EC-project “STRAIGHT” (QLRT-200-00276)

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

Technical Report

Drying Quality Assessment

Work package 3

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Abstract

The European Commission funded project "STRAIGHT" deals with investigation of the effects of novel methods on the reduction of deformation during drying and under service conditions. The work plan of the project comprises various work packages, for each of which a Technical Report is foreseen as final deliverable. This Technical Report summarizes findings resulting from work package 3 "Drying Quality Assessment". Eight different techniques and combinations thereof have been analysed with respect to the capability to improve straightness of timber during drying and under service conditions. In the report a short description on the drying quality assessment methods is given. Major bottlenecks and problems are addressed. In addition, the beneficial effects of the various treatments are analysed and discussed. Attached to the report a digital data base containing the individual quality data is provided.

Keywords: timber drying, straightness, drying quality
Preface

The STRAIGHT project QLRT-CT-2001-00276 "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 and was completed at the end of 2004. Martin Greimel was the EU contact for this study.

This Technical Report is the final outcome of work package 3. It is one of the deliverables described in the Technical Annex of the contract to the STRAIGHT project.

Project participants which have contributed to this Technical Report are listed below:

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This Technical Report summarizes results and findings of work package 3 "Drying Quality Assessment" and relates to all sub tasks of work package 2 "Novel Methods for reduction of deformation". Special acknowledgement has to be given to the technical staff of the institutes, to the group of student workers and to the supporting industrial enterprises. Without their help and support the huge amount of work in form of far more than 1.000.000 individual measurements would not have been possible.

Hamburg 2005

Johannes Welling
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Annex: CD containing STRAIGHT drying quality data base
1 Introduction (Objectives)

The objectives of the work package 3 of the STRAIGHT project are:

- to assess the quality of the timber dried using one or several of the novel processes described in work package 2 of the STRAIGHT project. These processes are:
  - High Temperature Drying
  - Novel Top Loading
  - Oscillating Drying Conditions
  - Twisted Pack Drying
  - Pre-Sorting
  - Green Gluing and Re-Engineering
  - Conditioning Technique
- to determine the optimum processes for production of timber with minimum distortion after drying

All partners involved (BFH, BRE, CHA, VTT, NTI, CTBA, TNO) carried out drying tests on laboratory and pilot scale. These experiments were carefully documented with regard to development of distortion.

In the STRAIGHT project special emphasis was given to European spruce species, which account for a very significant part of the European softwood sector. A very high percentage of the spruce sawn timber is used in the building sector. For structural application straightness of the sawn timber material is an important quality factor.

In Central and Northern Europe the predominant spruce species is Norway spruce, whereas in the UK and Ireland Sitka spruce is most frequently cultivated and used.

Norway spruce originates from sustainably managed forests throughout Europe. Depending on the site conditions it grows slowly (Northern Scandinavia) or fast (Southern Scandinavia, Germany, Austria).

Sitka spruce mainly originates from plantation type managed forests in UK and Ireland. These forests have been set up throughout the last decades. Sitka spruce is fast growing and normally shows much wider annual rings as compared to Norway spruce.

Within the STRAIGHT project both species were examined with respect to distortion propensity and with regard to the effectiveness of measures to prevent the distortion which develop during the drying process.
2 Methodology

2.1 Sampling

At the very beginning of the project the partners decided to focus all investigation activities on sawn timber which is very prone to develop unwanted distortion.

Sawn timber, which is extremely suffering from down grading and value losses after kiln drying, comprised boards which are:

- produced from small diameter logs,
- produced from upper stem sections,
- cut in the vicinity of the piths.

In industrial language studs fitting to the above definition are often specified as "2exlog" or "boxed pith" (see Figure 1).

Figure 1: Type of material used in comparative tests throughout the STRAIGHT project

All partners used "2exlog" studs in all work packages, except for WP 2.6 (Green gluing and re-engineering), where special emphasis was given to boxed pith studs.
"2exlog" studs were either specially produced (partner BFH) or selected from the running production of sawmills.

In order to get material which could be used for comparative studies, two strategies for producing "matched samples" were allowed (fig. 2).

Option 1 was production of two matched samples from a long stud. Option 2 was selection of two studs from one single stem. Option 2 was much more labour intensive. In a normal sawmill the selection of two adjacent studs from one single log automatically involves an interruption of the material flow, because the studs have to separated from the normal flow of material. Therefore, in most of the cases, option 2 (split pack batten sampling) was used.

![Figure 2. Split pack batten sampling (exchange every second board)](image)

In most cases battens were purchased at local sawmills and then processed in the laboratory of the partner institutes. Reference and treatment trials were carried out in the same laboratory.

However, in some cases material was exchanged between laboratories. In this case the reference material stayed in the material providing institute, whereas the package to be treated with one of the novel methods was send to the partner institute. In these cases the packages were carefully wrapped in PE foil. Drying was avoided by using express delivery services.

2.2. Measurement of quality parameters

At the beginning of the project all participating institutes agreed on the parameters to be used for defining the quality of the dried studs after the kilning process. The parameters to be determined were:

- twist (mm / 2000 mm)
- bow (mm / 2000 mm)
- spring (mm / 2000 mm)

and in addition

- moisture content (by electrical resistance, capacitance type or oven dry method)
- distance to the pith
- annual ring width
- grain angle
In order to have a common base for comparison a moisture interval of 15-18% was defined as target moisture content (MC). Not in all cases it was possible to really hit this target moisture content precisely. In some cases the average MC of the experimental kiln load deviated from the target MC. In addition, some spread of moisture content around the average MC was found in each kiln load. Especially with freshly cut spruce timber the variation of initial moisture content can be enormous. Moisture content of battens consisting mainly of sapwood may yield more than 100% MC, whereas those containing mainly heartwood would only have approx. 45-50% MC.

It must be stated that due to these MC differences the comparison of the various kiln loads, proveniences and treatments was rather difficult.

Before trials were started all participants agreed to use a similar way of measuring distortions. Each of the institutes developed and used different measuring instruments or systems, but the geometry of the measurements for determination of twist, bow and spring were the same. When ever the length of the battens to be tested differed from 2000 mm length, the measured results were transformed to 2000 mm results.

During the project each participant experienced that for most of the quality parameters measurements some degree of uncertainty existed. Even with very careful execution of the measurements some distortion of results between the experiments and certainly between the results of the various partner institutions could not be avoided. For the different parameters the reasons for these uncertainties are given below:

a) twist

For measuring twist one of the ends of a batten must be used as the reference. This normally is achieved by pressing down one end onto a flat plane. Kiln dried boards, especially 2xlog studs tend to cup due to the annual ring orientation. Depending on the amount of cupping and depending on which face of the batten was pressed on the flat plane, different results were obtained. It also is also quite obvious that the amount of pressure used will have some influence on the result.

b) bow and spring

When measuring bow and spring the amount of twist is a disturbing factor. As for measuring twist, the determination of bow and spring implies a reference plane. The board to be measured has to be aligned with this plane and a twisted end makes it difficult.

c) moisture content

The only really reliable method for determination of moisture content is the oven dry method. However, the oven dry method is a destructive method. Therefore it could not be applied on the battens to be assessed for distortion. In many cases a test slice was cut at the end of a batten, but due to the vicinity of the slice to the end of the batten, its MC is biased towards low MC results (end drying effect). Because of this the electrical resistance type method was used to determine moisture content. But this method also has some disadvantages, e.g. location, penetration depth of the electrodes, calibration curve, temperature of the wood, etc.
Taking into consideration that all drying induced distortions are directly related to moisture content due to the linear relationship between moisture content and shrinkage, it becomes obvious that errors in determination of moisture content automatically will have some effect on the interpretation of the degree of distortion.

d) distance to the pith

For determination of distance to the pith a template was used. This template consisted of a number of concentric rings which had to be aligned with the shape of the annual ring on the battens to be assessed. Since annual rings in trees do not always form a perfect circle, the estimated value for the distance to the pith also contains some uncertainty.

![Template with concentric rings for determination of distance to the pith. Middel of the outer flat side of the batten is the reference point for determination of distance to the pith. Value can be directly read from the template.](image)

e) annual ring width

Assessment of annual ring width involved an averaging process. Estimation is somewhat influenced by the orientation of the rings.

f) grain angle

Grain angle is considered to be one of the most important factors having an influence on the development of twist. Grain angle is an inherent wood property which is characteristic to each individual stem or even board. Under normal conditions spruce trees in their early years show a grain angle between 2% and 6% or even more. When the tree becomes older grains angle slowly decreases in the outer annual rings. At high age grain angle can even change direction.

As can be expected, grain angle shows a large genetic variation between individual trees. When it comes to assessment of the effects of a specific treatments on twist behaviour it is obvious that the determination of grain angle is of utmost importance.

Grain angle is best determined in zones of clear wood on flat sawn surfaces where the board’s flat side builds a tangent to the annual ring.

Grain angle can be determined by means of the "scratching method". A needle mounted in a handle is pulled along the longitudinal axis of the board to be assessed. The needle
follows the grain angle which has to be measured by using a goniometer in reference to the longitudinal axis of the board.

Another way for manual determination of grain angle was recently developed in Sweden. The instrument is called S-GAG device (see Figure 4). A knife type blade to which an indicator is attached is pushed into the wood. The blade orients itself in the direction of the grain angle, the degree of which is indicated by the mechanical instrument. A pre-condition for correct measurements is the precise alignment of the instrument's axis with the longitudinal axis of the board which is not an easy task at all. Because of the low values of grain angle (normally between -2° and +6°) even small mis-alignments result in measuring errors in the same order of magnitude as the grain angle itself.

![Figure 4: Photo of S-GAG from measurements on logs](image)

Originally the S-GAG device was developed for determination of grain angle on stems. In the STRAIGHT project some of the participating institutes used the S-GAG device to determine grain angle on sawn timber battens. In addition the scratching method was used. Correlation between S-GAG values and scratching values was rather poor. But, it must also be stated that on one single board, when the scratching method is repeated at various positions, a wide range of readings can be observed.

Having this in mind, it must be recognised, that one of the obviously very important board characteristics leading to twist could not be determined with high precision within the scope of the STRAIGHT project.

A rather reliable laser-based system (using the so called tracheid effect) has already found industrial application. But, this method was not available within the STRAIGHT-project.
3 Novel methods for reduction of deformation

Within the STRAIGHT project 8 (9) different novel methods were examined regarding its potential to reduce deformation. These methods were: High Temperature Drying (WP 2.1), Novel Top Loading (WP 2.2), Oscillating Drying Conditions (WP 2.3), Twisted Pack Drying (WP 2.4), Pre-Sorting stem-wise or board-wise (WP 2.5), Green Gluing and Re-Engineering (WP 2.6) and New Conditioning Techniques (WP 2.7). Additionally, twisted sawing was examined (not part of the contract).

In this technical report the details of the various treatment methods are not described. We refer to the specific technical report for each work package.

Here, we rather want to examine under which conditions the different methods eventually could be used to improve the overall performance of sawn timber.

- **High temperature drying (HT)**

HT drying is not a novel process. It has been used for decades, especially in New Zealand, Australia, South Africa, Chile for drying Pinus radiata and in Southern USA for Southern Pine. In Europe some experience was gained in the sixties and seventies of the past century, but HT drying did not really succeed because of various reasons.

HT drying changes the colour at the surface of the kiln dried material. Customers did not like such colour changes, even though many people did admit, that the colour change was not severe, because a substantial difference to normal temperature dried material could hardly be seen after some weeks of exposure to sun light and or outdoor conditions.

HT drying can not be carried out in normal kilns, which are designed for normal temperatures. Therefore, HT drying involves heavy investment, not only in HT kiln, but also in heating systems. Whereas in USA, Australia and many other countries saturated or overheated steam was used for heating of kiln, in Europe hot water heating systems where widely used. Hot water heating systems do not allow drying temperatures above 80-85°C. A switch to HT drying therefore involves installation of additional heating systems.

- **Novel top loading**

Top loading of packages to avoid deformation also is not new. It has been used since long with varying success. The novelty in this project was the test of top loading systems which do not apply static loads (e.g. concrete or metal block), but rather apply pressure by means of pneumatic or hydraulic systems. This allows to apply and change the load during the process. Such equipment was first installed in Norway. Because such systems do not exist in the other countries, partners in the project used static loads to test the effects.

- **Oscillating drying conditions**

In all large industrial batch kilns drying conditions automatically oscillate when the direction of air flow is reversed. Frequency of the climatic oscillations is equal to the reversal interval. Amplitude of the climatic conditions is normally not controlled in industrial kiln drying processes. Within the STRAIGHT project the potential effect of climate oscillations on the formation of deformation was examined. In case of positive effects the findings could be easily transferred to industrial application by just changing the air flow reversal intervals and by controlling drying conditions (drying schedule adjustment).
Twisted pack drying

It was found that in industrial kiln loads a large percentage of all boards show a similar amount of twist at the end of the process. The idea of twisted pack drying is to place packages on inclined separators in order to force the boards in a pre-twisted condition with is opposite and somewhat greater as the expected twist. During drying, when grain angle induce twist develops, this twist is restrained. As result a low degree of twist is expected.

Pre-sorting

By stem-wise pre-sorting for grain angle stems with extreme grain angle can be sorted out. Boards produced from such stems, most likely account for a high percentage of the boards which have to be down-graded or even rejected due to extensive twist.

By board-wise pre-sorting sawn timber with high initial MC should be separated from those boards which has a much lower MC. By doing so the MC variation within a kiln load is reduced and over-drying to low moisture content can be avoided. Over-dried boards normally show a much greater twist compared to boards for which the target MC was hit.

Green gluing and re-engineering

The idea behind re-engineering and green-gluing is to split up boards which most likely will develop a lot of twist and glue them together again in a way where the two adjacent parts restrain each other.

New conditioning techniques

Conditioning is normally carried out at the end of the drying process to release drying stresses and to make moisture distribution across the boards thickness more uniform. Steaming is also applied at the beginning of drying processes for complete heating up of the cross section and to assist smooth and fast drying.

New conditioning techniques is a novel physical method with temperature as a central parameter. It aims at softening the material with extreme twist and releasing stresses/deformation under a pre-twist condition. This will finally result in a reduction of twist at the end of the treatment.

Twisted sawing

When stems are sawn into timber while the stem is slow turned, twisted green boards are produced. Such artificial twist could counterbalance the twist which is due to grain angle during drying. The result would be more or less straight boards.
4 Data base

All partners involved in the STRAIGHT project have carried out quite a number of laboratory, pilot scale or industrial tests. At the very beginning of the project a standard procedure for documentation of drying quality results was discussed. A template for provision of experimental data with respect to drying quality and especially with respect to deformation was developed.

Nevertheless, most partners provided data in various formats reflecting the specific needs and conditions of the experimental set-ups, all of them containing the basic information described in the template mentioned before.

A list of drying experiments (laboratory, pilot scale or industrial scale) is presented below. In total approximately 100 drying experiments were carried out. In each experiment between 10 and several thousand boards were dried. Not all were examined for drying induced deformation. In average 50 boards were inspected and analysed. In some cases (e.g. all BFH, full kiln loads equals 108 boards) all boards were fully analysed.

Considering that a full assessment of parameters for one single board consists of approximately 20 results (parameter), each of which was derived from approx. 5 individual measurements before and 5 after drying, one can estimate the number of measurements and data produced throughout the project.

20 parameters
10 measurements (5 before, 5 after drying)
50 boards examined
100 drying tests carried out

Approximately 1.000.000 measurements were carried out. This number does not yet include the assessment of post drying behaviour carried out by Chalmers University (see Technical report for WP 5).

To present all data in the paper version of this report does not really make sense. Therefore, we have attached a CD to this report with a data base in which all individual data are contained. The directory of the CD is structured per partner in the consortium. For each partner the experimental data are presented.

Table 1 presents the files contained on the CD, its allocation to the partners and a short description of the type of experiment.

In Figure 5 the tree structure of the CD directories are presented.
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5 Determination of optimum processes

Within the STRAIGHT project each participating institute carried out the evaluation of its own experiments or which had been carried by another institute on behalf of that partner using specific equipment.

For each of the WPs a technical report was edited comprising the evaluation of the results and addressing and discussing the possible beneficial effects of the treatment.

When comparing of the various treatments tested within the STRAIGHT project the following general and summarizing statements can be made:

- all treatments have some effect of the development of deformation during drying
- each of the treatments considered can be varied over a wide range of conditions
- results achieved by varying these treatment conditions are also influenced by other drying conditions (e.g. initial MC, schedule, final MC, quality of timber, species (Norway spruce or Sitka spruce), provenience, age, etc.)
- the amount of such effects in most cases could not be quantified because some of the influencing parameters were either unknown, not analysed or not reported
- a multi-factorial comparative analysis of the effect of the different treatments and combinations of these was not possible

With respect to the evaluation of the individual treatments the following can be stated:
High temperature drying

High temperature drying should be considered a drying process of its own. The outcome of this process in terms of moisture content reduction can be compared to other heat and vent drying processes, but due to high temperatures used a softening of the lignin matrix takes place. This undoubtedly has considerable effect on stress development (drying stresses) and on stress relaxation under restraint as effected by top-loading. High temperature drying can be combined with the following treatments: top loading, oscillating conditions, pre-sorting, twisted pack drying, pre-sorting stem-wise and board-wise, green gluing and re-engineering and special conditioning.

Restrainment of grain angle induced deformation under high temperature drying conditions do not necessarily result in long term form stability. Under changing climatic conditions the positive effects can be diminished over time.

The positive effect of high temperature conditions on the development of deformation has to be balanced against other effects which also have an influence on drying quality and value of timber (MC variation, internal stresses, checking, colour change, etc.)

Novel top-loading treatment

Top-loading had a positive effect on the development of deformation, especially it helped to reduce twist. This positive effect was found by all partners.

In large industrial kilns, in which several packages are placed on top of each other, the level of top loading is quite different. Additional top-loads, regardless whether they are applied by means of constant weight or devices which allow application of variable pressure, will act like an additive, thus superimposing pre-loading, which results from the weight of the timber stack, and top-loading.

The novelty with variable top-loading is that during the kiln drying process additional loads can be applied whenever this is required. At the beginning of a kiln run, when MC is still well above fibre saturation no shrinkage occurs and consequently the risk for drying induced deformation is low. Constant top-loads would superimpose on stack weight thus putting very high pressure on the lower packages (risk of indentation of stickers, sticker marking). The variable top-loading allows to apply top-load at later stages of the kiln run, when shrinkage takes place and deformation must be restrained.

A real optimum weight to be used as top-load has not been found. Top-loads below 200 kg/² do not show pronounced effects, very high top-loads up to 1000 kg/m² are effective, but they bear the risk of damaging the lower packages in large industrial kiln. Good results were achieved with top-load between 400 kg/m² and 600 kg/m².

Top-loading has been found to have positive effects in combination with other treatments. The full benefit of HT drying can only be achieved if the timber is restrained. HT drying without top-loading does not make a lot of sense – as far as deformation reduction is concerned. The same is true for twisted pack drying. The principle of twisted pack drying involves not only restraint of deformation, but rather a drying under additional stress action opposite to the grain angle and shrinkage induced deformation. Only when the movement of timber is restrained by top-loading the full beneficial effect can be utilised.
**Oscillating conditions**

Oscillating conditions can have a positive effect on drying quality, but this positive effect is not necessarily related to deformation. Oscillating conditions allow to dry sawn timber faster than under non-oscillating conditions. To achieve the same drying quality more severe schedules can be used.

This positive effect certainly can be utilised in direct conjunction with top-loading or twisted pack drying. The positive effects should be additive. Pre-sorting, regardless whether applied stem-wise or board-wise, will turn out beneficial in conjunction with oscillating conditions, drying of re-engineered and green glued sawn timber and new conditioning techniques.

**Twisted-pack drying**

Twisted-pack drying should be considered as a special form of top-loading. Actually, the full benefit will only be achieved if twisted pack drying is combined with top-loading or at least placement of the twisted-pack in the lower levels of a kiln load where the weight of the upper packages acts like a top-load.

In principal, twisted pack drying can be applied in conjunction with all other methods. HT in conjunction with top-loading and twisted-pack drying has been tested and will certainly have positive effects. The same is true for pre-sorting board-wise for moisture content.

Some people might argue that sorting out stems with great grain angles will eventually make twisted-pack drying obsolete, because extreme twisted boards will not be produced anymore. But especially for the remaining material with a lower average and rather uniform grain angle, the twisted-pack drying will help to produce a very good quality in terms of twist deformation, because a large part of the grain angle induced twist can be avoided.

When it comes to long term form stability, it has to be considered that twisted-pack drying can only suppress twist for a while. Over longer periods of time, and especially when the drying material is not kept under load, the memory effect of wood will produce some slow spring back effect and the suppressed twist of the sawn timber will recover.

**Pre-sorting**

As stated before, the positive effect of pre-sorting stem-wise sorting for grain angle will have very positive effect on deformation development. This positive effect can be achieved in conjunction with all other treatment methods. Positive effects of board-wise sorting for moisture content could not be finally verified.

At the time being, the mayor problem with pre-sorting is that reliable methods applicable under rough industrial conditions do not yet exist.

Sorting for moisture content in the range above fibre saturation (FSP) is heavily affected by density of the individual board. Without proper density compensation the results are not satisfying. The commercial measuring instrument used in this project (in-line capacitance MC meter) was somehow blind with respect to the MC range above approx. 45%. This means that realiable sorting classes could only be above FSP and below FSP. Such type of sorting probably does not justify the considerable investments (measurement,
machinery and logistics) which are necessary to split up a production line into two flows of sawn timber with different MC.

**Green gluing and re-engineering**

Green gluing and re-engineering should not be considered as some kind of drying process. Re-engineering does involve drying, but the principle of green gluing and re-engineering follows another philosophy. The propensity to develop twist, which is characteristic for a certain type of boards (boxed pith combined with slope of grain) is utilised in such a way that the forces acting in the material are used to neutralise themselves.

Considering this, top-loading under optimum conditions should not be necessary when re-engineered material is kiln dried. The same is true for twisted pack drying. HT probably will not be applicable, because glues will not withstand the very high temperatures. Pre-sorting stem-wise will make re-engineering unnecessary, because the naughty boys are sorted out. Pre-sorting for moisture content probably will not be necessary, because boards with boxed pith produced from adult trees with a certain diameter normally will not have a very high moisture content.

**New conditioning techniques**

New conditioning can be applied on severely twisted boards. Such boards will have to be sorted out and submitted to a separate heat treatment in a pre-twisted condition.

New conditioning techniques can also be used in combination with all other treatments. The overall positive effect will be superimposed on the effects of other treatments. But it will be extremely difficult to estimate or determine precisely to which extend the new conditioning treatments have contributed to the positive effects.
6 Conclusions

Within the STRAIGHT project drying quality issues played a central role in the evaluation of all experimental set-ups, regardless whether laboratory, pilot or industrial scale trails were conducted.

Precision of measuring methods for determination of drying quality was not always satisfying. Especially methods for determination of grain angle, which was considered to have the strongest impact on twist deformation during drying, produced rather poor and not at all reliable or reproducible results.

Application of each individual novel treatment included in the investigation will produce some positive effect with respect to deduction of drying induced deformation or improvement of the drying process itself. But, none of the treatments should be considered by its own. Optimisation of the production of sawn timber in view of producing "straight" timber always has to take into account that deformations occurring during drying are not produced by the drying process. They rather develop due to inherent properties of the sawn timber (mainly slope of grain, annual ring orientation, percentage of juvenile wood) in combination with the normal shrinkage.

None of the treatments tested is able to change these inherent wood properties nor does it avoid shrinkage. Most treatments aim at suppressing the deformation by means of loading or restraintment. This automatically implies that such suppression eventually is not permanent. Deformation, normally developing during the drying process, might develop during later, e.g. after delivery to the customer, at the building site or - even worse - during the use phase.