawn timber

The “quality” of sawn timber is based on various factors including, visual appearance, strength, straightness, sawing accuracy and moisture content variation (e.g. MC average, standard deviation and gradient). The relative importance of each quality factor depends on the intended end use application of the timber.

For example, in joinery applications the visual appearance has a very high importance, but the timber must also be straight (i.e. low distortion) and be dried accurately to the target moisture content. In contrast, for construction applications the visual appearance of timber and initial moisture content are often of secondary concern and structural performance is of utmost importance. The different quality factors can be listed in order of importance for all timber applications. However, one factor – straightness – has to be taken into consideration in almost every case.

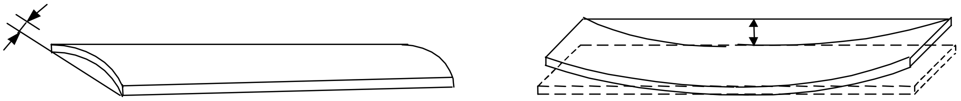
2.1 Distortion

Distortion is the general term used to describe any deviation in a piece of timber from “true”. The four main types of distortion are twist, bow, spring, and cup (see Figure 1).



Twist

Spring / Crook



Cup

Bow

Figure 1. Types of distortion found in sawn timber.

The optimal shape and form of sawn timber, at any moisture content, is perfectly square-edged and straight. In reality, this is rarely the case. Deformation does occur, in some cases, whilst the timber is green (mostly bow and spring), but the majority occur when timber is being, or has been dried.

The definition for each type of distortion (twist, bow, spring and cup) and how they are measured is given below:

Twist

Twist is the spiral distortion of a piece of timber lengthwise plane. It is measured over a distance of 2 m along the piece, at a width of 100 mm. Twist is often expressed as a percentage of the timber width.

Bow

Bow is the curvature of a piece of timber lengthwise in a plane normal to its broad face. Bow is measured as the height of the bow within a 2 m length of the piece. In a long section bow is often measured at the worst position.

Spring

Spring is the curvature of a piece of timber lengthwise in a plane normal to its narrow edge. Spring is measured as the height of the deformation within a 2 m length of the piece. In a long section spring is often measured at the worst position.

Cup

Cup is the curvature of a piece of timber across the width of the broad face. It is measured as the difference in height from the edge, to the centre of the piece and is stated as a percentage of the timber width. Cup is normally not a problem for structural timber, but does lead to severe material losses when planing is required.

In this project, the deformation values given in Table 1 were used as the maximum acceptance limits for distortion for material measured during the project. These values are close to limit values used in various timber grading standards and are valid at 15% moisture content only. When comparing material at different moisture contents, it is reasonable to calculate predicted values of distortion at 15% MC from the values measured at another known MC.

Table 1. Acceptance levels for distortion at a moisture content of 15%.

Distortion	Allowed in STRAIGHT
Twist	4 mm / 2 m / 100 mm
Bow	4 mm / 2 m
Spring	3 mm / 2 m
Cup	2 mm / 100 mm

2.1.1 Cause of distortion

The main cause of twist, bow and spring is the variations in lengthwise shrinkage and movement in a piece of timber.

Some species have growth stresses that are freed as a result of sawing. These stresses cause deformations whilst the timber is green.

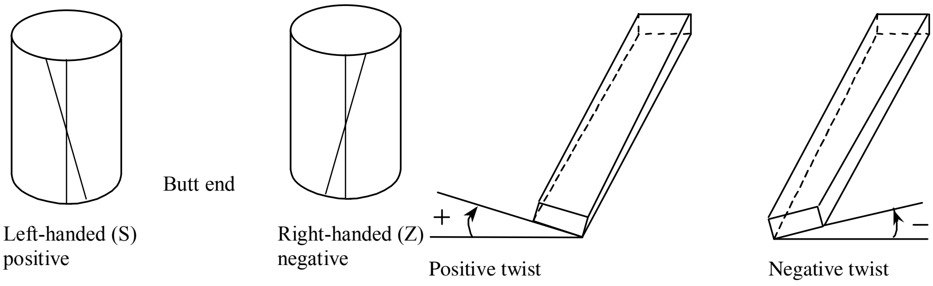
Extensive research has been performed to understand the reasons for longitudinal shrinkage variations and its effect on deformation. A common finding is that the major cause of twist is the deviation of grain direction in the direction of the timber. Stevens and Johnston (1960) produced a model for calculating twist when the timber is unrestrained during drying. This model is based on annual ring curvature, spiral grain angle and tangential shrinkage strain.

$$\alpha = \frac{2Ls\theta}{r(1-s)},$$

where

α = angle of twisting
θ = grain angle
l = testing length of the timber piece
r = radial distance of pith to the centre of the piece cross section
s = tangential shrinkage.

Spiral grain angle and annual ring curvature jointly account for about 65% of the variation in twist. In most cases, studs sawn close to the pith have a positive twist angle (Mishiro & Booker 1988; Johansson et al. 2001), whilst studs sawn further away from the pith displayed either a positive or a negative twist (see Figure 2b). Spiral grain angle results from the tendency of wood fibres to grow in a spiral pattern around the trunk of the tree. In the case of spruce, the spiral grain angle close to the pith is zero. The left-handed spiral grain develops and continues to increase during subsequent growth, often reaching a maximum value within the first ten annual growth rings. The grain angle then decreases towards zero. Later in the life of the tree, the grain angle may change direction to become right-handed. The grain angle in this direction increases slowly, continuing with stem growth. The left-handed spiral grain angle is defined as positive (see Figure 2a) and the right-handed spiral grain angle as negative.



a) Spiral grain angle on logs b) Twist in studs

Figure 2. Definition of positive and negative direction of spiral grain angle and twist.

Bow and spring are induced by variations in longitudinal shrinkage. Johansson (2002) has measured spiral grain angle, annual ring curvature, juvenile wood, knots, annual ring width, compression wood, cracks, wane, density, shrinkage and skew sawing of studs. None of the measured parameters were able to explain bow and spring statistically. Detailed studies to determine how longitudinal shrinkage varies within a stud were conducted. A simple model was developed to calculate bow and spring on the basis of variations in longitudinal shrinkage. This model shows that most of the bow and spring caused by changes in moisture content can be explained by variations in longitudinal shrinkage.

2.1.2 Distortion in-service

The distortion that causes the greatest problems to the building industry is that which occurs after the timber is dried and delivered to the building site. Normal practice is to deliver timber to site at a moisture content of about 16–20%. The moisture content of a piece of timber inside a heated building will normally much lower than this, due to further drying of the timber in-situ. This additional drying occurs in an uncontrolled manner at the building site or after the timber is built into the structure. As a result, the distortion of the timber increases and consequently raises building costs as construction workers have to treat each piece of timber separately or reject the timber completely. This uncontrolled drying is referred to as "in-service" conditions.

Twist in timber is normally zero until the fibre saturation point (theoretical state in which the cell cavities are empty of water and the cell walls are saturated, in softwoods this is approximately 27% MC) is reached, after which twist increases almost linearly with decreasing moisture content (Johansson et al. 2001). When this timber is re-wetted, the twist decreases again. If the timber is dried without top load, the magnitude of twist will be the same each time the moisture content reaches a certain level (i.e. twist is reversible). Methods can be used to lower twist directly after drying. However, some of these methods lead to a material that is less reversible and the distortion increases after each moisture cycle. This type of material can cause problems in many parts of the chain; from the sawmill to the building site and finally to the finished structure.

As part of the STRAIGHT project, the distortion of timber during in-service conditions was investigated. Material from the seven different treatment processes was left unrestrained in a climate room and subjected to moisture content changes from 18% to 10% and back to 18% In this report, the mean absolute twist at each moisture content is presented and the percentage of studs that exceed the limit for twist of 4 mm per 100 mm width, over a 2m length (4 mm / 100 mm / 2 m) at 15% MC, both during adsorption and desorption, are presented. Spring-back is best described as the increased twist observed at a specific moisture content (in this work 18%) as a result of moisture cycling.

Spring back alone doesn't tell how effective a straightening method is. Small reduction in twist by a particularly method leads also to small spring back and vice versa.

2.2 Other drying related qualities

The final moisture content of a piece of dried timber and its uniformity throughout the section is regulated by the drying process. The moisture content of the timber can influence dimensional changes that occur when in use. Excessive dimensional changes can be avoided if the timber has been dried to a moisture content similar to that which it will attain when in use.

Splits and checks which occur on timber surfaces after drying is a common result of intensive kiln drying. These can be avoided with correct drying schedules.

Drying will also affect the final colour of the timber, higher temperatures resulting in darker colouration. Drying will also affect the behaviour of knots and flow of resin in coniferous timber.

3. Methods to minimise distortion

Distortion can be reduced by sorting a pack of green timber and removing all pieces considered to be prone to warping. This increases the value of the pack, which will distort less when dried. In order to make this an economical approach to reducing distortion, a valuable application must be found for the rejected material.

When the material is prone to distort, there are two principal methods to minimise deformation during drying:

- pre-deform the timber in the sawing process so that it is straight after drying and conditioning
- counteract the deformations during drying and conditioning to give an end product that is straight. In this case, special drying measures (i.e. high temperature, oscillating temperature and RH, and steaming) may be used to enforce the straightening effect.

The STRAIGHT project investigated each of these variations to determine the relationships between log and timber properties and timber deformation. This information is useful when sorting out material prone to distort.

Different drying methods and treatments such as high-temperature drying, oscillating drying schedules, pre and post steaming, top loading, twisted pack drying and a novel conditioning method were studied and analysed.

Twisting the log during sawing to produce pre-twisted battens has also been studied. After drying, these battens were straighter than battens sawn using the traditional process.

Additionally, re-engineering of timber is a promising new method of reducing distortion: green boxed-pith battens were sawn along the batten length into two halves which were then green-glued back together again in various orientations before drying. In the case of back to back orientated halves, the twisting forces counteracted each other during drying and the batten remained straight.

Technical and economical analyses were performed in order to gauge the commercial viability and competitiveness of each method investigated for industrial production.

This information should help the woodworking industry choose the most suitable methods of minimising distortion for their specific plant and production line.

In this chapter, the different drying methods and approaches to minimising distortion during drying are presented. The optimal processes and their advantages, as well as costs, are presented and discussed.

Figure 3 shows a schematic sawmill layout. The action points of different timber straightening approaches proposed in this project are marked with capital letters. In the following text, the different approaches are discussed in the order of the sawmill process. In the conclusion (chapter 4), the methods are ranked according to their suitability for application to the timber industry.

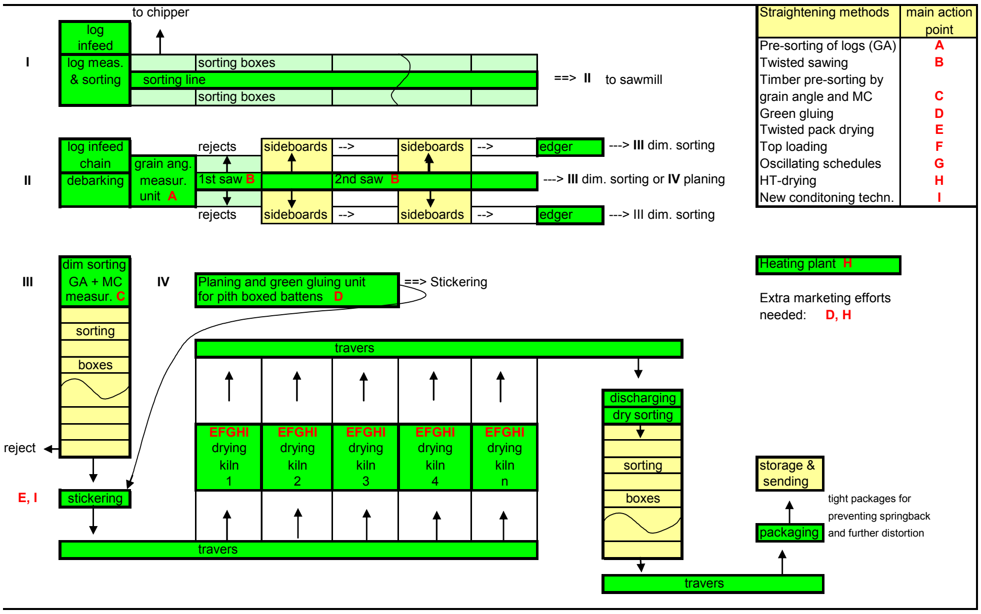


Figure 3. Schematic sawmill layout and process stages in which timber straightening methods are applied.

3.1 Pre-sorting of logs due to spiral grain angle

Robert Kliger, Marie Johansson & Magnus Bäckström
Chalmers University of Technology, Sweden

The propensity for timber to twist is primarily a result of spiral grain. The ability to grade trees in the forest or logs prior to conversion in order to avoid the use of raw materials with a large tendency to twist could be very important to the sawmilling industry. A method that would enable material with a high tendency to twist to be excluded, irrespective of the sawing pattern and drying methods used would reduce the number of rejects currently made following primary processing. Material which has a tendency to twist can be used in applications with less stringent limits on distortion. It is recommended that raw material (logs) with large and positive spiral grain angles (greater than 6° and left-handed) should be rejected before conversion to sawn timber and possibly be re-directed to the pulp and paper industry.

At present, there are various techniques for measuring the spiral grain angle on trees prior to harvesting or on logs prior to sawing. A suitable method in sawmills for sorting logs prior to sawing is based on the laser technique. A laser beam is directed perpendicularly onto to the wood surface. The laser spot on the surface is oval in shape with the longer axis in the direction of the fibre. The grain angle of the timber is measured using a special camera that detects any distortion of the laser spot. The disadvantage of this method is that trees or logs must be debarked before it can be used.

There are also manual methods for measuring grain angle. In the so-called scratching method, a sharp needle is drawn unrestrained along the tangential surface of the timber or log, leaving a scratch in the direction of the fibre. The angle between the fibre direction and the timber or log axis can be measured. This method is slow and is not currently suitable for industrial application.

A similar principle to that described above, is applied when an instrument called the S-GAG (Figure 4). A special knife is pressed onto the surface of a tree or log. As the knife enters the log or tree it orients itself in the fibre direction, working especially well when the wood is wet. The angle between the knife and the shaft of the instrument is then read off a scale. The advantage of this method is that measurements can be made on trees and logs through the bark. With further development, this method could be suitable for industrial application.

Figure 4. The S-GAG – an instrument used to determine the spiral grain angle on coniferous trees.

3.1.1 Method

Material was selected at the Södra Timber sawmill in Värö, Sweden. Approximately 1000 logs were screened during normal log sorting by representatives of the Swedish Timber Measurement Council (VMR) at Värö. Logs which were predicted to contain a large spiral grain angle were selected during this process and stored separately at the sawmill. The spiral grain angle of the logs was measured through the bark using the S-GAG by staff from

Chalmers University of Technology. The aim was to find logs (with a diameter of > 30 cm) representing various spiral grain angles (SGA) and place them into four groups: painted green SGA < –3°, painted white –3° < SGA < 3°, painted blue 3° < SGA < 8° and painted red SGA > 8°. These measurements were terminated when a sufficient number of logs had been found in each group. Table 2 shows the mean diameter and spiral grain angle under bark for the four groups of logs. The material delivered to the Södra Timber sawmill in Värö came from the south-western parts of Sweden from an area within a 90km radius of the sawmill.

Table 2. Mean spiral grain angle and diameter of the 32 logs selected for pre-sorting. Group colour codes: see text and Figure 6.

Group	Number of logs	Mean spiral grain angle (std. dev.) [°]	Mean diameter (std. dev.) [cm]
1 (white)	11	–0.36 (1.65)	38.0 (4.7)
2 (blue)	7	4.57 (2.51)	38.8 (6.6)
3 (red)	10	10.53 (1.48)	34.1 (4.5)
4 (green)	4	–4.31 (2.56)	34.2 (3.5)

The logs were transported to a small sawmill for conversion into studs measuring 50 x 100 mm. Each log was sawn to maximise the number of studs obtained from each log, see Figure 5. This number varied between 5 and 20 studs per log. In total, 282 studs were produced. The material was dried at “normal” temperature in a compartment kiln with standard stickering distances at the bottom of the stack. The target moisture content of the timber was 18% with a drying time of five days. After drying, the material was transported to the university laboratory where each length was cut to 2500 mm. A hook was attached to one end of each stud and the material hung in a conditioning room to obtain a uniform moisture content of 18% (at an ambient temperature of 22 °C and relative humidity of 90%). The material was hung from the ceiling to avoid the effect of outer restraints on the material, i.e. to expose the material to the worst possible conditions and subject all the material to the same treatment.

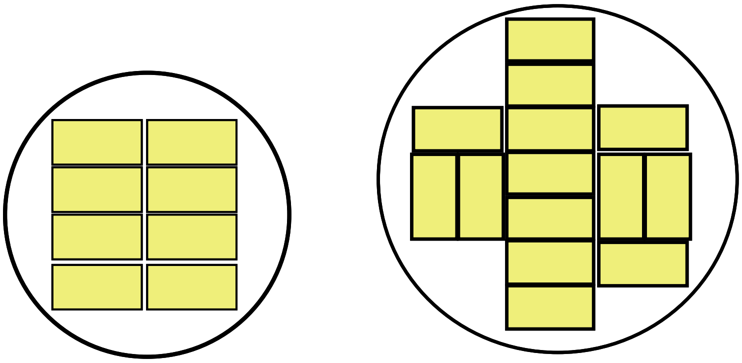


Figure 5. Examples of sawing pattern.

3.1.2 Results

Twist measurements were undertaken on the studs directly after conditioning the timber in the laboratory to a moisture content of 18%. The median values for measured twist are shown in Figure 6. The results were conclusive; the larger the spiral grain angle measured on logs the larger the twist of studs after drying.

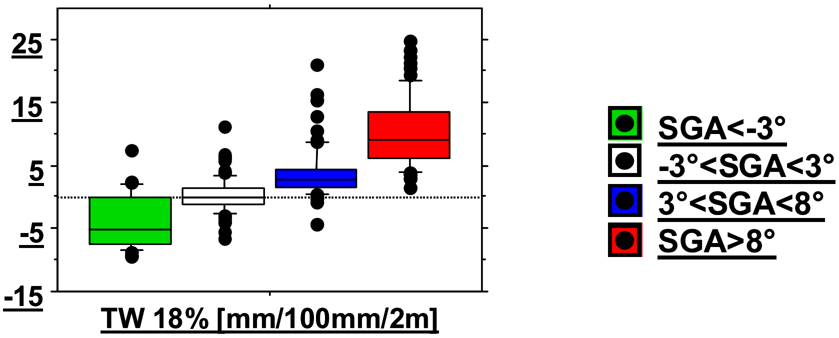
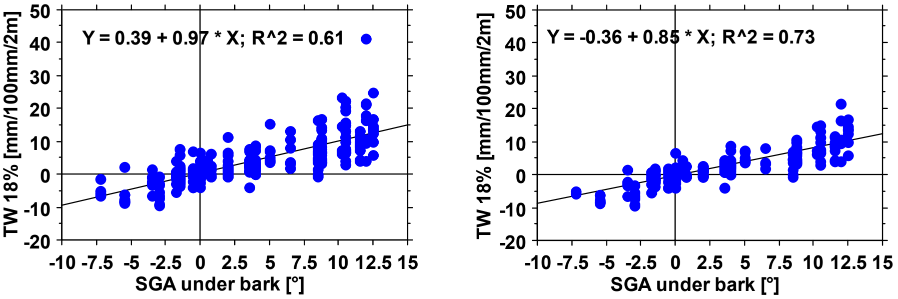


Figure 6. Twist after conditioning to 18% MC for all studs, divided into four groups of different spiral grain angle (SGA). Box plot showing the 10th, 25th, 50th, 75th and 90th percentile values.

Measurement of the spiral grain angle under bark on logs provides a good indication of the propensity of the raw material to twist after sawing and drying (Figure 7).



a) All studs (n = 282)

b) Studs close to the pith were not included (n = 227)

Figure 7. Relationship between twist (TW) on studs measured after conditioning to 18% MC and spiral grain angle (SGA) measured on logs under bark prior to sawing.

The percentage of all studs that fell within the acceptance limit of 4 mm / 100 mm / 2 m for twist was 58%. The percentage of studs sawn close to the pith that met the acceptance limit was less than 35%. The central area around the pith, approximately 50 x 50 mm^2, needs extra measures in converting to sawn timber or re-engineered products (see chapter 3.4) for meeting the stringent requirements of the construction industry on twist. This is necessary because of the high percentage of studs rejected when sawn from this area. When logs with a diameter greater than 300 mm are processed, the exclusion of this central core does not represent a significant loss in the timber yield. But in most European sawmills the average log diameter is quite small. High percentage of timber is sawn near the pith (see chapter 4.1). So it is neither possible nor economical to exclude the pith region out of sawn timber production. Sawmilling industry has a cancelling task to convert the timber so that the clients are satisfied with the timber and timber products. This has also been the task of this research project. More innovations are needed!

Pre-twist sawing or re-engineering of the central part of logs can be used to reduce twist on material cut from the central portion of a log, see chapters 3.2 and 3.4. When studs sawn close to the pith (< 50 mm) were excluded from the calculation (n = 227), the percentage of studs that fell within the acceptance limit of 4 mm, increased to 64%. In order to propose boundary limits in terms of SGA measured on logs under bark, the changes in the percentages of studs that would have met the twist acceptance limit of 4 mm is presented in Table 3. Boundary limits for SGA are presented as the lower limit (right-handed spiral grain, see Figure 2) and the upper limit (left-handed spiral grain). As more stringent SGA boundary limits were applied, the number of studs included in the analysis decreased. Also shown in Table 3, is the percentage of studs that would have achieved the 4 mm acceptance limit for twist, when studs sawn within 50 mm of the pith were excluded from the analysis. This is because twist in these studs is not related to the SGA under bark.

*Table 3. Boundary limits in terms of spiral grain angle (SGA) measured on logs under bark and percentage of studs that fell within the acceptance limit of 4mm for twist measured at 18% moisture content. * Only studs sawn further than 50 mm from the pith are included.*

SGA Lower limit	SGA Upper limit	Accepted % (No.)	* Accepted % (No.)
all	all	58.2 (282)	63.9 (227)
–7	12	61.3 (266)	67.6 (213)
–7	10	69.0 (234)	75.6 (189)
–7	7	77.4 (199)	81.9 (166)
–6	6	78.2 (193)	82.1 (162)
–5	5	83.7 (178)	88.6 (149)
–4	4	84.6 (162)	89.6 (134)
–3	3	88.8 (125)	95.1 (103
–2	2	90.5 (105)	94.3 (87)

3.1.3 Straightness in-service

Un-restrained studs were subjected to moisture content changes from 18% to 10% and back to 18% in a climate controlled room. After each conditioning period, the twist was measured. This test was designed to simulate the worst possible in-service conditions for studs to ensure that they remain fit for purpose during use. It aimed to see how stable the improved straightness methods performed, when placed in similar conditions.

The studs were split into the four spiral-grain-angle-under-bark groups (see chapter 3.1.1), to study the effect of varying spiral grain angle on twist in in-service conditions. The results show that twist was at its lowest in the group with a spiral grain angle between –3° and 3° and doubled when the material was dried down to 10% from 18% MC. The twist increased slightly after moisture cycling (spring-back = difference in twist after the first and third cycle with end MC of 18% in both), and was greatest for material with a spiral grain angle larger than 8° (Figure 8). Twist increases with increasing absolute value of grain angle at both MC levels (10 and 18).

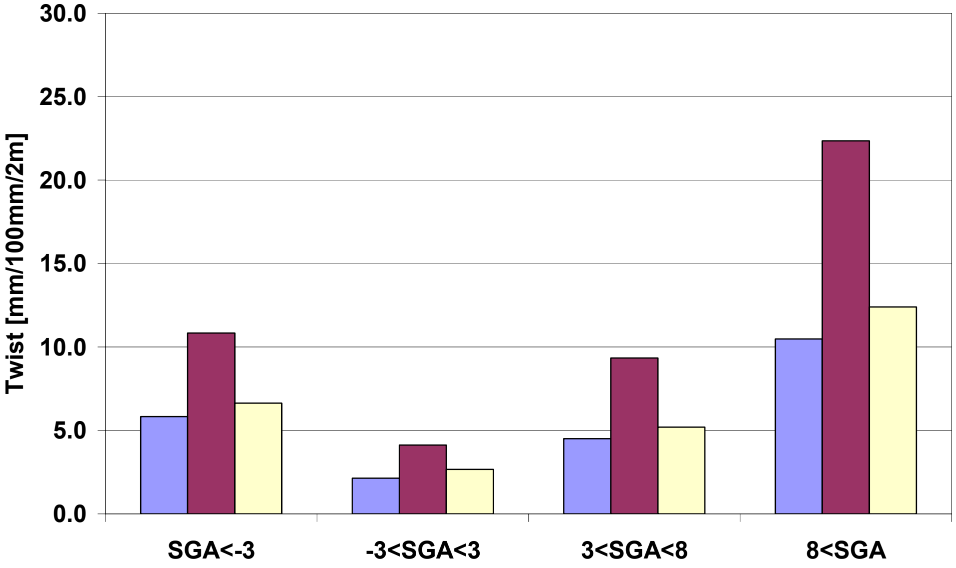


Figure 8. Mean absolute twist at 18% MC (first column in each group), at 10% MC (second column in each group) and at 18% MC (third column in each group) in different log spiral grain angle groups.

The number of studs that met the acceptance limit for twist was greater for studs from logs with a small spiral grain angle under bark. In the group with a spiral grain angle under bark larger than 8°, only four percent of the studs achieved the acceptance limit (Table 4). These studs came from large diameter logs, which normally yield a greater number of studs which achieve the twist acceptance limit than material from small diameter logs.

Table 4. Percentage of studs that met the acceptance limit for twist at 15% MC after 3 months conditioning at 85% RH / 23 °C and after additional 3 months moisture cycles at 30% RH and 85% RH without restraint.

Group	Studs passing limit at 15% MC after first cycle, %	Studs passing limit at 15% MC after 3rd cycle, %
SGA < –3°	40.0	30.0
–3° < SGA < 3°	79.7	77.4
3° < SGA < 8°	34.7	24.5
8° < SGA	3.8	3.8

3.1.4 Cost assessment

Introducing the pre-sorting of logs according to SGA measured under bark requires either changes in the requirements set for logs delivered to the sawmill or, the rejection of some logs prior to normal production. The initial cost for a sawmill to install laser equipment capable of measuring SGA after debarking (if logs are graded at the sawmill) is estimated to be approximately 5000 €. At present, SGA is not measured during the harvesting process, as harvesters are not equipped with a device that can measure SGA. It is also very difficult to estimate all costs involved in the sawmilling process to provide a reasonable assessment of whether pre-sorting logs in terms of SGA is profitable.

The costs relating to various stages in the sawmilling process given in this section are based upon studies by Ragnarsson (2003) and by Säll (2003), and reflect the economic situation experienced by sawmills in Sweden between 2002 and 2003. An exchange rate of 1 € = 9 SEK has been used to calculate the costs given below.

The cost of raw material was estimated to be 73 €/m^3. This estimate was for spruce logs class 2 or 3, with a top diameter of over 29 cm and based on 560 SEK/m^3 to process the timber including transportation, 50 SEK/m^3 grading and 40 SEK/m^3 screening costs. The sawing yield was 62% of the total log volume for logs with diameters between 29 and 50 cm. These logs were sawn into studs of dimensions 50 x 100 mm. The income from the bark and chips produced as a result of sawing was 18 €/m^3 and the income from rejected logs (with too large SGA) used for pulp, was 28 €/m^3. The rejected logs could be suitable for use as pulpwood or sawn timber for low-quality products. Production costs for sawn studs were estimated to be 40 €/m^3 which included measuring the SGA on logs and sorting. The cost assessment for sawn timber, as agreed in this project, was based on prices of 200 €/m^3 for studs which fulfil the requirement limit of 4 mm / 100 mm / 2 m for twist and 140 €/m^3 for studs which do not fulfil this requirement.

Based on the estimated costs for sawmill operations given above, and the distribution of logs in different SGA classes used (Ragnarsson 2003), there was no additional profit to be made from grading logs according to SGA in this study. This economic outcome may not, however, be representative of all regions or sawmills. The availability of logs with a more relevant distribution of SGA may change this outcome. It should be noted that each log can produce various numbers of studs and these distributions are not related to diameter. The profit from sawing studs from large diameter logs increases when the boundaries of SGA are widened. However, the differences in yield, and therefore profit, for SGA > 7° and SGA of 5–6° are small.

According to interviews with some small and medium-sized Swedish sawmills, the income from pre-sorting logs could be high. They claim that their investment paid for itself very quickly when logs with large spiral grain angle were excluded. The reason being that a few logs with a large spiral grain angle cause more production problems than larger numbers of logs with a small spiral grain angle. Sawing the large diameter logs to other dimensions (i.e. larger studs) could attract higher prices than assumed above. The economic value of customer perception, when producing better quality sawn timber in terms of straightness, is another important factor that cannot been included in the cost estimate.

3.2 Pre-twisting during sawing

Robert Kliger, Marie Johansson & Magnus Bäckström
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There are many ways to avoid excessive twist in sawn timber. One solution to the problem is to avoid utilising the material closest to the pith. This solution is especially good for large-diameter logs, where losing an area of 50 x 50 mm around the pith does not have such a large effect on timber yield when compared to small diameter logs, where this option is not feasible. Removal of the central piece of timber, measuring 50 x 50 mm, from a log with a diameter of less than 200 mm will result in a significant reduction in yield. A special sawing method, known as pre-twisted sawing, may solve this issue. Pre-twisted sawing **can only be used on small diameter logs,** or the central section of a larger log.

3.2.1 Method

The hypothesis being tested was that studs sawn from small-diameter logs would become straighter after drying if they were sawn with a certain amount of negative pre-twist. To enable a comparison between studs sawn with pre-twist and studs sawn in the conventional way to be made, it was decided to saw two studs measuring 50 x 100 mm from each log. One stud was sawn with a small negative pre-twist, whilst the opposite stud (from the same log) was sawn straight (Figure 9). By rotating the log slightly during sawing, it is possible to produce studs with a slightly negative pre-twist. There are many techniques available to rotate a log during sawing. In this project, a small horizontal band saw was used to saw the logs. The band saw was moved in the vertical plane whilst the logs were moved along the horizontal plane by the saw table. One end of the log was clamped and the log rotated as the log was fed through the saw.

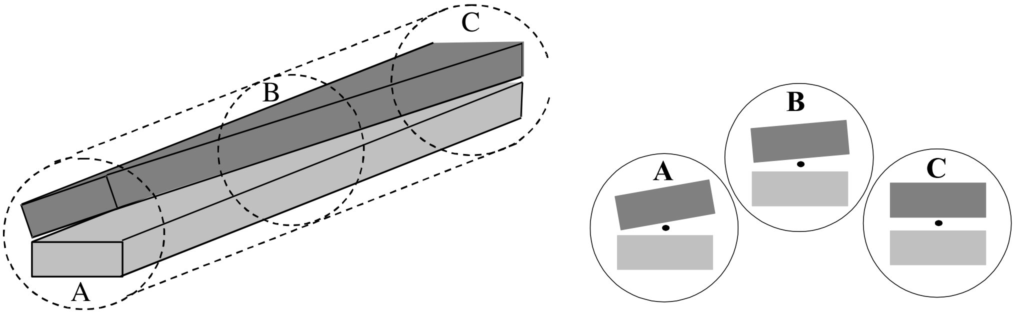


Figure 9. Two sawn studs – one stud (dark pattern) applying the novel sawing technique and one stud (light pattern) applying traditional sawing technique.

The first saw cut was made to remove the upper part of the log. When the log was fed through the saw, it was rotated slightly so that a slight pre-twist was created in the upper section surfaces. The saw blade was then lowered 50 mm. The second cut was also made while the log was being rotated. In this manner, two parallel saw cuts were made and produced an evenly thick stud with slight negative pre-twist. The third cut was made without rotating the log and gave the log half a straight surface. This resulted in a wedge-shaped board, containing the pith, sawn between the two studs. The half-log was then turned 180 degrees and the fourth cut made, creating a straight stud. The centre of the cross-section of both studs was approximately the same distance from the pith.

Two different options for twisted sawing were also tested. The first method involved sawing all the logs with a standard pre-twist of 3.5° / 2 m. The second method involved using an individual pre-twist based on the measured spiral grain angle under the bark of the log. These two sawing methods were used to determine whether a standard pre-twist would be sufficient to obtain straighter material or better results would be obtained using individual pre-twist values.

The material selected for this study comprised of 100 small-diameter logs with a mean diameter was 19.2 cm. To obtain a variation in spiral grain angle in the logs, half the logs were selected from a coastal (windy) site and half the logs from an inland (sheltered) site. The spiral grain angle and diameter of the logs were measured. The logs from each site were organized according to ascending spiral grain angle under bark. They were then sorted and each alternate log was placed in a separate group, making two groups of 50 logs. This segregation was carried out to obtain two groups of material with the same variation in spiral grain angle.

After sawing, the pre-twist in all 200 studs was measured. The material was then dried in the central part of a stack, in a commercial progressive-type kiln, at a temperature of approximately 60 °C. To reach the target MC of 18%, a drying time of 5 days was recorded. The twist was then re-measured after drying and the material transported to the university where it was prepared for conditioning. A hook was attached to one end of each stud and the unrestrained material hung from the ceiling of a climate room and conditioned, at a constant temperature of 23 °C, to 18% MC.

3.2.2 Results

The twist was measured directly after sawing to show that the studs had the desired pre-twist and that the vast majority of the studs sawn straight did not have any twist. The results showed that the material sawn to produce a standard pre-twist had an average negative pre-twist of –6.5 mm / 100 mm / 2 m, with a standard deviation of 0.6 mm / 100 mm / 2 m. The matched material sawn straight, had an average twist of 0.1 mm / 100 mm / 2 m, with a standard deviation of 0.6 mm / 100 mm / 2 m (Figure 10).

The material sawn with individual pre-twist (rotation) had an average pre-twist of –6.2 mm / 100 mm / 2 m with a standard deviation of 2.4 mm / 100 mm / 2 m. The material sawn to be straight had an average twist of 0.2 mm / 100 mm / 2 m, with a standard deviation of 0.7 mm / 100 mm / 2 m (Figure 11).

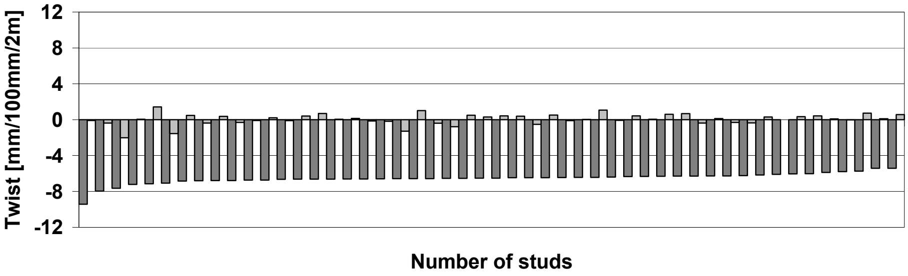


Figure 10. Twist values on studs sawn with a standard pre-twist which correspond to 3.5° / 2 m on average (dark colour) and the matched stud (light colour) directly after sawing.

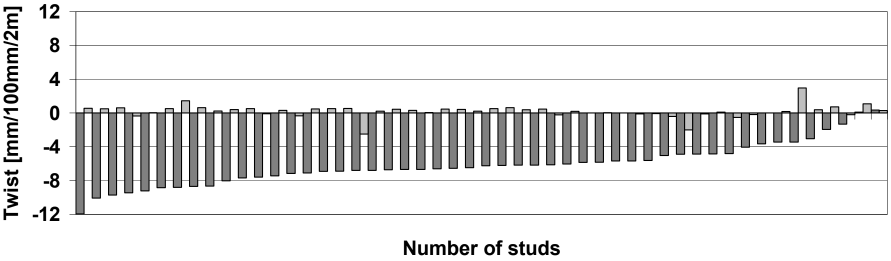
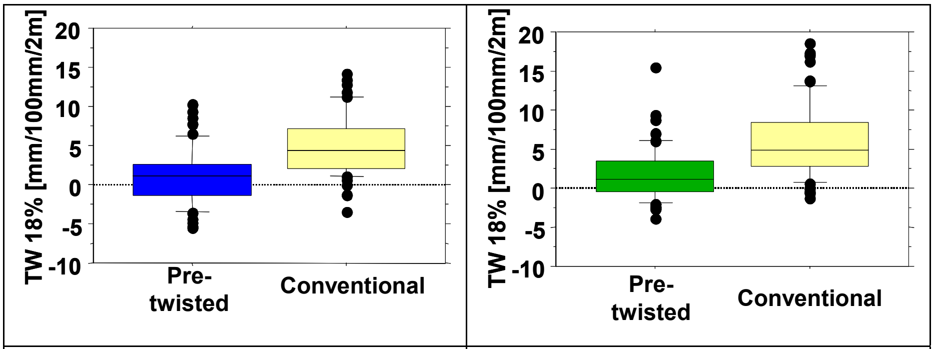


Figure 11. Twist values on studs sawn with an individual pre-twist (dark colour) and the matched stud (light colour) directly after sawing.

The twist in the material was measured again directly after drying. The results showed that all the material had twisted and only four out of the 200 studs exhibited a decrease in the amount of twist. The change in twist was larger for the material with sawn pre-twist than for the straight sawn material. The average change in twist for the studs with a standard pre-twist and with individual pre-twist was approximately 25% higher than the average increase in twist for the corresponding straight sawn studs. As anticipated, material sawn with pre-twist was straighter than the straight sawn material due to the negative pre-twist introduced during sawing (Figure 12). The average pre-twist for the two groups, standard rotation or individual rotation, was the same and no difference in twist after drying was found between the two groups.

The percentage of studs that achieved the acceptance limit of 4 mm / 100 mm / 2 m for twist was quite low for the straight sawn material. Directly after drying, only 30–35% of the studs fell within the limit. For material sawn with a pre-twist, the number of studs that met the acceptance limit was almost 60%. The same levels of acceptance could be seen when the material was conditioned to 18% MC. Optimising the pre-twisting process to produce completely straight studs at a specific target moisture content after drying should be possible.



a) Standard rotation for all studs

b) Individual rotation for all studs

Figure 12. Levels of twist after drying for the studs sawn conventionally and studs sawn with the novel sawing technique (pre-twisted). Box plot showing 10th, 25th, 50th, 75th, and 90th percentile.

3.2.3 Straightness in-service

The unrestrained studs were subject to a change in moisture content from 18% to 10% and back to 18% in a climate controlled room. After each conditioning period, the twist was re-measured. This test was designed to simulate the worst possible in-service conditions for studs to ensure that they remain fit for purpose during use. It aimed to see how stable the improved straightness methods performed, when placed in similar conditions.

The results show that lower levels of twist were found on studs sawn with a standard and individual pre-twist than on straight sawn studs. Conditioning the timber from 18% to 10% MC resulted in about the same absolute increase in twist for straight sawn and twisted sawn studs. Spring-back (difference in twist at 10% MC) was quite similar in all groups (Figure 13).

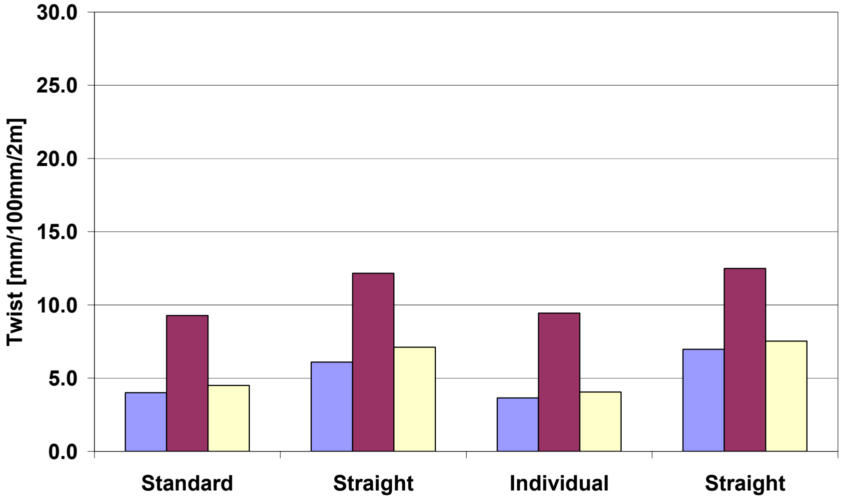


Figure 13. Absolute mean twist at 18% MC (first column in each group), at 10% MC (second column in each group) and at 18% MC (third column in each group). Each group of columns represents a treatment.

The percentage of studs that achieved the acceptance limit for twist was greater for the pre-twist sawn material than for straight sawn material (Table 5).

Table 5. Percentage of studs that met the acceptance value for twist at 15% MC after 3 months conditioning at 85% RH / 23 °C and after additional 3 months moisture cycles at 30% RH and 85% RH without any restraint.

Group	Studs passing limit at 15% MC after first cycle, %	Studs passing limit at 15% MC after 3rd cycle, %
Standard pre-twist	40.0	36.0
Straight	30.0	30.0
Individual pre-twist	48.0	46.0
Straight	26.0	22.0

3.2.4 Cost assessment

Introducing pre-twisting for small-diameter logs is a new concept. To the best of our knowledge, there are no commercial sawing machines capable of rotating a log during sawing, nor a feeding system that rotates a log during the sawing. The cost of a procedure of this kind is difficult to estimate. Producers of sawing equipment have development costs which would add an additional cost to the existing sawing or feeding equipment. This type of investment would be a one-off cost. This cost, interest rate, repayment period and other factors are shown in Table 6. The cost assessment has been made based on the assumption that sawn and dried timber production was 100 000 m^3/year, the price for studs which fulfil the requirement limit of 4 mm / 100 mm / 2 m for twist was 200 €/m^3 and the price for studs which do not fulfil this requirement was 140 €/m^3. The reduction in value due to limit for twist (Table 6) and the percentage of timber which passes this requirement at 18% MC is as follows:

– value reduction for conventional sawing = [1 – (0.32 + 0.68 x 140/200)] x 100% = 20.4%

– value reduction for pre-twisted sawing = [1 – (0.6 + 0.4 x 140/200)] x 100% = 12%.

Table 6. Comparison between studs (50 x 100 mm) of Norway spruce sawn either pre-twisted or straight (conv. sawing) and dried in a conventional kiln to 18% MC.

Norway spruce **studs 50 x 100** mm	Conv. sawing 18%	Pre-twisted 18%
Initial data		
Production capacity, m^3/a	100000	100000
Acquisition cost, million Euros		0.5
Repayment period, a	12	12
Interest rate, %	6	6
Price of heat, €/kWh	0.02	0.02
Price of electricity, €/kWh	0.04	0.04
Timber value, €/m^3	200	200
Drying time, h	100	100
Heat consumption, kWh/m^3	300	300
Electricity consumption, kWh/m^3	25	25
Labour and maintenance costs, €/m^3	2	2
Value reduction due to limit for twist, %	20.4	12.0
Costs, €/m^3		
Capital costs, rotation of logs	0.00	0.60
Interest payable, timber during drying	0.14	0.14
Energy	7.00	7.00
Labour and maintenance	0.00	2.00
Value reduction due to limit for twist	40.80	24.00
Total €/m3	***47.9***	***33.7***
Change conv. saw > pre-twisted saw, %		**–29.6**

Table 6 shows that the twisted-sawing of logs is economical. The saving is almost 30% due to large improvements in straightness and assumed acquisition costs of half a million euros. Even if the acquisition cost of the feeding equipment were six million euros, the saving would still be around 16%. When studs were conditioned without any restraint to 10% moisture content, the improvement was much smaller (potential gains were less) at 0.7%. The main reason for this outcome was that pre-twisting in this project was not optimised for this low moisture content.

3.3 Pre-sorting of timber according green moisture content and density

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Brookhuis Micro-Electronics BV, Netherlands

3.3.1 Method

Pre-sorting timber on the basis of moisture content and density allows the timber to be separated into drying groups with similar drying characteristics. This offers better drying economics through optimised drying times, and a more homogeneous moisture content throughout the pack after drying. Distortion is therefore reduced by avoiding over drying.

Pre-sorting of green material will be of particular interest to sawmills producing large quantities of stock with standard dimensions, but will be of less interest to those producing specific sized sawn timber cut to order. The material stream can be split into a dry and a wet fraction for separate drying for standard sized stock only. For randomly sized sawn timber, splitting up an order is not a viable option.

Currently, no reliable and cheap method of measuring moisture content and density of green timber is available. Resistance type MC-meters are only suitable for moisture contents below 25%. Above fibre saturation point, electrical resistance changes with increasing MC are very small.

Capacitance type meters are more suitable as they measure the total amount of water in wood. In order to accurately calculate the MC of “green” timber, the density of the timber must also be known. Brookhuis Micro-Electronics has been manufacturing moisture meters and similar equipment for a number of years. As part of the companies research and development programme, it was decided to develop an in-line moisture metre which had the ability to read the moisture content of freshly sawn material. This would allow the material to be split into groups with similar green moisture contents in order to dry the timber more effectively and efficiently.

3.3.2 Results

A sawmill in Austria was selected for the initial industrial trials. An FMI in-line moisture meter (Figure 14) was installed into the green sorting line where a group of scientists and student workers from Brookhuis, along with the industrial partner carried out a series of tests. Brookhuis evaluated the in-line MC data on the green material in comparison to with the results obtained from oven dry samples removed from each green board as the in-line meter generated a reading. On completion of the assessment at the sawmill the material was transported to Hamburg (BFH), where drying experiments were undertaken. The material was split into 3 fractions, a) < 22%, b) 22–35%, c) > 35%, and each was dried separately. It can be seen from the fraction limits that only the last group was green and the other two groups pre-dried. The results were as expected. Drier (pre-dried) fractions required less time to dry than the wetter fractions. The results for deformation, however, were not so clear cut.

Figure 14. FMI Sensor of capacity type moisture content meter manufactured by Brookhuis.

More than 300 boards, sufficient for 2 measuring experiments were measured. The first test run was analysed using the oven-dry method to assess the correlation between FMI in-line moisture meter readings and actual moisture content (Figure 15).

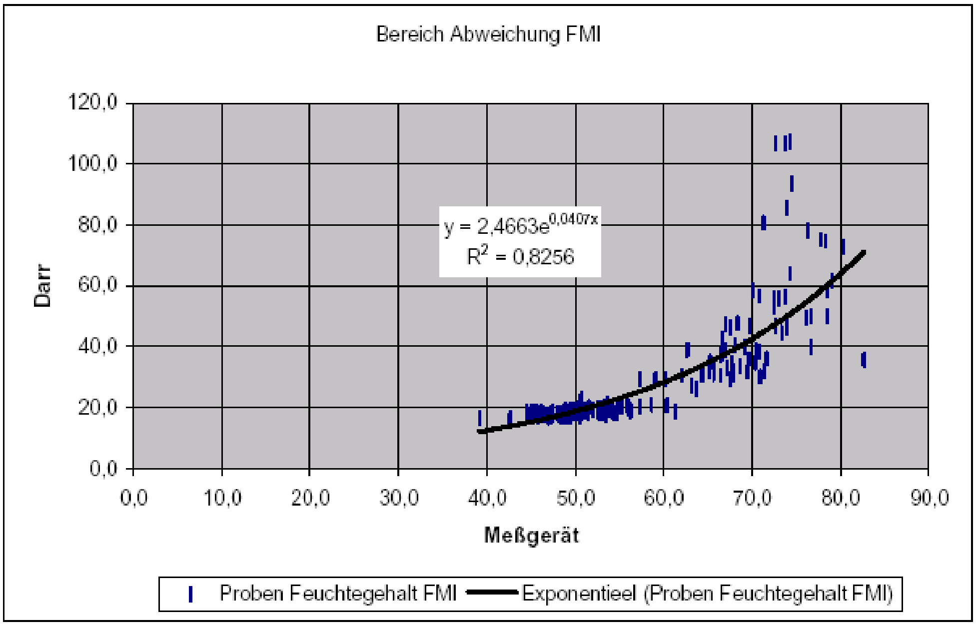


Figure 15. Correlation between electrical MC measurement and oven dry method in the first industrial test.

The accuracy of the MC measurement was not high enough to sort the timber into drying groups. A density measuring device had to be added to the system to enable further research work to be undertaken and obtain more accurate results. On the other hand low density sapwood has often high initial MC. The proportion of heartwood present in the timber should also be measured, as drying of the timber shipping dry can result in the sapwood and heartwood having a similar MC despite a large difference in their initial moisture contents. Further work is on-going to find out proper criteria to divide green timber in groups with similar drying charasteristics.

3.4 Green gluing & re-engineering

Geoff Cooper & Keith Maun
Building Research Establishment, UK

3.4.1 Method

The principle objective of this study was to reduce or eliminate excessive distortion which occurs on spruce battens cut from the centre of the log. Previous work undertaken on UK spruce at BRE has shown that battens containing the pith have a tendency to distort to a far greater degree than those cut further from the pith.

The excessive distortion exhibited by boxed-pith battens (Figure 16) can be reduced by careful kiln drying and the application of top-weight. Even so, the levels of distortion, especially twist, in a large percentage of kiln dried battens containing the pith, exhibit twist levels well above the acceptance limit of 4 mm / 100 mm / 2 m (Figure 17).

In order to prevent a large percentage of boxed-pith battens being consigned to the reject bin, BRE put forward the idea of utilising a moisture insensitive adhesive (an adhesive which can be used on “wet” timber) in conjunction with a re-engineering process (splitting battens along there length and re-engineering whilst “green”). It was hoped that that re-engineering boxed pith battens with a moisture insensitive adhesive would result in battens drying much straighter than normally dried material. This material could then be used in higher quality applications where distortion must be kept to a minimum.

The work was split into two stages. The first stage involved selecting a quantity of “green” boxed-pith battens and re-engineering them in different orientations to identify which “set-up” showed the best improvement in distortion over solid control samples. The second stage involved selecting a larger number of battens and re-engineering them in the best orientation to verify the results obtained from the first stage of the work.

Figure 16. Boxed pith batten.

Before the initial work was undertaken, a small trial was carried out to modify the normal sawing pattern used in the UK to deliberately produce a boxed pith batten from each log sawn. This process proved much easier than first thought. The trial being successful in producing and separating the boxed pith battens from the remaining material.

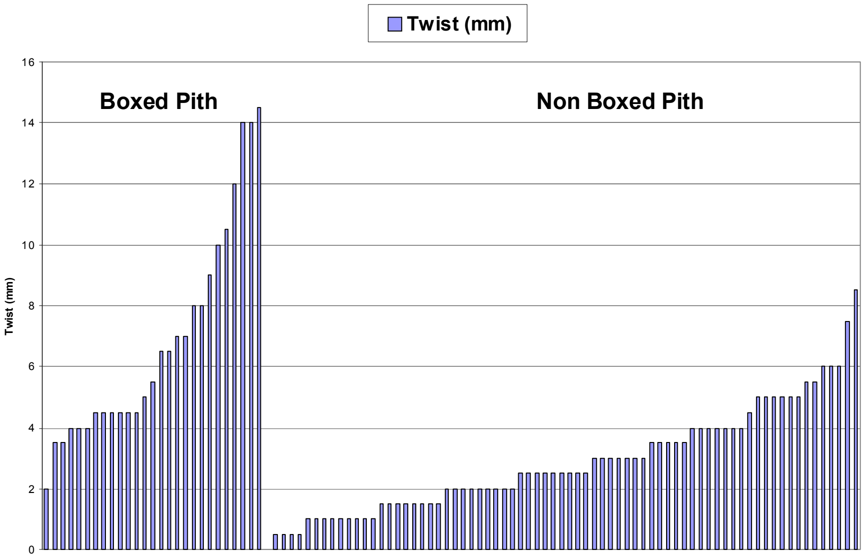


Figure 17. Twist o f boxed-pith and non-boxed-pith battens after drying.

This initial trial produced a number of findings:

- To modify the sawing pattern of a log to force a boxed pith batten, a reduction in log utilisation of approximately 1% (overall for battens and boards) should be expected.
- The boxed pith conversion may be applied to all logs, or the mill may choose to sort the logs by diameter and only cut boxed pith battens for re-engineering from larger logs. This would depend upon the customer requirements dictating the sizes to be sawn.
- The central boxed pith battens should be cut approximately 5 mm oversize.
- In order to ensure all the boxed pith battens are forwarded to the same collection bin, the drop sorter should be set-up to select oversized battens based upon thickness. This will isolate all of the boxed pith battens and direct them to the specified bin ready for re-engineering.

The first stage of the re-engineering process consisted of assessing over 200 battens, using two types of moisture insensitive adhesive, on 9 different re-engineered orientations. Sets of boxed pith battens were split along there length, the outer board surfaces being lightly planned and bonded together in one of the selected orientations. The battens were then dried using a medium temperature conventional kiln schedule similar to that used for drying normal material of the same species.

In this best practice guidance document, only three orientations bonded with one type of adhesive (polyurethane) will be described, although the results indicated that both types of adhesives tested performed equally well. The orientations not included in the results performed worse than the three being described here.

Three main orientations were assessed (Figure 18). Back to back (BB), back to face (BF) and face to face (FF). An equal number of solid boxed pith reference pieces were also assessed.

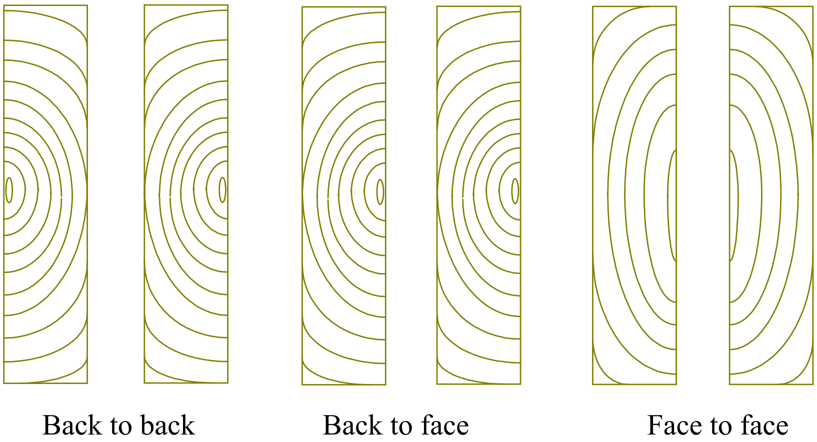
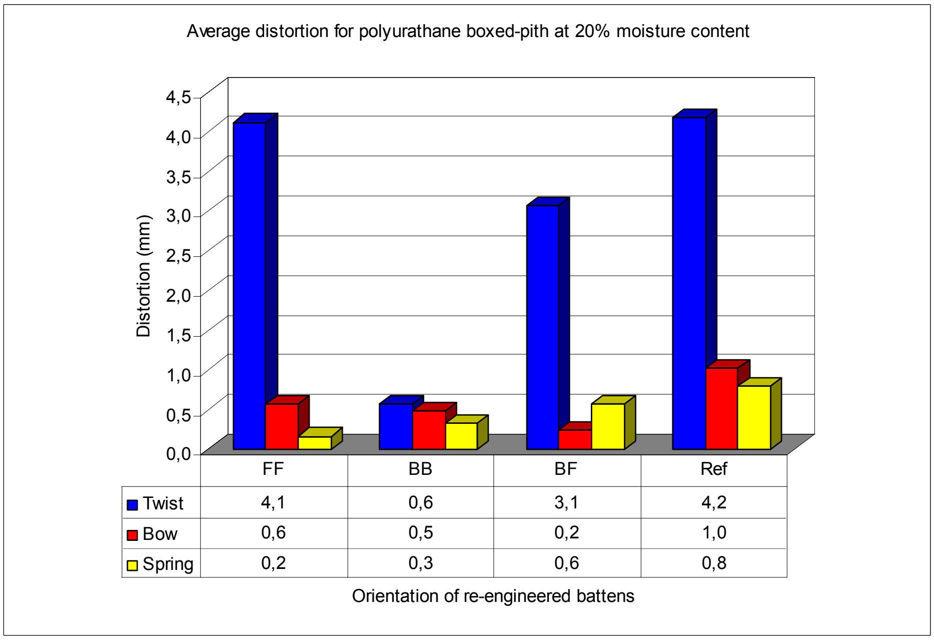


Figure 18. Re-engineering lay-up options.

3.4.2 Results

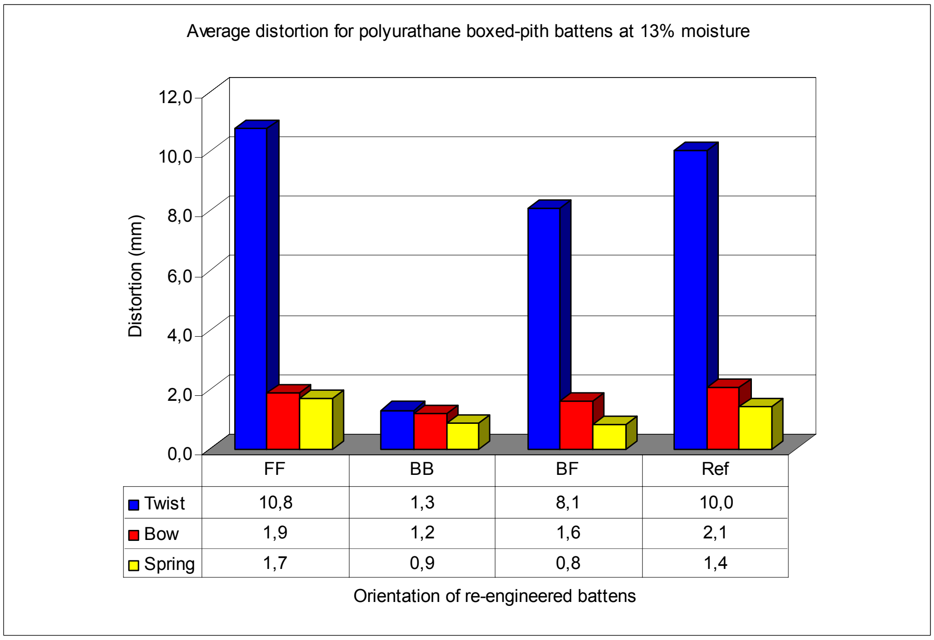
When all the selected battens were re-engineered, the timber was dried to a target moisture content of 20% using a medium temperature kiln schedule. After drying, twist, bow and spring was measured. These measurements were repeated after additional conditioning of the re-engineered battens to 13% MC. The results from the three different orientations and controls are shown in Figures 19 and 20.



	FF	BB	BF	Ref
🟦 Twist	4,1	0,6	3,1	4,2
🟥 Bow	0,6	0,5	0,2	1,0
🟨 Spring	0,2	0,3	0,6	0,8

Figure 19. Deformations of re-engineered battens after drying to 20%.

The results shown in Figure 19 clearly indicate that re-engineering "green" boxed pith battens in a "back to back" orientation prior to kiln drying significantly reduces distortion when compared to the solid reference material and battens re-engineered in a "back to front" and a "front to font" orientation. Further conditioning of the battens down to a moisture content of approximately 13%, shows dramatic increases in distortion in the reference battens and those re-engineered in a "back to front" and a "front to front" orientation compared to those re-engineered in a "back to back" orientation (Figure 20).



	FF	BB	BF	Ref
🟦 Twist	10,8	1,3	8,1	10,0
🟥 Bow	1,9	1,2	1,6	2,1
🟨 Spring	1,7	0,9	0,8	1,4

Figure 20. Deformation of re-engineered battens after drying to 20% and additional conditioning to 13%.

Stage 2. Verifying the initial results

Due to the relatively small number of battens used to test each orientation in Stage 1, further work was undertaken on a larger sample of re-engineered boxed pith battens, in a "back to back" orientation, along with the associated reference pieces (Figure 21).

Figure 21. Boxed pith batten, split along its length & bonded in a "back to back" orientation.

50 "green" freshly processed spruce boxed pith battens (50 x 100 x 4800 mm) were selected from the green chain at one the UK's large softwood sawmills. The battens were tagged with plastic numbers and cross-cut into two sets of 2400 mm length material. Every other batten from each set was separated out to create two almost identical groups of battens. The first set of battens was lightly planed on their broad surfaces, sawn along their length, and bonded in a back to back orientation with a moisture insensitive polyurethane adhesive. The battens were then pressed for 30 minutes in a vertical press (Figure 22).

Figure 22. Re-engineered battens being pressed.

After pressing, both the reference material and re-engineered boxed pith battens were dried (without restraint) to a target moisture content of 14% using a medium temperature kiln schedule (Figure 23).

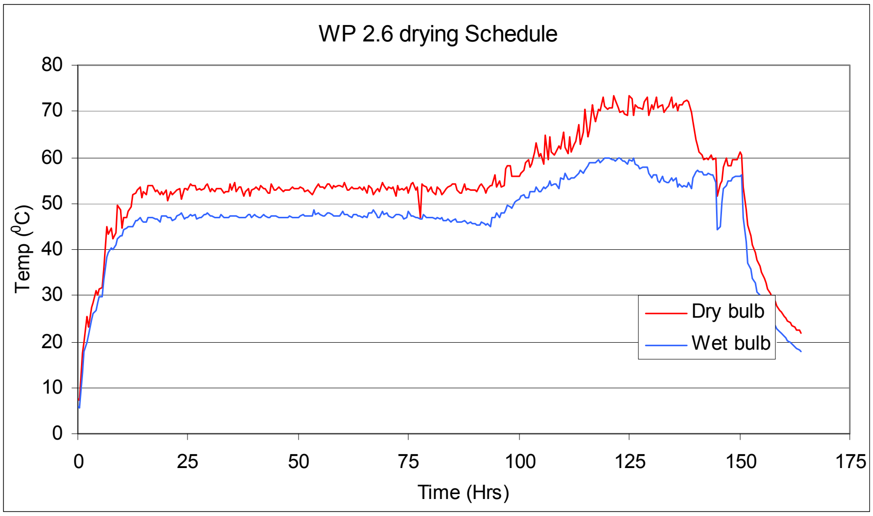


Figure 23. Medium temperature kiln schedule.

After drying was completed, the battens were measured for levels of twist, bow, spring and moisture content. Figure 24 shows the average values for each of the three types of distortion, and Figure 25 presents the individual twist values on both the reference battens and the re-engineered battens after drying to an average moisture content of 14% and sorted in reducing levels of twist. These results verify previous results, demonstrating that re-engineering in a “back to back” orientation significantly reduces twist when compared to reference material taken from the same batten. A difference between the current assessment and the previous work was a lack of improvement in the levels of bow and spring. On further investigation, it was found that much of the material used in this part of the work contained relatively high levels of compression wood. This is shown by the higher average values for bow and spring in both the reference and re-engineered material (Figure 24) in comparison to material measured in the first assessment (Figure 20).

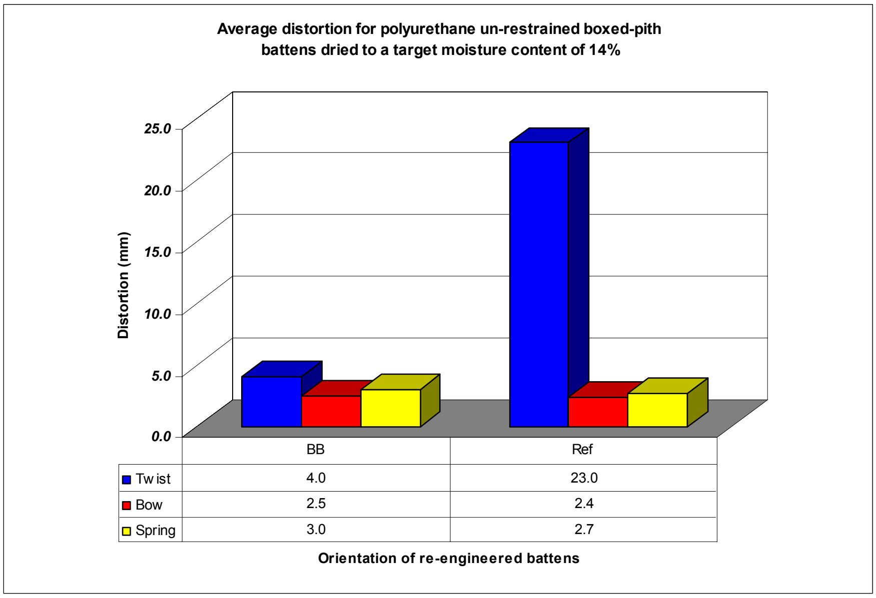


Figure 24. Deformation of "back to back" orientation re-engineered & reference battens after drying (without restraint) to 14%.

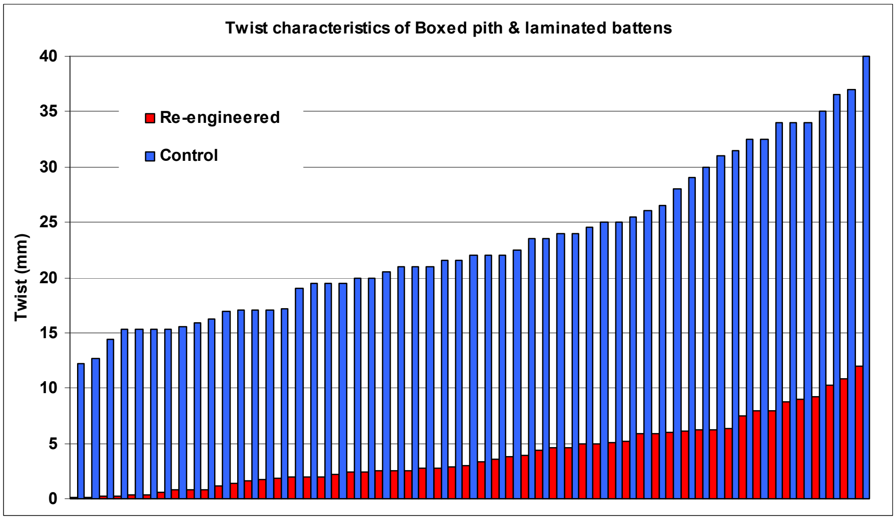


Figure 25. Twist characteristics of boxed pith battens bonded in a back to back orientation and reference solid sections dried without restraint.

3.4.3 Straighness in-service

The aim of this assessment was to determine whether the improvements shown in distortional characteristics from the "green" gluing and laminating of boxed pith studs remained stable when exposed to end-use environments. Unrestrained laminated and reference battens were subjected to several different moisture cycles over time and allowed to equilibrate during each cycle. This test was particularly important to establish whether experimental battens remained fit for purpose during construction and in use. The laminated and reference battens were conditioned in three different environments. Temperature and humidity were set to ensure batten moisture contents equilibrated to 18%, 10% and 18% respectively. The battens were then assessed for distortion at each equilibrium stage.

Results indicate that the mean twist exhibited by the green-glued re-engineered material during the cycling of conditions was negligible when compared to the twist exhibited by the boxed pith reference battens (Figure 26). Both materials were dried unrestrained.

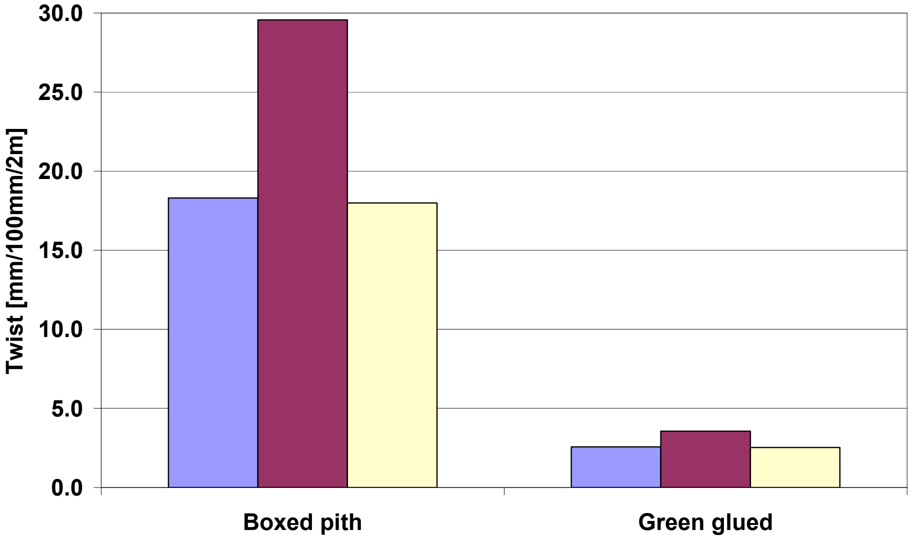


Figure 26. Absolute mean twist at 18% MC (first column in each group), at 10% MC (second column in each group) and at 18% MC (third column in each group). Each group of columns represents a treatment. The material has been hanging unrestrained in climate rooms.

The percentage of re-engineered studs that fell within the acceptance limit for twist at each stage of the cycling process was very high for the green-glued studs. However, none of the reference material incorporating boxed pith met the acceptance limit for twist at any stage of the cycling process (Table 7).

Table 7. Percentage of studs that met the acceptance limit for twist at 15% MC after 3 months conditioning at 85% RH / 23 °C and after additional 3 months moisture cycles at 30% RH and 85% RH without any restraint.

Group	Studs passing limit at 15% MC after first cycle, %	Studs passing limit at 15% MC after 3rd cycle, %
Boxed pith	0.0	0.0
Green glued	70.9	72.7

Results indicate that boxed pith battens glued in a back to back orientation prior to drying remain significantly more stable during changes in environmental conditions than boxed pith control battens (Table 7). These results are extremely encouraging considering that the drying of the green glued laminated battens and the in-service assessment were undertaken with no top-loading or restraint of any kind.

3.4.4 Cost assessment

Introducing the re-engineering and green bonding method into a sawmill environment requires changes in sawing practices, sawing set-ups and log sorting diameter classes. The cost of these one-time changes would not be high. The investment in setting up a re-engineering line to include processing, gluing and curing introduces additional operations and their costs are given later in this section. Considerable advantages can be gained by re-engineering boxed pith battens (Figure 24). All 50 boxed pith reference battens would be classed as rejects at the machine stress grading stage (visual override criteria) due to excessive distortion (twist). In comparison, only two of the re-engineered samples would have failed at this stage. It must be stressed that all the battens in this workpackage were dried without any form of top-loading. It is believed that the addition of top-loading would further reduce the incidence of excessive twist in both the laminated and boxed pith battens. A sawmill using this process to market re-engineered boxed pith battens would find it advantageous to refer to them as special ("straight") studs, rather than include this material in the general construction material grades. In doing so, the product could realise a greater market value and potential, thereby covering the costs of re-engineering and ensuring a significant profit margin.

Using a cost benefit analysis tool developed at BRE, the cost of producing re-engineering boxed pith battens was calculated. The input parameters included machine capital costs, running costs etc. Table 8 provides a list of items included in the cost of introducing a new re-engineering line into an existing sawmill.

Table 8. Associated costs for a "green" gluing & re-engineering line.

Item	**Cost**
Basic data:	
Re-saw	28480
Planer	85440
Press	113920
Sum of extra investments (€)	227840
Interest rate (%)	
Depreciation time (a)	5
Handling and maintenance costs (€/day)	226
Floor area cost (€/day)	24
Price of electricity (€/day)	45.11
Utilisation factor	0.7
Adhesive costs (€/kg)	4.4
Spread rate (gms/m^2)	150
Quantity of re-engineered material produced (m^3/day)	50
Cost of re-engineering (€/m^3)	**29.9**

Taking into account the purchase, housing and operation of a new re-engineering line capable of producing 50 m^3 of re-engineered boxed pith material per day (8 hour shift), each m^3 of re-engineered material would cost £21 (€30) to produce. This cost would of course be in addition to normal processing and drying.

After re-engineering and green bonding, the material would re-enter the normal processing line prior to being dried.

A further one-off cost would be in certifying the new product as fit for purpose or, producing a new machine grading setting to deal with the new product.

3.4.5 Cost benefits

Although this process requires a certain capital investment to purchase machinery and install an extra line to the normal sawmill production, it will produce savings on rejects, increase the quality perception of sawn material and provide a new value added product to the product line. During the normal drying process between 5% and 10% of each kiln load will be classified as rejects. Green gluing and laminating the boxed pith portion of a kiln load would considerably reduce these reject figures.

Laminating costs could be reduced further by increasing the throughput of boxed pith material through increased capacity of the laminating line.

3.5 Top loading

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Norwegian Institute of Wood Technology, Norway

The main objectives of this section of the STRAIGHT project were

- to develop new approaches for top loading and to determine their effects on the deformation of sawn timber during drying
- to provide the basis for the design of commercial systems for top loading to reduce deformation during drying.

Tests have been conducted by NTI, BFF, BRE and VTT. NTI has also used variable top loading, less loading when the timber was wet, to avoid crushing the timber under stickers, and higher loading when the timber was getting dry. Other partners have used different constant top loads during drying and the tests have been carried out in both laboratory and industrial kilns.

3.5.1 Method

The final distortion of dry timber can be reduced by restraining material during the drying process. Top loading of the kiln load is a successful method that can be used to keep timber straight. However, spring-back may lessen the benefit of this method in many cases. More permanent deformation reductions can be achieved using optimised drying and conditioning schedules.

Top loading is the most effective method of reducing distortion which develops in the uppermost layers of the drying stack. Battens deeper into the stack are held flat under natural restraint from the weight of the top layers of timber. The optimum top load for keeping the timber straight during drying depends on the wood species and its mechanical properties (modulus of elasticity and creep behaviour), dimension, drying schedule and drying pre-treatment.

Timbers stiffness is affected by its dimension. Thin, wide boards require far less restraint to keep them flat against the stickers than thick square-sectioned beams. Broad battens have high stiffness in the direction of their width and will tend to spring. To avoid spring, the top load should be high enough to enable friction forces to clamp the battens in place and restrict movement. Wide battens are usually sawn symmetrically and the bowing forces counteract each other. This leads to straighter timber (less spring) compared to narrow battens dried without top loading. Live sawing and drying is traditionally used for joinery material mainly to minimise deformation.

Analogously, side loading (clamping) prevents spring. In a normal kiln, it is not so easy to arrange side supports for the stack and side pressure would need to be maintained as the timber shrinks.

3.5.2 Results

Top loading is beneficial in reducing deformation. It is especially effective in reducing twist levels, and to a lesser extent bow and spring.

The optimal top load depends on the timber species, timber dimensions, target moisture content, height of timber stack and the number of stickers used per layer. Limiting factors of the technique is the crushing strength of timber under stickers, top loading mechanism and kiln construction.

The minimum requirement for effective top loading is that it should keep the timber straight during the whole drying process. In the STRAIGHT project, the species assessed was limited to Norway spruce and Sitka spruce (50 x 100 mm). On the basis of the results obtained, recommendations for successful top loading of different species and dimensioned timber could be drawn.

Deformation of timber under top loads is affected by the number of stickers used and the coefficient of friction between the timber and stickers, especially with spring (less restricted movement in the side direction), where the timber shrinks and gaps between battens form. Only when there are sufficient frictional forces between stickers and timber, can this be avoided. When very few stickers were used, the battens were able to deform between stickers. Bow is particularly common where large distances between stickers occur.

3.5.2.1 NTI Results: Effect of top loading level

NTI analysed the effect of top loading level on the development of distortion and the percentage of timber to fall within the acceptable distortion limits. Figure 27 presents the type of system used during assessment at the Haslestad sawmill. The same kind of system was also used at the Begna sawmill, where NTI performed tests.

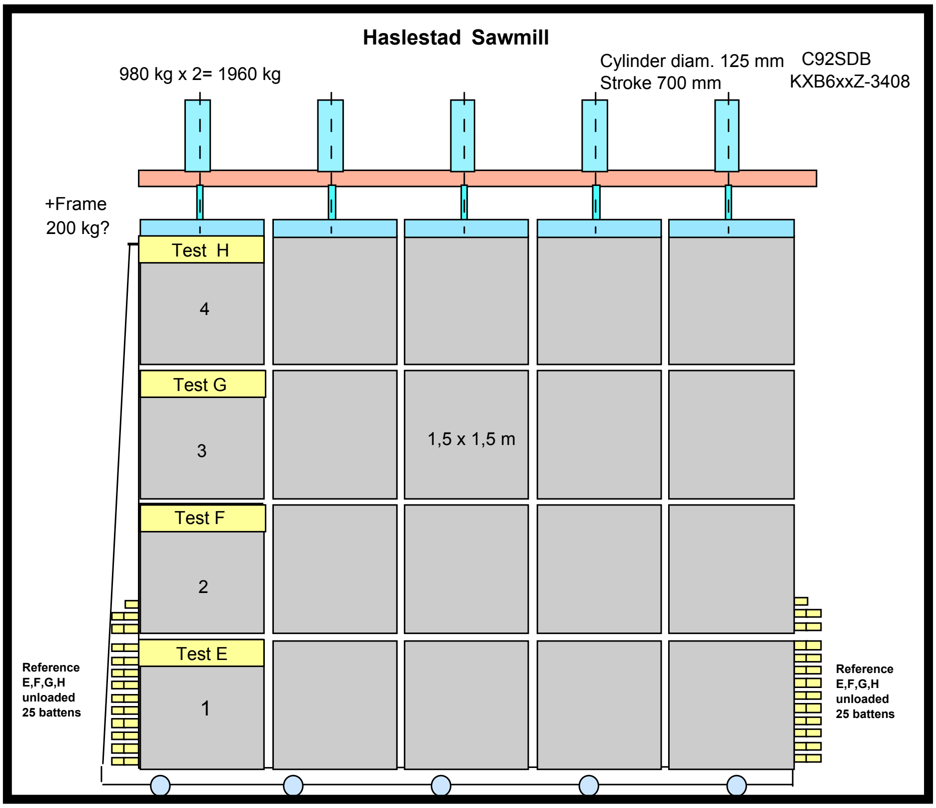

Figure 27. Drying charge at Haslestad sawmill. Test material was located at top of every package on one side of the kiln charge. Reference material was laid unrestrained on stickers on both sides of kiln load.

Moisture content (MC), board thickness and grain angle were measured before drying. Measurements of grain angle were carried out using the S-GAG device shown in Figure 4. MC, twist, bow and spring were measured on each batten where it had been positioned under the last sticker in the layer and the free end of the batten. (In many Northern European countries, the kiln charge is made up of different length battens within a pack. This results in many boards being unsupported at one end due to the piece being slightly too short to reach the next sticker.) Twist direction, sticker marks, annual ring width and the length of free end were also measured after drying.

Figure 28 shows the effect of top loading on twist after drying.

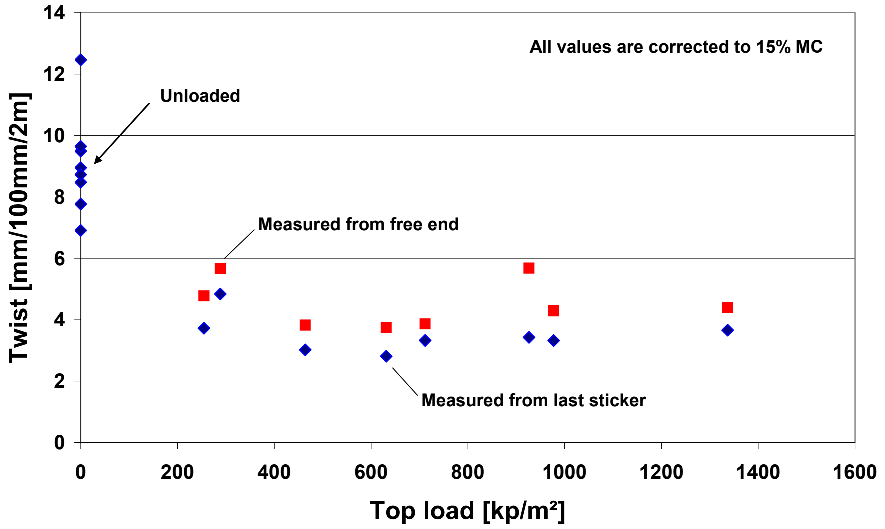

Figure 28. Degree of twist (mm / 2 m / 100 mm) of 50 x 100 mm unloaded and loaded battens measured from last sticker and from free end.

Corresponding results for bow and spring are shown in Figures 29 and 30.

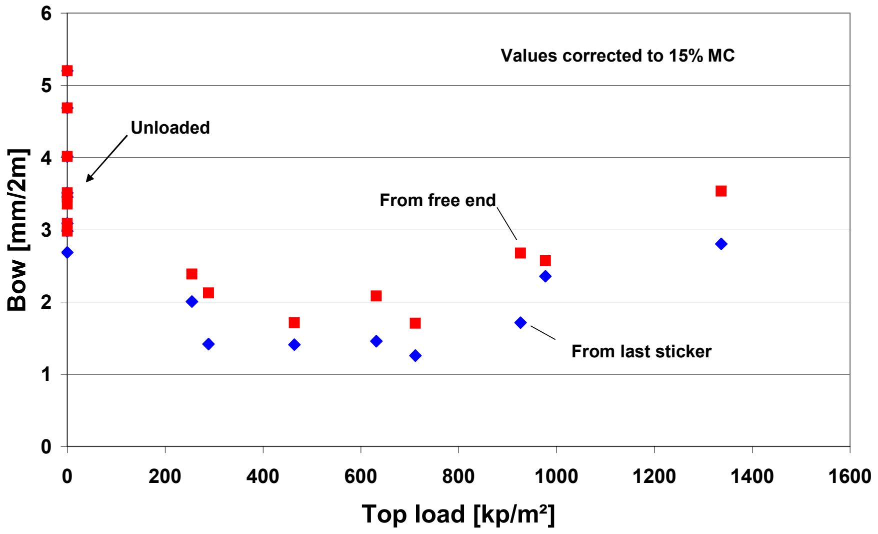

Figure 29. Degree of bow (mm / 2 m) of 50 x 100 mm unloaded and loaded battens measured from last sticker and from free end.

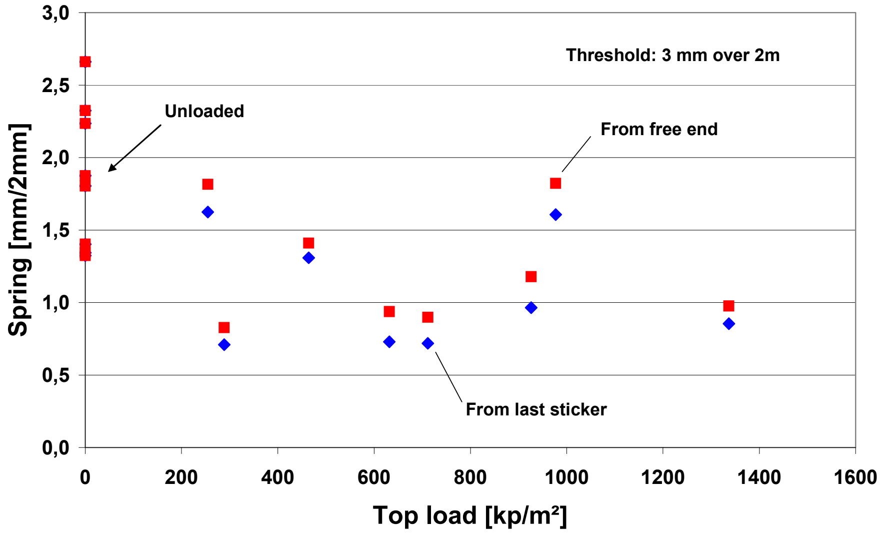

Figure 30. Degree of spring (mm / 2 m) of 50 x 100 mm unloaded and loaded battens measured from last sticker and from free end.

The percentage of dried timber that met the acceptance limit for twist of 4 mm / 2 m / 100 mm is presented in Figure 31.

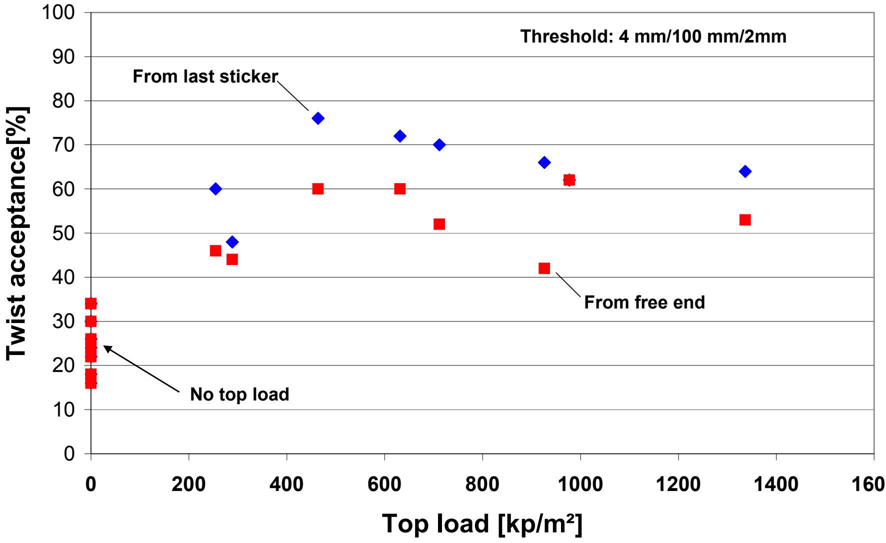

Figure 31. Influence of top load on the acceptance levels of twist (industrial tests). 50 x 100 mm^2 Norway spruce after drying. Acceptance levels for twist 4 mm / 2 m / 100 mm or less.

The conclusion from the industrial tests was that top loading had a substantial influence on twist, bow and spring, with the greatest influence being on twist. For example, the reduction in twist, bow and spring for one test run with loaded and unloaded battens is shown in Figure 32 and shown visually in Figure 33.

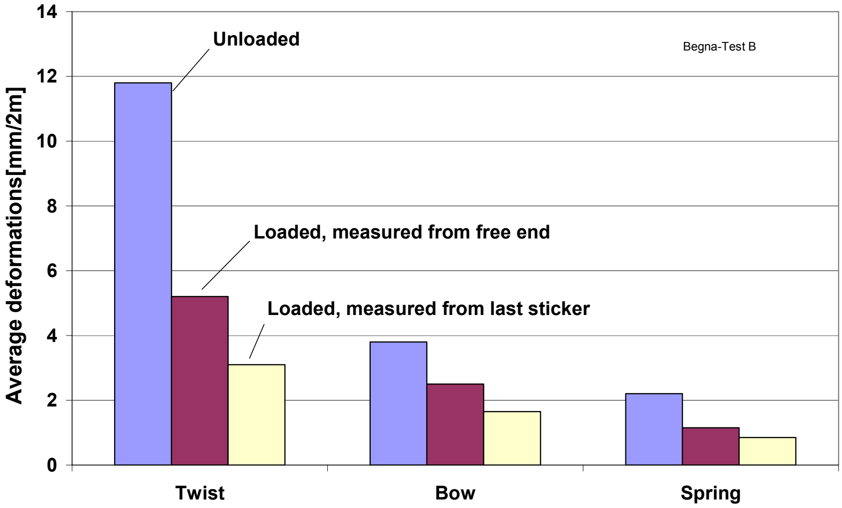

Figure 32. Influence of top load on average twist levels during industrial tests. The twist is measured over 2m from the last sticker and over 2m from the free end between stickers. Norway spruce, 50 x 100 mm.

Figure 33. Unloaded and loaded battens after drying.

Sticker marks

The influence of top load on sticker marks was of interest. Deep sticker marks could be termed a defect, and as such, could limit the amount of top pressure applied (Figure 34).

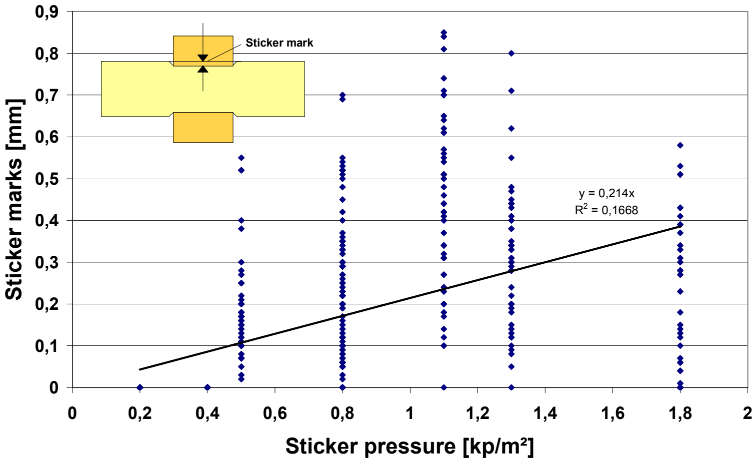

Figure 34. Influence of sticker pressure on sticker marks.

The effect of top load and sticker marks was not clear. Although sticker marks were influenced by the amount of top load, the marks observed were not considered to be a problem at either of the sawmills, even at the highest top load pressures. Sticker marks will be most pronounced in the pith area, and at the edges of the back side of battens due to shrinkage and subsequent cupping. These areas tend to be planned, and therefore, the sticker marks would only to a little degree influence final yield. In thinner boards, cupping forces will be too small to have a similar effect on yield.

The effect of batten thickness on the sticker marks was also tested. Results showed a small, but significant correlation existed between increased sticker marks and thicker battens. An analogous test of the influence of annual ring width showed no correlation.

The overall conclusion from these tests was that a clear correlation between top load weight and resulting distortion does exist. Reductions in twist, bow and spring levels were found with increased top load up to a threshold level. For Norway spruce battens of dimensions 50 mm x 100 mm, the tests showed an “optimum” load of approximately 600 kg/m². This load was sufficient to keep battens straight during drying.

The effect of the extra top load was most significant in the top layers of the upper package and gradually decreased with increasing distance from the top to the base. No further benefit was achieved from adding extra top load, when the weight of the timber itself was sufficient to keep the timber straight. This effect is shown for twist in Figure 35.

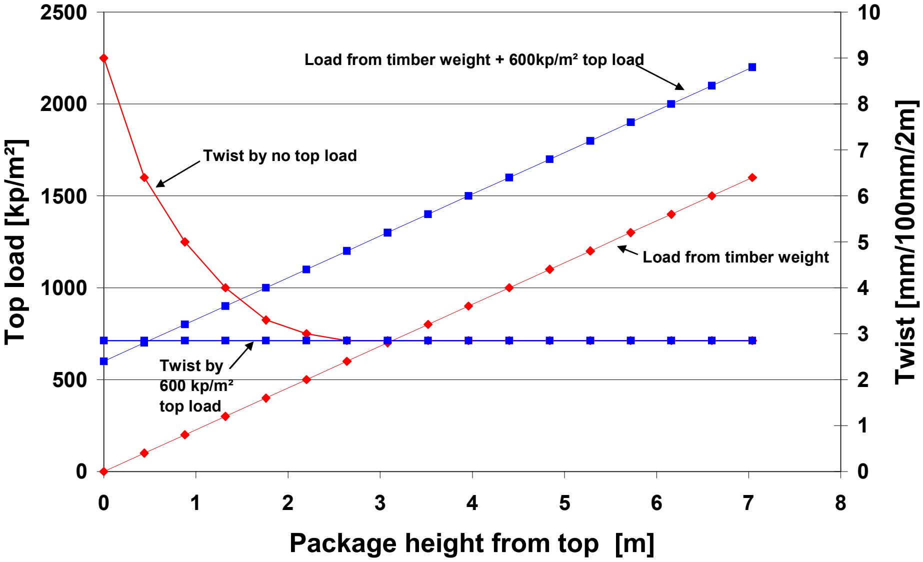

Figure 35. The influence of top loading and no top loading on the twist in different package heights from top.

3.5.2.2 Results of VTT: Effect of grain angle and top loading on deformations

During industrial tests carried out by VTT at the Kotka Sawmill of Stora Enso Timber Ltd, the effect of grain angle and top loading on deformation was studied. Different top loading groups were located in different positions in the kiln charge (Figure 36).

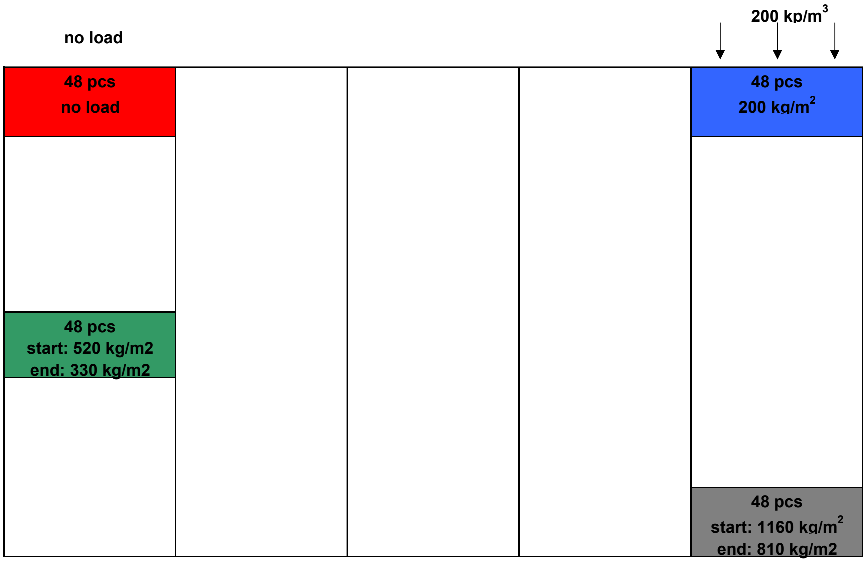

Figure 36. Top loading groups in drying assessments at Kotka sawmill.

The effect on twist of top loading and grain angle is illustrated in Figures 37 and 38.

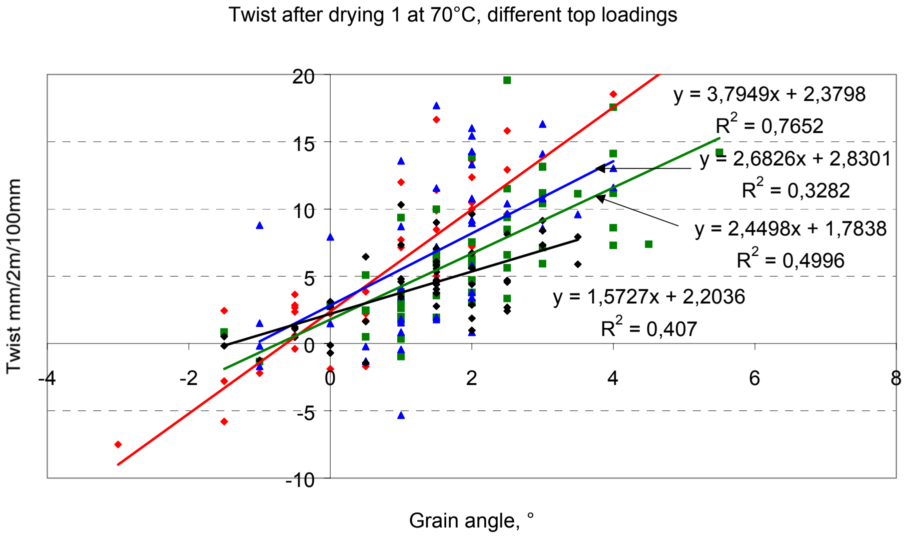

Figure 37. Effect of top loading (see Figure 36) and grain angle on twist during industrial drying at 70 °C.

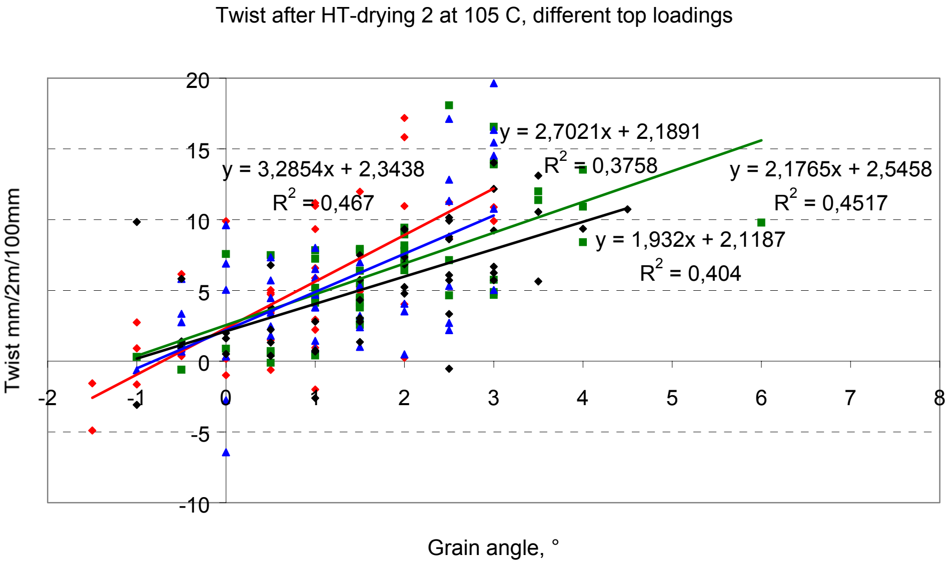

Figure 38. Effect of top loading (see Figure 36) and grain angle on twist during drying at 105 °C.

Figures 37 and 38 indicate that increasing the amount of top loading reduced the levels of twist. From assessments, drying temperature did not appear to have a significant effect on batten deformation. The figures shown confirm that grain angle was the main cause of twist in timber.

For industry, it is important to know how much of the timber fulfils their quality requirements, i.e. material suitable for building and further processing. Figure 39 shows the percentages of timber that met the acceptance limits for twist, bow and spring after industrial drying tests at the Kotka sawmill. All distortion values were corrected to a 15% moisture. It must be noted that measurements were made after 2–4 weeks storage in an indoor climate. The spring-back effect which occurs after drying may have increased the deformation values from those produced immediately after drying. This would be a common situation occurring in mills carrying out any further processing.

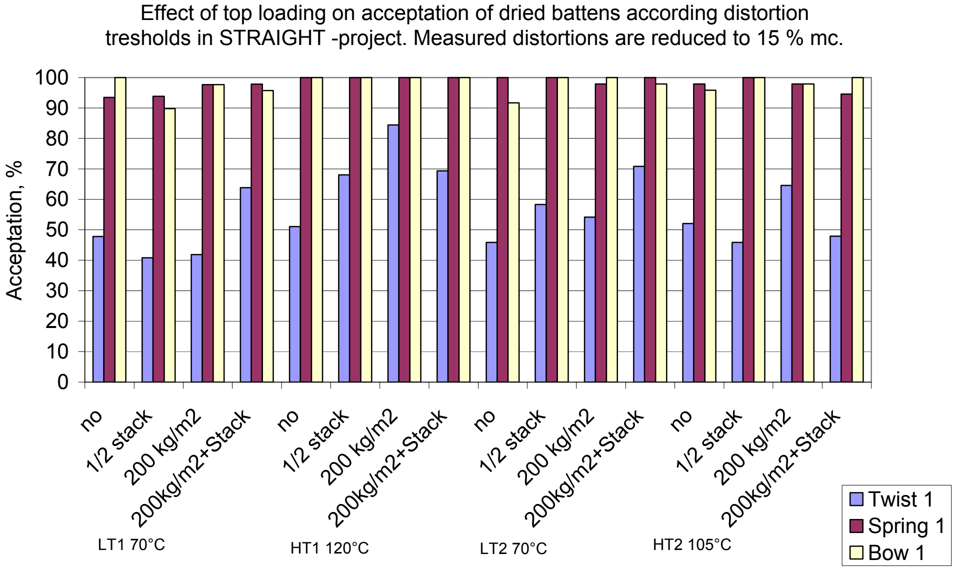

Figure 39. Acceptance levels of twist, spring and bow according to rules adopted in the STRAIGHT project (see Table 1). In every drying charges there were three top loaded and one unrestrained dried group. Measured distortion values were corrected to 15% moisture content.

It can be seen that in most cases bow and spring achieved the required acceptance limits. However, battens (spruce) sawn from small diameter logs, often failed to meet the required acceptance limit set for twist

In conclusion, suitable levels of top loading reduced deformation. For 50 x 100 mm battens of Norway spruce, a top load level of 500 kp/m^2 was sufficient to reduce distortion to a minimum. However, the spring back effect occurring after drying led to increased twist which counteracted some of the improved quality achieved by top loading.

3.5.3 Summary and discussion

The main objective of the assessment was to assess the correlation between top load and distortion. The work undertaken concentrated on determining the levels of distortion that occurred in relation to different top loads. A range of top loads were used in the drying tests, from zero to a very large load of 3418 kg/m^2.

Figure 40 shows the influence of top load on twist for all 107 results. The large spread of results is indicative of a large dependence on parameters such as grain angle and other growth characteristics.

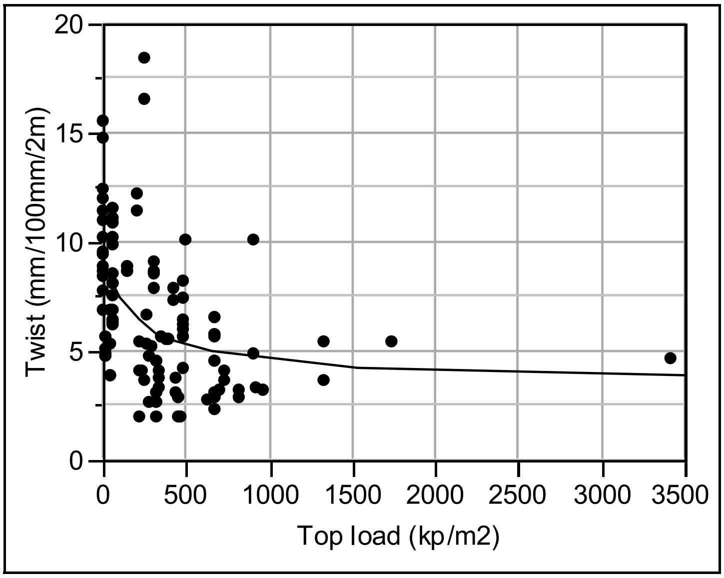

Figure 40. Influence of top load on average twist for all tests.

As seen in Figure 40, the largest improvements of twist were achieved using top loads between zero and 600 kp/m².

There was a steep reduction in the twist when increasing the top load from zero to approx. 600 kp/m². From this level onwards, the gain was marginal and probably less economically justifiable.

Whereas top loading has a significant effect on reducing levels of twist, it is difficult to find any correlation with improvements in spring. Figure 41 shows a combination of results obtained from BRE, NTI and VTT which show spring values under different top loads.

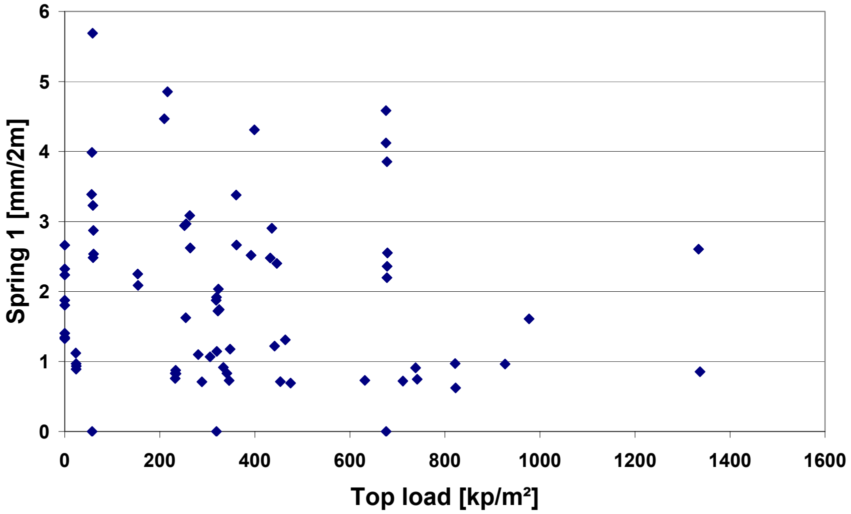

Figure 41. Influence of top load on average spring levels (BRE, NTI, VTT).

Figure 42 shows results of measurements of bow under different top loads. The plot shows average levels of bow from assessments at BRE, VTT and NTI. Results indicate a reduction in bow with increased top load up to approximately 400 kp/m². Above this level, bow appears to increase.

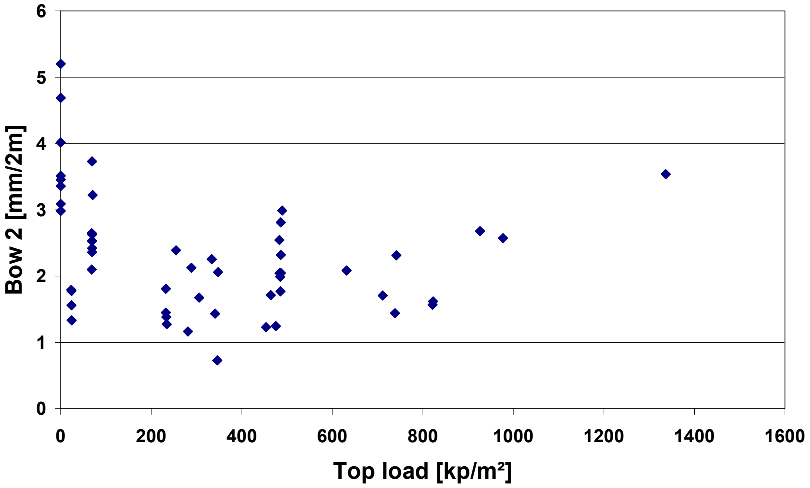

Figure 42. Influence of top load on average bow (BRE, NTI, VTT).

3.5.4 Conclusions

Top loading can be used successfully to reduce twist and bow in sawn timber. The highest levels of reductions were found to occur mainly in twist, slightly less so in bow, with seemingly little effect occurring on spring.

The recommended top load, sufficient to keep the battens straight during drying, was 600 kp/m². An increase in the top load above this level only produced a marginal reduction in the distortion. For bow, a further increase in the top load, in combination with inaccurate sticker and support positioning, led to a loss of the benefits of reduced distortion. Precise alignment of the stickers and supports would improve the benefits when large top loads are used.

An important observation from all the tests was the rapid decrease in deformation at the lightest top load application. This indicates that even a relatively small top load has a considerable influence on deformation. A top load of 300 kp/m^2 (half the optimum load) produced 80% of the distortion reduction achieved at the optimum load. The optimum top load, from an economic perspective, is likely to be lower than the technically observed optimum load of 600 kp/m^3.

3.5.5 Recommendations

3.5.5.1 Top loading design

There are two different ways of applying the top load:

- using concrete (or another material) blocks laid on top of the upper packages (Figure 43)
- using pneumatic or hydraulically operated frames to place a force on the top packages (Figure 44).

When using concrete blocks, the weight of each block must be known in order to calculate the applied pressure. For example, a 5400 kg weight placed on a package of width 1.5 m and length 6.0 m, will achieve a top load of 600 kg/m².

The depth of the concrete blocks needs to be approximately 250 mm, based upon a specific weight of 2400 kg/m³ for concrete.

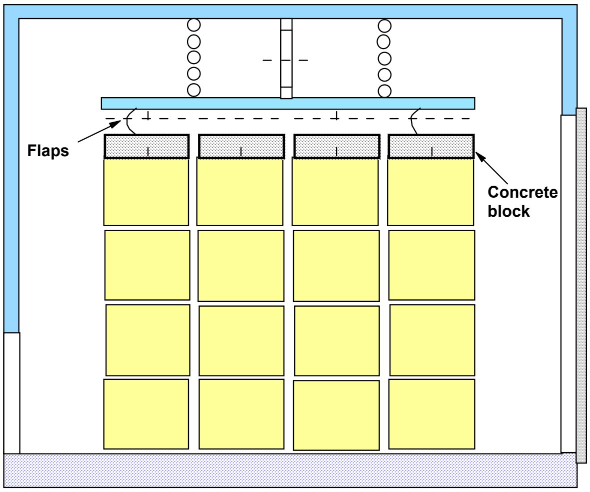

Figure 43. Compartment kiln with concrete blocks as the top loading mechanism.

Depending on the capacity of the fork lift, the concrete blocks should either be lifted with the top package, or be placed on the top package after the top package has been placed in position. The latter method could be difficult using normal forklifts with a tower mechanism as this may collide with the intermediate roof between the fans and the timber before the forks reach the necessary height.

In large kilns with high stacks, the parcels must be stabilised using a different method, as the height of the parcels causes problems for the concrete block top loading method.

Another problem which occurs in kilns without top loading is how to reduce or stop the air leakage above the top packages. As the timber packages and concrete blocks sink during drying, the distance between the intermediate roof and the blocks will increase. This increased gap makes it more difficult to stop the air leakage, although rubber or plastic flaps with sufficient height can be used to alleviate this problem.

A disadvantage of using concrete blocks for top loading, rather than pneumatic loading, is the application of a full load from the start of the drying process. This type of load can impose a high a sticker pressure in the lower packages at the start of the drying process because the packages are very wet and heavy.

A benefit of using concrete blocks over pneumatic loading is the lower capital investment involved. This benefit must be compared against the extra labour costs that would be incurred to position and secure the blocks for each kiln load. Also, the use of concrete blocks for top loading will reduce the kiln capacity because of the additional height of concrete blocks laid on top of the kiln load. Whereas, pneumatic loading equipment is located in the roof space of the kiln and would not affect the kiln capacity.

An alternative to concrete blocks, are steel frames. Steel has a specific weight of 7800 kg per m^3 compared to about 2400 kg/m^3 for concrete, and therefore, depending on the compactness of the frames, could reduce the height needed for top loading elements.

Applying the top load pneumatically or hydraulically via steel frames (Figure 44), also known as dynamic top loading, can bring many benefits to drying over the use of concrete blocks.

There are different ways of constructing compartment kilns with dynamic top loading. The most common way uses two or three pneumatic cylinders connected to a steel frame that covers the area of the top package for each package row. Due to slightly different package heights, the use of single frame for all package rows is not recommended.

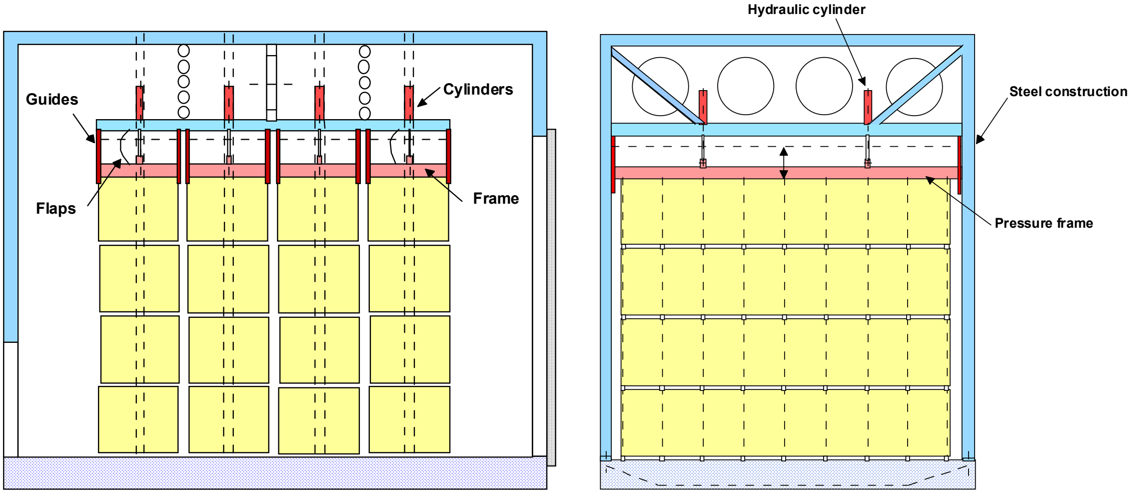

Figure 44. Principal drawing of compartment kiln with hydraulic or pneumatic top loading.

Normal industrial air pressure is between 8–10 bar. With a cylinder diameter of 12.5 cm, the maximum pressure which can be applied would be between 981–1227 kp. Two cylinders is the minimum number of cylinders required to give a maximum frame pressure of 2454 kp. For a package size of 1,5 m x 6 m, the specific pressure would be 273 kp/m². In order to get the maximum distortion benefits from top loading, the number of pneumatic cylinders should be four, giving a specific top load of 546 kp/m².

Water hydraulic cylinders could be used as an alternative to pneumatic cylinders. Water pressure can be at least 10 times higher than the pressure from air cylinders, meaning fewer cylinders, with smaller cylinder diameters required to produce the same pressure. For example, two water hydraulic cylinders, with a diameter of just 6.3 cm, could produce a specific pressure of 546 kp/m^2. In addition to the benefit of fewer cylinders, the use of high pressure water hydraulics affords opportunities for recycling water within the production facility. Water used in the hydraulic system could be used to control the relative humidity in the kiln, particularly in the heating up and conditioning stages and, pressurised water mist could be used as an effective fire extinguisher.

Depending on the total package height, the cylinder stroke must be adjusted to take up the shrinkage and the necessary clearance for loading the kiln.

One important benefit of using dynamic top loading is the possibility of installing flexible air flaps between the frame and the intermediate floor. This would reduce the air leakage above the packages completely.

The use of dynamic top loading would reduce the risk of package collapse if the construction is correctly designed for taking up horizontal forces. These forces may be taken up in the rods, if heavy pneumatic cylinders with large piston rod diameters are used. For smaller cylinders with smaller rods, the horizontal forces must be taken up in the frames by means of guides between the frames and the kiln wall, as shown in Figure 44. Another solution would be to use separate, heavy guided rods between the frame and the cylinder rod.

A top load of nearly 5 tonnes per row would give a total top load of almost 20 tons for four package rows. Such a load must be taken up by the kiln construction, either by the weight of the kiln itself or a combination of kiln weight and a transfer of the load through the walls to the ground as indicated in Figure 44. The intermediate wall between the timber and the fans must also be rigid enough to withstand the loads from the cylinders.

In new build kilns, the maximum forces that can be applied to the kiln fabric can be calculated and taken into account when designing the kiln. This would ensure that the forces are balanced, for example by transferring them to the base of the kiln.

In existing kilns, the top load can exceed the weight capacity of the kiln, forcing the sawmill to invest in extra internal reinforcements to hold the load. Economically, it may be better to use concrete blocks or steel frames for top loading.

3.5.5.2 Practical application

In Nordic countries, the use of dynamic top loading is now spreading to almost all new compartment kilns at sawmills. This suggests that the sawmills and kiln operators have had positive feedback regarding the benefits of the dynamic loading equipment.

At the start of the test period, only a few sawmills had installed dynamic top loading. Begna Bruk and Haslestad Bruk were the first two sawmills in Norway to install dynamic top loading and have assumed an active role in industrial tests organized by NTI.

In the test period, which ran for one and a half years, the test team shared the learning experience of using dynamic top loading with the kiln operators and technical staff.

In both sawmills, the equipment was a totally new technology to the kiln operators and the only problem raised was assessing how much pressure should be applied at the different stages of the drying process. Both sawmills ended up applying 30% of the maximum load at the start of the drying. This was increased to full load, at a calculated moisture content of 40% and 30%, for the Begna Bruk and Haslestad Bruk sawmills respectively. In the test period, no problems with the equipment were experienced.

After installation of the top loading kilns, it was immediately noticed by the secondary processing sections of the sawmills that the timber was straighter and caused less problems following drying and during the subsequent processing stages.

At one of the sawmills, the number of stickers was increased from seven to nine. This led to a reduction in twist of the free ends between the stickers. To realise the full benefits of a reduced sticker distance, the dunnage and supports in the top frame must be aligned with the stickers.

For both sawmills, an extra benefit was achieved, none of the packages have collapsed or toppled over in the new dynamic top loading kilns. In the older kilns, at least one serious package collapse occurred during drying the same time causing a hold up of more than a month.

High temperatures, high humidity and low pH conditions within a kiln combine to produce a highly corrosive environment. Cylinders, pipelines and pressure frames used to produce a top load must therefore, be made from non corrosive materials.

3.5.6 Straightness in-service

Material assessed in the top loading investigation was subjected to a change in moisture content from 18% to 10% and back to 18% in a climate controlled room. Twist was measured after each conditioning period. This test was designed to simulate the worst possible in-service conditions for studs in order that they remain fit for purpose during use. The aim of the assessment was to investigate how stable the improved straightness of the top loading was when placed in in-service conditions.

From the top loading investigation, two sets of studs; one set from NTI and another from VTT were studied.

Three groups of studs were tested from the NTI set; timber dried with a top load of 0, 600 and 1300 kg/m^2. The results for these three groups showed that the twist was lowest for material dried with a top load of 600 kg/m^2. However, the relative increase in twist, upon conditioning to 10%, was larger for timber dried with top load, than timber dried without top load. The absolute increase was about the same in all groups. Spring-back, although small, was relatively greater for the material dried with top load than without but the absolute increase was about the same in all groups (Figure 45).

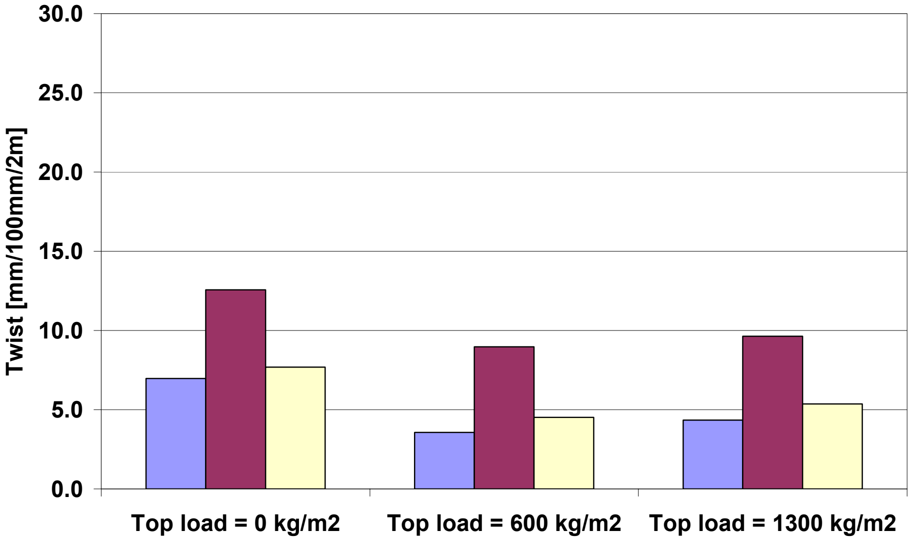

Figure 45. Absolute mean twist at 18% MC (first column in each group), at 10% MC (second column in each group) and at 18% MC (third column in each group). Each group of columns represents a treatment.

The percentage of studs that achieved the acceptance limit for twist of 4 mm / 100 mm / 2 m was higher for material dried with top load than for material dried without top load. There was little change in the percentage of studs failing to meet the limit as a result of moisture cycling (Table 9).

Table 9. Percentage of studs that met the acceptance limit for twist at 15% MC after 3 months conditioning at 85% RH / 23 °C and after additional 3 months moisture cycles at 30% RH and 85% RH without any restraint.

Group	Studs within limit at 15% MC after one cycle, %	Studs within limit at 15% MC after 3rd cycle, %
0 kg/m^2	29.0	29.0
600 kg/m^2	40.0	36.0
1300 kg/m^2	39.5	39.5

Six groups of studs were assessed from the VTT set, timber dried with top loads of 0, 200 and 700 kg/m^2 in two drying temperatures. The results showed that the difference in mean absolute twist between the different groups was very small. The relative increase in twist was larger for material dried with top load than for material dried without top load. The measured spring-back was small for all groups, although largest for material dried with top load (Figure 46).

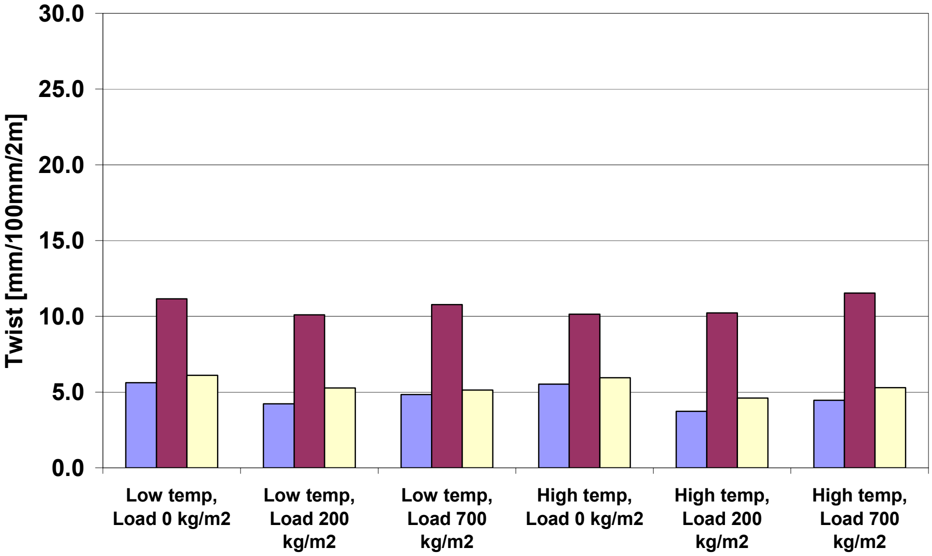

Figure 46. Absolute mean twist at 18% MC (first column in each group), at 10% MC (second column in each group) and at 18% MC (third column in each group). Each group of columns represents a treatment.

The difference in the percentage of studs that met the acceptance limit for twist of 4 mm / 100 mm / 2 m was relatively small (Table 10).

Table 10. Percentage of studs that met the acceptance limit for twist at 15% MC after 3 months conditioning at 85% RH / 23 °C and after additional 3 months moisture cycles at 30% RH and 85% RH, without any restraint.

Group	Studs within limit at 15% MC after first cycle, %	Studs within limit at 15% MC after 3rd cycle, %
Low temp, 0 kg/m^2	25.0	22.9
Low temp, 200 kg/m^2	33.3	29.2
Low temp, 700 kg/m^2	31.3	25.0
High temp, 0 kg/m^2	37.0	37.0
High temp, 200 kg/m^2	35.6	33.3
High temp, 700 kg/m^2	25.0	25.0

A cost assessment concerning top loading is presented in chapter 4.4, Table 30.

More detailed results are presented in Tronstad 2005.

3.6 Drying and re-conditioning on pre-twisted board

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3.6.1 Method

Distortion can be reduced by keeping timber straight during drying. As timber is dried, a straightening effect can be achieved by twisting the timber in the opposite direction (from the straight position) against its inherent direction of twist. Increased tension created using this method is expected to enhance creep during drying. The experimental work in this project has confirmed this theory and has also found that, in addition to mechano-sorptive creep, temperature induced creep is also activated under these conditions.

Temperature induced creep enabled the introduction of a deformation and use of heat treatment to improve straightness without a simultaneous drying process. This effect can be used to straighten dried studs with excessive twist.

Pre-twisting one single piece of timber during drying is relatively easy, but pre-twisting an entire stack in a kiln is far more complicated. It is possible to predict the optimal pre-twist angle for each individual board from its grain angle. However, an individual treatment is not possible in an industrial environment. In an industrial case, the kiln stack has to be treated as a whole, and the pre-twist angle selected with the aim of minimising the average final twist. A simple, low cost pre-twisting system for industrial kilns could have high market potential.

One pre-twisting method, presented and analysed in this report, is an inclined basement under each kiln stack. Alternatively, a similarly inclined support could be placed on the kiln wagon, if wagons are used. In both cases, the end of the kiln stack would be supported by tilted supports or a supporting surface at a specific angle. This angle decreases uniformly toward the middle of the stack and increases again in the opposite direction on the other end of the stack support (Figure 47). The pre-twisting effect would be highest in the bottom part of the kiln stack, and gradually decrease upwards. Ideally, boards prone to twist should be placed as the bottom package, or in the bottom part of the stack. These boards with the highest tendency to twist can be separated from the total volume of material based on grain angle measurement. The angles of the stack support should be selected to minimise the average twist and the standard deviation of twist of all the boards in the stack after drying and storage. Some level of deformation must be acceptable, and could be specified in the relevant standards and individual sales contract when the system is supplied. The deformation limits used in this project are given in Table 1.

Figure 47. Inclined supports on a timber wagon (left) and a stickered kiln stack (right). From drying tests performed by SP Trätek.

Problems that may arise from tilted stacking include, poor stability of the kiln stacks, difficulties with automatic stickering (if the pre-twist is realised already at that stage), unloading after drying and possibly uneven airflow through the stacks. Co-operation with machine suppliers, who could make modifications to existing equipment, would be necessary to resolve the problems.

Timber that is excessively twisted after drying (untreated or treated with any of the methods discussed in this report), can be re-stacked and corrected by pre-twisting in a separate heat treatment stage under top load. An alternative method would be to include these boards in the bottom package for “drying” a second time in a pre-twisted position, as described above. However, it should be noted that whilst almost all green boards have a tendency to twist in the same direction, these boards may need a separate correction stage due to being highly twisted in both directions.

3.6.2 Results

Drying tests have been performed in both the laboratory and full scale trials with an aim to determine the optimal pre-twisting angles, optimal top loads and the effect of normal (60 ^{o}C) and high-temperature (115 ^{o}C) drying on resulting twist. Different practical aspects, such as tilted basement floors for the kiln stack, pre-twist at different stack heights and the stability of the stack have also been studied.

Laboratory tests

The laboratory tests were performed in a small kiln with 1.5 m long boards (Figure 48). Each board was fastened into holders at both ends. The holder at one end was fixed, whilst the other could be turned around the board axis and then fixed in the desired position. In this way, each board was individually pre-twisted and dried in that position. The torsional force exerted by the board on the holders was measured continuously and a series of tests were performed in order to determine the relationship between pre-twist angle, board properties and twist after drying.

Figure 48. Twisting of timber during laboratory kiln drying at SP Trätek in Sweden. Direction of pre-twisting is opposite to the natural direction of twist in timber.

The results of these tests are summarised by Figure 49. The dotted line in the upper part of the diagram shows the relationship between grain angle (measured by the scratch method on the outer sapwood side of the board) and twist after drying, if the board is allowed to move freely. The line for zero pre-twist corresponds to the maximum improvement that can be obtained with top loading. In this test, there were no free board ends as there would be in a normal kiln stack. As shown in Figure 49, keeping the board straight during drying reduces the twist by almost 60%. This result correlates well with the results presented in section 3.5 on top loading.

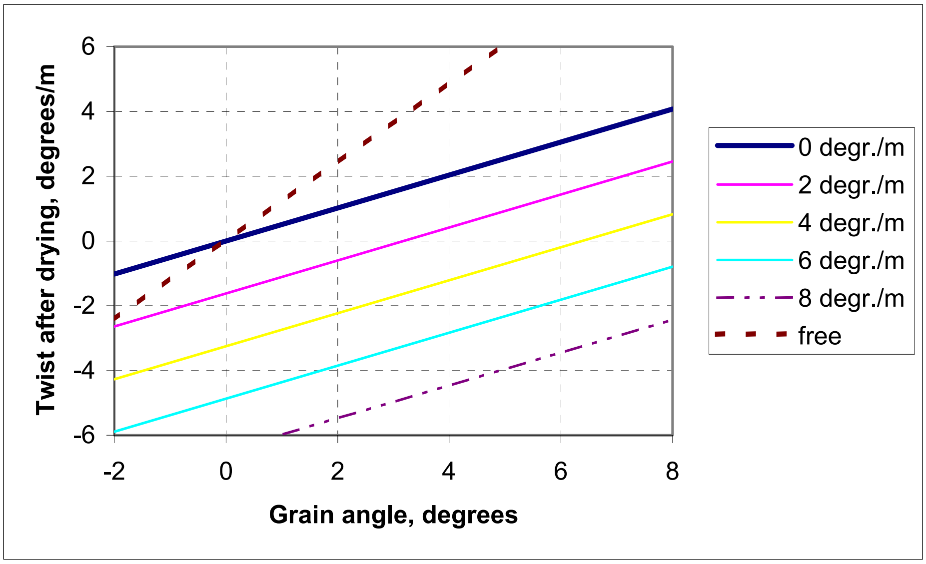

Figure 49. Relationship between grain angle, pre-twist and twist after drying for 47 x 100 mm Norway spruce (laboratory tests).

The most important result shown in Figure 49 is the possibility to further reduce twist by using an individual pre-twist based on the grain angle of the board. However, individual treatment would not be practical in an industrial environment. For Norway spruce boards sawn close to the pith, the average grain angle was 1.5–2 degrees. Pre-twisting all boards by about 1.5 degrees/m would result in an *average* twist after drying of close to zero. The number of accepted boards would be increased considerably from current levels.

The plots in Figure 49 were valid for 47 x 100 mm Norway spruce sawn close to the pith, and dried to about 15% MC with a "normal" drying schedule. No statistically significant influence of other variables, such as density or final MC, was found. There should be a dependence on final MC, but the MC variation was perhaps too limited for this to be detected. It would be expected that the results for other board dimensions would be different to this one, but the general principles shown in Figure 49 would remain the same.

In the tests where the force exerted by the board on its holders was measured, some interesting trends that could be used in industrial processes were revealed. The force measured was affected by two components, creep and a change in torsional stiffness. These were the result of changes in board temperature and MC. The change in torsional stiffness was measured separately to enable this to be separated from the creep behaviour. The result from this test is shown in Figure 50.

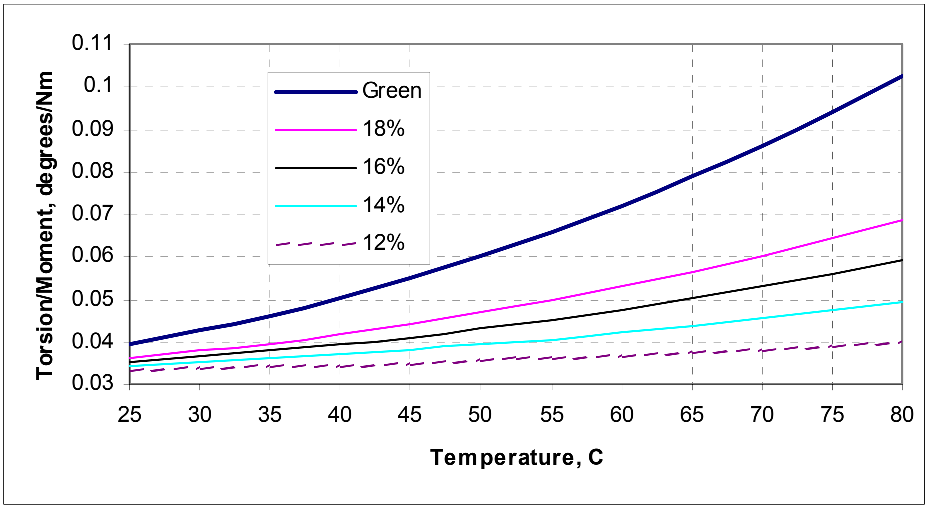

Figure 50. The ratio between the torsional moment and the resulting torsion as a function of temperature and MC for 50 x 100 mm Norway spruce.

It can be seen that both temperature and moisture content have a considerable influence on torsional stiffness. This information is useful when determining the top load required to prevent boards pre-twisting during the drying process. The behaviour of pre-twisted boards during drying can be described in more detail. This is illustrated by Figure 51.

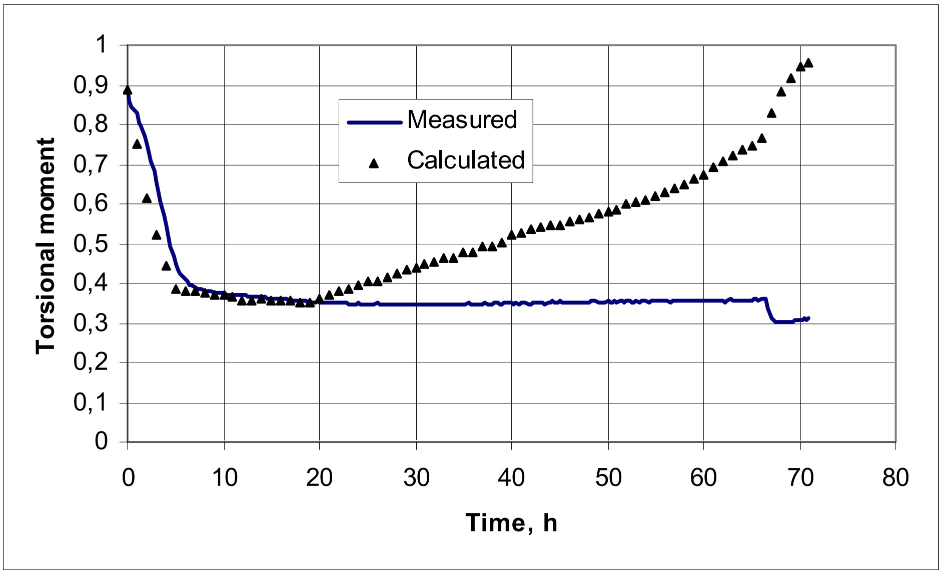

Figure 51. Comparison of measured torsional moment and predicted values (assuming no creep behaviour).

In Figure 51 the solid line represents the measured torsional moment, and the triangular points show calculated values assuming purely elastic behaviour without any creep. During heating (0–6 hours), the force changed considerably, solely due to a change in stiffness, as both curves show similar trends. During the drying phase (6–66 hours), the curves began to diverge, indicating that creep was occurring. Since the board MC changes whilst the temperature remains almost constant, this had to be mechano-sorptive creep. During the final cooling phase, the two curves diverged further, indicating that temperature induced creep had occurred. As the board MC was almost constant at this stage, and the only changes were in the temperature, this second creep phase was obviously triggered by a change in temperature. The result was confirmed by tests with boards wrapped in plastic, to avoid changes in MC, where creep only occurred during the cooling phase.

In summary, the laboratory tests have shown that twist after drying can be decreased by drying the boards in a pre-twisted position, and that the proportion of accepted boards can be considerably increased. It was found that boards that had already been dried and were twisted beyond the accepted level, could be "corrected" by a pre-twisted with heat treatment.

Industrial tests

The first industrial test consisted of both low temperature drying at about 60°C (LT drying) and high-temperature drying at about 115°C (HT drying). In both cases, 54 boards were dried in a pre-twisted position and compared to 54 boards dried without pre-twist. The centre piece of 3 ex log (three parallel battens processed from one log), 41 x 147 mm Norway spruce, was dried in the bottom package of the kiln stack. Wedges used for pre-twisting had an inclination of 3:50 and were in opposite directions at both ends of the stack (horizontal in the centre) corresponding to a pre-twist of 1.19 °/m. The results are summarized in Table 11 and Figure 52.

Table 11. Results from industrial drying tests with normal and pre-twisted boards in both low and high temperature. Values represent average ± standard deviation.

Test	Grain angle degrees	Final MC %	Twist mm / 100 mm / 2 m	Twist °/m	Accepted boards %
LT reference	2.1±1.2	13.9±0.9	4.3±2.9	1.2±0.8	56%
LT pre-twist	1.8±1.4	13.5±0.9	0.6±2.6	0.2±0.8	83%
HT reference	2.0±1.2	14.2±1.2	3.1±2.4	0.9±0.7	67%
HT pre-twist	1.5±1.4	14.0±1.2	–0.5±2.1	–0.1±0.6	96%

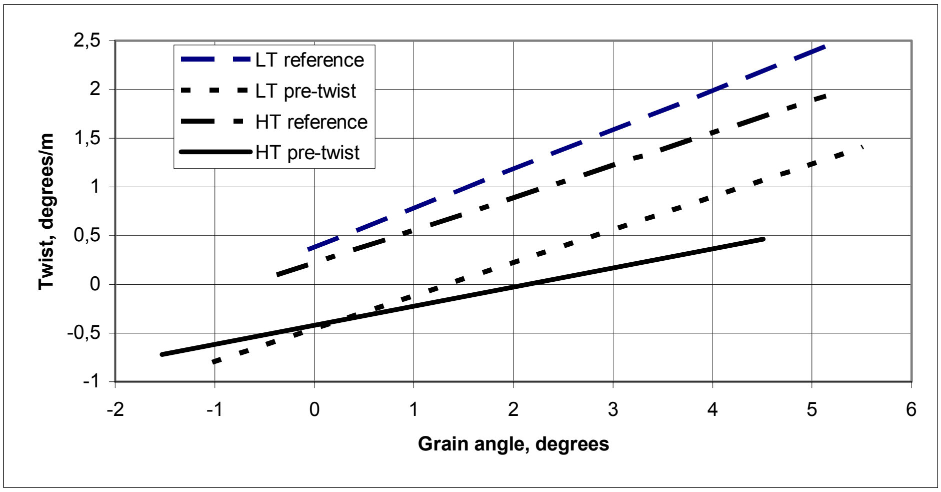

Figure 52. Relationship between grain angle and twist after drying in industrial tests.

Figure 52 shows that the pre-twist method decreased the average twist to a level close to zero in both the LT and HT assessments.

The proportion of acceptable boards had increased considerably as a result of the pre-twist method. This was due to two changes; the average twist was closer to zero and the standard deviation had decreased slightly. In general, a decrease in the range of twist values measured seemed to be true.

Another industrial test was performed at a different sawmill using Norway spruce, 38 x 125 mm, cut using a 2 ex log sawing pattern. A conventional drying schedule was used with a wet bulb temperature of 70 ^{o}C and dry bulb temperature increasing from 78 to 87 ^{o}C. The average final MC was 13.2%. The aim of this test was to find out how far the reduction in twist, experienced due to a tilted basement, extended up a kiln stack. In addition, the pre-twist method was investigated. The stack configuration used in the kiln is presented in Figure 53.

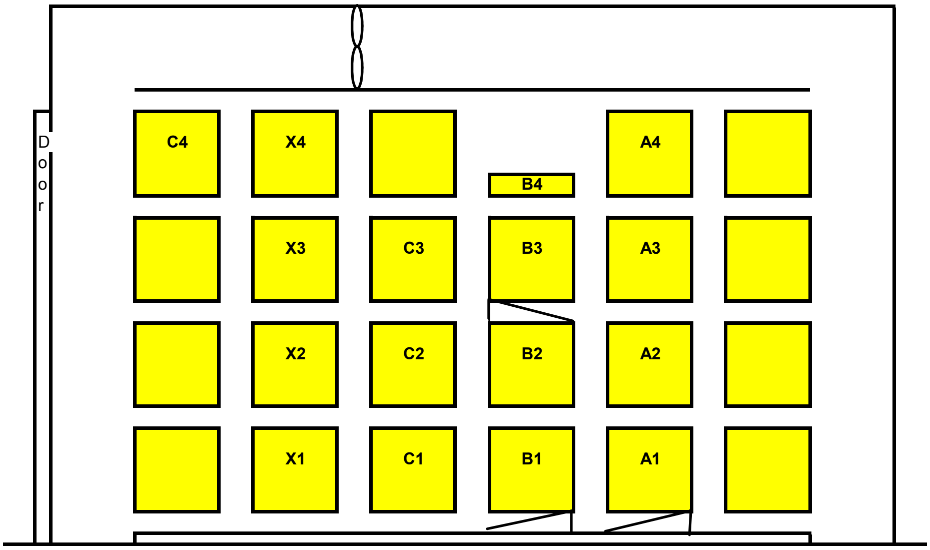

Figure 53. Stack configuration during the test. The locations of the wedges are indicated.

The analysis of the "C-stack", not pre-twisted and representing normal drying procedures, showed that the twist after drying depends significantly on the grain angle and not on the position within the stack (height from the basement). The initial weight of the 21 board layers above the samples taken from package C1 seem to have been high enough (about 460 kg/m^2 when green) to keep all sample boards straight during drying. The results are illustrated in Figure 54. The average grain angle for all 88 boards was 0.33°, and the average twist after drying was 0.62 °/m. The average grain angle for this kiln stack was remarkably low, explaining why no dependence on location in the stack was observed.

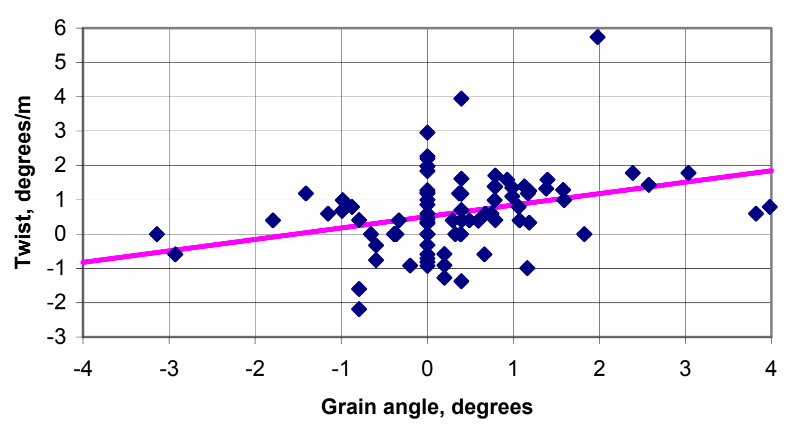

Figure 54. The relationship between grain angle and twist after drying for boards taken from a kiln stack without pre-twist.

The “A-stack”, pre-twisted with wedges inclined at 28:162 at both ends of the stack and corresponding to a pre-twist angle of 3,50 °/m was analysed. The amount of pre-twist selected was high in order to see clearly how far up the stack the effect was observed. When the twist after drying was analysed, it was found that the twist was highly dependent upon both grain angle and location of the board in the stack (Figure 55).

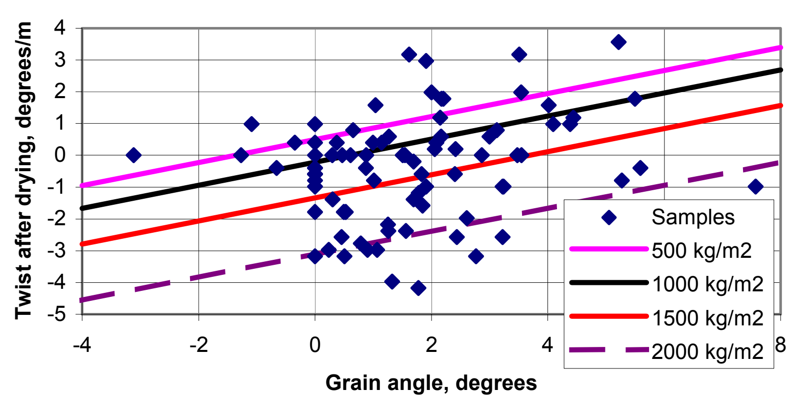

Figure 55. Twist after drying as a function of grain angle and board location in the pre-twisted A-stack (expressed as initial top load in that location: A1 = 2000 kg/m^2, A4 = 500 kg/m^2).

Figure 55 shows that the effect of the inclined basement decreased upwards through the stack. Packages A3–A1 showed a gradually increasing influence from the wedges, but only the bottom package A1 was strongly influenced. This means that boards prone to twist (for instance boards selected based on measured grain angle) should be placed in the bottom part of the kiln stack.

Finally, the “B-stack”, inclined basement counteracted by wedges in the opposite direction between packages B2 and B3, was analysed. In principle, only packages B1 and B2 were pre-twisted and packages B3 and B4 were not (Figure 56).

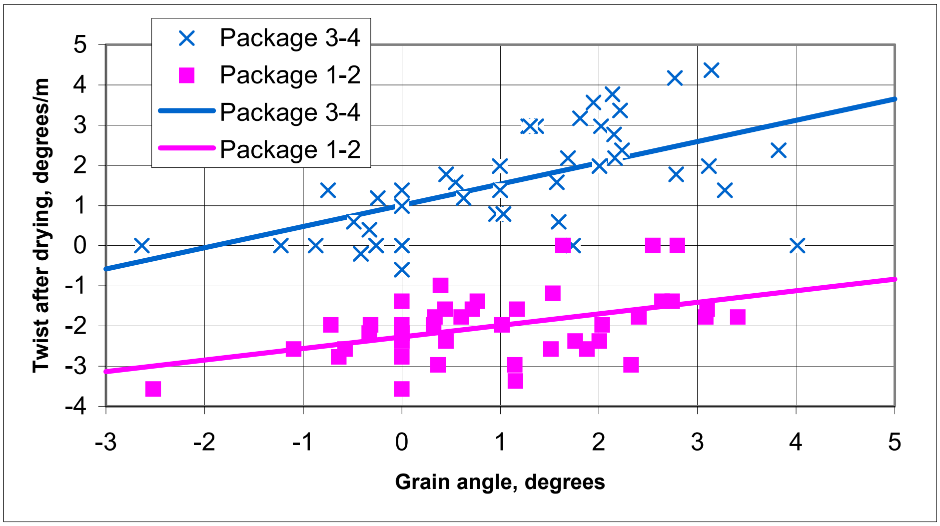

Figure 56. The effect of inclined wedges both (under and above the test packages 1 and 2) on the resulting twist. The reference packages 3 and 4 are top loaded but not pre-twisted (see Figure 53 packages B1–B4).

The upper line in Figure 56 is slightly steeper than the line in Figure 54 and the uppermost line in Figure 55, but the location in the diagram is approximately the same. This indicates that the drying behaviour in packages B3 and B4 corresponded to drying without pre-twist. Taking into account the fewer boards in the “B-stack” (Figure 53), the lower line in Figure 56 is in good agreement with the lower lines of Figure 55. As expected, this showed that the effect occurring in the bottom packages corresponded to drying with pre-twist, but with a more uniform pre-twist angle in the vertical direction than in the “A-stack”.

Re-conditioning

The aim of the first industrial re-conditioning test was to analyse a heat treatment process applied to already dried boards that were highly twisted. Norway spruce studs, 45 x 100 mm, with a target moisture content of about 12% were used in the assessment. The test was performed with a single stack in an otherwise empty kiln. The kiln stack configuration is presented in Figure 57.

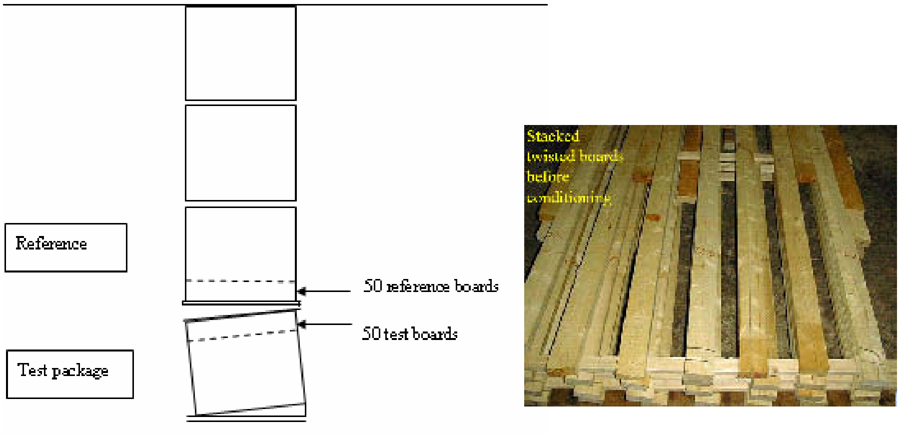

Figure 57. Kiln stack configuration and stacked twisted boards in the first industrial re-conditioning text.

All four packages consisted of conventionally dried boards with dimension and target MC as described above. 100 boards with excessive twist were selected and divided into two groups of 50. These groups were placed in the stack, located where the pre-twist wedges are shown and indicated in Figure 57. The inclination of the wedges at the ends of the package was 1:12.1, corresponding to a pre-twist of 1.62 °/m. The heat treatment was performed in a climate that produces an EMC of 11–12% for duration of 5–6 hours. In this climate, the change in board MC was minimised.

Before heat treatment, all boards from both groups were measured for twist, weight, grain angle, etc. After heat treatment, the stack was removed from the kiln and left to cool, stickered under ambient conditions. The twist and weight of each board was measured again before the original kiln stack was reassembled and the heat treatment was repeated. At the end of the second treatment, the stack was cooled and the twist, weight and MC of each board were recorded. The results for the reference group (without pre-twist) are shown in Figure 58, and the results for the pre-twisted group are shown in Figure 59. The average values for both groups are presented in Table 12.

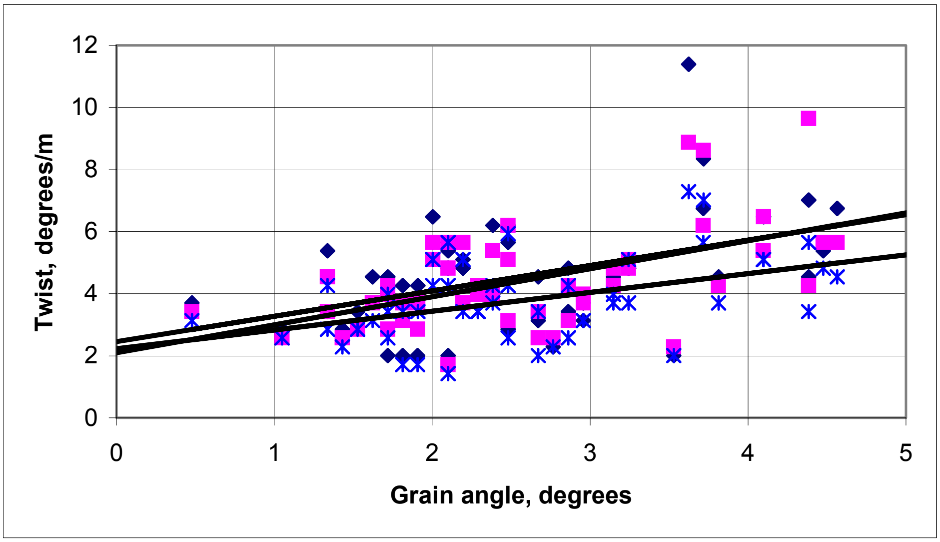

Figure 58. Twist of boards in the reference group. The uppermost regression line corresponds to the initial situation and the lowest line corresponds to the final situation after the second heat treatment.

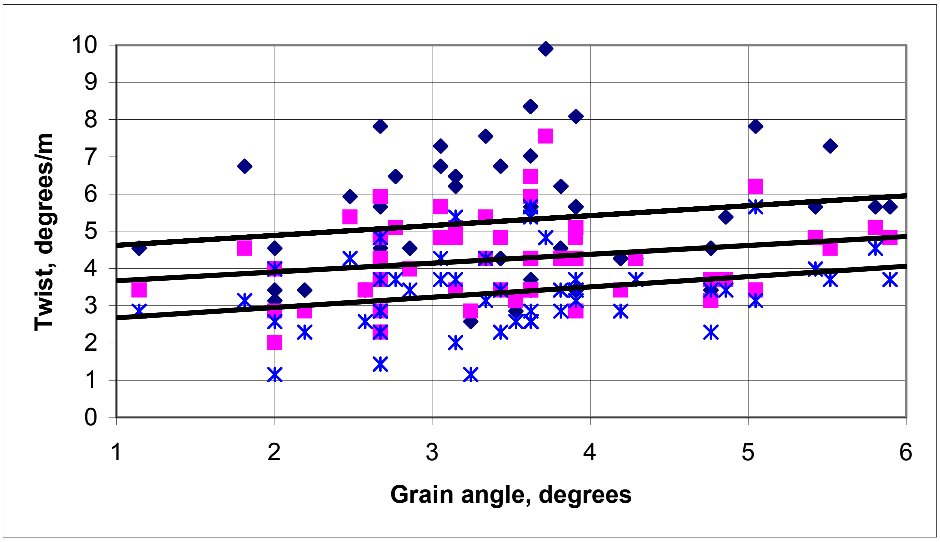

Figure 59. Twist of boards in the pre-twisted group. The uppermost regression line corresponds to the initial situation and the lowest line corresponds to the final situation after the second heat treatment.

Considering the results for the reference group first, it can be seen that the group of boards used in the test consisted of extreme samples. The average grain angle was high, and the average twist before treatment was considerably higher than the value expected from the grain angle (see Table 12 and Figure 58). The first heat treatment, without pre-twist, had a small, but not statistically significant effect on the amount of twist. However, the second treatment produced a significant reduction in the amount of residual twist.

Table 12. Average results from the first industrial re-conditioning test.

	MC %	Grain angle degrees	Twist degrees/m	Twist mm / 100 mm / 2 m
Reference				
Initial	9,58	2,60	4,58	16,2
1. treatment	10,14	"	4,44	15,7
2. treatment	10,16	"	3,80	13,4
Pre-twisted				
Initial	9,20	3,49	5,28	18,7
1. treatment	9,88	"	4,26	15,0
2. treatment	9,93	"	3,36	11,8

The results for the pre-twisted test group are presented in Figure 59 and Table 12. These boards had more extreme twist prior to heat treatment. Unfortunately, the average grain angle and the slope of the curves for the two groups differ so, the average values should not be used to make direct comparisons. In the section the average grain angle values (2.60…3.49 degrees) and the initial values are very similar and a comparison within this section is justified. Both heat treatments of pre-twisted boards have had a clear influence on the twist. The second treatment had an almost equally strong impact as the first one.

The MC of the boards was lower than the target MC of 12% which may be due partly to the extra handling of the boards before the heat treatment. The MC increased slightly during the two treatments, but this change was so small that the amount of mechano-sorptive creep should be negligible. This indicated that the change in temperature was responsible for the change in twist during the treatment, at least as far as the pre-twisted group was concerned.

However, the change in twist as a result of the heat treatment was smaller than predicted by the laboratory tests. An obvious reason for this is that packages above the level of the boards analysed consisted of already *dried* boards, i.e. their weights were relatively low, approximately 880 kg/m^2 at that height in the kiln stack. The boards in the pre-twisted group were initially twisted in the "wrong" direction so, as a first step, a force was needed to straighten them and then an additional force was needed to create the actual pre-twist. Finally, as seen in Figure 50, dried boards have a higher torsional stiffness than green boards. As a result of these factors, a considerably higher top loading was needed in these types of processes. This provides an explanation for the smaller effect observed in the industrial trials than in the laboratory, and may also explain why the second step in Figure 59 was almost equal to the first step. If the boards in the reference group were actually pre-twisted in the wrong direction (instead of being straight) in the first treatment, this would explain the absence of any effect. In the second treatment, this situation had improved.

A second industrial reconditioning test was performed with a heavier top load. Again, previously dried Norway spruce boards, 45 x 100 mm that were highly twisted were selected. Of these, 15 were used as reference samples and not pre-twisted and 30 boards were tested with pre-twisting. These battens were placed at the bottom of a kiln stack in the stack configuration presented in Figure 60.

The wedges used had an inclination of 1:12.1 (stack end) corresponding to 1.62 °/m. The top load at the level of the test boards was approximately 1500 kg/m^2, a much higher load than in the previous industrial test. The method used in this test was not a pure heat treatment because the test boards were already dry and their MC change was limited.

After the drying process was completed, the stack with the test boards was left in the kiln to cool before they were measured. Only one treatment of this kind was applied to the boards under test.

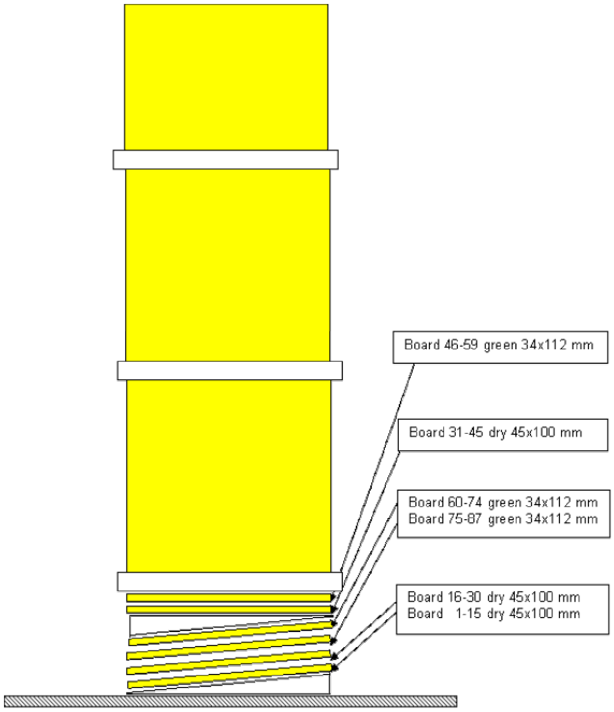

Figure 60. Kiln stack configuration in the second industrial re-conditioning test which was performed in a normal drying process.

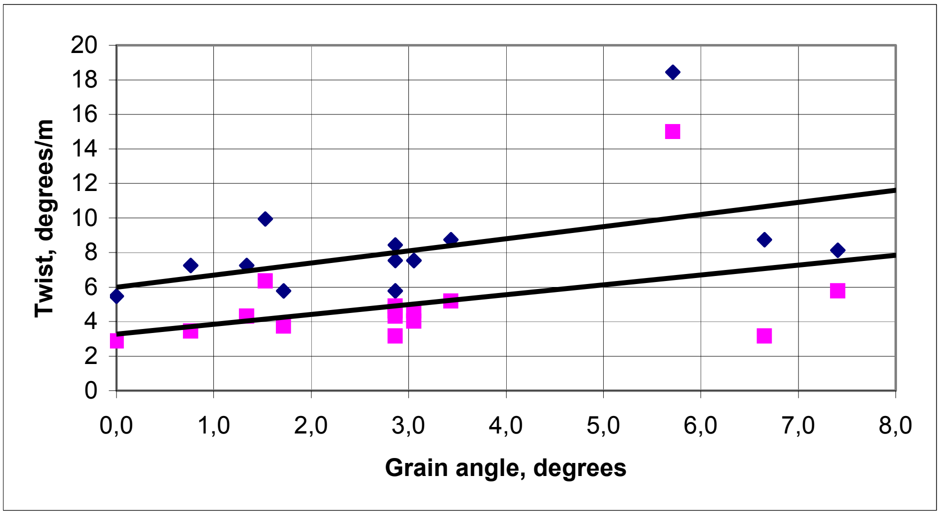

Figure 61. Twist of boards in the reference group. The upper regression line corresponds to the situation before treatment and the lower line to the final situation.

The results for the reference boards (board numbers 31–45 in Figure 60) are presented in Figure 61, and average values shown in Table 13. These boards initially showed an even more extreme level of twist than in the previous test (Figures 58 and 59). The treatment of the boards, without pre-twist, clearly reduced twist. The average twist decreased by about 38%. This indicated that the top load was adequate, contrary to the findings of the previous industrial test. This result shows that highly twisted dry boards can be partly corrected by "re-drying" in the bottom part of a kiln stack.

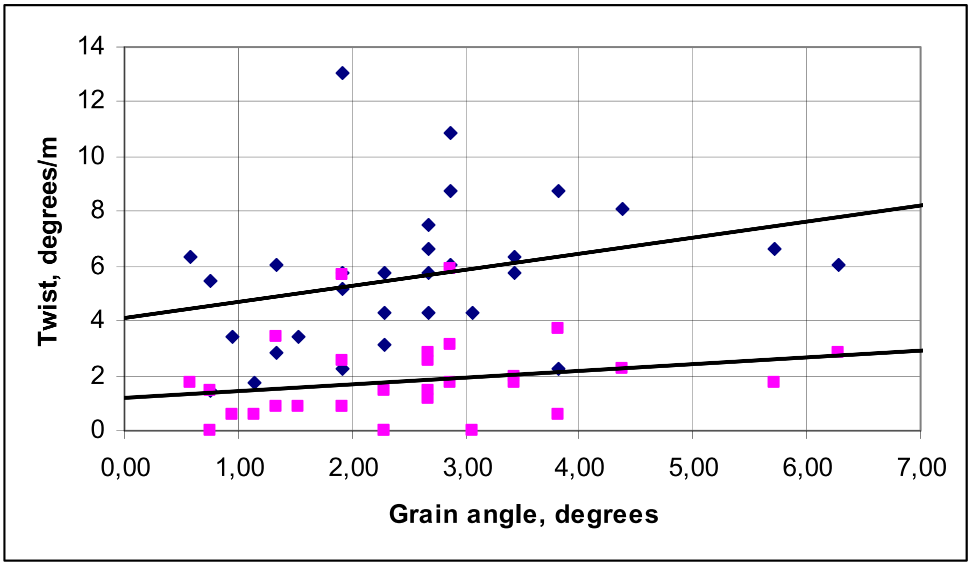

Figure 62. Twist of boards in the pre-twisted group. The upper and lower regression lines correspond to the situation before and after treatment, respectively.

The results for the pre-twisted boards (board numbers 1–15 and 16–30 in Figure 60) are presented in Figure 62, and average values in Table 13.

The initial twist was again very high, but differed from the material in the reference group and so; the groups should not be compared directly. The pre-twist had a considerable effect on the twist after the treatment and the reduction in twist was about 67%.

Table 13. Average results from the second industrial re-conditioning test.

	MC %	Grain angle degrees	Twist degrees/m	Twist mm / 100 mm / 2 m
Reference				
Initial	~14	3,07	8,15	27,9
Treated	~11	"	5,03	17,3
Test				
Initial	16	2,54	5,62	19,4
Treated	11	"	1,82	6,4

As shown in Table 13, a decrease in moisture content was observed during the treatment. However, this change was small and the mechano-sorptive creep should have been limited. This indicates that the change in temperature was primarily responsible for the twist reduction. The test confirmed that highly twisted dried boards could be corrected by re-drying them in a pre-twisted position in the bottom package of a kiln stack.

3.6.3 Straightness in-service

Four groups of material were assessed for straightness in service, material dried flat and material dried pre-twisted at high and low temperatures. Boards were subjected to a moisture content change from 18% to 10% and back to 18% in a climate controlled room. After each conditioning period, the twist was measured. This test was made to simulate the worst possible in-service conditions for the boards to ensure that they remained fit for purpose during use. The aim was to see how stable the improved straightness of pre-twisted boards were in in-service conditions.

The results showed that twist was lower for the pre-twisted material than for the material dried flat. The spring-back effect (i.e. difference in twist between first and third cycle, MC ~ 18%) was very low for the boards dried pre-twisted at high temperature, although somewhat larger for the material pre-twisted at low temperature (Figure 63).

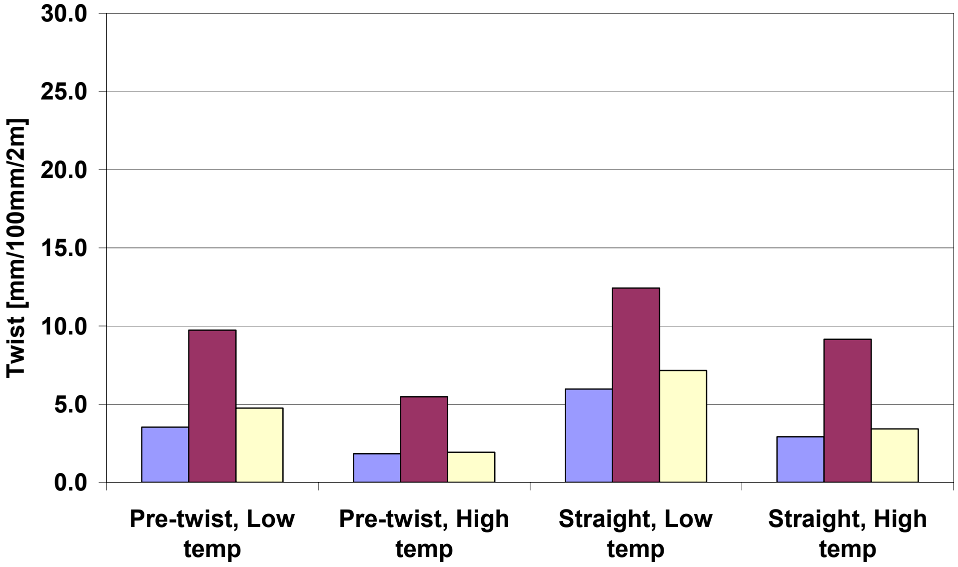

Figure 63. Absolute mean twist at 18% MC (first column in each group), at 10% MC (second column in each group) and at 18% MC (third column in each group). Each group of columns represents a treatment.

The percentage of boards that achieved the acceptance limit for twist of 4 mm / 100 mm / 2 m was high for the stud's pre-twisted using high-temperature drying. The percentage of studs that met the limit for twist was higher for the pre-twisted timber than for the reference timber in both high and low temperature drying (Table 14). *Note that the boards were of a larger dimension in this work than those used elsewhere in the project; larger dimension material normally twists less than smaller dimension material.*

Table 14. Percentage of boards below the threshold value for twist at 15% MC after 3 months conditioning at 85% RH / 23 °C and after additional 3 months moisture cycles at 30% RH and 85% RH without any restraint.

Group	Boards passing limit at 15% MC after one cycle, %	Boards passing limit at 15% MC after 3rd cycle, %
Pre-twist, low temp	38.9	33.3
Pre-twist, high temp	77.8	77.8
Straight, low temp	20.4	18.5
Straight, high temp	38.9	35.2

For the conditioning phase, two groups of material were tested; timber conditioned with a pre-twist and timber conditioned flat. The level of twist was high for both these groups and the spring-back effect small (Figure 64).

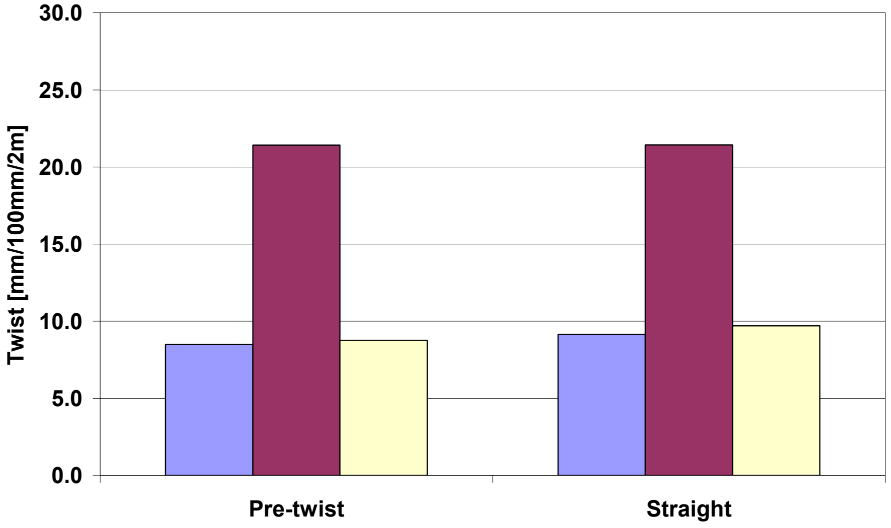

Figure 64. Absolute mean twist at 18% MC (first column in each group), at 10% MC (second column in each group) and at 18% MC (third column in each group). Each group of columns represents a treatment.

All of the boards tested with this treatment exceeded the acceptance limit for twist. The boards were selected to have the most twist after drying, and the spiral grain angle was large.

3.6.4 Recommendations

The laboratory and industrial tests on pre-twisting boards during drying and re-conditioning previously dried boards under similar process conditions have clearly shown that a substantial reduction of twist can be achieved.

The implementation of these methods in practice can be divided into two tasks: 1) detection and separation of boards prone to twist and 2) arranging the pre-twist procedure for these boards.

It is well known that, in general, boards sawn close to the pith are more prone to twist than boards sawn further out. The sawing pattern used provides a simple method by which boards needing treatment can be separated. For instance, boards sawn from a 2 ex log, or the inner pair of boards sawn from a 4 ex log, are known to end up with an average twist of about 1 °/m after conventional drying. If these boards are dried pre-twisted, it is possible to achieve an average twist close to zero, with the same or even better standard deviation. This results in a higher percentage of boards meeting the acceptance limit for twist of 4 mm / 100 mm / 2 m, as seen for example from the results in Table 11. Therefore, the sawing pattern can be used as a first step towards the detection of boards prone to twist.

A more individual method of detecting boards prone to twist, would be to measure the grain angle of each board and divert those with a grain angle above a specified threshold. Very few Norway spruce boards would have a large enough right-handed grain angle to exceed such a threshold and so this parameter may well be ignored. The grain angle can be measured based on the tracheid effect with a laser beam. This is a relatively simple method for on-line measurement and seems to be the only method suitable for use in an industrial environment. This grain angle measurement method has already been adopted by various sawmills.

Lower twist was observed in boards dried, without pre-twist, and located at the bottom of a normal kiln stack. This was particularly apparent where the kiln stack top load was not large enough to have an effect on the levels of twist. To achieve an improvement in twist, boards prone to twist could be collected and placed in the same package which would then be positioned in the bottom part of the kiln stack. This procedure combined with a grain angle measurement has been used successfully by one sawmill to reduce the incidence of twist.

This method utilises an inclined base in the kiln, or an inclined support on the kiln wagon, if wagons are used. In the tests described above, wooden wedges were manually placed below each sticker row in the kiln stack. From an industrial perspective, this would be far too complicated. As illustrated by Figure 55, the effect of the inclined base decreased up the stack. The boards most prone to twist should therefore be placed in the bottom part of the stack, and less critical fractions higher up. The inclination of the base should be selected so that the average twist of the whole stack approaches zero after drying. In fact, a slightly higher inclination is recommended to take into account spring-back that will occur before the board reaches its end-use.

A general inclination that can be used successfully in any kiln should be used initially to dry the timber. Then, based on knowledge about a specific kiln, and the way timber is normally dried in it, the inclination may be adapted to that kiln. The general inclination can be determined roughly from the data presented in this report, but the final adjustment (taking into account local conditions and requirements) would have to be done on a trial-and-error basis. Alternatively, a varying inclination could be used. This could be achieved using either a hydraulic, adjustable support for the kiln stack, or a series of removable (by fork-lift) bottom plates, enabling the desired inclination for each kiln batch to be selected.

The re-conditioning process, a heat treatment of boards in a pre-twisted position would be most suitable for the correction of dried boards that already exhibit an unacceptable amount of twist. As these boards require a lot of pre-twisting (the actual twist plus some pre-twist past zero in the opposite direction), and as the boards are stiff (Figure 50), the force required would be relatively large. Heat treatment of the dried boards would require a heavy top load, or other twisting device as the weight of a stack of dry boards may be too low to exert enough straightening force (see the first industrial re-conditioning test).

An easier re-conditioning mode could be to re-dry the boards pre-twisted in the bottom part of a normal kiln stack. These twice dried boards will, however, finally end up slightly too dry, which could be acceptable in many cases, especially if the alternative is to use it as fuel. It should also be observed, that if these boards are re-dried straight (without pre-twist), their twist will decrease but less than if re-dried with pre-twist.

The number of boards with excessive twist after drying depends on the methods used in the drying process. If no, or insufficient, measures to reduce the twist have been used, this number may be high. In this case, the drying process should be changed to produce a lower average twist, instead of solving the problem by using the re-conditioning procedure. On the other hand, if a "twist-reducing" drying process has been used, and the average twist after drying is close to zero, there may be boards with extreme values of twist, with both a positive and a negative twist. This would require two different correction processes, one for each twist direction. Thus, the drying process has to be optimised if a re-conditioning process is to be used to correct twisted boards. It should also be noted, that the re-conditioning procedure can be repeated several times if the desired "correction" is not achieved in the first treatment.

3.6.5 Cost assessment

Instead of making theoretical cost estimations, a calculation carried out for a recent implementation has been used (Uusijärvi 2004). The total production of the sawmill was approximately 210000 m^3/annum of which about 60000 m^3/annum was handled by the system implemented. The system comprised a laser grain angle measuring device to detect boards with a high grain angle. Selection was based on a dynamic threshold, with 25% of the total number of worst boards being selected. Selected boards were marked with a colour spray which was detected further downstream by a colour photocell and directed to a separate storage bin. Every fourth kiln package was comprised of these marked boards and placed in the bottom package of each kiln stack. In this implementation, no pre-twist was used in the kiln.

The investment for this system was in the region of 28000 €, and the yearly operation cost was about 17000 €/annum. The observed benefit for the installation consists of two parts. Firstly, the percentage of boards with an acceptable twist was increased slightly and, secondly, the average final board length was also increased due to less material being removed from the free end to reduce distortion. These corresponded to approximately 72000 €/annum, which equated to a return on investment time of half a year.

It may, of course, be noted that the same result would have been achieved using a sufficiently high top load on the kiln stacks. However, if a pre-twist procedure was added to the system described, a grain angle measurement device would be necessary to select and direct boards prone to twist to the bottom part of each stack, where pre-twist would be most efficient (Figure 55). In this case, a considerably greater increase in the number of boards meeting the acceptance limit for twist would be achieved, even if a simple inclined bottom plate was used. This suggests that a similar or better time scale for the return on investment for the complete system may be realised.

3.7 Oscillating drying schedules

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As research studies have shown, creep under load increases when temperature and relative humidity change, the idea of oscillating drying schedules to promote creep and produce straighter timber was investigated.

3.7.1 Method

In conventional drying schedules, the set point values of temperature and relative humidity are constant for a long period or change slowly. In an oscillating drying schedule, the base schedule is modified such that relative humidity varies rapidly around an average value. This has some effect on the drying rate, especially in the surface layers of timber, although this does not normally provoke substantial increases in surface moisture content of the timber. For some species, interim moisturising, or end steaming of the surface during drying improves the total drying process. Surface layers that are too dry, slow down the movement of moisture from the wood to the drying air.

In normal industrial batch kilns, drying conditions are automatically oscillating due to the reversal of the air flow direction. When the air passes through the pile, the temperature is reduced and the equilibrium moisture content (EMC) increases. Drying conditions on the inlet side of the pile are harsher than on the air outlet side. When the air flow is reversed, the part of the kiln load that was exposed to mild climate conditions is now exposed to harsher conditions. The airflow direction is usually changed every 1 to 4 hours and produces a “natural” oscillating schedule, especially for timber in the side packages of the kiln load (Figure 65). In the middle packages, the climate does not vary as much due to these changes in airflow direction.

Under industrial conditions, the parameters of the air leaving the stack are monitored but not controlled. The beneficial effects of oscillating drying conditions are not yet fully understood, nor are their use well established. For this project, BFH has studied oscillating schedules and analysed their effect on the progress of drying and on deformation.

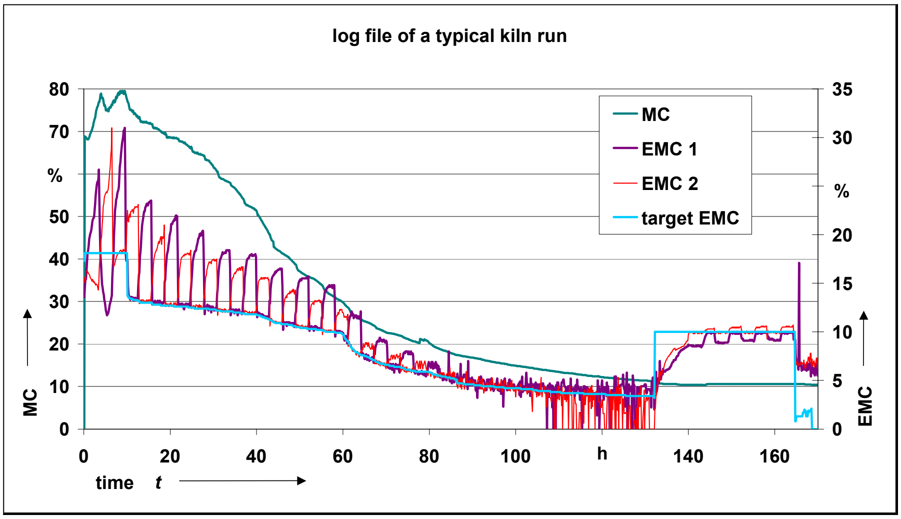

Figure 65. Equilibrium MC at both sides of the drying charge in an industrial batch kiln.

In batch kiln drying, the conditions on the air outlet side are rarely controlled. It is, therefore, important to plan the oscillating schedules to periodically change the moisture content in the surface layers of the wood.

A total of 8 kiln runs (four with Norway spruce, four with Sitka spruce) were carried out in a semi-industrial kiln. Kiln drying parameters were varied which included, severity of the schedule and type of oscillation (frequency and amplitude) corresponding to different reversal times in full size industrial kilns. The tests simulated the behaviour of the outer packages of timber in a large kiln. Part of the kiln load was top loaded to determine the impact of top loading, in conjunction with oscillations on the deformation behaviour (Figure 66).

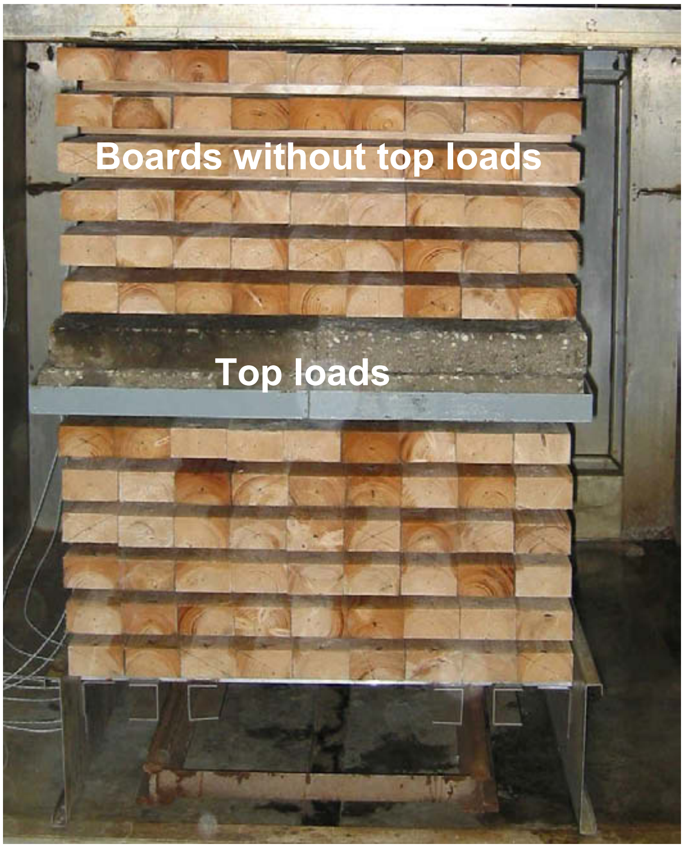

Figure 66. Kiln load in semi-industrial size kiln.

The drying times necessary under various oscillating conditions (reversal times) were compared with the quality of the boards achieved after drying. The target moisture content of 14% was not achieved precisely in all kiln runs so; drying times are presented for moisture intervals which were valid for all kiln runs. As a reference for the experiments with Norway spruce, a schedule with a one-hour reversal time (oscillation period) was chosen (Tables 15 and 16).

Table 15. Four drying schedules for Norway spruce.

Schedules for Norway Spruce				***severe***	***mild***		***long***	***short***	
				1A + 1B	***2A + 2B***	***amplitude EMC***	***1A + 2A***	***1 B + 2B***	**air speed**
step	**time *h***	***°C/h***	**temp. °C**	**EMC %**	**EMC %**	**% absolut**	**frequency *h***	**frequency *h***	***m/s***
heating up		10/h	60	14	14	-	-	-	2.5
warming	3		60	14	14				2.5
MC > 50			60	12	14	+/- 3	2.5	1	2.5
50-45			60	12	14	+/- 3	2.5	1	2.5
45-40			60	12	14	+/- 3	2.5	1	2.5
40-35			62	11	13	+/- 3	2.5	1	2.5
35-30			64	11	12	+/- 3	2.5	1	2.5
30-25			66	10	11	+/- 2	2.5	1	2.5
25-20			68	8	9	+/- 2	2.5	1	2.5
20-15			70	6	6	+/-1	2.5	1	2.5
15-10			70	5	5	+/- 0	0	0	2.5
conditioning	6		65	14	14				2.5
cooling			35	13	13				2

Table 16. Four drying schedules for Sitka Spruce.

						amplitude EMC	***Oscillation time***		
Schedules for Sitka Spruce							***long***	***up to 2.5***	***slow up to 3***
					4A	***3A 3B 4B***	***3A***	***3B***	***4B***
step	**time *h***	***°C/h***	**temp. °C**	**EMC %**		**% absolut**	**frequency *h***	**frequency *h***	**frequency *h***
heating up		10/h	60	14		-	-	-	
warming	3		60	14					
MC > 50			60	14	const	+/- 3	2.5	1	1
50-45			60	14	const	+/- 3	2.5	1	1
45-40			60	14	const	+/- 2.5	2.5	1	1
40-35			62	13	const	+/- 2.5	2.5	1.5	1
35-30			64	12	const	+/- 2	2.5	1.5	1
30-25			66	11	const	+/- 2	2.5	2	1.5
25-20			68	9	const	+/- 2	2.5	2.5	2.5
20-15			70	6	const	+/-1	2.5	2.5	3
15-10			70	5	const	+/- 0	0	0	0
conditioning	6		65	14					
cooling			35	13					

3.7.2 Results

Norway spruce

Air reversal in large kilns reduces MC deviation and or shortens drying times. Small MC deviation results in less over drying and thus, less warped timber. Therefore, it is important to find the optimum oscillation parameters for different kilns.

It can be seen that the oscillation of the kiln climate had an effect on deformation. Top loading also reduced the twist and bow slightly when piles were top loaded (Table 17).

Table 17. The effect of oscillating the kiln climate and top loading on twist, bow and checks of Norway spruce. Drying sets 1A and 2A with long climate oscillation and drying sets 1B and 2B which were references with short oscillations.

Run	Interval 63–17% MC		Percentage of studs below threshold		Percentage of studs with checks
	Drying time (h)		Twist	Bow	
			< 5 mm / 2000 mm		
1A	65	Top Load	58	90	25.1
		No Load	53	94	
1B	95	Top Load	43	90	22.5
		No Load	30	75	
2A	75	Top Load	41	92	2.6
		No Load	30	98	
2B (Reference)	85	Top Load	32	96	5.8
		No Load	20	87	

On Norway spruce, the best results were obtained using a severe schedule 1A, with a 2.5 h oscillation time and top loading.

For each of the test schedules, the drying time could be shortened considerably, by optimising the oscillation time, without adversely affecting the resulting drying quality. Schedules with a 2.5 h reversal time produced much better results than those with 1 h reversal time. The mild schedules, 2A and 2B, produced less checking but more deformation, whereas, the severe schedules, 1A and 1B, produced low deformations and, in the case of 1A, a very short drying time.

Even without top loading, twist was reduced by oscillation using schedule 2A when compared to the reference schedule 2B. When checking is critical, mild schedules should be used. When drying time and deformation are critical, harsher schedules can produce better results.

Hard conditions, combined with a short reversal time, can prolong drying time, as was experienced with schedule 1B. When using mild conditions, a 2.5 h reversal interval reduced the drying time and, at the same time, improved the timber quality.

Sitka spruce

When drying Sitka spruce, short reversal times at the initial stages of drying have a positive effect on drying time and resulting quality. The effect of top loading is evident for oscillating conditions and very pronounced for constant (no oscillations) conditions, which prevail in progressive kilns.

For all tests with Sitka spruce, the mild schedule from the first series of experimental work was chosen. This schedule was modified with respect to oscillation time and amplitude. Schedule 4A maintained constant conditions during each step. Schedules 3A, 3B and 4B, started with high amplitude that was continuously reduced as drying proceeded, (to simulate the conditions in large industrial kilns). Schedule 3A was run with a constant oscillation time of 2.5 h, whilst schedules 3B and 4B started with a short reversal time of 1 h that was increased to 2.5 h towards the end of the schedule. In schedule 3B, the oscillation time was slowly increased to a maximum of 2.5 h, where as, schedule 4B had a long initial period with a short reversal time, which was sharply increased to 3 h towards the end of the drying schedule.

Compared to the mild schedules 2A and 2B on Norway spruce, the drying times achieved in the tests with Sitka spruce were very similar at moisture contents between 63% and 17%. Results for the oscillation schedules were all quite similar with respect to drying quality (deformation and checking) for the two species. Only for schedule 3A, with a long oscillation time, did the drying time increase.

The “constant” schedule 4A resulted in the longest drying time and produced the best result with respect to drying quality (deformation and checking).

As already experienced with Norway spruce, top loading had a very positive effect on the drying quality of Sitka spruce. In all experiments, the drying quality was improved by the application of a top load. A pronounced increase was observed for the constant schedule (approximately equivalent to the conditions in a progressive kiln).

In the case of Sitka spruce, long reversal times in the high moisture content region (schedule 3A) tended to have a negative effect on drying quality as twist was quite pronounced (Table 18). A short reversal time at the initial stages of the kiln run should only be increased when fibre saturation point has been reached.

Table 18. The effect of oscillation of kiln climate and top loading on twist, bow and checks of Sitka spruce. Dryings 3A, 3B and 4B with climate oscillation and drying 4A (reference) with constant conditions.

Run	Interval 54–17% MC		Percentage of studs below threshold		Percentage of studs with checks
	Drying time (h)		Twist	Bow	
			< 5 mm / 2000 mm		
3A	78	Top Load	32	96	1.7
		No Load	19	87	
3B	69	Top Load	42	93	3.2
		No Load	35	87	
4B	69	Top Load	37	96	0.5
		No Load	35	93	
4A (constant)	80	Top Load	74	96	0.6
		No Load	42	83	

Between Sitka spruce and Norway spruce, no significant differences in drying behaviour (time) and drying quality were observed. Short reversal times, until fibre saturation point was reached were beneficial for Sitka spruce. Top loading was beneficial in all drying situations.

3.7.3 Straightness in-service

Selected material from the oscillating schedule work was subjected to a moisture content change from 18% to 10% and back to 18% in a climate controlled room. After each conditioning period the twist was measured. This test was designed to simulate the worst possible in-service conditions (free hanging boards) for boards to ensure that they remain fit for purpose during use. The aim was to see how stable the improved straightness was placed in in-service conditions.

For the investigation of drying and reconditioning of pre-twisted boards, two sets of timber studs were used, Norway spruce and Sitka spruce. For the Norway spruce boards, eight groups of material were tested. The test runs used were 1A, 1B, 2A and 2B (Table 17), and each run comprised two groups, one dried with top load and one without top load. The results showed that top loading led to reduced twist compared to drying without top load. Any difference in terms of straightness between the various drying schedules was not apparent. The relative increase in twist was between 80% and 120% when wood MC reduced from 18% to 10%. The spring-back (deformation difference between first and third climate perod) was relatively small (Figure 67).

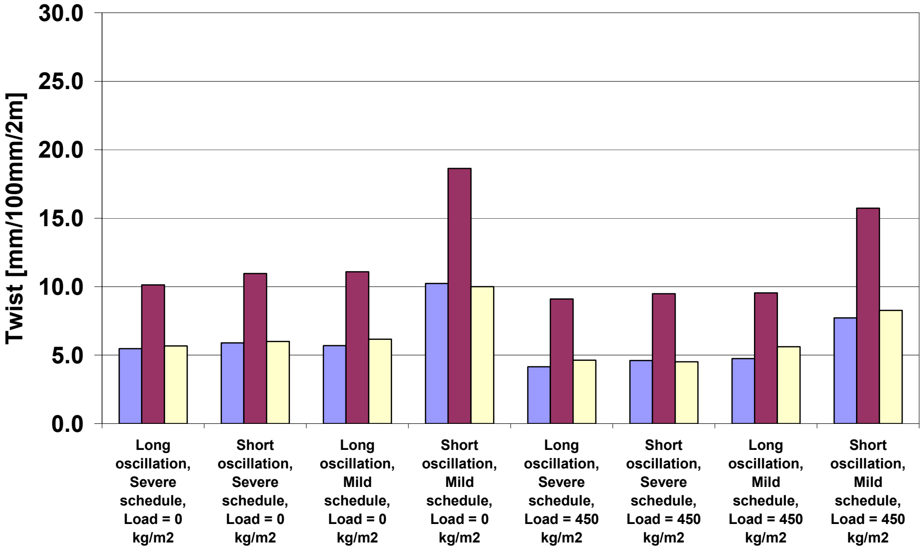

Figure 67. Absolute mean twist at 18% MC (first column in each group), at 10% MC (second column in each group) and at 18% MC (third column in each group). Each group of columns represents a treatment.

The percentage of boards achieving the acceptance limit for twist (4 mm / 100 mm / 2 m), was approximately the same in all groups, except run 2B, which produced more twisted material (Table 19).

Table 19. Percentage of boards below the threshold value for twist at 15% MC after 3 months conditioning at 85% RH / 23 °C and after additional 3 months moisture cycles at 30% RH and 85% RH, without any restraint.

Group	Boards below limit at 15% MC after first cycle, %	Boards below limit at 15% MC after 3rd cycle, %
1A, no top load	25.0	26.8
1B, no top load	32.1	32.1
2A, no top load	32.1	25.0
2B, no top load	7.1	3.6
1A, top load	39.3	32.1
1B, top load	32.1	35.7
2A, top load	35.7	35.7
2B, top load	14.3	14.3

For Sitka spruce, two groups of boards were tested using test run 3A. A reference group was dried in a normal conventional kiln. The results showed small differences between the oscillated material and the reference material. The increase in twist when wood MC reduced from 18% to 10% was the same for both groups but the spring-back was slightly larger for the reference material than for the oscillated material (Figure 68).

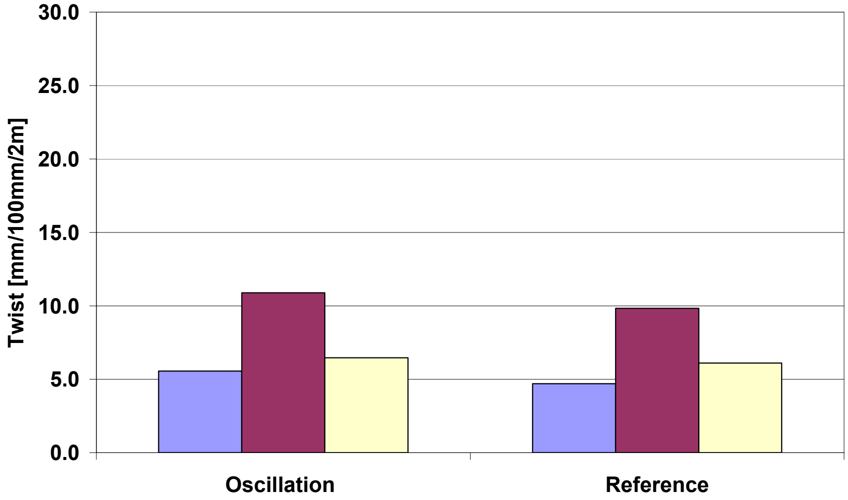

Figure 68. Absolute mean twist at 18% MC (first column in each group), at 10% MC (second column in each group) and at 18% MC (third column in each group). Each group of columns represents a treatment.

The percentage of boards that achieved the acceptance limit for twist was slightly higher for the reference material than for the oscillated material (Table 20).

Table 20. Percentage of boards that achieved the threshold value for twist at 15% MC after 3 months conditioning at 85% RH / 23 °C and after additional 3 months moisture cycles at 30% RH and 85% RH without any restraint.

Group	Boards exceeding the limit at 15% MC after first cycle, %	Boards exceeding the limit at 15% MC after 3rd cycle, %
3A	28.6	25.0
Reference	34.5	30.9

3.7.4 Cost assessment

There are no additional costs associated with using oscillating drying conditions in the batch drying of sawn timber. All batch kilns equipped with installations for the automatic reversal of air flow direction will have means to modify the reversal interval.

Based on knowledge about the current schedules being used, the kiln operator should try to make incremental adjustments to the reversal intervals. Reversal times between 1 and 2.5 hours in softwood drying operations tend to deliver the best results. An optimum reversal time for all types of kiln, species and thickness cannot be defined. In many cases, as described earlier, a drying time reduction of 10% can be achieved without any negative effect on drying quality.

Drying time reduction automatically leads to a considerable cost savings, not necessarily in energy costs, but certainly in depreciation cost.

Reductions in drying time lead to an increase in drying capacity which can have a very positive effect on income. More timber can be dried in a given time interval without any additional investment.

3.8 High temperature drying

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3.8.1 Method

High-temperature drying (HTD) refers to drying at temperatures above 100 °C. The heat and vent principle normally used for drying at temperatures below 100 °C can be used for high-temperature drying. However, it is more common to release the steam generated from the drying timber, using the natural overpressure in the chamber. No fresh air will be drawn into the kiln, resulting in the drying being undertaken using superheated steam. In principle, with the wet bulb temperature would be 100 °C, as long as there is no air leakage from the kiln.

The concept of using HT-drying to minimise distortion is based on two facts, wood creeps more in high temperatures than in low temperatures and the equilibrium moisture content of timber is reduced slightly with increasing temperature. Therefore, deformation occurring in-service after HT-drying is reduced compared with conventionally dried timber.

Creep is strongly dependent upon the moisture content of the wood and is most significant in hot and wet wood. Some research findings have shown that increased wet bulb temperatures have resulted in straighter timber. At the beginning of the drying schedule, after heating up and when the timber is still wet, the timber temperature is about the same as the wet bulb temperature. At the final stage of drying, the timber temperature will reach the dry bulb temperature.

The benefits gained by using HT-drying vary according to research reports. The reason for this is due primarily to the different properties of various wood species and drying schedules. Many researchers put this down to the so called "softening" temperature of wood, the temperature at which wood is plasticised. This temperature varies for different species and is highly dependent upon the moisture content of wood. In some cases, the softening temperature is below 100 °C, but in the case of dry timber it tends to be over 150 °C. The theory is that the process softens the lignin, increasing the creep of wood.

Steaming before drying makes it possible to heat up the timber without drying it. Mild schedules with high wet bulb temperatures enhance the softening effect and the resulting creep leads to reduced distortion after drying.

High diffusivity and permeability allow fast drying and will affect the moisture gradient through the timber cross section during drying. When free water is present in the wood, the moisture gradient is low and the MC just below the surface is high. For wood with low diffusivity and permeability, drying is slow and the gradient is very high at the beginning of drying. For wood with high diffusivity and permeability, there is a greater tendency to creep since very dry surface layers, as would occur in the wood with low diffusivity and permeability, tend to creep less. Therefore, the reduction in distortion (benefit of HT-drying) for timber that already has a low tendency to creep is less than at lower (normal) drying temperatures.

During superheated steam drying (a type of high-temperature drying), the wet bulb temperature is 100 °C. This produces a high EMC in the kiln and therefore the moisture gradient, timber to air, is low. The use of superheated steam should thus reduce the deformation in timber in most instances where HT-drying is used.

3.8.2 Tests and results

High-temperature drying tests on Sitka spruce have been conducted in France, Netherlands, Sweden and Finland in both the laboratory and industry. Different drying schedules with and without pre-steaming have been tested and analysed. The initial drying phase was conducted at temperatures below 100 °C as there is a heightened risk of severe collapse developing if wet Sitka spruce is dried at temperatures above 100 °C. Once the moisture content of the drying timber had achieved a moisture content of approximately 30%, the main drying was initiated with steam temperatures between of 105 °C and 120 °C.

The target MC of the kiln loads was 15%, with the results being compared with conventionally dried boards. All conventional drying was carried out at temperatures between 60 °C and 75 °C.

Figure 69 presents the results of Sitka spruce trials. The positive effect of steam drying with top loading is clear. Also, HT-drying without top loading caused considerably more distortion than conventional temperature drying without top loading.

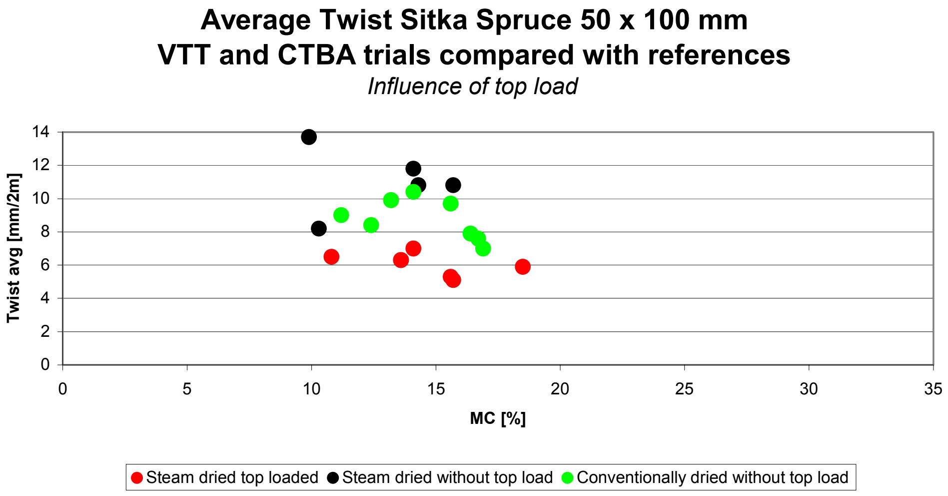

Figure 69. Average twist after HT-drying with and without top loads, and after conventional drying without top loads.

Table 21 shows that there was no difference in distortion between the two HT-drying temperatures tested (105 °C and 120 °C).

Table 21. Influence of drying temperature on the twist of Sitka Spruce when dried with top load. The average final moisture content was 14.7%.

Temperature, °C	Twist, mm / 2 m
105	6.0
120	6.1

Influence of post-steam conditioning of Sitka Spruce

TNO performed eight drying trials on Sitka spruce to investigate the influence of post-steam conditioning. Post-steam conditioning is carried out at a temperature between 90 °C and 100 °C. During this phase, a high relative humidity is maintained to produce a climate with an EMC value of 15%. All tests were performed with a top load of 500 kg/m^2 and the average values are summarised in Table 22. Final moisture content is the main factor found to influence twist.

Table 22. Comparison between the average values obtained in tests by VTT and CTBA without steam conditioning and by TNO with steam conditioning.

	Final MC %	Twist mm / 2 m
No conditioning (VTT-CTBA)	14.7	6.0
Steam conditioning (TNO)	15.8	5.4

Results indicate that post-steaming does not seem to affect distortion. However, its use is still recommended to reduce the moisture gradient, case hardening and, in some cases, cracks within the timber.

The main assessment criteria for the methods and schedules has been distortion. Other drying quality factors must also be considered when selecting a drying method. Advantages of HT-drying (105 °C–120 °C) over conventional drying (60–75 °C) include

1. 50–75% shorter drying times (depending on final quality requirements)
2. reduced drying time that allows greater flexibility in deliveries
3. lower energy costs (due to enclosed drying system)
4. lower capital costs (kiln and timber in kiln and increased turnover).

Disadvantages of HT-drying compared with conventional drying include

1. heat energy production (the heating fluid (water, steam, oil) has to be heated to at least 140–150 °C to achieve high-temperature drying temperatures; traditional heating plants at most sawmills are not sufficient to generate these temperatures)
2. that HT-drying causes the timber to darken slightly
3. difficult to avoid inner cracks in thick timber (over 50 mm)
4. difficult to obtain a homogeneous final MC if the average final MC is high (15% to 20% moisture content)
5. small (0–5%) reduction in strength
6. that HT dried timber is a new product needing separate handling at the sawmill and also initial extra marketing efforts.

Pressure steam treatment (PST)

At VTT, the pressure steam treatment has successfully straightened dried, twisted timber. The process uses saturated steam at high-temperature (150–160 °C, dry and wet bulb the same) to soften the wood. Conditions should be right for effective creep when the wood has softened whilst the moisture content has not dropped too low.

Twisted timber was stacked with stickers in a modified pressure vessel and a top load of 320 kg/m^2 applied. An example of the schedule used is shown in Figure 70.

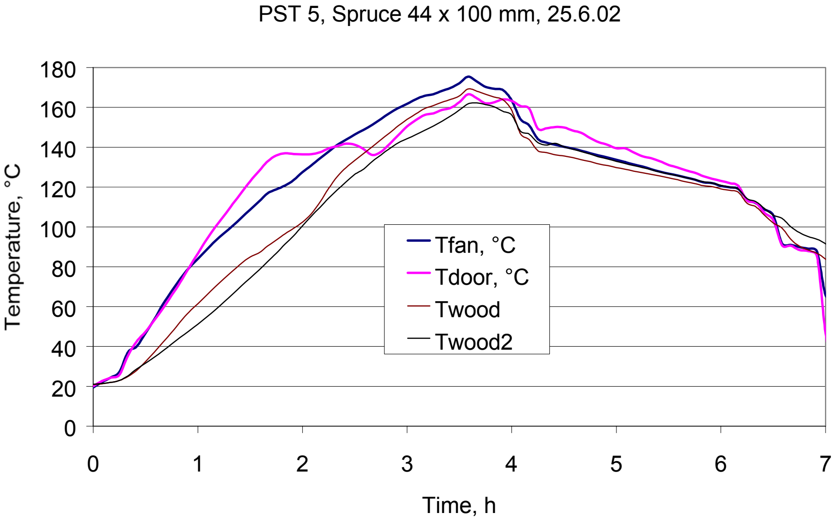

Figure 70. An example of pressure steam treatment schedule.

Figure 71 shows timber in the vessel before and after the treatment, and an example of the effect on twist can be seen in Figure 72.

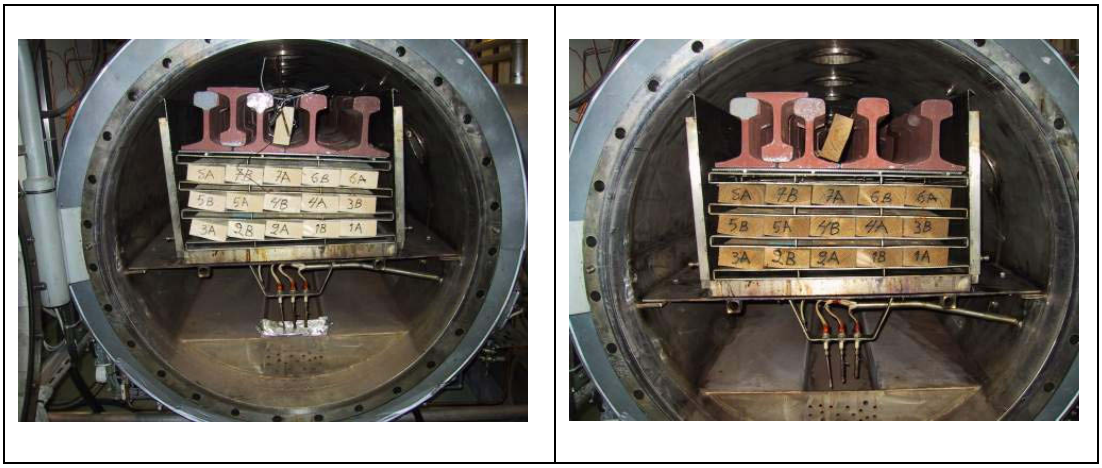

Figure 71. Timber in the vessel before and after pressure steam treatment.

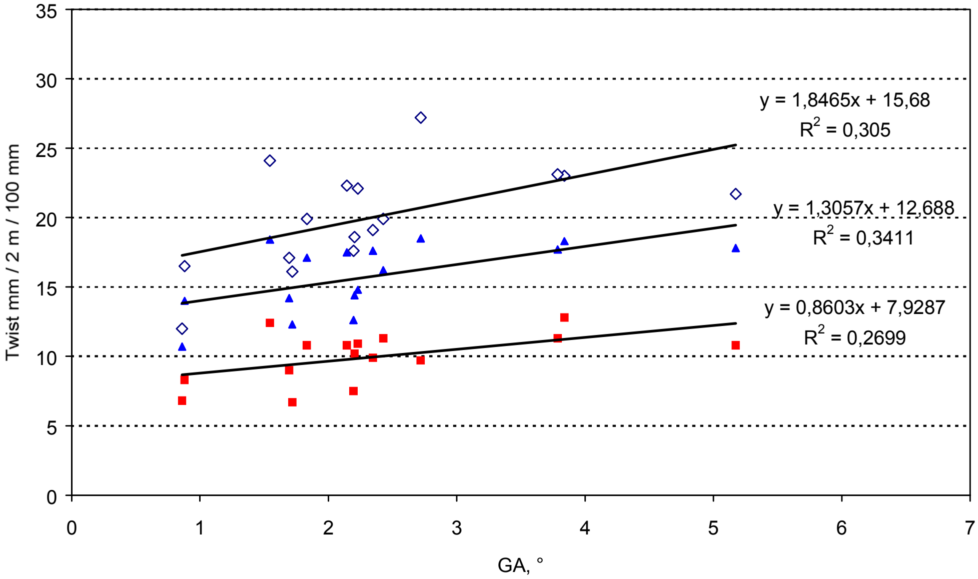

Figure 72. Twist before (upper line) and after (lowest line) the treatment and after additional storage for 6 weeks. The average MC was 8.1% before the treatment and 7.7% after the treatment and storage.

Figure 71 shows that the top loading weight should have been increased for getting the timber stack flat during the treatment and cooling. Figure 72 shows that the permanence of straightening was poor and spring back in 6 weeks storage large. This method may produce better results with twisted boards underneath the charge (see chapter 3.6).

Taking into account the high costs and small capacity of a special pressure vessel, the commercial viability of this method is poor.

3.8.3 Straightness in-service

Battens subjected to high-temperature drying assessed for straightness in-service. Unrestrained battens were subjected to a moisture content change from 18% to 10% and back to 18% in a climate controlled room. After each conditioning period the twist was measured. This test was designed to simulate the worst possible in-service conditions for battens in order to ensure that they remain fit for purpose during use. The aim was to gauge how stable the improved straightness was in in-service conditions.

For high-temperature drying, three test sets were evaluated, two of them in combination with other treatment processes, top loading and pre-twisting during drying. The third test set was high-temperature dried Sitka spruce, conducted in the Netherlands. The results showed that the mean twist was similar for both timbers dried by high-temperature and the low temperature kiln drying methods. This material had a negative spring-back, i.e. the twist was smaller after moisture cycling (Figure 73).

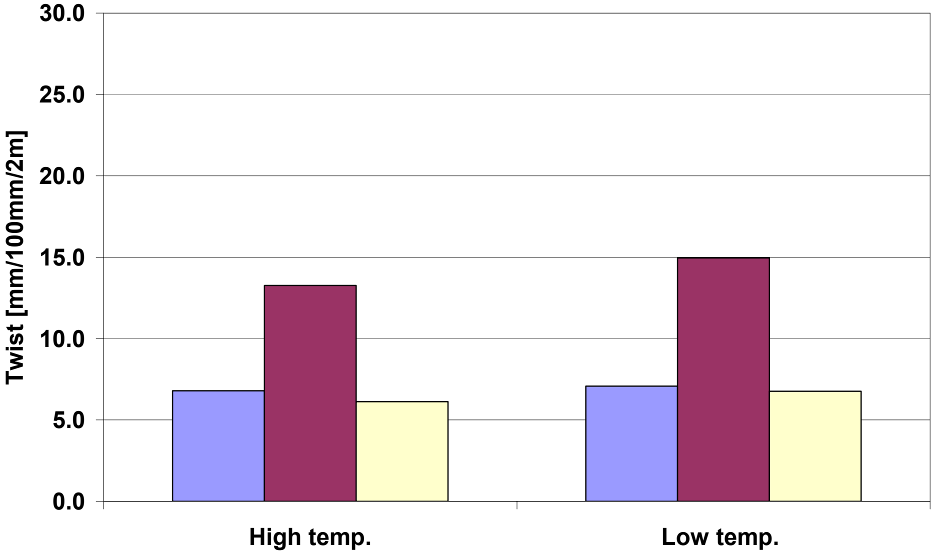

Figure 73. Absolute mean twist at 18% MC (first column in each group), at 10% MC (second column in each group) and at 18% MC (third column in each group). Each group of columns represents a treatment.

The number of battens that exceeded the acceptance level for twist was slightly lower for the high-temperature dried material than for the reference material (Table 23).

Table 23. Percentage of battens that exceed the threshold value for twist at 15% MC after 3 months conditioning at 85% RH / 23 °C and after additional 3 months moisture cycles at 30% RH and 85% RH without any restraint.

Group	Battens exceeding the limit at 15% MC after first cycle, %	Battens exceeding the limit at 15% MC after 3rd cycle, %
High temperature	26.5	32.7
Reference	32.7	36.7

3.8.4 Cost assessment

The drying costs of high-temperature drying depends largely on local situations at sawmills. Table 24 shows a comparison of drying costs in a sawmill where high-temperature water or steam is readily available. The cost analysis will change if a new heating plant is required.

The additional costs of separate handling, sorting, packaging, marketing and selling of HT-dried timber can easily exceed the cost savings of this rapid and energy efficient method.

Table 24. Comparison between HT drying and conventional kiln drying (batch kiln for joinery timber and one stage continuous drying kiln for shipping dry timber).

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

Table 24 shows that HT-drying is most economical when drying to low moisture contents. Shorter drying schedules cut capital and energy costs. In this example, normal “shipping dry” timber is dried in a continuous kiln, common in Nordic countries. The use of a heat exchanger makes it energy efficient. Savings are higher when “shipping dry” timber is produced using HT-drying compared with low temperature batch kiln drying.

4. Summary of feasibility of new straightening methods

Some of the straightening methods studied have proven to be both effective and useful for the sawmilling industry in Europe. In most cases, the improvement in straightness is not permanent and if not used within a fairly short time frame will exhibit some degree of spring-back. However, despite spring back, the material can tends to be straighter than the corresponding reference material.

In some cases, the drying techniques is good enough that the material remains straight in the short term, for example, before further processing of the timber into glued constructions e.g. doors and windows. In most cases, the material needs to stay straight for a relatively long period before being fixed into their end use location, for example as joists, supporting beams and panels in construction. Finally, in a fewer cases, the timber is not fixed in use and must stay straight in varying environment conditions. The feasibility of using the improvement methods to produce timber for these three very different perspectives has been analysed.

In order to assess the total effect of new straightening methods, the proportion of logs and timber requiring straightening treatment must be known. The following section discusses this issue.

4.1 Material with a propensity to distort

Only a proportion of logs and the resulting sawn timber will have the tendency to twist excessively. Swedish studies (Kliger 2001) have shown that sawn timber from large logs with severe spiral grain will twist excessively during normal drying. The percentage of logs showing this feature varies greatly and may account for between 1% and 5% of the total volume of logs processed.

On the other hand, small logs with a diameter of less than 160 mm will produce timber with a propensity to distort because it is sawn near the pith and its dimensions are small.

To get an idea of how large the distortion problem is, the percentage of these small diameter logs has been calculated from log statistics from a Finnish sawmill. The amount of small dimension spruce timber sawn close to the pith has also been calculated from timber statistics. Only boxed-pith battens and inner boards, 32–50 mm thick and 75–125 mm wide, cut using a paired ex log sawing pattern have been considered.

Figure 74 presents the proportion of small logs and Figure 75 presents the proportion of small dimensional timber being processed at a sawmill in Finland.

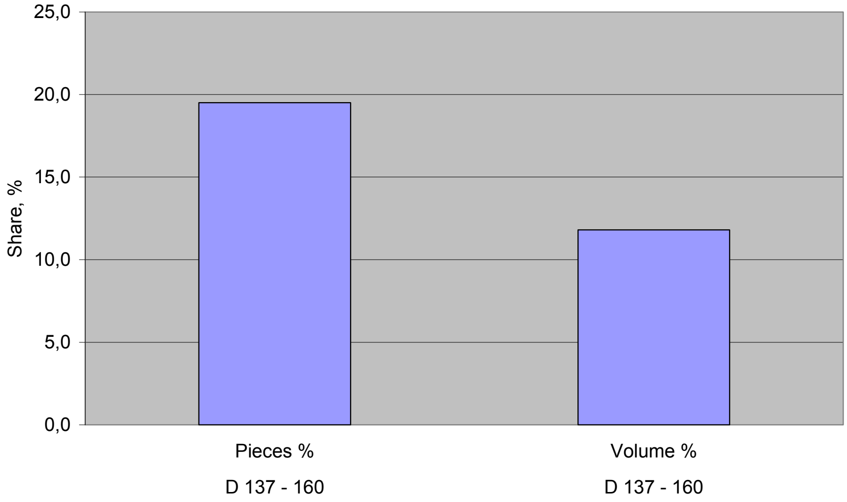

Figure 74. Percentage of small diameter Spruce logs at one Finnish sawmill.

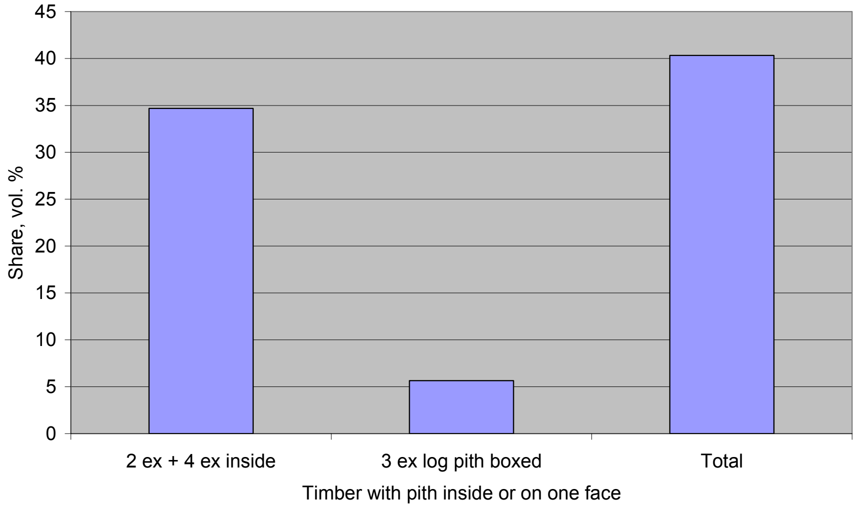

Figure 75. Percentage of small dimension timber (32–50 x 75–125 mm) sawn close to the pith at a Finnish sawmill. Spruce production.

The figures shown in Figure 74 show that about 20% of logs, about 12% of log volume, requires some measures for straightening timber. The volumetric share of small dimensional timber is about 40% of the total timber production. Therefore, the amount of timber that would no longer be rejected, as a result of using straightening methods, is very high.

4.2 Forms and permanence of straightening

High-temperature drying, top loading, twisted pack drying, new conditioning techniques and oscillating drying schedules described in this manual are methods that use the effect of creep in timber during drying. These techniques enable creep to reduce the deformation of timber compared to the natural deformations that would occur in free drying. A disadvantage of these methods is that the spring-back effect reduces the beneficial straightening effect. This reduction is time and climate dependent and is difficult to predict.

The twisted sawing method uses the natural twisting of the timber as a basis for cutting. As the timber is dried it straightens, and this form is retained after drying, without the spring back effect.

Green gluing, i.e. re-engineering the timber, results in very straight timber with a reduced tendency to distort during drying. Deformation forces are used to counteract each other and the timber stays straighter. For the optimum straightening effect, constructions must be symmetrical and the forces fully compensate each other.

Pre-sorting of logs and timber can be used to discard material prone to twist or to identify proper and effective measures for straightening of battens and end products.

4.3 Factors of feasibility

In a feasibility study of straightening methods, the pros and cons of each technique were analysed. The costs of methods already in use (e.g. top loading) are the simplest to analyse. In the case of new methods, some assumptions are necessary to produce cost estimations.

The advantages of straightening timber can be calculated using the price difference between straight and distorted timber. Material flow during processing is better with straighter battens as these do not cause costly breaks in production that slow the process, and result in higher production capacity and better profitability.

In the schematic sawmill layout shown in Figure 3, the stages at which the different straightening methods should be carried out are shown.

Sorting logs according to the grain angle under bark is most readily carried out with a laser technique after debarking, i.e. just before sawing (A). A GA-measurement can also be undertaken adjacent to log sorting with S-GAG measuring system on bark covered logs or, as an alternative, material can be pre-sorted whilst in the forest using a modified S-GAG device mounted on a harvester.

Twisted sawing is achieved by modifying the in-feed and out-feed devices of sawing machines (B).

Timber pre-sorting according green MC and grain angle can be arranged in combination with dimensional sorting (C).

HT-drying (D), top loading (E) and oscillating schedules (F) are methods undertaken inside the kiln. The twisting of timber in twisted pack drying (G) and the new conditioning technique (I) can be carried out with faceted sleepers in the kiln if is loaded by forklift. If kiln wagons are used, the timber twisting should be carried out at the sticker or stacking machine.

Green gluing (H) is the only method that requires a separate production line with sawing, planing, gluing and assembly pressing. However the major advantage of this approach is that the method and machinery required to produce timber with improved straightness has been proven.

4.4 Summary of methods and their advantages and disadvantages

In Tables 25–33, the pros and cons of the different approaches evaluated in the STRAIGHT project are presented. The methods are discussed in order of the sawmilling process.

Pre-sorting of logs due to spiral grain angle (SGA)

Table 25. Pros and cons of pre-sorting large diameter logs (d > 20 cm) according to grain angle under bark.

Description of the method Raw material (logs) with a large SGA (SGA > 3°) measured under bark is more prone to twist than logs with a smaller grain angle. Logs with excessive spiral grain should not be utilised for sawn timber when the timber is prone to twist after drying and whilst in-service. The ultimate boundary limits of SGA, optimised from an economics basis, needs to be decided.
How does this method increase the straightness of timber Material sawn close to the pith or as boxed pith is most prone to twist. Timber sawn further away from the pith is normally straighter if the SGA is within ± 3°. Logs with a SGA larger than ± 7° should be rejected or used in applications with less stringent requirements on straightness. For Example: 10 studs of dimensions 50 x 100 mm are sawn from one large log and dried to 18% MC. If a log has a SGA less than 3°, it is probable that only 2 studs (20%) will be rejected (i.e. studs closest to the pith). If a log has a SGA larger than 7°, it is highly probable that all 10 studs (100%) will be rejected as a result of high twist levels. For values of SGA between 3° and 7°, each sawmill must consider where limit should be set.
Special demands on the drying process and kilns No special demands as a traditional drying process are used. If incorporated with other drying processes, for example with top load, straightness may be improved even further.
Effects of the method on other timber quality factors than deformation No effects.
Effects on other processes at sawmill (No effects.) The SGA measurement unit should be located immediately after the debarking process and before a log is fed into the first saw. Handling and storage areas

for rejected logs have to be arranged. Problems related to the sawing of logs and handling, sorting and packing of twisted battens after drying are reduced by rejecting twist-prone timber. Savings as a result of eliminating these problems can be considerable. Sawing large-diameter logs in alternative dimensions may provide higher returns than can be achieved by producing studs.

Effects on drying and conditioning costs.
No effects. Improved drying or conditioning methods can be applied as an additional measure.

Extra processing and handling costs.
Sorting timber at a sawmill into an extra compartment requires additional handling of the logs. This has to be taken into account when analysing the profitability of pre sorting logs.

Effect on product mix. Are extra product groups and extra handling or marketing efforts necessary?
No effects. Product marketing can use the fact that the dried timber has a more uniform quality with less twist.

Other factors affecting the implementation of this method in industry
Cost of grading logs with regards to SGA under bark.
Logs can be graded in the forest using a harvester. SGA on logs with bark (for example, modified S-GAG) can be measured and rejected as appropriate before they leave the forest.
Logs can also be graded in a sawmill using laser methods for measuring SGA prior to sawing. It is estimated that about 2% of all logs have a SGA that is too large, i.e. larger than ± 7°. The initial cost to a sawmill (if grading logs) is estimated to be about 5 000 euros.

Pre-twisting during sawing

Table 26. Pros and cons of compensation sawing of small diameter logs to minimise twist in sawn timber after drying.

Description of the method
Almost all small logs (diameter < 20 cm) have a left-handed grain angle (GA). These logs are priced between the price of logs for pulp and those for sawn timber and so, sawn timber (often used as studs) is cheaper from small logs than from larger logs. To improve the quality in terms of twist, a pre-twisted sawing method is proposed. This means that small logs are rotated during sawing as a way of compensating for the left-handed SGA. This timber will become much straighter than “normally” sawn timber after drying.

How does this method increase the straightness of timber

Material sawn close to the pith or as boxed pith studs are most prone to twist. Timber sawn further away from the pith is normally straighter if the SGA is within ± 3º. Theoretically, this method can be optimised so that all timber is "straight", with respect to twist, at the final moisture content after drying. Logs should be sawn with as much pre-twist as necessary to produce straight material after drying to the required target moisture content.

Currently, timber cut from small diameter logs does not fulfil the twist level requirements after drying. Pre-twisted sawing will improve this timber by almost 100% if individual rotation is applied based on measured SGA under bark. A standard rotation of 1.5 º/m to 2 º/m may improve straightness by 50%.

Special demands on drying process and kilns

The traditional drying process is used. Stacking studs prior to drying may add some additional cost. Packs with twisted studs will have a slightly larger volume than studs sawn straight.

Effects of the method on other timber quality factors than deformations

No effects.

Effects on other processes at sawmill

Alterations to the feeding line are necessary where logs are transported to the saw or a new and modified saw.

Individual rotation of each log requires measurements of SGA on every log prior to sawing.

Effects on drying and conditioning costs.

No effects. Improved drying or conditioning methods can be applied as an additional measure.

Extra processing and handling costs.

No extra processing and handling costs assumed that the twist of green timber does not cause any damage during processing.

Effect on product mix. Are extra product groups, extra handling or marketing efforts necessary?

No effects. Marketing could state that straighter dried timber, with respect to twist, is produced.

Other facts affecting the implementation of the method in industry

The initial cost to a sawmill is estimated to be between 500,000 and 2 million euros.

Plus the cost of grading logs according to spiral grain angle under bark, if individual rotation of each log is necessary.

Pre-sorting of timber due to green moisture content and density

Table 27. Pros and cons of timber pre-sorting by green moisture content and density.

Description of the method Green timber is sorted into two or three groups with a capacity-type in-line moisture meter. The sorting criteria should separate battens into groups with similar drying characteristics and each group is dried with an optimised schedule to a specific target MC. This method reduces the average drying time and thus increases the drying capacity of the facilities. Overall MC deviation is also reduced. This method is suitable when part of the timber is pre-dried (dry logs, air conditioned material). When all the timber is fully fresh there is no or very small advantage of the pre-sorting by green moisture content.
How does this method increase the straightness of timber? Distortion increases with decreasing MC. The method minimises MC variation and the amount of over dried material. This reduces twist and hence the amount of rejected battens.
Special demands on drying process and kilns This method is suitable for large sawmills and common batten dimensions. It is possible to divide the material flow into two or three parallel kilns. The kilns may need to be smaller than they are at present.
Effects of the method on other timber quality factors than deformations The timber moisture content is more uniform.
Effects on other processes at sawmill The green sorting line requires a greater number of sorting bins to separate out the extra batches of material.
Effects on drying and conditioning costs. Due to shorter average drying times, the drying capacity of the facility increases and drying costs decrease. Conditioning time also decreases due to the uniform MC of the charge after the drying phase.
Extra processing and handling costs. Sorting and handling of smaller groups will increase costs.
Effect on product mix. Are extra product groups and extra handling or marketing effort necessary? None.
Other facts affecting the implementation of the method in industry None.

Green gluing

Table 28. Pros and cons of re-engineering boxed-pith battens by rip-sawing, planning, green gluing and pressing.

Description of the method Timber which is prone to twist during drying is re-engineered by ripping, planing and green gluing before drying. Traditionally, logs are sawn along the pith to produce two battens from the centre, both with a high tendency to twist. In the new approach, one boxed-pith batten is sawn from the middle. This reduces the twisting propensity of the other battens. The middle batten is then sawn along its length into two pieces and is reassembled in a back to back orientation by green gluing prior to being kiln dried. During drying, the twist in both pieces will counteract each other resulting in straighter timber.
How does this method increase the straightness of timber? Battens sawn further away from the pith are straighter than material sawn near to the pith. The re-engineering of boxed-pith battens results in much straighter timber. This leads to overall increase in straightness and reduced rejection rates.
Special demands on drying process and kilns None.
Effects of the method on other timber quality factors than deformations Pith may be visible on the new surfaces of re-engineered battens.
Effects on other processes at sawmill The sawing set ups need adjusting. The boxed-pith material needs an extra sawing, planing and gluing production line. Straighter timber will have a positive effect on the handling of dry timber in the processing chain, and hence productivity.
Effects on drying and conditioning costs. None or not known.
Extra processing and handling costs. An extra production line and extra outlet from the sawing line for material to be re-engineered is required.
Effect on product mix. Are extra product groups and extra handling or marketing efforts necessary? The new material will require extra marketing before customers accept re-engineered battens as a product. Because the product dries much straighter than normal solid timber,

it may be sold as a special product for a much higher premium. For some purposes, the strength properties may need to be determined.
Other facts affecting the implementation of the method in industry None.

Pre-twisted board drying

Table 29. Pros and cons of pre-twisted board drying.

Description of the method The timber package being dried is twisted in the opposite direction during drying to the natural twist of the battens. In industrial kilns, timber will be dried stacked on inclined sleepers at the bottom of a kiln or on a kiln wagon. The inclination angle of sleepers reduces from one end to the middle of the wagon and increases again on the other side in the opposite direction. This method is particularly effective on the bottom layers of the kiln stack. The effect lessens moving up the stack so when sorting and stacking, timber with the highest grain angle should be placed at the bottom part of the stack.
How does this method increase the straightness of timber? Twisting timber in the opposite direction to its natural deformation initiates tension forces and creep. Optimum twisting of the timber package during drying will ensure the timber is straight after drying and storage (spring-back effect).
Special demands on drying process and kilns The drying process does not require any modifications. The twisting of kiln loads can be arranged with faceted sleepers at the bottom of the kiln. In case of kiln wagons, the bottom of the carriage should include the inclination mechanism.
Effects of the method on other timber quality factors than deformations None.
Effects on other processes at sawmill Timber with excessive slope of grain has to be sorted and positioned in the bottom packages of the drying stacks. Practical solutions for different stickering, stacking, transporting and drying systems have to be established. Straighter dry timber will have a positive effect on the handling of the timber in the processing chain, and hence productivity.

Effects on drying and conditioning costs. Pre-twisting slightly reduces the drying capacity.
Extra processing and handling costs. Pre-sorting according to grain angle, separate handling of pre-sorted material and sorting or stickering as well as pre-twisting devices lead to extra costs.
Effect on product mix. Are extra product groups, extra handling or marketing effort necessary? None (the amount of rejected battens is reduced).
Other facts affecting the implementation of the method in industry The pack twisting technique can also be used in the new conditioning technique. When dry, twisted battens are twisted in the opposite direction to the deformation arising after drying and conditioned in a kiln.

Top loading

Table 30. Pros and cons of top loading.

Description of the method Top loading is the application of an additional pressure on the top packages during drying. The top loading system may consist of a constant load applied by means of concrete blocks or a variable load applied using pneumatic or hydraulic cylinders attached to a frame. The latter method is normally equipped with flexible flaps minimising air leakage over the top packages. The pressure on the frame will also prevent packages tilting. This method is limited to batch kilns.
How does this method increase the straightness of timber? By keeping all the timber (except the free ends protruding between the stickers) under restraint, the timber is forcibly held straight during the drying process. Due to high temperatures in the kiln, the timber is partially plasticised and will creep when the distortion forces due to shrinkage are activated. As a result of creep, when the pressure is released, the timber will be considerably straighter than timber dried without restraint.

Special demands on drying process and kilns

When using concrete blocks etc. to apply pressure on the top package, no special demands are required of the kiln construction. Depending on the concrete thickness, the loading volume might be slightly reduced.

When using pneumatic or hydraulic activated top frames, the kiln itself must be able to withstand the tension forces in the kiln walls. A positive effect on the drying process occurs due to the increased air speed through the timber resulting from the prevention of air leakage over the top packages.

Effects of the method on other timber quality factors than deformations

No change in drying quality (checking, etc.) is observed by the industrial kiln operators.

Special attention focused on possible increased sticker marks due to the increased pressure. Tests have however shown that even with the highest pressures on the bottom packages, the sticker marks were only in the range of 0.2–0.3 mm. If sticker marks are a problem, the variable pneumatic top load can apply a gradual increase in the load, as the compression deformation of wood is highly dependent on the moisture content. Wet timber has the lowest strength and highest deformation.

Effects on other processes at sawmill

Straighter timber will have a positive effect on the handling of the timber in the processing chain, and hence productivity. Single operators have observed that the processing line runs with fewer interruptions.

Effects on drying and conditioning costs.

The use of top loading will require additional investment in loading equipment. The level of investment will depend on the type of top loading and the type of kiln. The use of concrete blocks will require the lowest capital investment, but the highest handling costs. Pneumatic top loading will require the highest capital investments but the lowest handling costs. The latter could be easily adopted in new kilns, but for existing kilns, installation will be dependent on the kiln construction.

An investment in top loading will lead to higher costs, but also higher income due to better quality products and higher productivity in re-manufacturing.

In Table 30-1, three methods are compared: drying in a kiln with pneumatic top loading, constant top loading with concrete blocks and drying in an identical kiln without top loading. Only additional costs and income are taken into account. This calculated example is based on the twist reduction obtained from the “last sticker”. Separate calculations will be made for twist reductions including the free ends (will differ depending upon sticker distance). A price/ratio of 0.7 is used for timber with a twist > 4 mm (C14) compared to ber with a twist < 4 mm (C18, C24, and C30). Timber with excessive twist, will therefore be un-saleable, and is not included in the calculation, but would reduce the price ratio even more.

Table 30-1. Example calculation (additional costs and incomes).

	Batch kiln with pneum. top load	**Batch kiln with concrete top load**	**Batch kiln without top load**
Basic data per kiln:			
Kiln capacity (4x4 packages), m^3/a	7000	6800	7000
Investment in top loading, €	30000	10000	0
Investment in tilting stop, €	0	6000	4000
Sum extra investment, €	30000	16000	4000
Interest rate (%)	4	4	4
Depreciation time(years)	10	10	10
Forklift cost incl. driver, €/h	35	35	35
Timber price (construction timber), €/m^3	200	200	200
Additional income per kiln:			
Timber value gain by top loading (4 pack. height), €/m^3	4,1	4,1	0
Timber value gain, €/a	28700	27880	0
Reduced downtime due to straighter timber, %	1	1	0
Increased income due to higher production (estimate), €/a	300	300	
Total additional income, €/a	29000	28180	0
Additional costs per kiln:			
Deprec. pneumatic/constant top loading/tilting stop, €	3000	1600	400
Average interest costs, €	600	320	80
Extra operation costs for tilting securing (8 hours per year), €/a		300	300
Extra forklift costs (15 hours per year), €/a		480	
Electricity/maintenance for compressor, cyl. etc. €/a	1000		
Total additional costs, €/a	4600	2700	780
Economical result per year:			
Yearly economical gain (Add. income - add. costs), €/a	24400	25480	-780
- Extra costs kiln without top load, €/a	780	780	
Total comparable gain per kiln, €/a	25180	26260	
Payback (years)	1,19	0,61	

The calculated example indicates a substantial economic gain by installing or using top loads. The gain per year is almost identical for pneumatic top loading and constant top loading using concrete blocks of approximately 25 cm thickness. The lower investment in concrete blocks will lead to a shorter payback time, but the pneumatic system will be far easier to use and will be more secure in large kilns with package heights of between 4 and 5. The pneumatic system will also allow a gradual increase in the top load, with the lowest pressure when the timber is wet and a higher pressure when the timber is dry, therefore avoiding sticker marks in the bottom packages. Total prevention of air leakage in the top layer will also be an extra benefit of the pneumatic top loading system.

Extra processing and handling costs.

The handling costs will be lower using top load, leading to reduced downtime and increased productivity. This is included in the cost calculations in Table 30-1.

Effect on product mix. Are extra product groups and extra handling or marketing effort necessary?

None.

Other facts affecting the implementation of the method in industry

None.

Oscillating drying schedules

Table 31. Pros and cons of oscillating schedules.

Description of the method

The kiln-drying climate is changed in short intervals so that the wood surface moisture content decreases and increases periodically. The drying schedule is oscillating in a normal batch kiln, most significantly in the outermost packages due air flow reversal. The drying climate varies considerably when the airflow is reversed. The climate can also be oscillated with heating and venting, and water or steam spraying. Normally, the kiln control system executes the given oscillating schedules.

How does this method increase the straightness of timber?

The short periodic moistening of the surface initiates mechano-sorptive creep which requires the variation of climate to be wide enough to re-wet the surface periodically. Mechano-sorptive creep reduces the natural deformation of timber when the battens are dried under top loading leading to some increased straightness.

Special demands on drying process and kilns

No special demands. The kiln must be equipped with air flow reversal capabilities. The kiln operator must first analyse the current situation before adjusting the reversal time.

Effects of the method on other timber quality factors than deformation

Special schedules may reduce moisture content gradients and case hardening. Drying time reductions in the order of 10% can be achieved without any negative effect on drying quality.

Effects on other processes at sawmill

None.

Effects on drying and conditioning costs.

Effect on energy consumption can be neglected. When drying time is reduced without negative effects on drying quality, the drying cost will automatically be reduced.

Extra processing and handling costs.

None.

Any positive effect of the system depends upon where the optimisation starts. If oscillating conditions are already close to the optimum, then no further effect can be achieved.

Effect on product mix. Are extra product groups and extra handling or marketing effort necessary?

None.

Other facts affecting the implementation of the method in industry

Eventually, drying capacity can be increased and so reduce the need for investment associated with the installation of new kilns.

High-temperature drying

Table 32. Pros and cons of high-temperature drying.

Description of the method

High-temperature (HT) drying is where drying is undertaken with temperatures which exceed 100 °C. Superheated steam drying is HT-drying without air. This can be achieved by boiling water in the kiln so that the air is forced out through outlet vents. When the steam is saturated at 100 °C (i.e. wet-bulb temperature is 100 °C), the vents can be closed and the steam will only be released due to excessive pressure within the kiln.

How does this method increase the straightness of timber?

When the temperature of wood is increased, timber softens and the creep under tension increases. Drying is carried out with a top loading system and will prevent distortion during drying and initiate tension in wood with a propensity to distort. This affects the creep and results in reductions in distortion compared to the unrestrained timber. Slight reductions in shrinkage and swelling propensity lead to small amounts of reduced deformation.

Special demands on drying process and kilns

HT-drying is only possible in kilns specially constructed for high-temperature and high humidity in the form of steam. The kiln has to be airtight, so that only controlled venting is possible, and good heat insulation is necessary. A steam generation system is needed, especially for the heating up and conditioning phases.

Effects of the method on other timber quality factors than deformations

HT-drying affects the colour of timber. In long drying schedules for thick timber, the colour of the material changes, producing wood that is darker than after low temperature drying. The colour change of thin battens in fast drying is only slight. So-called “caramelising”, the change and darkening of sugars and other nutrients in sapwood, only darkens the surface layer of timber. Often, this layer is so thin that it can be removed by planing. However, there is a danger that the grey discoloration spots will penetrate deeper, so HT-dried timber including sapwood is not suitable for decorative use such as furniture and panelling.

Long HT drying schedules slightly reduce the strength of timber but the modulus of elasticity is not affected.

Paint and glue adhesion properties are not affected by HT-drying Adhesion is good, but in adhesion strength tests, the percentage of fracture in the solid wood is higher than in painted or glued LT-dried timber. The main reason for this is that HT-drying has made the wood slightly more brittle.

Effects on other processes at sawmill

In most cases, investment in a new heating plant is necessary. Water temperature in a heating plant is normally only 115 °C, which is not high enough for HT-drying.

Material flow, after sawing, has to be divided to one more line, i.e. for HT-drying. In most instances, HT-dried material has to be handled separately from LT-dried material and so handling costs are increased. Also extra marketing efforts may be necessary.

Effects on drying and conditioning costs

If all necessary facilities, like a heating plant with high water temperature capability, exist, cost calculations are relatively simple. Otherwise, investment in a new heating plant has to be taken into consideration.

It is important to ensure that the material dried using different methods are comparable.

With HT-drying, the average moisture content can be reduced very quickly, but MC deviation remains high and MC gradient and case hardening is, for many purposes, unacceptable. Measures to increase the drying quality will increase the total drying time and reduce the drying capacity.

In Table 32-1 HT-drying (HTD) is compared with LT-drying (LTD). The calculations are highly dependent upon local situations. In this case, the cost reduction achieved by HT drying is only an example.

Table 32-1. Comparison between HT-drying and conventional kiln drying (batch kiln for joinery timber and one stage continuous drying kiln for shipping dry timber).

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

It can be seen that the capital costs for HT-drying are less than for LT-drying because of faster drying. Heat consumption is reduced, partly due to short drying times and partly because fresh air is not being taken in and heated in HT-drying. There is a smaller cost reduction associated with shipping dry. One reason is that continuous drying kilns have heat exchangers.

Extra processing and handling costs Dividing the material flow in a sawmill to include one extra line needs additional handling. This has to be taken into account when analysing the profitability of HT-drying.
Effect on product mix. Are extra product groups and extra handling or marketing efforts necessary? Adopting HT-drying changes the product groups being produced. HT-drying material should not be mixed with LT-drying material, even if the customer can use both materials for the same purpose.
Other facts affecting the implementation of the method in industry None.

New conditioning techniques

Table 33. Pros and cons of new conditioning techniques.

Description of the method Dried timber is sorted to remove excessively twisted battens which are then re-stickered. The package is twisted in the opposite direction to the original twist and conditioned in a special climate under top load to improve distortion.
How does this method increase the straightness of timber? Twisting and pressing a package initiates forces which tend to straighten the timber. The special conditioning climate promotes the creep. This new conditioning technique is patented in Sweden.
Special demands on drying process and kilns A package twisting mechanism, extra top loading and climate generating and controlling systems will be required.
Effects of the method on other timber quality factors than deformations Eventually a decrease of moisture content gradient and case hardening will occur.
Effects on other processes at sawmill A special stickering system for twisted material is required. A normal stickering machine is not appropriate.

Effects on drying and conditioning costs. Conditioning costs depend on process time and the conditions within the chamber.
Extra processing and handling costs Extra stickering of twisted material. Secondary sorting.
Effect on product mix. Are extra product groups and extra handling or marketing effort necessary? None.
Other facts affecting the implementation of the method in industry None.

4.5 Comparison of the straightening methods

The methods studied must be ranked according to certain criteria; straightness, permanence of straightness, increased income due to quality improvement, investment and operating costs etc. The “best solution” depends on which criteria are most important. Table 34 presents the effects of different methods on some evaluation criteria.

Table 34. The effect of straightness improvement methods on costs, timber quality and processes at the sawmill (< reduced, << much reduced, > increased, >> much increased).

improvement method	defor-mations	drying capacity	drying costs	handling costs	incomes due quality	checking
A.Log pre-sorting according GA	<	-	-	>	>	-
B. Twisted sawing	<<	-	-	>	>	-
C. Pre-sorting acc. MC in drying groups[3]	<	>	>	>	>	-
D. Re-engineerin + wet gluing	<<	-	-	>>	>>	<
E. Twisted table drying	<<	<	-	>	>	-
F. Top loading	<	<[2]	>	<>	>	-
G. Oscillating schedules[1]	-	>	<	-	-	<
H. HT-drying	<	>	<	>	-	-
I. New conditioning techniques	<	<<	>	>	>	-

improvement method	colour changes	MC deviaton	strength	saleability	
				normal	separately
A.Log pre-sorting according GA	-	-	-	yes	
B. Twisted sawing	-	-	-	yes	
C. Pre-sorting acc. MC in drying groups[3]	-	<	-	yes	
D. Re-engineerin + wet gluing	-	?	?		yes
E. Twisted table drying	-	-	-	yes	
F. Top loading	-	(<)	-	yes	
G. Oscillating schedules[1]	-	<	-	yes	
H. HT-drying	>	>	<		yes
I. New conditioning techniques	-	?	-	yes	

[1] optimised air reversal

[2] if concrete top loads are used. With pneumatic or hydraylic top loading there is no capasity reduction.

[3] when all the timber is not fresh (pre-dried) before drying

Exact figures for improved straightness and economical gains are not easily shown. The profits due to improved straightness are dependent on allowable deformation, timber price for different quality classes and also the stage of the straightness measurement.

4.6 Summary of the straightening methods

The best methods for increasing straightness are twisted sawing, re-engineering by green gluing and twisted table drying. The first method needs development work on machinery and is only suitable for the smallest logs, which can be sawn without side boards i.e. the sides will be chipped.

Re-engineering of boxed-pith material needs investments in a new production line and knowledge, but it brings a significant improvement in overall straightness. One alternative is to find other uses for boxed-pith battens.

Log sorting according to spiral grain angle is very useful if the disqualified logs can be directed to processes other than sawing, but without a reduction in log value. Material with large spiral grain angle should already be sorted in the forest by harvesting. The logging machine can be equipped with a grain angle measuring device.

Twisted table drying and the new conditioning technique, based on an angled base for the kiln load, will need new technical solutions, especially for mass production. In small sawmills where fork lift trucks are used to fill kilns, the technique can be adopted without difficulty.

Top loading increases straightness most successfully in the upper most layers of the kiln load. Cost calculations show that the pay back time can be less than one year. This method can be recommended for all batch kilns.

High-temperature drying promotes the straightness of sawn timber when top loading and twisting of the kiln load are used. However, when deciding on a drying method such as HT-drying, many other important factors need to be considered. These include heating medium, colour changes of timber and the need for separate handling of HT-dried material in the production and selling stages.

Sorting of timber into drying groups according initial moisture content, and perhaps density, requires a more reliable measuring system for green timber than is currently available. When such a system is developed, the pre-sorting method might be useful in large scale production.

The key factors for ensuring straight timber are the quality of the raw material, sorting of logs or timber, properly functioning kilns with top loading and dense or careful stickering. The improvement of boxed-pith timber by re-engineering is a reasonable alternative.

4.7 Selection of straightening methods at sawmill

Sawmill layout, raw material and product mix affect the implementation of the proposed quality improvement methods. In Figure 76, a decision tree provides guidance on selecting the ideal straightening measures to adopt.

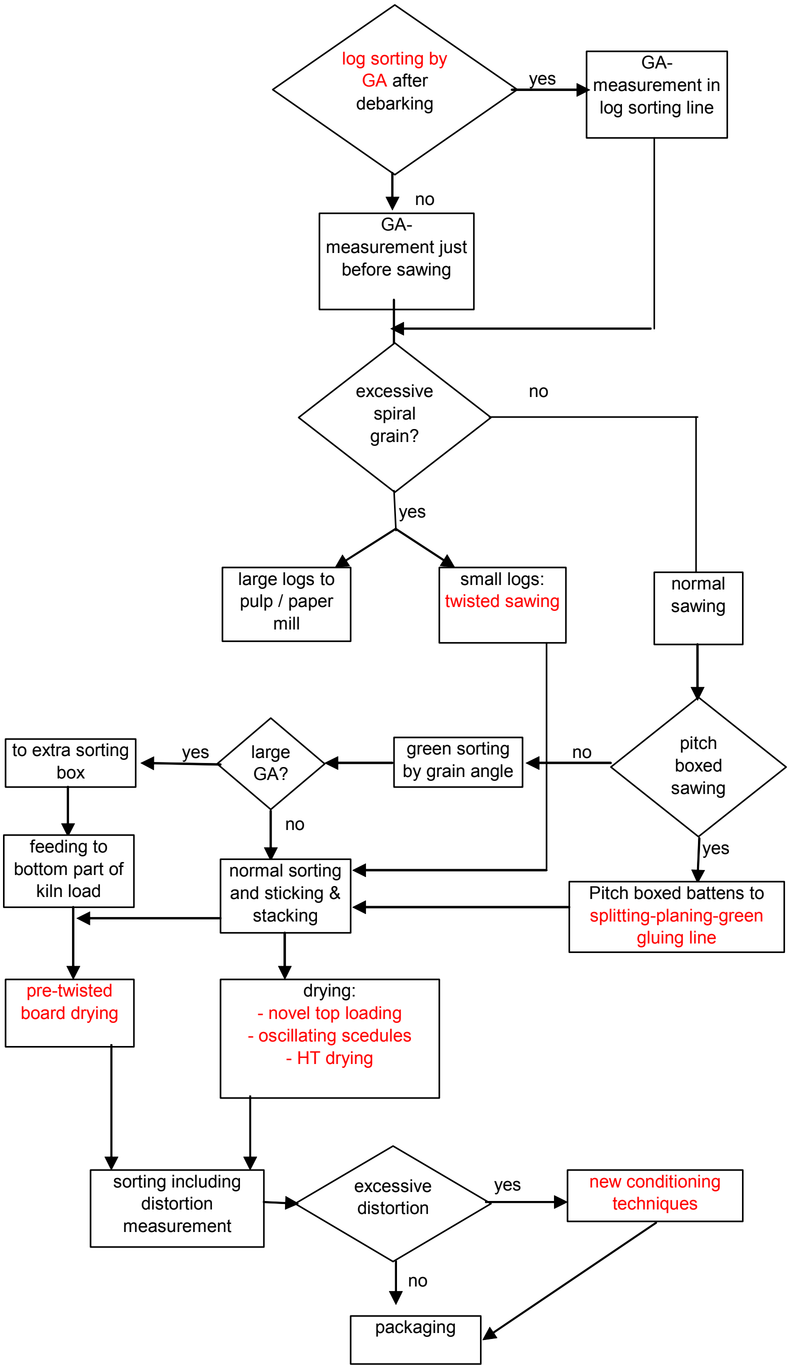

Figure 76. Decision tree for selecting an applicable quality improvement method in a sawmill.

5. Summary

In the EU funded STRAIGHT project, different drying, sorting, conditioning and re-engineering methods were investigated in order to minimise the distortion of sawn softwood timber. This publication presents all the methods studied, their pros and cons in relation to the sawmilling process and the end use of the sawn timber. The straightness improvement methods are ranked according to the percentage of structural timber falling within a maximum distortion level, when straightness is the main criteria. Other important criteria include extra drying and handling costs, the effects of methods on quality factors other than straightness, and the saleability of material with a normal sawmill production.

The methods studied were a) pre-sorting logs according to spiral grain angle, b) twisting of small diameter logs during sawing to counteract natural direction of twisting, c) re-engineering of boxed-pith battens using green gluing by splitting battens along their length and re-engineering whilst “green”, d) twisting the load, during drying in the opposite direction to natural twist using angled support sections on the kiln wagon to counteract the normal direction of twist, e) top-loading of the kiln load, f) oscillating drying schedules to enforce mechano-sorptive creep to reduce twist, g) high-temperature drying and finally h) new conditioning techniques where dried twisted timber is re-stacked and stickered on angled support balks which promote opposite twisting during special conditioning.

The best straightening results were achieved by re-engineering boxed-pith battens using green gluing before drying. The most cost-effective method assessed was the top-loading and correct stickering of drying charges. How cost-effective the opposite twisting will be depends on the practical solutions to be developed. The disadvantage of top-loading, as well as of opposite twisting during drying, is the effect of spring-back: timber that is fairly straight directly after drying gradually reverts to original distortion levels as environmental changes occur. Methods of drying, where the timber is susceptible to the spring-back effect, are suitable if the timber is kept under pressure after drying or used in construction soon after drying or re-engineered so that the eventual spring-back effect is prevented.

Sorting logs and battens with large grain angles considerably improves the straightness of the sawn timber.

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Measures for improving quality and shape stability of sawn softwood timber during drying and under service conditions

Best Practice Manual to improve straightness of sawn timber

Abstract

In the EU funded STRAIGHT project, different processing methods (drying, sorting, conditioning and re-engineering) were investigated in order to minimise the distortion of sawn softwood timber. This Best Practice Manual summarises the main outcome from the study and was primarily written for industry. This manual describes the methods studied, and the advantages and disadvantages they bring to the sawmilling process and end uses of sawn timber. The methods for improving straightness are ranked according to a distortion acceptance percentage measured over the central 2000 mm portion of structural batten, when straightness is the main criteria (twist 4 mm / 100 mm, bow 4 mm, spring 3 mm & cup 2 mm / 100 mm). Other important criteria included in each assessment is extra drying and handling costs, the impact of using different methods on other factors of quality and the improvement in the saleability of material from normal sawmill production.

The methods studied were a) pre-sorting of logs according to the angle of spiral grain, b) twisting small diameter logs during sawing to counteract natural direction of twist, c) re-engineering boxed-pith battens using green gluing (splitting battens along their length and re-engineering whilst “green”), d) twisting the drying load in the opposite direction to natural twist (the support sections on the kiln wagon were angled to counteract the normal direction of twist), e) top-loading of the kiln, f) oscillating drying schedules to introduce mechano-sorptive creep to reduce twist, g) high-temperature drying and finally, h) new conditioning techniques where dried, twisted timber was re-stacked and stickered on angled supports to promote opposite twisting during special conditioning.

It was found that the best straightening results were achieved by the re-engineering and green gluing of boxed-pith battens before drying. The most cost-effective method of improving straightness of timber was top-loading. How cost-effective the opposite twisting will be depends on the practical solutions to be developed. The main disadvantage of top-loading and counter-wise twisting during drying was the amount of “spring back” which occurs when timber is subjected to gradual changes in environmental conditions. These methods of drying are deemed suitable if the timber is kept under pressure or used soon after drying or re-engineered so that the spring-back effect is reduced.

Keywords
dimensional stability, distortion, straightness, sawn timber, quality improvement, drying, service conditions, Best Practice Manual, recommendations, sorting

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In the EU funded STRAIGHT project (QLK5-CT-2001-00276), different processing methods (drying, sorting, conditioning and re-engineering) were assessed to identify the most appropriate methods for minimising distortion in sawn softwood timber.

It was found that the most effective method for reducing distortion was re-engineering. This method uses centrally cut boxed-pith sections which were found to be the most susceptible material to develop severe distortion. The selected pieces were sawn along the longitudinal axis, turned in a back to back orientation and bonded (whilst “green") with a moisture in-sensitive adhesive. The bonded sections are then dried conventionally. With this method, battens sawn further away from the pith are naturally straighter, improving the overall quality of the resulting production.

Top-loading has also been found to be a successful and cost-effective method for improving the straightness of timber although, a more effective method is pre-twisting during drying. The main disadvantage of both methods is the levels of “spring back" which occur when timber is subjected to gradual changes in environmental conditions (in-service conditions) after drying. These methods of drying are deemed suitable if the timber is kept under pressure directly after drying, or re-engineered in order to reduce the spring-back effect.

This Best Practice Manual summarises the pros and cons of all the methods studied in the project and has been produced to help sawmills reduce distortion levels in softwood timber during drying. It should also be a useful tool for future investment decisions.

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