

Advances in drying of wood

NTI-papers from COST-E15 seminars 2000-2004

Foredrag avholdt ved COST-E15 seminarer 2000-2004

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Preface

COST (Cooperation in Science and Technology) is a long term EU-project with the objective to increase the scientific and technical cooperation in Europe. The project was started in 1971 with 19 member countries, which has now increased to 36 member countries. EU is secretariat and pays travel and board for the participants. Separate COST Actions for different areas are organised. From 1994, the establishment of separate Actions in forestry and forestry products has been possible. In the fall of 1999 an Action in drying was established with the name "Advances in drying of wood", and was given the title COST-E15.

COST-15's main objectives were to coordinate research activities in the field of wood drying between the different European countries and to reinforce technology transfer to the industry.

The COST-E15 Action is now finished, with the last meeting held in Oslo in September 2004. A total of 20 countries have participated.

Possibly the most important part of COST-E15 has been the diffusion of information through several drying seminars held in different countries, with extensive participation from the industry.

Norsk Treteknisk Institutt (NTI) has participated actively in these seminars with several papers. As none of these seminars have taken place in Norway, and few Norwegian representatives from the industry have participated abroad, the papers from NTI has been gathered in this report. Those who would like to have access to the other papers from the COST-E15 seminars can contact NTI.

Blindern, April 2005

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Forord

COST (Cooperation in Science and Technology) er et langsiktig EU-prosjekt med målsetting å øke samarbeidet innen europeisk vitenskap og teknologi. Prosjektet ble startet i 1971 med 19 medlemsnasjoner, som nå har økt til 36 nasjoner. EU har sekretariatet og betaler reise og opphold for deltagerne. Det blir organisert egne "COST-actions" (COST-aksjoner) for forskjellige fagområder. Fra 1994 ble det åpnet for å søke om opprettelse av egne Aksjoner innen skogbruk og skogprodukter. Høsten 1999 ble det startet en egen Aksjon innen tørking med tittelen "Advances in drying of wood", som fikk betegnelsen COST-E15.

COST-E15 fikk som primære målsettinger å koordinere forskningen mellom de forskjellige institutter innen tørking av tre og bidra til å spre kunnskap om tørking til industrien. Aksjonen ble organisert med to medlemmer fra hvert land som deltagere i Management Committee (Knut Magnar Sandland og Sverre Tronstad) og fire medlemmer i to Working Groups (Sandland og Tronstad pluss Erik Hartz og Peder Gjerdrum).

COST-E15 aksjonen er nå fullført med det siste møtet arrangert i Oslo i september 2004. I alt 20 land har deltatt.

Kanskje den viktigste delen av COST-E15 har vært informasjonsspredningen gjennom flere tørkeseminarer avholdt i forskjellige land, med stor deltagelse fra industrien. Ved hvert seminar ble det avholdt en rekke foredrag om forskjellige emner innen tørking, tilpasset både forskere og industrirepresentanter.

Treteknisk har deltatt aktivt i disse seminarene med flere foredrag. Da ingen av disse seminarene har vært i Norge, og få norske industrirepresentanter har deltatt i utlandet, er foredragene som Treteknisk har holdt samlet mellom to permer og utgitt som en rapport.

Da det ville koste for mye å oversette foredragene og diagrammer/figurer til norsk, har vi tillatt oss å presentere foredragene i originalversjonen, dvs. på engelsk.

De fleste foredragene er her presentert i artikkelform, mens to foredrag er presentert i foredragsform (Powerpoint).

De som ønsker tilgang til de andre foredragene som er avholdt på COST-E15 seminarene kan henvende seg til Treteknisk.

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1. How can the European sawmilling industry actively improve timber drying?

Sverre Tronstad

Dette foredraget ble etter oppfordring fra COST-E15-styret avholdt på det første seminaret i Edinburgh i 2000.

2. Possibilities to control deformations in wood during drying to meet the requirements from timber end-users

Knut Magnar Sandland og Sverre Tronstad

Foredrag avholdt på det andre seminaret som var ved VTT i Helsinki 2001.

3. Drying quality of softwood based on 140 industrial tests in Norwegian sawmills and actions to improve the quality

Sverre Tronstad, Knut Magnar Sandland og Håkon Toverød

Foredrag avholdt på det andre seminaret som var ved VTT i Helsinki 2001.

4. Increased yield by reduced cupping – Reflections and initial experiments of press drying

Knut Magnar Sandland og Sverre Tronstad

Foredrag avholdt ved tørkeseminar i Santiago de Compostela, Spania 2002.

5. Dynamic top loading

Sverre Tronstad

Foredrag avholdt ved seminar i Limerick, Irland 2003.

6. Various properties influencing the development of checks in knots during drying

Kjersti Folvik og Knut Magnar Sandland

Foredrag avholdt ved avsluttende seminar i Athen 2004.

7. Quality control in kiln drying

Håkon Toverød og Sverre Tronstad

Foredrag avholdt ved avsluttende tørkeseminar i Athen 2004.

8. After drying service

Sverre Tronstad

Diskusjonsunderlag brukt ved gjennomføring av rundebordskonferanse ved avsluttende COST-seminar i Athen.

1. How can the European sawmilling industry actively improve timber drying?

Sverre Tronstad

Abstract

One main goal and one of the two working areas of the COST-E15 Action is "Technology and information transfer between research and industry". Actively run Kiln Drying Clubs can be an effective way of obtaining this goal.

A Kiln Drying Club has been active in Norway since 1983, with Norsk Treteknisk Institutt (NTI) as co-ordinator. The reason for starting the club was the increasing importance of artificial kiln drying and the need for updated information on new drying techniques and quality requirements for the kiln operators, who often are alone with their problems at the sawmill.

At the moment (2000), the club has members from 46 sawmills, representing about 75 % of the timber production in Norway. The club has a board of 4 sawmill members and a project leader from NTI. The membership is open only for sawmillers, but representatives from kiln manufacturers are normally, one at the time, invited to the meetings.

The financing of the club activities is a combination of state funds (35-50 %) and the value of the work performed through research and test activities carried out by the member sawmills.

The main activities in the club are as follows:

- self testing and examination of the technical and economical status of member kilns after procedures worked out by the project leader, who collects and analyses the incoming data
- research activities in the wood research institute based on the members' priority list
- participation in international projects and in working groups on quality and standardisation
- club meetings in 2-3 different districts in Norway
- written information to the members through NTI's technical bulletins

The activities in the club have had a positive effect on the general knowledge of wood drying in the industry and have lead to measurably better drying results. Countries or districts that have no Kiln Drying Clubs are recommended to investigate the possibility of starting one.

Introduction

Kiln drying is one of the most important processes in the sawmill industry and has a decisive influence on the production costs and final quality of the wood, and therefore on the total sawmill economy.

The quality requirements from the customers are increasing, and are expressed through new and stricter standards. This leads to a pressure on developing better drying methods and better drying schedules, in research institutes, by the kiln manufacturers and in the wood industry itself.

It is thus of great importance that the kiln operators and the production leaders as soon as possible get updated information on the research results, the quality requirements and the latest technical news.

The COST E-15 has seen the importance of this information transfer, and therefore named one of the two main working areas "Technology and information transfer between research and industry".

One way of obtaining a broad and effective information transfer to the industry is by running Kiln Drying Clubs.

As early as in 1983 it was therefore decided to start a Kiln Drying Club in Norway. The main goal of the Club was to transfer information from research and kiln manufacturers to the industry and thus give the kiln operators a possibility of sharing information between themselves, as they often are alone at the sawmill with their drying problems. For the last seven years, the members of the Kiln Drying Club have also been actively taking part in research activities.

Organisation of the club

The first meetings started already in the 1970s, but the Club was formally organised in 1983 with Norsk Treteknisk Institutt (NTI) as co-ordinator.

The club meetings are open to sawmillers, with preference to the kiln operators and production leaders. Representatives from all kiln manufacturers and their dealers were also invited in the beginning, but it soon turned out not to be a good solution. The meetings can be too much dominated by discussions between the different kiln manufacturers, and also in a way hamper the free exchange of views between the kiln operators on different kiln drying systems.

We are of the opinion that the Kiln Drying Clubs should primarily be run for the kiln operators, and should therefore be different from ordinary open meetings and seminars like the one we have today. In Norway we also arrange drying related meetings in another association, *The Wood Industries' Technical Association*, where representatives from all the kiln drying companies can be members and take active part in the meetings, presenting papers and small exhibitions.

Anyway, the kiln manufacturers will normally have a lot of interesting information to give to a Kiln Drying Club. We have therefore ended up with inviting representatives from one kiln company at the time to the meetings, to inform about their latest news. At the following meeting a new company is invited, and so on. This seems to work well.

We have normally arranged club meetings in two to three districts in Norway, to avoid extensive travelling distances for the kiln operators. We try to locate the meeting place near a sawmill with a new or otherwise interesting drying installation.



Fig. 1. Interested members at one of the district meetings.

The club meetings were initially one day meetings starting with papers in the morning session. After lunch we arranged a small excursion to the mentioned sawmill. This normally took one and a half hour, and ended up with an afternoon session with papers and a final discussion. Most of the papers are presented by researchers from NTI. But also researchers from other institutes, kiln operators or production leaders from the industry and the representative from the kiln manufacturer are invited to present papers. Sometimes we also invite researchers from other countries.

We have experienced that one-day meetings often can be hectic, with too many papers and discussions. Last year we therefore tried one and a half day meetings that started at six o'clock in the afternoon, with some "lighter" papers and demonstrations, and ended with dinner and social gathering in the evening. The main meeting and papers were presented on the following day. This arrangement was successful and will be followed up at later meetings. In addition to the club meetings we send written information directed to the members through the technical bulletins of NTI.

The financing of the club activities was in the first years based on a combination of state information funds through NTI and a small fee collected from the club members at each meeting.

In 1993 the kiln drying club was reorganised to a so-called “technology circle”. This means that the activities in the drying club also include projects in the drying field, that are of common interest to the sawmill industry. These projects are partly financed through state research funds, and require that at least 50-65 % of the activities are financed by the industry itself by direct funding and through participation in the projects. All projects are selected by the industry members through a priority list.

Starting with app. 30 sawmills, the number of members in the reorganised club have now increased to 46 sawmills, representing about 75 % of Norway’s timber production. The club is formally organised with a board of 4 sawmill members and a project leader from NTI.

Activities and results

The first project with active research participation from the industry started with collecting information on the “status quo” of the members’ drying kilns. Based on project descriptions and data sheets worked out by the project leader, the club members in the sawmills collected data from their own kilns on end moisture content, moisture gradients and casehardening. In addition to these data, the sawmills were asked to give information about the “history” of the timber before drying, the kiln type, the drying climate, the conditioning time and climate etc.

44 sawmills carried out this initial test, and the data were collected and analysed by the project co-ordinator of the Drying Club. The results gave important information on the status of the drying quality by normal kiln drying and in addition interesting data for analyses of several functional relationships.

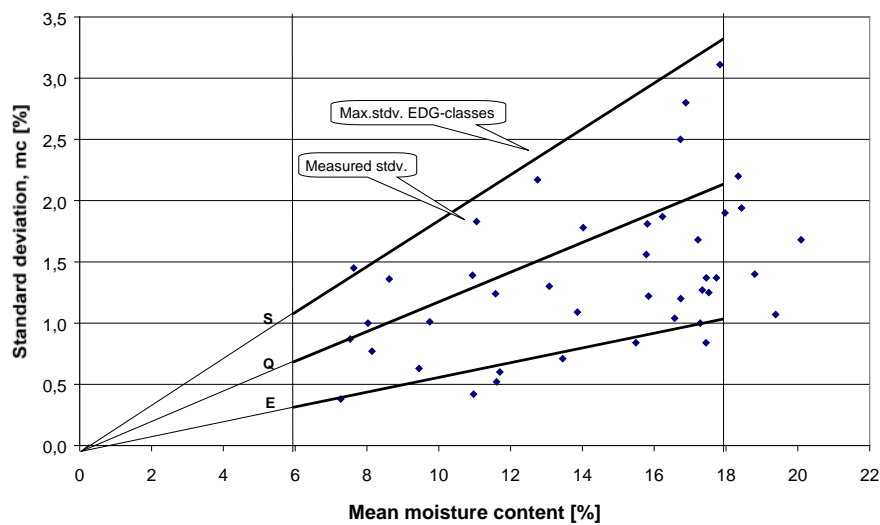


Fig. 2. Stdv. in moisture content of the initial industrial tests compared to the requirements in the EDG-proposal.

Another important use of such data is in connection with the work with the EDG-recommendation on assessment of drying quality and in the ongoing CEN-adaptation, where the data (see Fig. 2) is used together with data from other European countries to define practical attainable levels of moisture spread, expressed as standard deviation by different moisture contents.

The proposed way of building up the requirements as to moisture content in the coming CEN-standard opens for an allowable range of the mean mc around the target mc in combination with a maximum stdv. To set practical attainable levels for the range in mean mc around the target mc, the data from such industry tests are also of great importance. In Fig. 3 we can observe the problems in practical drying of hitting a set target moisture content.

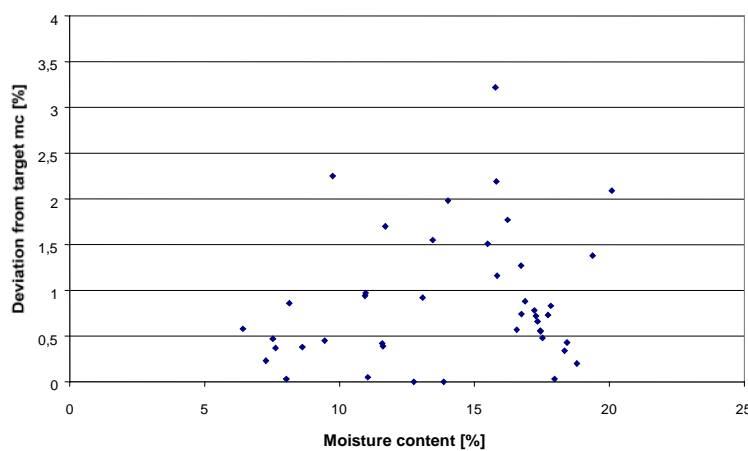


Fig. 3. Deviations from target moisture content by different moisture content levels.

This seems to be a common problem in drying, and has thus led to further work to find better control methods to hit the target moisture content. In this connection, the Kiln Drying Club has actively participated with funding and testing in the so called IMCOPCO-project.

By the increasing use of higher temperatures in softwood drying, it was of further interest to study the level of casehardening in practical industrial drying. The initial tests showed fairly good results compared to the levels set in the Nordic standard INSTA 141, where prong tests were used. New industrial tests, where the results were compared to the stricter EDG-recommendations with the so-called slicing tests, showed the necessity of an upgrading both in the general knowledge of casehardening and in the technical standard of the "spraying system" of the kilns.

This led to studies on different systems for effective moistening of the drying air, with special emphasise on high-pressure water spraying. The high-pressure system gave a quick and effective moistening of the air, and several sawmills have adopted this system in their kilns.

Intensive information at the Club meetings about the nature of casehardening and how to abolish it, combined with better spraying systems in the kilns, has led to a far better understanding of the problem and to better drying results in the industry.

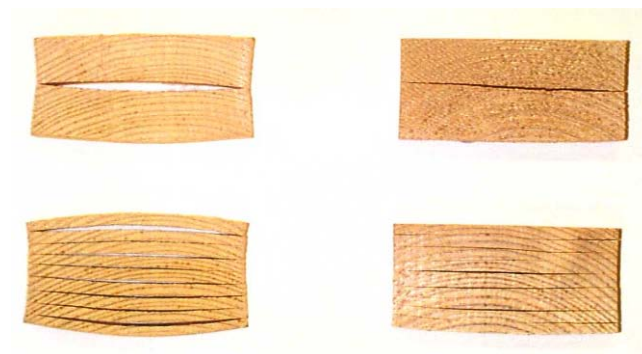


Fig. 4. Example of effective conditioning in an industrial test, illustrated by means of a 2-slice and a 9-slice test.

Better understanding of conditioning, and also equalising, has also had a positive effect on the spread in end moisture content at the member kilns. In 1993/94 more than 30 % of the industrial tests had a standard deviation in the end moisture content above 1,6 %. In 1996 this percentage was reduced to 14 %, ending up with only 5 % in 1996.

In addition to the tests above, the Kiln Drying Club has performed extensive tests on the drying quality as to checking before and after drying, and has developed a calculation model for drying costs with additional industrial testing and done

industrial tests with top loading and sticker distance and its influence on the deformations of type twist, bow, crook and cup.

The importance of loading the timber to avoid warping during drying, together with more information about moisture in wood to the dealers and retailers, are at the moment the areas of highest priority in the Kiln Drying Club. The initial tests on warping (Fig. 5) have shown the importance of reducing the warping and thereby strengthening the competitiveness of wood against other materials. Further studies on warp reduction by top loading has started in the industry, followed up with laboratory tests by variable load as function of the moisture content.

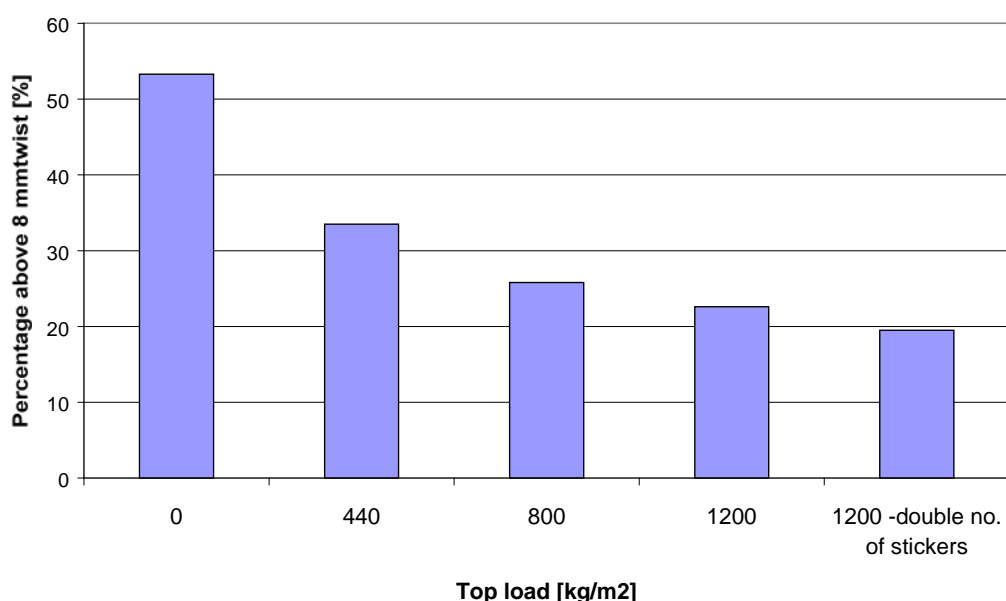


Fig. 5. Influence of top load on twisting of timber. Results from 24 industrial tests on 50 mm x 150 mm timber measured over 3 m.

These examples clearly show the unique possibility of using the Kiln Drying Club actively to carry out research work under industrial conditions. We must remember that hundreds of industrial kilns are running every day with different species, different schedules, different drying principles etc. and with different drying results. By using the club members to collect all this information and the club co-ordinator to analyse the results, you will get important information about the quality status in general, and in addition several interesting correlations between drying conditions and drying results.

At the club meetings the results of the analyses are presented and discussed. We have the firm impression that the members of the club through their own "homework" have learned much more about drying quality and the factors that influence the quality, than by solely presenting papers or written information to the industry.

Another important effect of a Kiln Drying Club is that the kiln operators from the different companies get acquainted, which opens for the possibility of taking contact later to discuss common drying problems.

The drying club can also be used as a feedback to the research institutions as to what drying problems are of greatest importance in the industry at the moment. This will help the institutes choosing industry relevant projects in their research activities. To make it easier to collect this information, a list of 20-30 possible areas of research activities are listed, and the members can make a grading of what is most important. In addition, the members can add research areas that are not on the list. A new questionnaire is sent out to the members every second or third year. Among the areas of highest priority at the moment can be mentioned:

- Information on drying and moisture relations to distributors and end users.
- Methods and equipment to hit the target moisture content.
- Methods for reducing deformations (twist, bow, crook, cupping).
- Reduced checking between sawing and kiln drying.
- Technical improvement of the conditioning systems.
- Methods of reducing the spread in end moisture content.
- Clear standards for moisture content measuring, casehardening and quality classes.

Conclusion

The kiln operator is one of the most important, but maybe also the “loneliest”, operator in the sawmill industry. Sixteen years of existence for the Kiln Drying Club in Norway has shown that there is need for a forum for kiln operators and production leaders to receive information, to share information with other colleagues and to make industrial tests of common interest in the drying field.

For those who want to start a kiln drying club, the following recommendations and experiences may be of interest:

- The financial part of the activities must be taken seriously from the start.
- Use a wood research institute as co-ordinator.
- The members should preferably be kiln operators and their production leaders.
- Invite representatives from the kiln manufacturers to the meetings, but preferably from one company at a time.
- We definitely recommend to include “home work” for the members.
- We recommend one and a half day meetings to make room for better social contact.

The Kiln Drying Club has been an effective way of technology and information transfer between research and industry, and has led to measurably better drying results.

For countries or districts that have no Kiln Drying Clubs, we definitely recommend to investigate the possibility of starting one.

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2. Possibilities to control deformations in wood during drying to meet the requirements from timber end-users

Knut Magnar Sandland and Sverre Tronstad

Abstract

Various investigations have been made in order to understand how to control the deformations in wood during drying. This is related both to traditional deformations as twist, bow, crook and cup, and deformations caused by casehardening in resawn timber.

In this research, the effect of using various load levels on the timber during drying to reduce deformations has been investigated. A loading system with pneumatic cylinders was built in the laboratory kiln at Norsk Treteknisk Institutt (NTI), and the effect of load level concerning reduction of deformations (twist and cupping) was measured.

The measurements were performed immediately after drying, and repeated after 1-2 weeks to detect the spring-back effect. In addition to measurement of twist and cupping, the depth of the sticker marks was also measured.

The results show that the potential to reduce twist deformation during drying by using a load system is high, and that the amount of pieces that have to be rejected because of twist almost can be eliminated. The effect of spring-back is rather moderate, and the main effect of loading is still present in the wood after unloading and storing for several days.

The sticker marks increased with increasing load level, but seem to be of no practical importance, even for the highest load in the tests.

The cupping was highly reduced under the stickers, and in a region of 15-20 cm from the stickers there was still some effect of the loading.

Introduction

When drying wood, deformations related both to wood properties and drying procedure occur. Deformations that mainly can be related to the inherent wood properties are traditionally bow, crook, twist and cup. These are a consequence of various shrinkage potential in the three main directions of wood, and that the shrinkage potential is different for various wood properties, e.g. low-density wood, high-density wood, compression wood, juvenile wood, etc.

Nowadays, the competition from other building materials than wood gets stronger all the time. These producers have no inhibitions to market their

own materials as superior compared to wood, not by focusing on possible advantages of their own products, but by focusing on possible disadvantages of wood. Especially different kinds of deformations in wood are used as an argument. Therefore, it is important to produce building materials of wood where these disadvantages are reduced to a minimum to maintain, or improve, the share of the market for wood based products.

The main focus in this paper is on how to reduce the occurrence of twist in timber during and after drying. Experiences from the Norwegian sawmill industry, based on measurements in the Norwegian Kiln Drying Club (Tronstad 1999, Tronstad *et al.* 2001), show that the potential for increasing the yield by reducing the twist deformations is high. Earlier research work also shows that use of top load reduces the twist deformations in wood (BRE 1998, Koch 1971, 1974, Weckstein & Rice 1970, Mackay *et al.* 1977, Simpson 1982), and a lot of sawmills around the world use top load to reduce deformations as twist during drying. Use of top load is often combined with high-temperature drying, especially in USA, Australia and New Zealand, to utilize the higher amount of creep in wood at high temperatures.

In spite of earlier investigations, several questions are still not answered. There are no clear guidelines for optimising the load for different drying schedules when drying the most common species in Norway, namely Norway spruce (*Picea abies* (L.) Karst.). The main objective has therefore been to investigate the effect of different load levels, and to what extent the twist deformations are reduced when the load is increased according to the increase in the compression strength of wood when it dries below the fibre saturation point. Some measurements of the spring-back effect are included. Measurement of cupping and sticker marks are also performed at the same test material.

The results are intended to give input to the industry in their work to improve the wood drying quality.

Material and methods

A loading system with pneumatic cylinders where it is possible to regulate the load during drying was built in the laboratory kiln at NTI. The system is shown in Fig. 1.



Fig. 1. The loading system in the laboratory kiln. Loaded timber at the bottom, and unloaded timber on top.

Four tests were performed with different load levels. An important aspect in the work was to examine the effect of load levels that approach the maximum compression strength of wood under the stickers. The lack of strength data for the actual species at temperatures and moisture content levels that correspond to the wood during drying is, however, obvious. It was thus necessary to estimate the compression strength from the few data that were found in the literature. Fig. 2 gives an overview of the estimations.

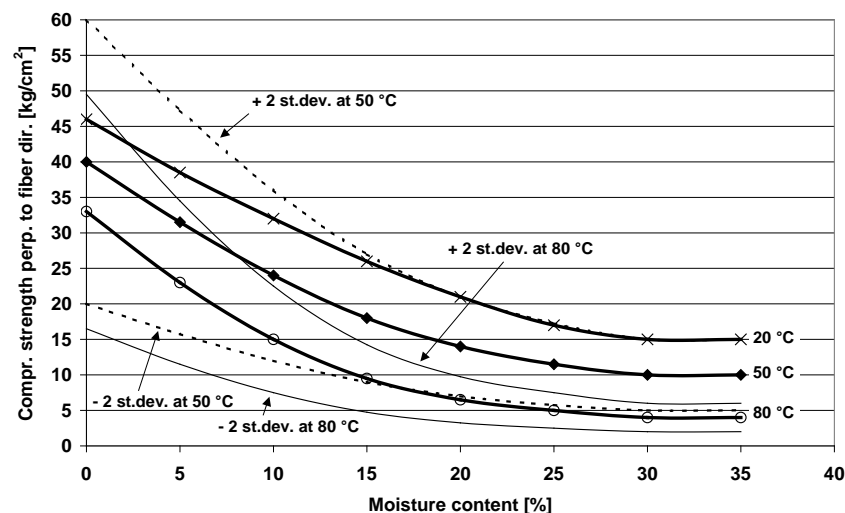


Fig. 2. Estimation of the compression strength perpendicular to fibre direction for Norway spruce at different levels of moisture content and temperature. Assumed curves for mean values at three temperature levels are given, together with assumed curves for ± 2 standard deviation for the two highest temperature levels. Based on data from Okohira, Wilson and Youngs in Gerhards (1982).

The estimation is based on traditional test data at 20 °C and 12 % moisture content for Norway spruce from Kollmann & Côté (1967). The adjustment for other conditions has thereafter been performed according to data from literature concerning the influence of moisture content and temperature. These references operate with other species than Norway spruce, but it is assumed that the main effects are, in general, comparable. It is, however, important to be aware of a considerable uncertainty connected with this estimation.

Four tests with different load levels were performed. For all tests, the material was timber of Norway spruce with a cross section dimension of 50 mm x 150 mm. The planks were taken near the pith in the log, but there was no pith in the planks.

For practical reasons, all four tests were not performed in the same period, and therefore it was not possible to use test material from the same logs in all four tests, as had been preferable when comparing the different load levels. Two and two tests were, however, performed in the same period, which means that the material for test no. 1 and 2 was taken from the same logs, while the material for test no. 3 and 4 was taken from other logs.

Each of the two groups of test material was collected by selecting 15 main planks with a length of at least 5 m at a sawmill. Each of these planks was cut into four test lengths for the laboratory kiln, and constituted the test material for two drying runs. In each test (drying run) it was then possible to have 15 loaded planks and 15 non-loaded planks, as reference, from the same main planks. The test planks for each run were taken from different locations in the longitudinal direction of the main planks, and possible systematic effects from the butt end to the top end in the planks were then avoided. The selection procedure of the test material is illustrated in Fig. 3.

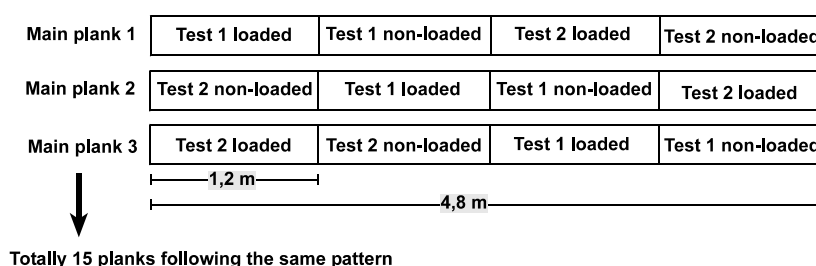


Fig. 3. Selection procedure for the test material. For test no. 3 and 4 the procedure was the same, and test 1 and 2 in the figure can then be replaced with test 3 and 4, respectively.

This experimental design gives a good basis when comparing loaded and non-loaded pieces in the same test (drying run), and when comparing different load levels that have been tested on test pieces from the same main planks (test 1 compared to test 2, and test 3 compared to test 4). It is necessary, however, to be more reserved when comparing test runs that have material from different sets of main planks, because the potential for deformations can be somewhat different in the two materials, although the aim was to get as similar material as possible.

In each test, 15 loaded and 15 non-loaded test planks were dried. There were five planks in each plank layer, which gives a package area of 0,9 m². The width of the stickers was 47 mm. There was one sticker at each end of the test planks. All planks were planed to the same dimension before drying.

The material was dried after the same drying schedule, where the dry bulb temperature increased from 52-53 °C in the beginning to 72-75 °C at the end. The wet bulb temperature was about 50 °C most of the drying period, but was dropped towards 45 °C at the end. No conditioning was performed. A drying time of 90-100 hours was necessary to reach the target moisture content of 12 %. Electrodes (resistance meters) were placed in the wood during drying to monitor the moisture content. It is of course almost impossible to hit the target moisture content exactly, even when using electrodes in the wood during drying. There will also be some spreading between the planks. In two tests, the moisture content was therefore checked in each test plank with a moisture meter (resistance type). By considering the loaded and non-loaded planks separately, the mean values for the four batches were 11,2 %, 10,7 %, 12,9 % and 12,6 %. The standard deviations were 2,7 %, 2,3 %, 2,5 % and 2,0 %, respectively. It is assumed that the moisture content is so similar for the different treatments that it is not brought in as a parameter in the further analysis.

In test no. 1, the load level was adjusted to a level that corresponds to the simulated compression strength in wood according to Fig. 2. The criterion was that the pressure under the stickers should not exceed the mean strength value minus two standard deviations during the drying process, as a safety margin to avoid unacceptable sticker marks in most of the planks. In this connection, it is also important to be aware that the estimations in Fig. 2 are based on data with a test duration of few minutes. When drying wood, the time aspect is hours and days, with generally higher deformations for the same load level as a result because of different creep mechanisms in wood.

In test no. 2, the motive was to study the effect at the bottom of a stack if a constant load is used during industrial drying. In practical drying with 3-5 packages in the height (4-6 m with stucked timber), the pressure will be constant on top, but will decrease downwards in the stack, most at the bottom, during drying, as a consequence of the removal of water. In this test, typical stack dimensions in Norwegian kilns are used as a basis for calculating the load reduction during drying. The start level is estimated in the same way as described for test 1.

In test 3 and 4, a constant load was used. This will be representative for the situation at the top of the stack during drying. Two different load levels were tested, one of them was relatively low. Table 1 shows an overview of the load levels in each test.

Table 1. Load levels and loading procedures for each test.

Test no. (kiln run)	Loading procedure	Loading level (pressure)	
		Whole package	Under stickers
1	Increasing load	3 080 – 4 320 kg/m ²	3,9 – 5,5 kg/cm ²
2	Decreasing load	3 080 – 2 460 kg/m ²	3,9 – 3,1 kg/cm ²
3	Constant load	1 350 kg/m ²	1,7 kg/cm ²
4	Constant load	710 kg/m ²	0,9 kg/cm ²

Immediately after drying, the deformations were measured. The twist is expressed as rise over the actual width, measured over the length of the test planks (1,2 m). The cup was measured under and between the stickers (at intervals of 10 cm) for the loaded pieces, while two measurements were taken at each plank for the non-loaded pieces. In addition, the maximum depth of the sticker marks was measured for each plank (in the middle of the pith side of the plank). All measurements were repeated after 8 (test no. 1 and 2) and 10 (test no. 3 and 4) days to detect the spring-back effect. In this period the planks were stored unloaded (standing) in a climate of 20 °C and 65 % relative air humidity, which corresponds to an equilibrium moisture content of about 12 %.

Results

Twist

The results for twist deformations immediately after drying are given as frequency distributions. In Fig. 3 the results from test no. 1 and 2 are given. These two tests, which have the highest load levels of the four tests, are based on the same material (main planks).

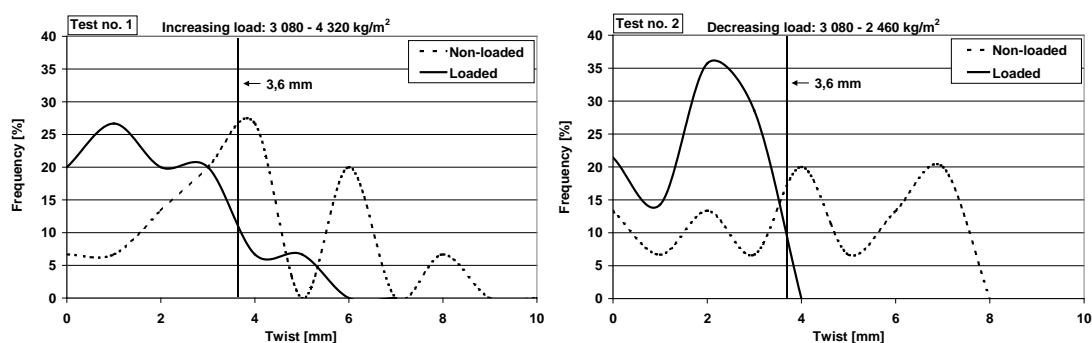


Fig. 3. Twist values immediately after drying for test no. 1 and 2, given as frequency distributions.

The twist is strongly reduced for the loaded timber compared to the non-loaded for these two load levels. A two-way analysis of variance (2-way ANOVA) for each test shows that the differences between the loaded and non-loaded planks

are clearly significant for both tests (test 1: $F=15,1$, $\text{Prob}>F=0,0016$, $DF=1-14$, test 2: $F=16,5$, $\text{Prob}>F=0,0014$, $DF=1-13$).

If a twist value of 1 mm rise per 25 mm plank width over a length of 2 m is used as a guideline for an accepted twist value in timber, it will give a value of 3,6 mm for the tested planks. This value is indicated in the diagrams in Fig. 3. For the loaded test pieces in test no. 1 and 2, 93 % and 100 % of the planks were within these limits, respectively. For the non-loaded test pieces the corresponding values are 73 % and 53 %, respectively.

The results show that the high load levels used in these tests result in a considerable improvement concerning reduction of the twist deformations during drying. Almost all of the test pieces are within an acceptable twist level in both tests. The fact that the improvement is a little better in test no. 2 with decreasing load, has to be attributed to non-controllable variations in wood properties and drying procedures.

In Fig. 4 the results from test no. 3 and 4 are given. In contrast to test no. 1 and 2, these tests have been performed by a constant load during drying, and at a lower load level. The same material (main planks) is used in test no. 3 and 4.

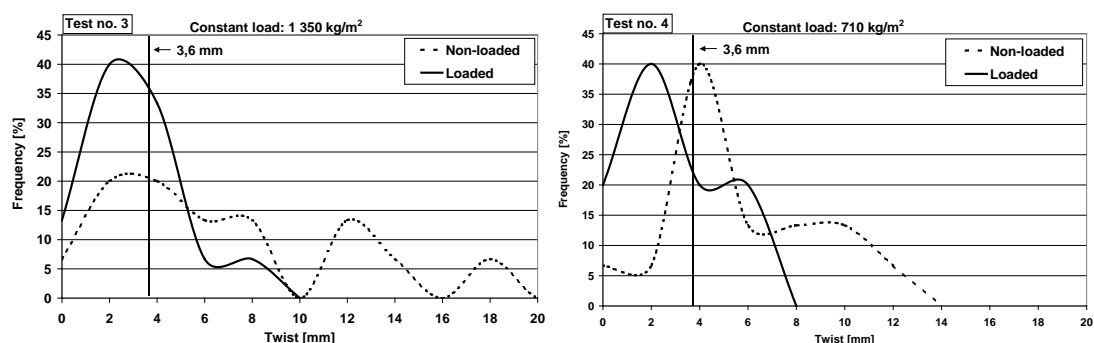


Fig. 4. Twist values immediately after drying for test no. 3 and 4, given as frequency distributions.

Also, in these two tests the twist is considerably reduced for the loaded timber compared to the non-loaded. A two-way analysis of variance (2-way ANOVA) for each test shows that the differences between the loaded and non-loaded planks are clearly significant for both tests (test 3: $F=14,7$, $\text{Prob}>F=0,0018$, $DF=1-14$, test 4: $F=33,0$, $\text{Prob}>F <0,0001$, $DF=1-14$).

A twist value of 1 mm rise per 25 mm plank width over a length of 2 m, which gives a value of 3,6 mm for the tested planks, is also indicated in the diagrams for test no. 3 and 4. For the loaded test pieces in test no. 3 and 4, 67 % and 73 % of the planks were within these limits, respectively. For the non-loaded test pieces the corresponding values are 33 % and 53 %, respectively. The fact that the improvement are somewhat better in test no. 2 with decreasing load, has to, as for test no. 1

and 2, be attributed to non-controllable variations in wood properties and drying procedures.

From the results and diagrams it can be seen that the yield, with reference to the indicated limit, is higher for the higher load levels that are used in test no. 1 and 2 compared to the lower load levels in test no. 3 and 4. It is important, however, to note that the potential for twist deformations is higher for the material used in test no. 3 and 4 compared to the material in test no. 1 and 2. When calculating percentual reduction in twist for loaded pieces compared to non-loaded (reduced twist in percent of twist in non-loaded pieces), the values for test no. 1-4 is 55 %, 60 %, 58 % and 64 %, respectively. From these values it is not reasonable to say that the highest load levels are more effective for reducing twist than the lower load levels. On the other hand, the load needed to attain a certain percentual twist reduction may be lower when the potential for twist is high in the wood, as in test no. 3 and 4. If this is the case, these two tests will be favoured when calculating percentual reduction. Results of Tronstad *et al.* (2001) indicate also that an increased load level, within a lower range than in these tests, has a clear effect concerning reduction of twist in timber.

A question of interest is to what extent the deformation is recovered when the timber is unloaded after drying. To detect the spring-back, the timber was stored unloaded for 8-10 days after drying, before new measurements were performed. The results are given in Fig. 5.

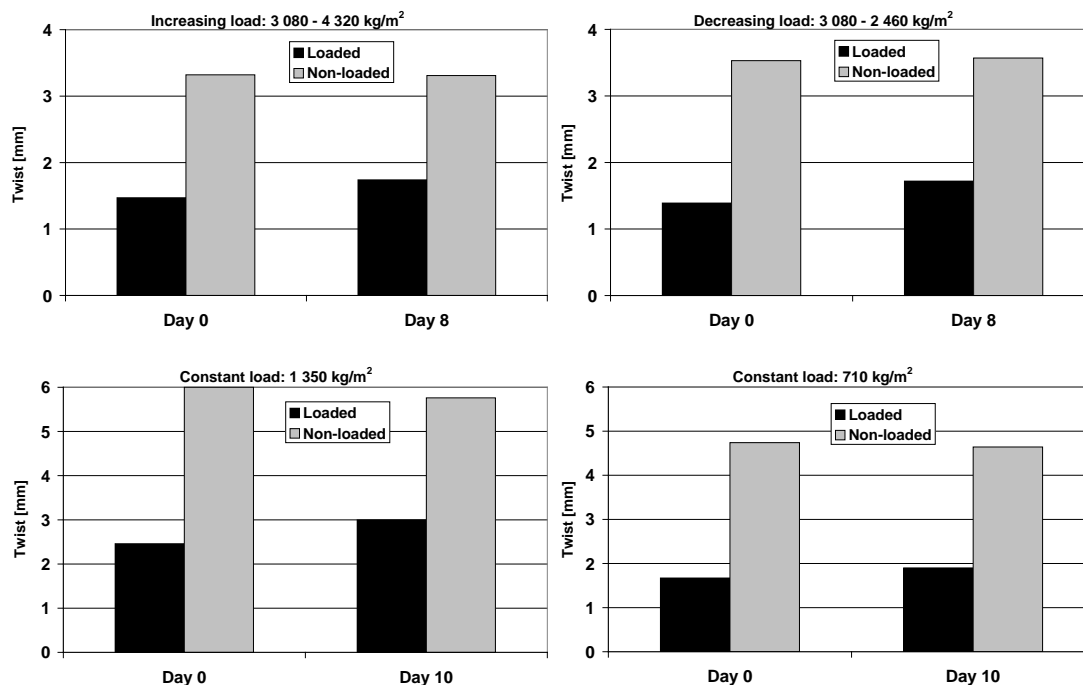


Fig. 5. The spring-back effect when the timber has been stored unloaded for 8-10 days after drying. The black and grey columns are mean values for loaded and non-loaded timber during drying, respectively (the non-loaded timber is included in the figure as a reference).

The figure shows that the measured spring-back is rather moderate, and the main effect of loading is still present in the wood. A 2-way ANOVA for each test shows, however, that the twist values are significantly higher after the storing period (test 1: $F=7,3$, $\text{Prob}>F=0,0169$, $DF=1-14$, test 2: $F=26,4$, $\text{Prob}>F=0,0002$, $DF=1-12$, test 3: $F=23,5$, $\text{Prob}>F=0,0003$, $DF=1-14$, test 4: $F=5,4$, $\text{Prob}>F=0,0361$, $DF=1-14$).

Sticker marks

Fig. 6 shows the result of the measurements of the sticker marks in timber for the different load levels.

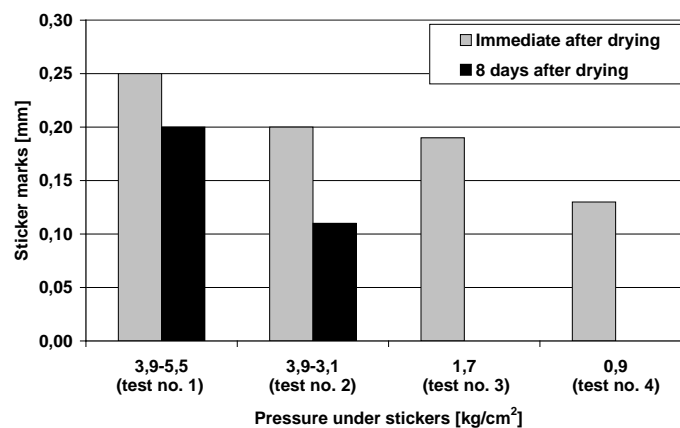


Fig. 6. Sticker marks immediate after drying and after eight days (test no 1 and 2).
In test no. 3 and 4 only measurements immediately after drying were performed.

In test no. 1 and 2 the load levels were adjusted to the assumed compression strength in wood. The results show that the sticker marks are highest in these two tests, but even at these pressure levels, the marks seem to be very moderate and of non-practical influence. The sticker marks decrease with decreasing load level, as expected.

The spring-back effect was measured after eight days in test no. 1 and 2, and there is a clear decrease in the sticker marks during this period.

Cup

The cup was measured under and between the stickers, and the results are shown in Fig. 7.

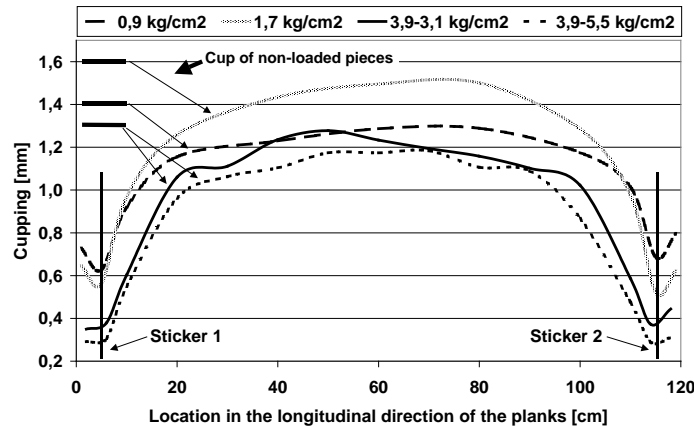


Fig. 7. Cup under and between stickers for the different load levels.
 The cup in the non-loaded pieces is indicated to the left at the top of the diagram.
 The figure is based on mean values for the tested planks.

The figure shows that the cupping is highly reduced under the stickers, and in a region of 15-20 cm from the stickers there is still some effect of the loading. Halfway between the stickers, the cup in the loaded planks is almost the same as in the non-loaded, although there seems to be some effect of the load also in this region.

To illustrate the spring-back effect concerning cupping, the results from one of the tests, test no. 1, are shown in Fig. 8.

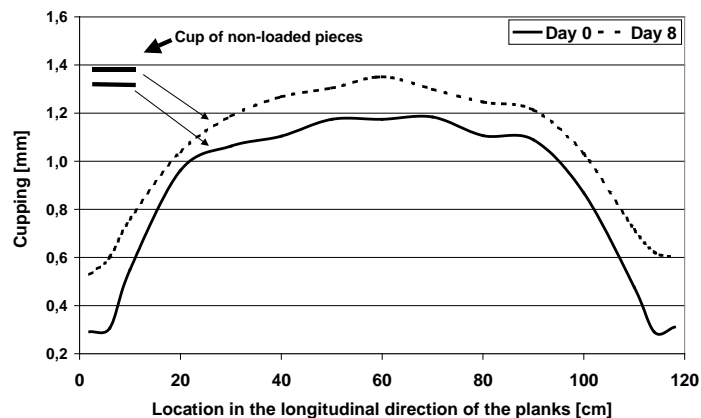


Fig. 8. Cupping immediately after drying and after a storing period as unloaded planks for eight days. Mean values for the tested planks.

From the figure it can be seen that there is some spring-back effect also for the cup deformations, although the pieces that were non-loaded during drying show some increase in cup after the period. The latter aspect must be attributed to small changes in moisture related conditions (equalising of moisture gradients and small changes in moisture content).

Discussion and conclusions

The investigation shows the high potential for yield increase in the sawmill industry by using a load system during drying to reduce twist deformations. For the two highest load levels that were used in this research, almost all of the test pieces were within an acceptable limit for twist deformation. For the corresponding non-loaded pieces, the twist deformations were considerably higher, and a considerable portion of such pieces must be rejected at sawmills because of twist.

The highest load level in this investigation was adjusted to the assumed compression strength in the wood. The question is whether the same improvement can be attained by using a lower load level. The tests show that the yield with reference to an indicated limit is higher for the higher load levels. The potential for twist deformations was, however, lower for this material than for the material used in the tests with lower load levels, and it is therefore difficult to come up with a clear conclusion concerning a possible effect of increased load levels. Further research is therefore necessary to better detect this effect. Because of the fact that the effect of load during drying also depends on the temperature level used, it is natural to include this parameter in further work.

The measured spring-back is rather moderate, and the main effect of loading is still present in the wood after the timber has been stored unloaded for 8-10 days after drying. By exposing the wood to cyclic changes in moisture content after drying and unloading, it is expected that the spring-back effect will, to some extent, increase because of the recovery of the mechano-sorptive creep. BRE (1998) has made experiments where timber of Sitka spruce was dried under load, and brought through different climates after drying and unloading. It is concluded that the twist restrained in the timber by top loading did not significantly re-occur under fluctuating conditions.

The sticker marks increased with increasing load level, but even at the highest load level the marks seem to be of no practical importance.

It should be pointed out that in this research the planks were planed before drying, and the pressure will then be rather equal in the whole length of the stickers. In practical drying there will be some variation in thickness from one plank to another. At high load levels the pressure under the stickers will be considerably higher in the thickest planks if they are placed between the thinner planks, with a risk of deeper sticker marks. This aspect is important also concerning reduction of twist deformation. High variations in thickness result in an insufficient pressure on the thinnest planks to reduce twist, as shown by Simpson and Tschernitz (1998).

The cupping is highly reduced under the stickers, and in a region of 15-20 cm from the stickers, there is still some effect of the loading. Halfway between the stickers there is, however, almost no practical effect.

To obtain an effect of loading concerning reduction of cup, the distance between the stickers has to be reduced considerably compared to the distance of 0,7-1,0 m that is usually used in sawmills today. This will also give a positive contribution to reduce twist, because the share of unloaded ends of timber will be reduced, and the load level can be increased without risk of unacceptable sticker marks. A question is whether a considerable increase in number of stickers is favourable, due to both practical and economic aspects.

Another drying procedure is press drying. In this method, the planks will be restrained in the whole length. Unloaded plank ends will then not be a problem concerning twist, and the cup will be restrained in the whole length of the plank. At NTI there is an on-going investigation where the aim is to study the effect of press during drying to reduce the cup. The results will be published when the investigation is finished.

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3. Drying quality of softwood based on 140 industrial tests in Norwegian sawmills and actions to improve the quality

Sverre Tronstad, Knut Magnar Sandland and Håkon Toverød

Abstract

During a period of six years, 140 industrial tests have been performed to get an overview of the different qualities of softwood drying in Norway, as a basis for a quality improvement program. The tests are carried out by the kiln operators at 40 different sawmills, based on detailed procedures worked out by Norsk Treteknisk Institutt (NTI). The qualities that have been tested are checking, moisture content, moisture gradients, casehardening and deformations.

The *checking* was measured before and after drying. The level of checking was low compared to the requirements, but clearly demonstrated the need for actions to reduce the pre-checking during the storage between stickering and kiln drying. The *moisture measurements* gave interesting information about the spread in moisture content and its correlation with the moisture level, the moisture gradients in the timber cross section and the ability to hit the target MC. The *casehardening* was tested in kilns with and without conditioning, and was compared to the levels in the INSTA and EDG-recommendations. Comprehensive tests were carried out to find the levels of the different *deformations* that arise during the drying process, including twist, bow, crook and cupping. The results were correlated to the applied top pressure on the packages.

For all the different drying qualities, methods have been proposed and partly tested to improve the quality, ending up with the development of a *drying quality control system* to follow up the quality of individual drying charges and of continuous process control.

Introduction

Softwood has through the years been the predominant building material in the Nordic countries. During recent years we have seen an ever-increasing competition from substitutes. The marketers of the various substitutes very often emphasize that their materials are better compared to wood, which always is described as a material that burns, rots, shrinks, swells, checks and deforms. Even if these assertions are pushed to the extreme, we must to a certain extent admit that these properties of wood are a problem. The wood industry must take these signals seriously. Users with no special connection to wood may accept these assertions without questioning, and switch to other building materials.

The main reason for the negative properties of wood is in most cases moisture related and can be traced back to the drying process and the moisture follow-up towards the end user.

The Norwegian sawmill industry and their research institute (NTI) have taken these signals seriously and seen the importance of an upgrading of the knowledge and performance of the drying process in the sawmill industry, in order to improve the drying quality.

The strategy for this upgrading was divided in three stages:

- A broad state-of-the-art testing of the different drying qualities in the sawmill industry.
- Assessment of the results, comparison between requirements and standards and priority of actions to improve the quality.
- Actions and follow-up tests.

The state-of-the-art tests were all run in the kilns of the members of the Norwegian Wood Drying Club that has 46 industry members. The test plans and forms were worked out by NTI in collaboration with the industry board and members, and all measurements were done by the kiln operators. The results were presented to the industry at several meetings where they were discussed and actions were prioritized. The results could lead to a direct upgrading of equipment and routines in the industry and further research to clarify problem areas.

In the following presentation the different qualities that were tested are presented for each type of quality, together with actions taken to improve the quality, and in some cases, results from follow-up tests of the actions.

Checking

Materials and methods

28 sawmills performed 36 different tests on the level of checking before and after drying. The tests were run under the following conditions:

- *Species* – Norwegian spruce (*Picea abies*) (92 %), Nordic pine (*Pinus sylvestris*) (8 %)
- *Thickness/width* – 50 and 63 mm/125-150 mm
- *Test period* – August to November – planks from logs stored water-sprayed for 9 weeks in average
- *Kiln type* – 30 compartment kilns (4 x 4 packages), 6 progressive kilns (two drying zones)
- *Drying schedule* – the normal schedules for each sawmill were used in the tests and will be described under Results.

The test planks, in average 110 per test, were taken from the second outer package from top. The checking was measured on the check-prone backside of the plank (opposite face of the pith), and the measurements were divided in end checks at the top and root end, and "normal" checks between top and root end. A total of 3800 planks were measured before and after drying.

Results

All sawmills gave information about their drying schedules used in the tests. The schedules in the drying phase did not vary significantly for the compartment kilns. In Fig. 1 the mean values for the dry and wet temperatures and the mean progress in the mean moisture content are shown. In the early tests in 1993, about 40 %, including the progressive kilns, did not carry out conditioning.

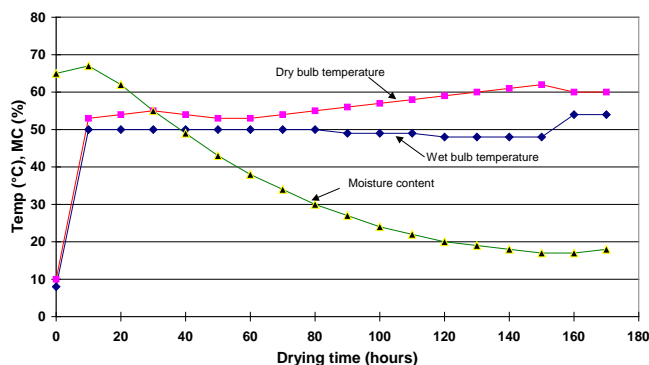


Fig. 1. Typical drying schedule for the compartment kilns in the 93/94 test.

The mean values for the checking are shown in table 1, where the checking is divided into checking before drying and after drying. The total checking was further divided into end checking top end, end checking root end and checking in between, called checking in the "middle".

Table 1. Mean values for the checking of 50 mm and 63 mm before and after drying.

Thickness mm	Checking before drying (% of length)				Total checking after drying (% of length)			
	Top end	Middle	Root end	Total	Root end	Middle	Top end	Total
50	0,4	0,4	0,5	1,3	1,1	2,20	1	4,3
63	0,4	0,5	0,6	1,4	2,2	4,20	1,7	8,1

As can be seen from the table, the total mean checking length after drying was for 50 mm thickness, 4,3 % of the timber's total length. For 63 mm thickness, the total checking length was 8,1 % of the total length.

Notice that a considerable part of the checking appeared before drying, with 1,3 % and 1,4 % for 50 and 63 mm respectively. 70 % of the total checking before drying came from end checking. Even after drying the end checking accounted for 50 % of the total checking.

There were considerable differences in the mean level of checking before and after drying, as can be seen from Fig. 2, with some extremes both ways from the middle values.

Compared to the requirements in the Nordic grading rules for pine and spruce, “Nordisk Tre”, all measured mean values indicated, however, a safe level compared to the requirements.

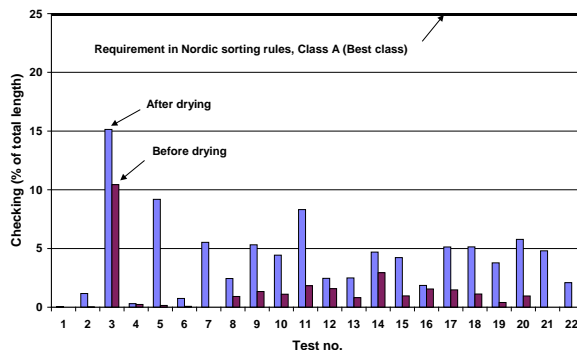


Fig. 2. Level of checking before and after drying for 50 mm spruce / pine, expressed as the mean total length of checks on the face opposite the pith in percentage of the total length of the timber.

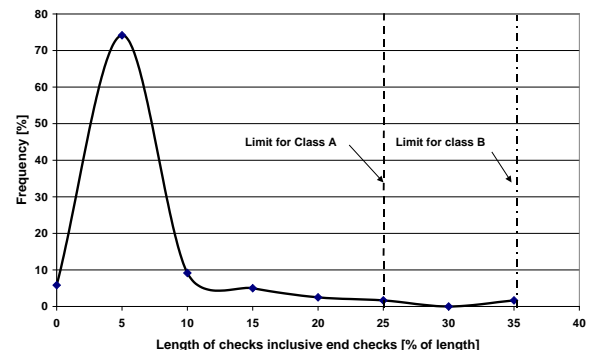


Fig. 3. Typical distribution of checking by drying of 50 mm spruce and pine at one sawmill, with indication of the limit in the Nordic sorting rules class A (best class) and B.

If we look at the length distribution of the checks as shown in Fig. 3 for a representative sawmill, the level of checking is more than acceptable compared to the requirements in class A and B in the Nordic sorting rules.

Actions

With a level of checking far below the requirements, no special research program was undertaken to reduce the checking. In the discussions with the industry, however, the importance of reducing the pre-checking was stressed together with the need for general upgrading in the fundamentals of checking. This has resulted in different actions at the sawmills:

Before drying

- Increased focus on water spraying of logs in storage at the mill.
- Reduction in storage time between packaging/stickering and drying.
- Shielding of package ends against direct sunshine.
- Water spraying of the timber in dry periods.

During drying

- Increase in the temperature level (wet and dry bulb), where possible.
- Better water spraying systems to reduce initial checks during the heating-up period.
- Training the kiln operators in the use of new stress models (Torksim).
- Controlled cooling of the timber before opening of the kilns.

Moisture relations

Materials and methods

70 different MC tests were run at the sawmills in the period 1993-1996, and are described in an NTI-report [4].

- *Species* – Norwegian spruce (*Picea abies*) (85 %), Nordic pine (*Pinus sylvestris*) (15 %).
- *Thickness/width* – 16-66 mm/100-200 mm, 70 % had a thickness of 50 mm.
- *Test period* – August to November – planks from logs stored water-sprayed for 11 (2-25) weeks in average.
- *Kiln type* – 37 compartment kilns (4 x 4 packages), 5 progressive kilns (two drying zones).
- *Drying schedule* – the normal schedules for each sawmill were used in the tests and are almost equal to the one in Fig. 1, except for some sawmills that had no conditioning. Target MC's were between 8 % and 18 %.
- *Number of measurements* – 93/94 tests; 20 x 2 measurements with resistance meters were taken from 4 packages each after drying, a total of 160 measurements per test. In addition, 8 oven-dry measurements were taken from each of the same 4 packages, in all 32 oven-dry tests per test. The test packages were distributed diagonally in the compartment kilns and vertically in the progressive kilns, as shown in Fig. 4. Altogether 42 sawmill tests. 1996-tests: 19 oven-dry measurements for initial and end MC were taken from package no. 2 from the top. A total of 27 sawmill tests were run.
- *Methods of measurement.* The end moisture content in the 93/94 tests was measured at two penetration depths of the planks, $\frac{1}{4}$ of the thickness to indicate the mean moisture content and $\frac{1}{2}$ of the thickness to indicate the core MC and for calculation of the moisture gradient. The 96 measurements were all according to the oven-dry method.

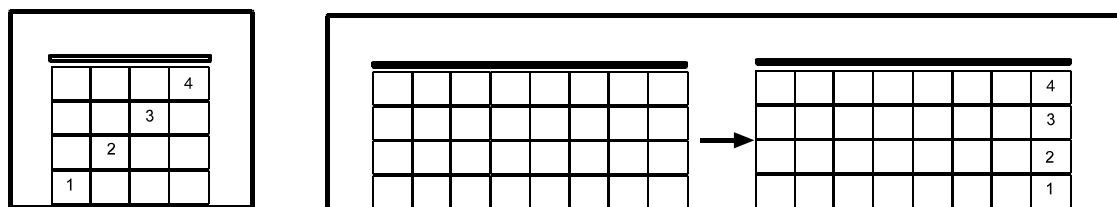


Fig. 4. Distribution of the test packages in the 93/94 tests.

Results

Initial and final moisture content

The initial mean moisture content showed a considerable variation from 18 % to 95 % for the different tests. The 18-20 % values are from companies buying shipping-dry timber for final drying. The spread in MC around the mean values was substantial, and in Fig. 5, which shows the oven-dry values from 1996, the spread expressed as stdv. is shown as a function of the initial MC.

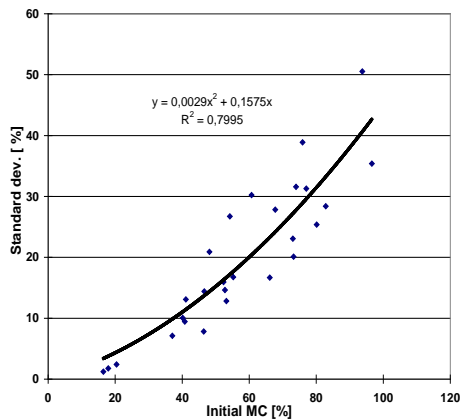


Fig. 5. Standard deviation in the initial MC as function of the mean initial MC. (96-tests).

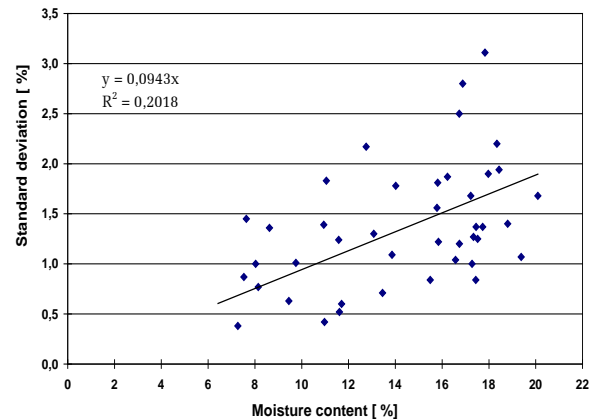


Fig. 6. Standard deviation in the final MC as function of the mean final MC. (93/94 tests).

The final moisture content in the 93/94 tests varied between 7 % and 20 %. In Fig. 6 the stdv. for the individual tests are correlated to the mean final moisture contents. With an assumption of zero stdv. by zero MC, the correlation between stdv. and final MC has an R-square of 0,2018, which is low, but significant.

Influence of package positioning in the test kilns

The position of the packages in the kilns had very little influence on the mean MC when calculated as an average of all measurements, as seen in Fig. 7.

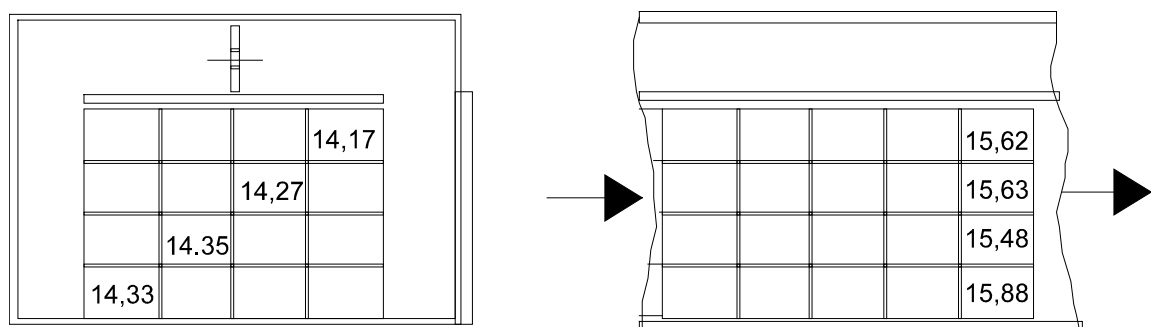


Fig. 7. Mean MC of all tests by the different positions of the packages in the compartment and progressive test kilns.

Deviation from target MC

In all tests, the kiln operator was asked to indicate the target moisture content before the test runs were started, in order to be able to test the ability to hit the target MC. In Fig. 8 the results of this test are shown as the deviation in the mean MC from the target MC.

As an average, the sawmills had an overdrying of 0,3 %. 55 % had a deviation from the target MC of $\pm 1,0$ %, 40 % between $\pm 1,0$ % and $\pm 2,0$ % and 5 % had more than ± 2 %.

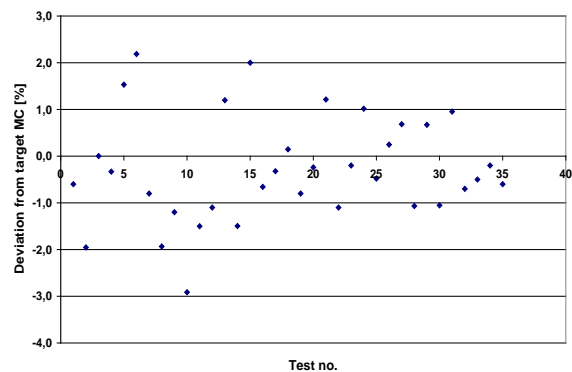


Fig. 8. Deviation from target moisture content.

Moisture gradients

The moisture gradient was measured with resistance meters as the difference between the core MC ($1/2$) and the MC ($1/4$) at a penetration depth of $1/4$ of the thickness. The results in Fig. 9 shown as a function of the MC, had, as expected, a certain trend towards an increase in the gradient with higher MC. The correlation is, however, low, due to all the differences in schedules and degrees of conditioning treatments.

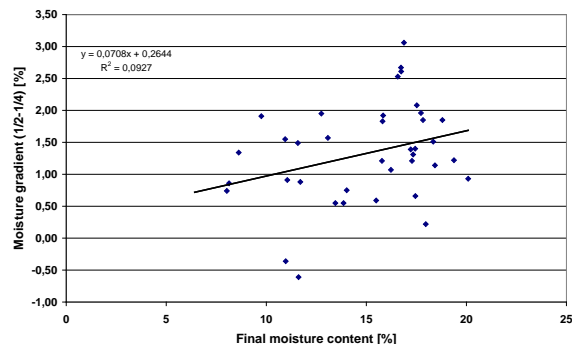


Fig. 9. Moisture gradients (1/2-1/4) by different MC's.

Comparison with existing MC standards

The final moisture was tested against the requirements in the Nordic drying standard INSTA 141 [1]. This standard sets a lower and upper limit for 84 % of all individual pieces, with different range widths for different target MC's. Tested against this standard, 86 % of all tests were within the requirements. For the 14 tests being outside the requirements, the main reason was a too large deviation between mean MC and target MC.

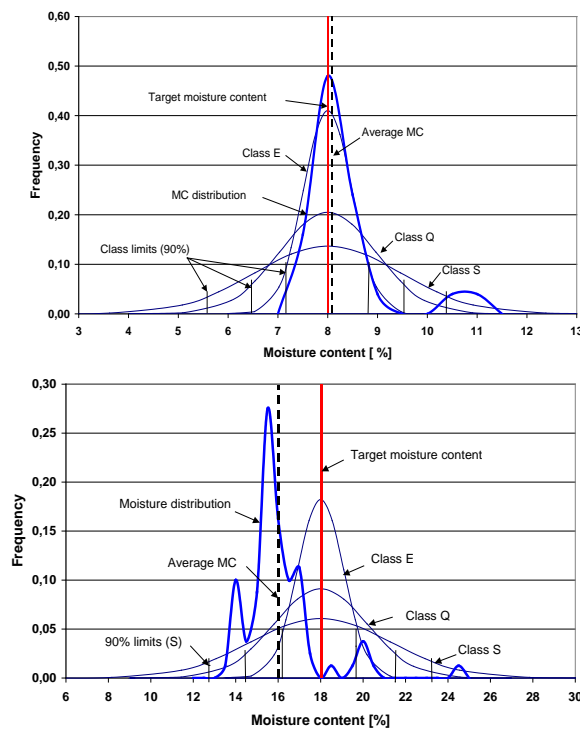


Fig. 10. Two examples of tests according to the EDG-proposal. In the upper diagram the test satisfies Class E, in the lower diagram the test only satisfies Class S due to over-drying.

Some tests were also done according to the EDG-proposal for European standard [2] with three different quality classes S (Standard), Q (Quality) and E (Exclusive). Two examples of these tests are shown in Fig. 10.

The INSTA standard has no requirements to the moisture gradient. Only the EDG-proposal has limits as to the moisture gradients. These limits (difference between the core MC and the MC at $1/6$ penetration depth of electrodes) are set to MC target $\times 0,4$ for Class S, MC target $\times 0,3$ for Class Q and MC target $\times 0,2$ for Class E. The limits are for 90 % of the pieces. With a recalculation of the values measured at a penetration depth of $1/4$ to a penetration depth of $1/6$ on an assumption of a parabolic moisture profile, 96 % of the tests satisfied Class Q and 69 % Class E.

Actions

The MC tests gave very interesting values as a base for upgrading the drying process and as background values in working out new standards. When discussing the results with the industrial participants, following actions were agreed upon:

- Reduction of the stdv. in initial MC by the same actions as under Chapter 2. A reduction in initial stdv. will also have a positive influence on the final stdv.

- Reduction in the stdv. in final MC by increased use of equalizing and conditioning treatments. Upgrading of the conditioning system to high-pressure water spraying. Training of kiln operators in how to perform proper equalising and conditioning.
- Higher focus on the importance of hitting the target MC. Establishment of the IMCOPCO-project with a subproject on in-kiln MC measurement and end moisture content control.

Follow-up controls over the years have shown a substantial reduction in the standard deviation of the end moisture content, with 30 % above 1,6 % in the first tests in 93/94, to 14 % in 1996 and only 5 % in the last tests in 1998.

Casehardening

Materials and methods

The degree of casehardening was tested according to two different principles, INSTA 141 (42 tests) and the EDG-proposal (15 tests). The INSTA-standard uses the prong test, while in the EDG-proposal a so-called slicing test has been adopted. In the EDG-method the gap in mm over 100 mm width after slicing and moisture equalizing is measured, and in INSTA 141 the ratio d_2/d_0 (prong width/reference width) after equalizing is the measure for the degree of casehardening. The sawmills ran their normal drying schedules as shown in the previous tests, and did not make any special efforts to change climate or prolong the conditioning time.

Results

The results are assessed according to the requirements in the INSTA 141-standard and the EDG-proposal for a European standard. The INSTA-requirements are classified as follows: $d_2/d_0 = 1,0-0,9$ (no casehardening), $d_2/d_0 = 0,9-0,8$ (minor casehardening), $d_2/d_0 = 0,8-0,6$ (middle casehardening) and $d_2/d_0 < 0,6$ (severe casehardening).

The EDG-requirements are classified as follows: Class E < 1 mm gap, Class Q < 2 mm gap and Class S < 3 mm gap. In the INSTA-tests the mean ratio d_2/d_0 for all measurements, including the sawmills that did not perform any special conditioning treatment, was 0,83, giving 32,8 % with no casehardening, 34 % with minor, 30,8 % with medium and 2,3 % with severe casehardening. In the EDG-tests, the mean gap for all measurements was 1,4 mm, with 80 % in class S, 53 % in class Q and 13 % in class E.

According to the requirements in the INSTA-standard, almost every sawmill seemed to have an "acceptable" casehardening level. This indicates that the wording of the requirements probably are set too low in this standard. The EDG-

requirements are considerably stronger and require a very good conditioning treatment to reach the Class E (Exclusive).

Actions

The tests proved the need for upgrading the conditioning treatment. The following actions were taken:

- Intensive research on the fundamentals of casehardening. Engagement of doctorate student in casehardening and wood deformations. [5]
- Laboratory and industrial tests of high-pressure water spraying. [3]
- Implementation of high-pressure water spraying in present and new kilns.
- Training of kiln operators in proper conditioning treatment.

Follow-up tests of the spraying equipment have clearly shown a far better ability to obtain high relative humidity during heating up and conditioning after installing high-pressure water spraying.

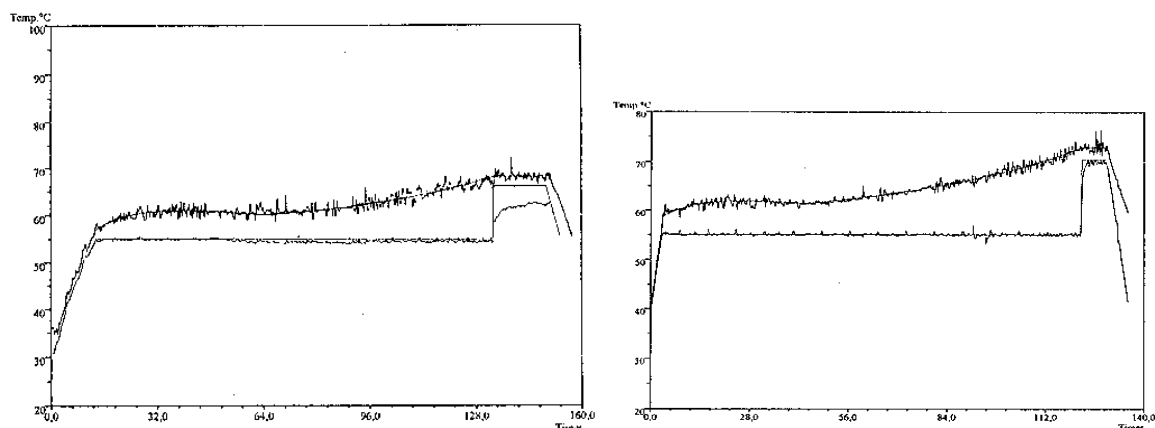


Fig. 11. Effect of high-pressure water spraying on the ability to increase the wet bulb temperature during heating up and conditioning. Low-pressure system to the left, new high-pressure system to the right.

This upgrading of the spraying equipment in combination with a better knowledge about conditioning treatment has completely changed the mean conditioning climate among the members of the Kiln Drying Club from a $\Delta \text{EMC} = -1,2 \%$ in 1993/94 to a $\Delta \text{EMC} = +2,1 \%$ in 1998.

(ΔEMC is defined as the difference between the EMC by conditioning and the mean moisture content at the start of conditioning). Follow-up tests in kilns with new high-pressure spraying systems have shown their ability to deliver timber in EDG-class E, when necessary.

Deformations

Materials and methods

Comprehensive tests have been performed in the period 1998-2000 to determine the level of warp in timber caused by the drying process. The tests were divided into industrial tests, described in this paper, and a laboratory test described in a separate paper [6] of this workshop. 22 sawmills have been involved in the project, with a total of 24 different tests. The initial tests were primarily run to find the general level of the different warping, twist, crook, bow and cupping and the influence of the package positioning on the warping. The position of the test packages, with an indication of the load distribution is shown in Fig. 12. The test material was 50 x 150 mm spruce that was dried to a mean MC of 14 %. The drying schedules were almost identical to the previous tests, but had a bit higher wet bulb temperature levels and more correct and intensive conditioning treatments.

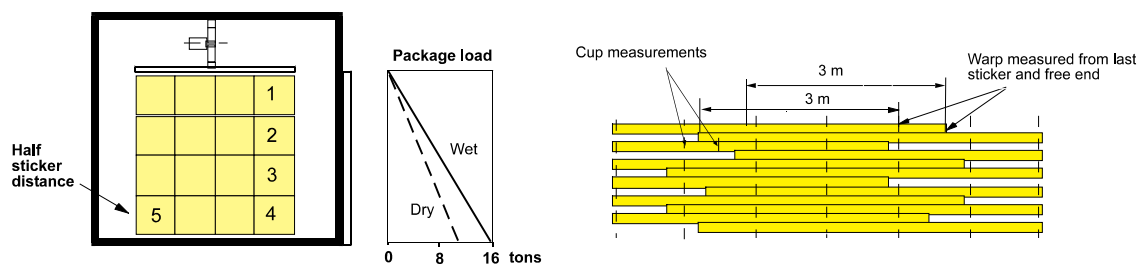


Fig. 12. Placing of test packages in kiln load with indication of load distribution (left) and point of measurements for warp and cup.

The warping was measured after drying over 3 m from the free end and from the sticker position. The cup was measured under the stickers and in the middle between two stickers, as shown in Fig. 12. All measurements were taken from the two top layers in each package, with the top layer in the top package as reference. App. 80 planks were measured in each test, in all nearly 2000 planks. The average number of stickers was 7 (Pk. 1-4). In package 5 the number of stickers was increased to 13 (half sticker distance).

Results

The degree of bow and crook was low and was minimally influenced by the position (and consequently by the top loading) of the samples in the kiln.

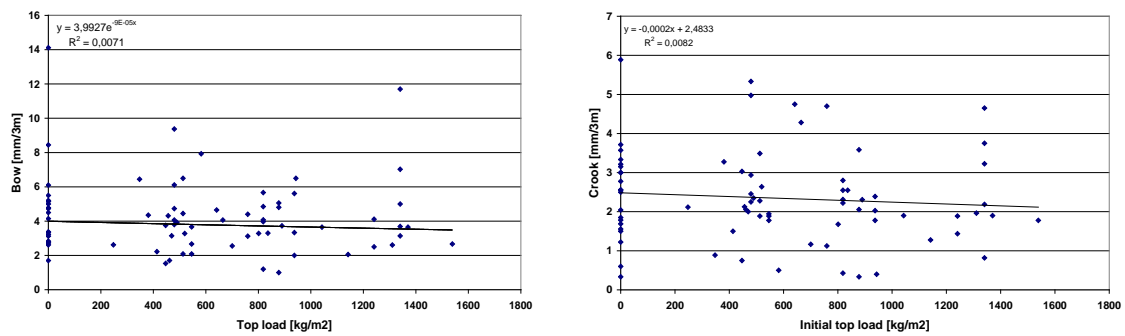


Fig. 13. Influence of top load on the average level of bow and crook.

The twist and cup were, however, significantly influenced. In Fig. 14, the amount of twisting is expressed as distribution curves for the different placing and mean top loading for the test planks. The measurements are taken over 3 m from the free ends at a mean moisture content of 14 %. The top layer (reference) had app. 1 % lower moisture content than the other samples.

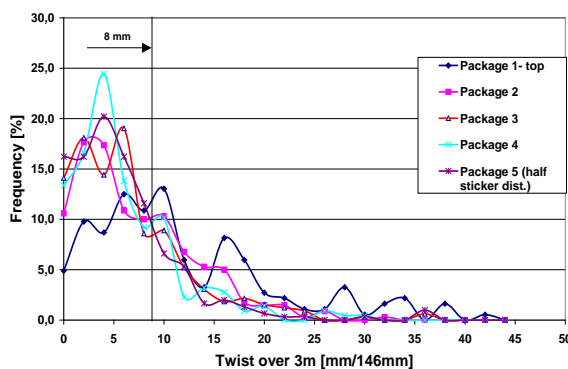


Fig. 14. Distribution of twisting at the different positions of the test samples.

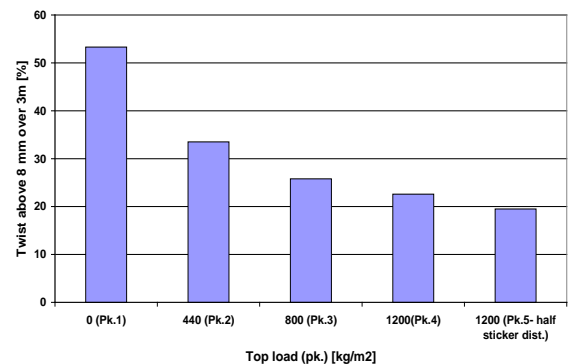


Fig. 15. Percentage of planks outside a limit of 8 mm twist, as a function of the top load.

If we set a limit for twisting to 8 mm over the 3 m measuring length, we can calculate the percentage of planks above this limit as a function of the top load as shown in Fig. 15. The diagram indicates clearly the importance of top loading as a means to reduce the twisting of timber during drying. The twisting is reduced to almost $\frac{1}{3}$ by a top load of 1200 kg/m² compared to no load. The reduction of the sticker distance to the $\frac{1}{2}$ with the same load, reduced the twisting, but not to the extent that was expected. The effect of a further increase in the top loading will be presented in a separate paper at this workshop.

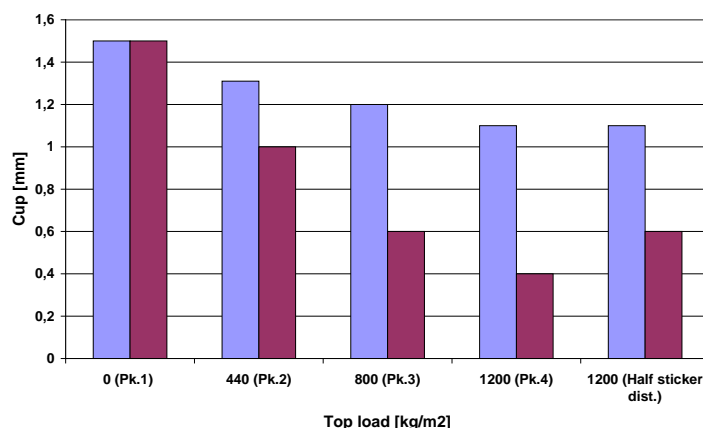


Fig. 16. Cup as function of the top load between and under stickers (dark column).

The twisting was clearly influenced by sticker position. Measured from the free ends, the twisting was about 20 % higher compared to measurements from under the stickers.

The cupping was influenced by the top load and the point of measurement, as shown in Fig. 6. The cupping under the stickers is dramatically reduced by increased loading. The top load has even an influence on the cupping at the midpoint between the stickers.

Actions

Warp has a very negative effect on wood as a building material. The tests have shown that the deformations can be considerable, especially twist. The tests have also clearly demonstrated the influence of top loading on the degree of deformations.

The test results have attracted great attention in the sawmills and have resulted in different actions to reduce the deformations:

- Controlled tests under laboratory conditions to obtain more data for optimum load level and degree of spring-back (see separate paper).
- New industrial tests with two types of top loads – constant top load by use of concrete blocks and variable top load by use of pneumatically operated steel frames.
- Design ideas for new kilns with high-pressure top load.

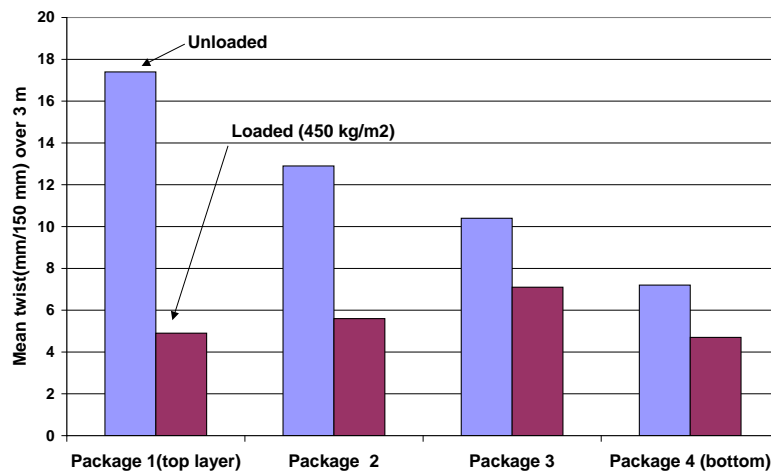


Fig. 17. Influence of top loading on twisting in one drying of 38 mm x 125 mm pine to 9 %.

One follow-up test with constant top load was run at a kiln doing final drying of 38 x 125 pine from 18 % to 9 %. The top loading equipment was made of concrete blocks giving a top pressure equal to 450 kg/m² on the top layer.

The results clearly indicate the positive influence of top loading. The sawmill

is very satisfied with the results and will equip all kilns with top loading. Even a top load of only 150 kg/m² in another test gave a reduction in the mean twisting in the two top packages of 15 % with 7 stickers and 38 % with 9 stickers, compared to no top load and 7 stickers.

The initial and follow-up tests have increased the interest among the sawmillers in equipping their kilns with top loading, and the first sawmills have already installed or ordered pneumatic top loading in their new kilns. The tests have clearly demonstrated the correlation between twisting and loading. Even relative small top loads can have a substantial positive effect on the twisting of the top layers. If the requirements to twisting are set very high, especially when drying to low MC's, the top load must, however, be increased to substantial higher levels to get a low percentage inside the requirements. With the requirements set in Fig. 14 and 15, a top load of 2,5 tons per square meter placed all planks within the limit according to laboratory test described in the separate paper [6].

However, normal kiln constructions are not designed to stand such loads, using pneumatic or hydraulic operated top loads. Therefore, we invite the kiln manufacturers to take this into consideration when they are designing their new kilns. The fan deck and the kiln walls must be able to withstand the bending and tension forces when applying the high pressures, and the wall construction must be sufficiently connected to the floor. The kiln should in a way be designed as a "hydraulic press", as shown in Fig. 18. To reach the high pressures, the cylinders should be of hydraulic type, preferably water hydraulics, having the possibility of using the same pump for the high-pressure water spraying.

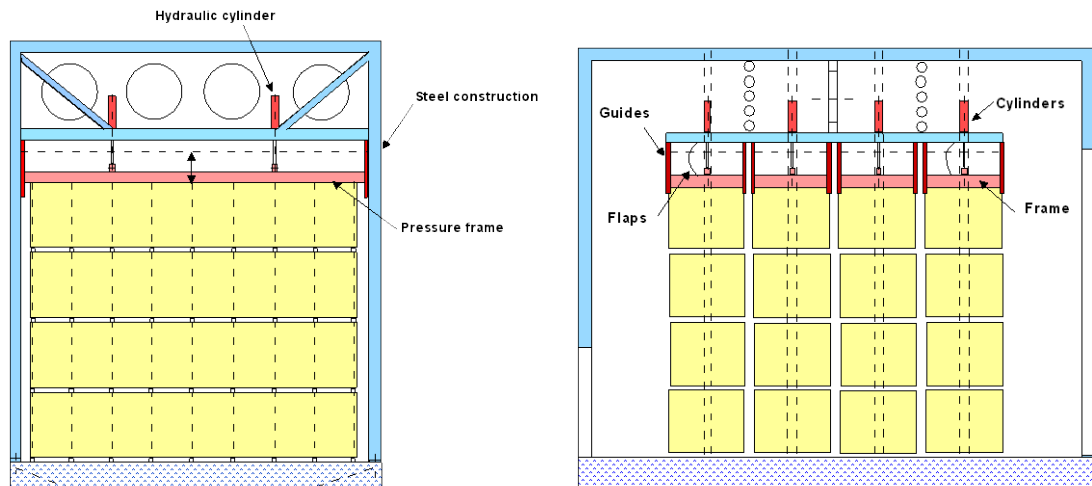


Fig. 18. The kilns should be especially designed for variable high top pressure on the packages.

Such a construction has two important advantages in addition to the reduction of the warp. With a hydraulic top load, the pressure frames prevents the packages from tilting, and with flexible flaps integrated in the top pressure system there will be no air leakage between the fan deck and the top packages.

Knowing that the crushing strength of the timber is dependant on the wood MC and temperature, such a system allows the top pressure to be gradually increased during drying without causing sticker marks. The influence of the pressure on the sticker marks by varying high specific loads and also the degree of spring-back in sticker marks and twisting, is described in a separate paper [6].

Control of drying quality

A drying quality control system has been developed to ensure the drying quality with respect to final moisture content, moisture variation and casehardening. The system consists of method recommendations and a simple spreadsheet program for handling and documenting measurements, both for batch-wise sampling and for continuous process control based on only 3-6 samples from each charge.

The system uses statistic quality control principles, calculates process limits from the measured input and compares these to tolerance limits for the product. This will help indicate whether the process is capable of producing the chosen product. The system is set up with the requirements for testing according to INSTA 141 and the proposed CEN-standard, but other standards, as well as special customer requirements, may also be entered.

Fig. 19 shows an example from one of the 18 sawmills that have tested the model. The dots represent averages for each batch, and the control limits represent the 99,7 % confidence interval for these observations. As long as the mean values for the observations are within the control limits, the process is under control. Similar control diagrams are included for standard deviation and casehardening.

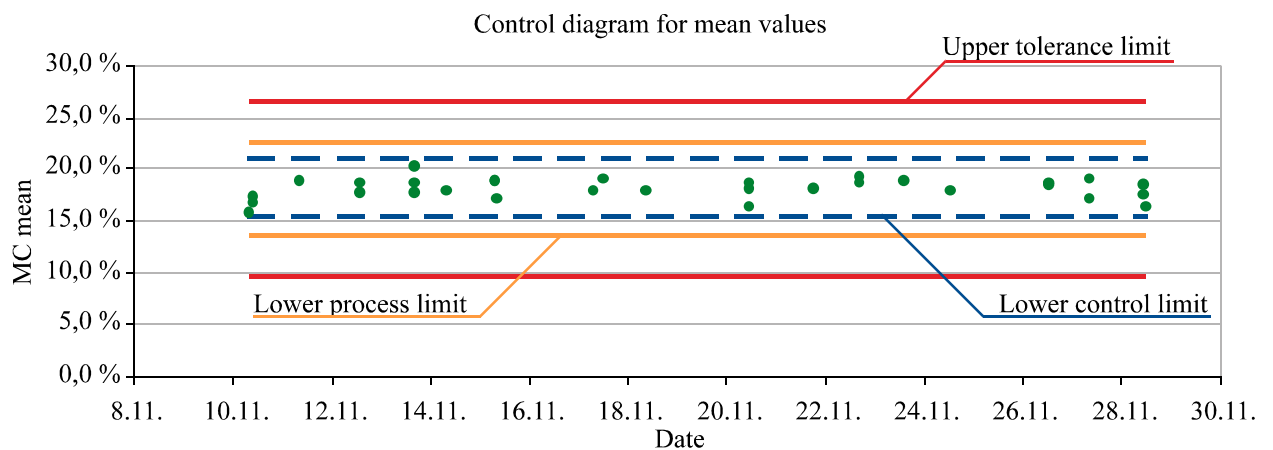


Fig. 19. Mean MC-values for drying batches compared to control, process and tolerance limits.

Conclusions

The strategy for raising the drying quality in the Norwegian sawmill industry, by a 3-stage program, has been successful.

- A broad state-of-the-art testing of the different drying qualities in the sawmill industry.
- Assessment of the results, comparison between requirements and standards and priority of actions to improve the quality.
- Actions and follow-up tests.

The initial testing of the degree of *checking* showed, as expected, great variation between the different sawmills, but the level of checking was in general low compared to the requirements in the Nordic grading rules. As the results were relative comfortable, no special research actions were taken. A reduction of the checking was still set as a goal, with focus on the reduction of end checks before drying and a general upgrading of the kiln operators on the knowledge of the principles behind the development and reduction of checks.

The comprehensive tests of the initial and final *moisture content* gave very interesting results and correlations. The standard deviations both in initial and final MC were clearly correlated to the mean MC, with very high standard deviations up to 50 % by high initial mean MC's. The stdv. in the final MC was in a way acceptable with almost 90 % following the INSTA 141 requirements. For the tests that were outside the standard, the main reason was a too large deviation from the target MC, which in general was a problem. The moisture gradients were in general low compared to the EDG-proposal. Actions through better equipment and knowledge about conditioning and equalising have led to a substantial reduction of the standard deviation in the end moisture content.

Due to insufficient spraying equipment, the initial tests of *casehardening* showed rather medium values, although the tests against INSTA was more than acceptable. However, this is due to rather low requirements in the standard.

Tested against the stricter EDG-proposal the casehardening level needed to be upgraded. Intensive research and upgrading of the kiln operators on the fundamentals of casehardening relief, combined with introduction of high-pressure spraying have had a very positive effect on the conditioning treatment in the sawmills.

The measurements of the different *deformations* in timber caused by the drying process, revealed need for actions to reduce the warp, especially twist. The positive effect of top loading was clearly demonstrated when correlating the twist against the load level. These tests in combination with laboratory tests have given basic data for necessary load levels to reach requested twisting levels. Several kilns have now installed pneumatic or concrete loads, with a substantial reduction in the warp as a result. Proposals for the design of compartment kilns with variable hydraulic top loads of high level have been discussed.

The action to improve the overall quality has for the time being ended up in a *drying quality control system* that is now adopted after comprehensive testing at the sawmills. With the ever stronger requirements from customers and standards, combined with stricter intake control, the need for a continuous follow-up of the drying quality at the sawmills will be of increasing importance.

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4. Increased yield by reduced cupping – Reflections and initial experiments of press drying

Knut Magnar Sandland and Sverre Tronstad

Abstract

The difference between radial and tangential shrinkage potential results in cupping deformations. To obtain a rectangular shape of the timber it is planed after drying, but the cup results in a considerable loss of volume. In conventional kiln drying the cupping is considerably reduced under the stickers due to the restraining effect, but this effect is almost ignorable between the stickers. To obtain a full cup reduction effect it is therefore necessary to use a system that is able to apply pressure over the entire length. It is thus of interest to discuss press drying as a method for reducing the cup.

The aim of this initial experiment is to study the influence of the pressure level on the rectangular yield of timber cross sections after drying. Two initial experiments were performed, at two different pressure levels.

The cross sectional shape of the press dried pieces differs principally from the unrestrained pieces. The yield is calculated for one set of pieces in each test. For the lowest pressure level, the rectangular yield is higher for the press loaded piece compared to the unrestrained reference piece. For the highest pressure level, the rectangular yield is lower for the press dried piece compared to the unrestrained reference piece.

The results indicates that it is possible to increase the yield of solid wood after drying and planing by using a suitable press. It has to be pointed out that very few test pieces were included in the experiments, and the statistical uncertainty in the given results is therefore high.

Introduction

When wood is dried to moisture contents below the fibre saturation point, various deformations occur in the timber. When considering deformations in the cross section of the timber, the difference between radial and tangential shrinkage potential results in the well known cupping deformation. For Scots pine (*Pinus silvestris*) and Norway spruce (*Picea abies*), the most used species in the Nordic countries, the radial shrinkage is approximately half of the shrinkage in the tangential direction, and respective shrinkage values of about 4 % and 8 % can be expected when drying the wood from green to absolute dry condition.

The amount of cup depends on the orientation of the annual rings in the cross section. The most common sawing pattern for Nordic pine and spruce is to take an almost square centre yield from the log that is further sawn into two or several planks, as shown in Fig. 1.

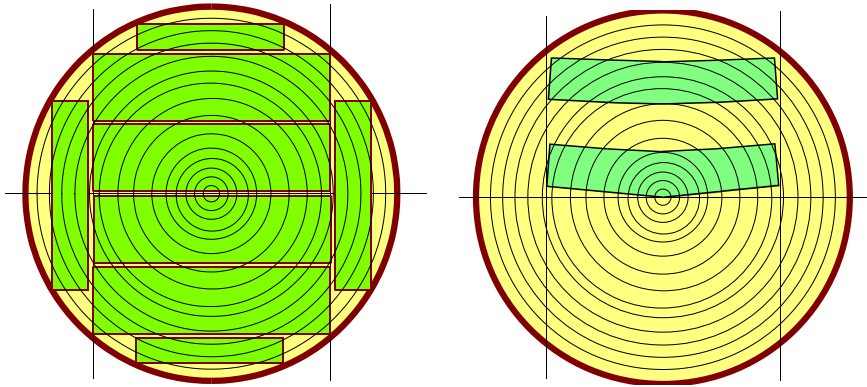


Fig. 1. Common sawing pattern for Nordic pine and spruce (left), and an example of the influence of annual ring orientation on the amount of cupping (right).

The amount of cup in the planks depends on the distance from the pith, plank thickness and width, moisture content and the degree of shrinkage anisotropy. Fig. 2 shows results from an investigation (Tronstad 1971), where the cup was measured in 50 mm thick planks of Norway spruce with various thickness and moisture content (the planks were taken near the pith, 2 x log, unrestrained during drying).

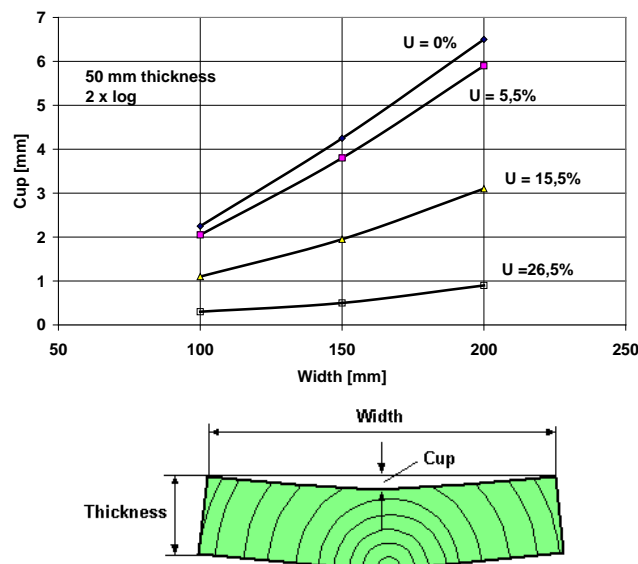


Fig. 2. The relation between cup, plank thickness and moisture content for planks of Norway spruce of 50 mm thickness (2 x log, unrestrained during drying) (Tronstad 1971).

To obtain a rectangular shape of the timber by planing after drying, the cup results in a considerable loss of volume. Fig. 3 shows results from an investigation (Tronstad 1971), where the volume loss is calculated for various plank widths and thicknesses at a moisture content of 15-16 % (Norway spruce).

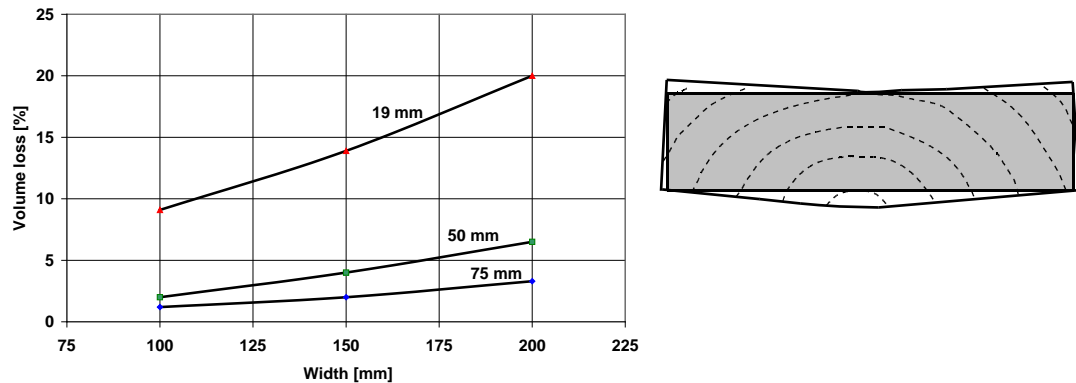


Fig. 3. Reduction in yield of timber of Norway spruce after planing caused by cupping, for various plank widths and thicknesses at a moisture content of 15-16 % (unrestrained during drying) (Tronstad 1971).

In ordinary kiln drying, the timber will be set under pressure through stickers, and the cup is therefore expected to be considerably reduced in the area under and near the stickers. The question is to what extent the cup is prevented between the stickers. In Fig. 4, some results are given concerning cupping under and between stickers with various load levels (Sandland & Tronstad 2001).

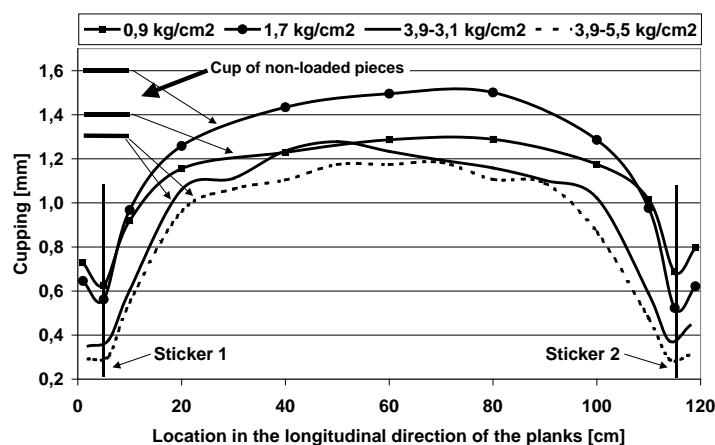


Fig. 4. Cup under and between stickers for different load levels (Norway spruce). The cup in the non-loaded pieces is indicated to the left at top of the diagram (Sandland & Tronstad 2001).

The figure shows that the cupping is considerably reduced under the stickers, and in a distance of 15-20 cm from the stickers, there is still an effect of the loading.

Halfway between the stickers, the cup in the loaded planks is, however, almost the same as in the non-loaded pieces.

These results indicate that it is difficult to obtain a reduced cup over the entire length of the timber by using stickers, because it requires an almost unrealistic small distance between each sticker, due to both practical and economic aspects.

To obtain a full cup reduction effect, it is necessary to use a system that can apply pressure over the entire length. It is therefore of interest to discuss press drying as a method for reducing cup. Press drying means that the planks will be under pressure in the entire length, which is favourable also in order to prevent other deformations such as bow and twist.

Press drying is a well known method, and several investigations are performed to describe various phenomena during the drying process. The press drying process prevents comprehensive deformations such as crook, bow and twist in the wood during drying (Simpson *et al.* 1988), as well as obtains a compression of the wood to change its mechanical properties to some extent. The press drying has also been combined with high temperatures in the press plates to obtain dimensional stability due to a heat treatment effect (Nakajima & Sugaya 1994). The temperature in the press plates will also influence the drying time, and various investigations have been performed to describe the relation between temperature, pressure and drying rates (Nakajima *et al.* 1994, Okoh 1984, Simpson & Tang 1990, Simpson *et al.* 1988). Press drying is also used in vacuum drying, where the press plates or microwaves transfer heat to the wood.

In most of the investigations concerning press drying, the pressure and temperatures are so high that the thickness of the timber is considerably reduced. The loss of thickness during the drying process decreases the yield, because larger green target thickness is necessary to obtain the desired thickness after drying. Tang & Simpson (1990) have made models to predict this loss of thickness for various temperatures and pressures.

The aim of this initial experiment is to study the influence of the pressure level on the rectangular yield of timber cross sections after drying.

Initial experiments

Based on the reflections given in the introduction, two initial experiments are performed to study the cross sectional shape of the timber after press drying. The number of test pieces is very low, and the uncertainty of the given results is therefore high. They, however, give some indications concerning the yield of timber after press drying.

Material and methods

Two tests at two different load levels were performed: 1,3 kg/cm² and 4,0 kg/cm². In each test, three planks with a green cross section dimension of 44 mm x 180 mm and a length of 30 cm were used. The planks were planed before drying and end coated with silicon to avoid drying in the longitudinal direction in the plank ends.

The planks were placed in a hot press for drying, and in both tests the plate temperature was adjusted to maintain a wood temperature of about 75-80 °C. The press was located in an ordinary indoor climate, with an air temperature and relative humidity of about 20-22 °C and 30-50 %, respectively. There was no forced air circulation around the test pieces.

The moisture content was measured by using electrodes (resistance meters) at two different depths in the wood (Fig. 5), at 1/3 of the plank thickness and in the centre (inserted from the edges of the planks). The moisture content before and after drying was also determined by the oven-dry method. In addition, the wood temperature was measured in the centre of one piece for each test run.

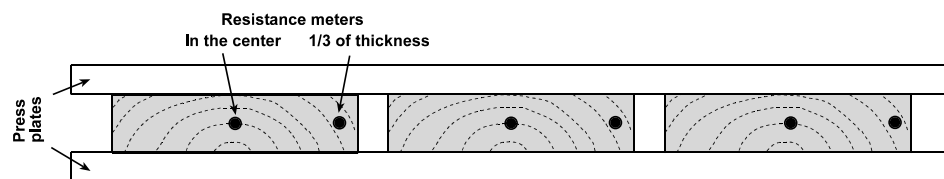


Fig. 5. Experimental setup for the press drying tests.

The dimensions of the planks were measured before and after drying, as shown in Fig. 6. The cup was measured after drying as shown in Fig. 2. The measurements of dimensions and cup were done on cross section slices of 15 mm thickness that were cut from the test planks. The measurements were performed immediately after drying and after 10 months in a climate of 20 °C and 65 % RH.

The casehardening was measured after drying by the 2-slice test method.

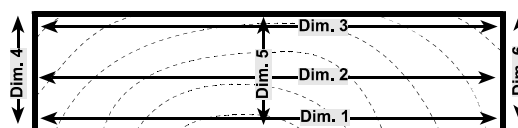


Fig. 6. Measurements of dimensions in the cross sections of the test pieces.

Results

Moisture content

The green mean moisture content for all test pieces was 86 %. The results of the measurements of the moisture content during drying by resistance meters are given in Fig. 7, together with moisture content after drying determined by the oven-dry method.

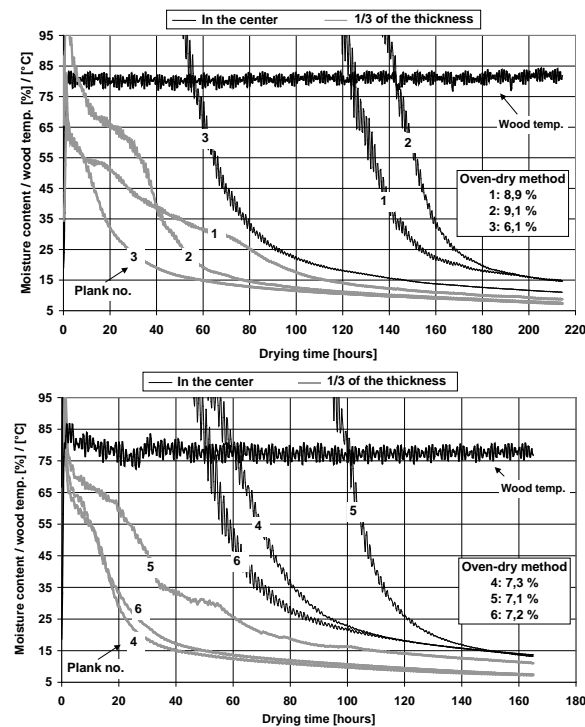


Fig. 7. Moisture content in two different depths of the wood during drying and the wood temperature. Upper: Low pressure level. Lower: High pressure level. The mean moisture content for the cross section pieces was determined by the oven-dry method after drying.

In a depth corresponding to $\frac{1}{3}$ of the plank thickness, the moisture decreases almost from the start of the drying, while in the centre, the moisture content is very high in a long period before it suddenly decreases rapidly. It is assumed that to a certain degree the amount of moisture transport through the edges is somewhat higher in press drying compared to conventional drying, which may have an influence on the moisture profiles.

Dimensions

The results of the measurements of plank widths are given in Fig. 8.

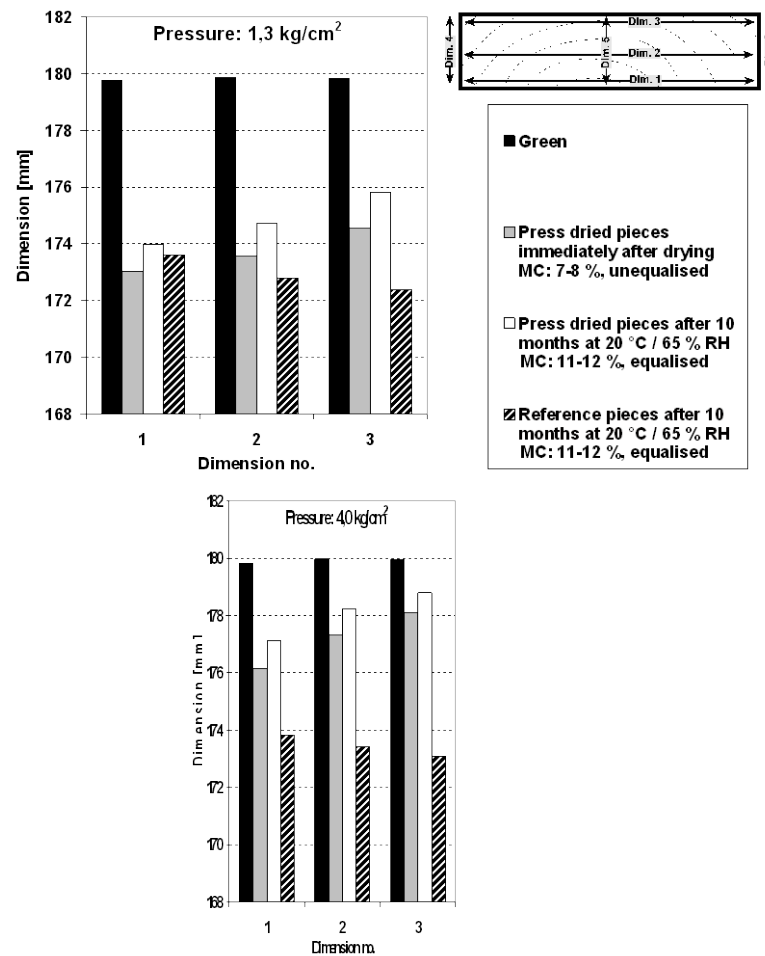


Fig. 8. Plank width at different conditions. Upper: Low pressure. Lower: High pressure. Mean values for the three pieces in each test.

When drying the planks unrestrained, like the reference pieces in Fig. 9, the width will be smaller at the bark side of the plank than at the pith side, due to the differences in tangential and radial shrinkage potential. For the press dried pieces, it is important to note that the opposite situation has occurred. The width at the bark side is observed to be greater than at the pith side (Fig. 9).



Fig. 9. For the press dried pieces, the width at the bark side is observed to be greater than at the pith side.

The difference between the press dried pieces and the reference pieces concerning the width, is therefore highest at the bark side and smallest at the pith side for both pressure levels.

Fig. 8 also shows that the width dimensions are greater for the high pressure level compared to the low pressure.

The increase in width of the loaded pieces during the 10 months storage period can be explained by the increase in moisture content (indicated in Fig. 8). A spring-back effect will work in the opposite direction, and the increase in moisture content is therefore the dominant effect in this period.

The results of the measurements of plank thickness are given in Fig. 10.

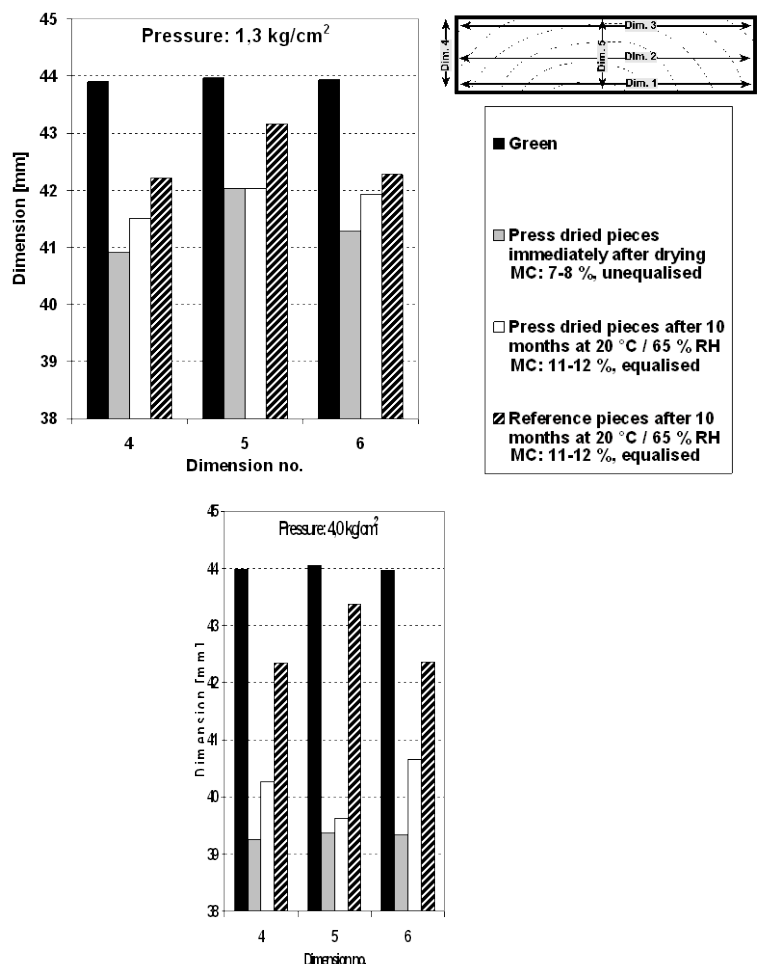


Fig. 10. Plank thickness at different conditions. Upper: Low pressure. Lower: High pressure. Mean values for the three pieces in each test.

When drying the planks unrestrained, like the reference pieces in Fig. 9, the thickness will be greater at the centre of the plank than at the edges due to the differences in tangential and radial shrinkage potential. This is also measured

on the lowest pressure level in the tests. For the highest pressure level the opposite situation has occurred after moisture equalising. The thickness at the centre is smaller than at the edges.

The thickness is, as expected, smaller for the high pressure level compared to the low pressure. The increase in thickness for the loaded pieces during the 10 months storage period can be explained by a combination of increased moisture content (indicated in Fig. 10) and a spring-back effect.

To explain the various shrinkage phenomena that are given above, pressure distribution at the planks during drying has to be considered. At start, the pieces are rectangular with smooth surfaces, and the pressure will be the same over the entire plank, as shown in Fig. 11.

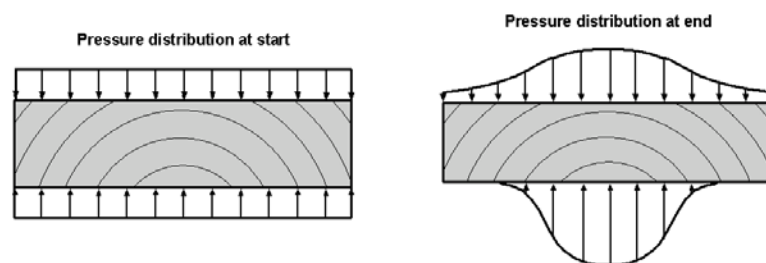


Fig. 11. Indicated pressure distribution in the cross section of the planks at start and at end of drying.

When the drying starts, the thickness shrinkage near the edges will be higher than at the centre, both due to the lower moisture content near the edges and the higher shrinkage potential in the wood (considerable influence of tangential shrinkage).

The planks have also a potential for development of normal cup. The forces when restraining the cup during drying will be highest near the edges of the bark side and at the centre of the pith side (if the planks are sawn symmetrically around the pith).

These two aspects will together result in an expected pressure distribution at the end of drying as shown in Fig. 11. This assumption is verified by observations and measurements of compression caused by grid plates placed between the timber and the press plates. This pressure distribution will give a restrained shrinkage over the entire bark side during the whole drying process. On the pith side, the pressure will gradually be concentrated towards the centre part of the width.

This explains why the width of the bark side is higher than of the pith side after drying and moisture equalising, as the friction between the press plates and the wood has restrained the shrinkage more at the bark side, with a higher amount of creep in the wood as a result.

Cupping

The results of the measurements of cupping are given in Table 1.

Table 1. Cupping (in mm), given as simple values for each plank in the two tests, both for the pith side and bark side of the planks (reference pieces have been unrestrained during drying).

	Pressure: 1,3 kg/cm ²			Pressure: 4,0 kg/cm ²		
	Immediately after drying			Immediately after drying		
Press dried pieces	Plank. no.	Bark side	Pith side	Plank. no.	Bark side	Pith side
	1	-0,3	-0,6	4	0,5	-
	2	0,7	-1,4	5	0,7	-
	3	-0,1	-1,0	6	-0,3	-
	After 10 months at 20 °C / 65 % RH			After 10 months at 20 °C / 65 % RH		
	Plank. no.	Bark side	Pith side	Plank. no.	Bark side	Pith side
Reference	1	-1,3	1,1	4	1,5	-0,5
	2	1,6	-1,7	5	1,7	-0,4
	3	-0,6	0,1	6	-0,3	1,2
	After 10 months at 20 °C / 65 % RH			After 10 months at 20 °C / 65 % RH		
	Plank. no.	Bark side	Pith side	Plank. no.	Bark side	Pith side
	1	1,3	-2,2	4	0,8	-1,8
	2	2,4	-3,1	5	1,9	-2,8
	3	2,2	-3,0	6	2,1	-3,1

Negative sign = convex cupping, otherwise: concave cupping

For unrestrained planks, the cup is concave at the bark side and convex at the pith side. Table 1 shows, however, that several press dried pieces have the opposite pattern, i.e. concave cupping at the pith side and convex cupping at the bark side.

A probable explanation of this can be attributed to the pressure distribution shown in Fig. 11, and the fact that the bark side of the planks are restrained to a higher degree than the pith side during drying, with higher amount of creep in the wood as a result.

The measurements indicate that the lowest pressure level is sufficient to obtain the desirable effect concerning cup reduction.

Yield

The most important aspect of the tests is to study whether it is possible to increase the yield of solid wood after planing by restraining the cup during drying. Fig. 12 shows one pair of test pieces, one press dried piece and the unrestrained reference piece, from each of the tests to illustrate the influence of cross section shape on the yield of solid wood after drying and planing. In each cross section picture, a rectangle that represent the possible yield of solid wood after planing is drawn in.

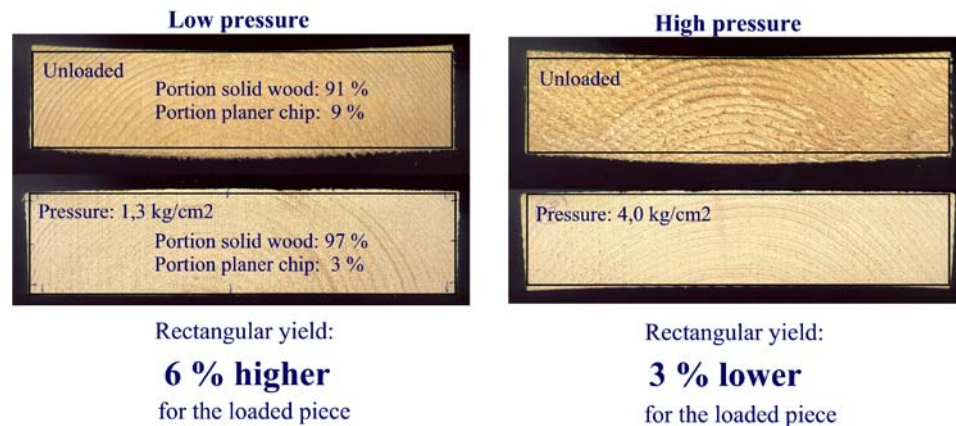


Fig. 12. Example of the influence of cross section shape concerning the yield of solid wood after drying and planing (moisture content level: about 11 %).

From the figure it can be seen that for the lowest pressure level, the rectangular yield is 6 % higher for the press loaded piece compared to the unrestrained reference piece. The percentage of usable timber will therefore increase, with a corresponding decrease in the amount of planer chips.

For the highest pressure level, the pressure has been too high, and the rectangular yield is lower for the press dried piece compared to the unrestrained reference piece. This is due to the considerable reduction of the plank thickness at this pressure.

It has to be pointed out that the calculations shown in Fig. 12 are done just for one set of test pieces, with the uncertainty it represents due to statistical validation. It indicates, however, that it should be a potential for increasing the rectangular yield of solid wood by press drying. Further tests are, however, necessary to detect optimal pressure level.

Casehardening

The results of the casehardening measurements are given in Table 2.

Table 2. Casehardening (gap over a length of 100 mm by the 2-slice test) given as simple values for each plank in the two tests.

		Plank no.	Gap [mm]
Pressure [kg/cm ²]	1,3	1	1,2
		2	1,9
		3	1,1
	4,0	4	0,9
		5	0,6
		6	0,7

The registered casehardening can be explained both due to a moisture gradient and mechanical restraining caused by the friction between wood and press plates.

Discussion and conclusions

The aim of this initial experiment was to study the influence of the pressure level on the rectangular yield of timber cross sections after drying. Two initial experiments were performed, at two different pressure levels. The temperature level was the same in both tests.

After drying, the cross sectional shape of the press dried pieces differs principally from the unrestrained pieces. The width at the bark side is larger than at the pith side, and the thickness is smaller and the width is larger for the press dried pieces. For several press dried pieces, the cup is in the opposite direction compared to the unrestrained pieces.

The rectangular yield is calculated for one set of pieces in each test. For the lowest pressure level, the rectangular yield is higher for the press loaded piece compared to the unrestrained reference piece. The percentage of usable wood will therefore be higher for the press dried planks, with a corresponding decrease in the portion of planer chip. For the highest pressure level, the pressure has been too high, and the rectangular yield is lower for the press dried piece compared to the unrestrained reference piece. This is due to of the considerable reduction of the plank thickness.

The results indicates that it is possible to increase the yield of solid wood after drying and planing by using a suitable press.

It has to be pointed out that very few test pieces were included in the experiments, and the statistical uncertainty in the given results is therefore high. They give, however, an indication of the possibilities to use press drying as a method for increasing the yield of solid timber by reducing the cup deformations.

Further research is necessary to determine the optimal pressure level with a higher degree of confidence. It is also of interest to vary the temperature level, which will influence both the optimal pressure level and the drying time. The influence of thickness variations within and between planks due to inaccuracy in the sawing process is also of interest to investigate.

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5. Dynamic top loading

Dynamic top loading

Part of Straight WP 2.2

Sverre Tronstad



Treteknisk 

Project Research Goals

- **Main goal:**
To find the influence of package loading on the degree of deformations of timber during drying
- **Other goals:**
Influence of the loading on the stickers marks
- *Influence of sticker distance on the degree of deformations*
- *Correlation between fibre angle and twist*

The results will hopefully give design basis for commercial systems to reduce deformations

Treteknisk 

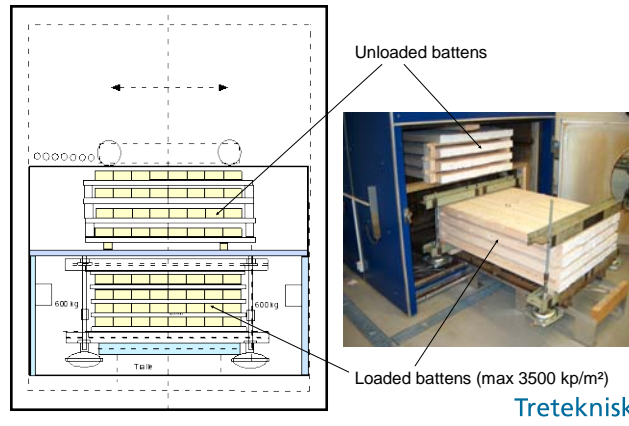
Participants in the workpackage WP 2.2 (top loading)

- **NTI (coord.) - dynamic top loading- normal temperatures**
- **BFH - constant loading - oscillating climate**
- **BRE - constant loading - normal temperatures**
- **VTT - constant loading - high and normal temperatures**

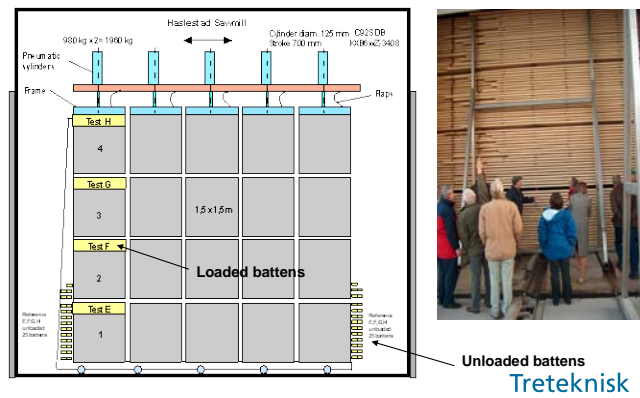
In this short presentation, only results from the dynamic top loading tests will be presented

Treteknisk 

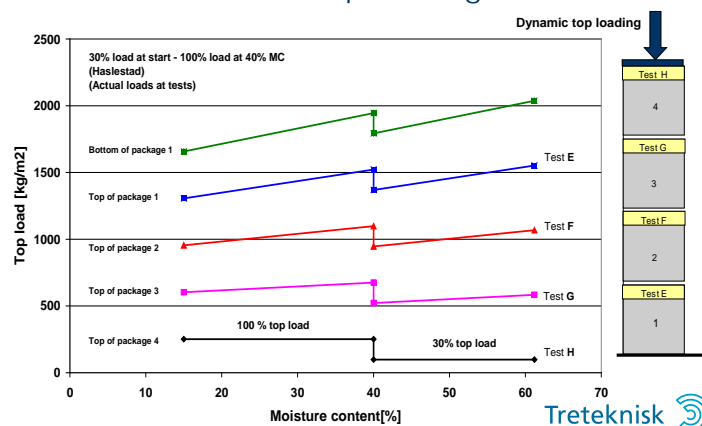
Kiln design and test arrangement in laboratory kiln at NTI (50x100 mm spruce)



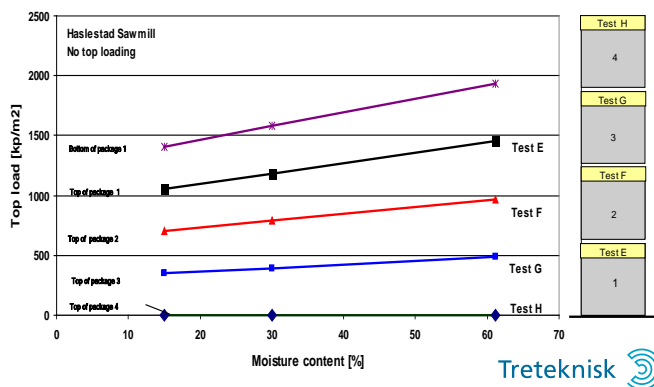
Kiln and test arrangement at Haslestad Sawmill, Norway (50x100 mm spruce)



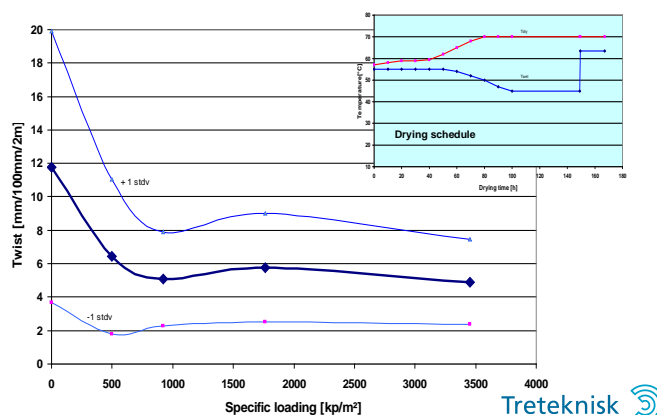
The specific package loading is dependant on the MC, the position in the kiln and the top loading



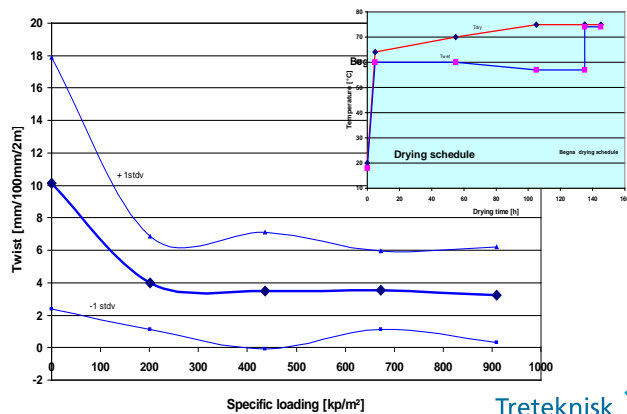
Specific package load without top loading



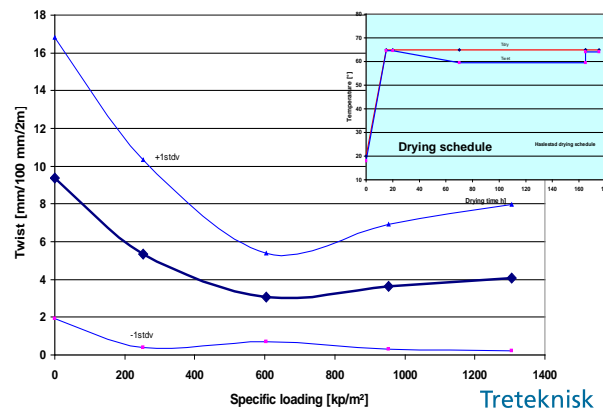
Twist - specific package loading (NTI lab. kiln)



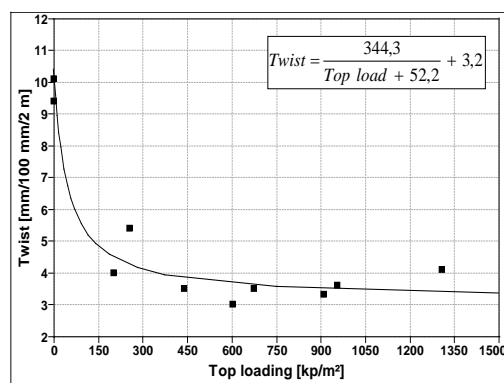
Twist - specific package loading (Begna Sawmill)



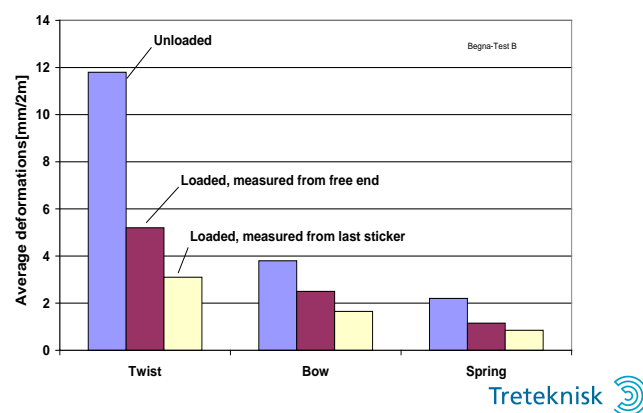
Twist - specific package loading (Haslestad Sawmill)



Average twist as function of top loading, based on the eight industrial tests



Bow and spring is also considerably influenced by the top loading

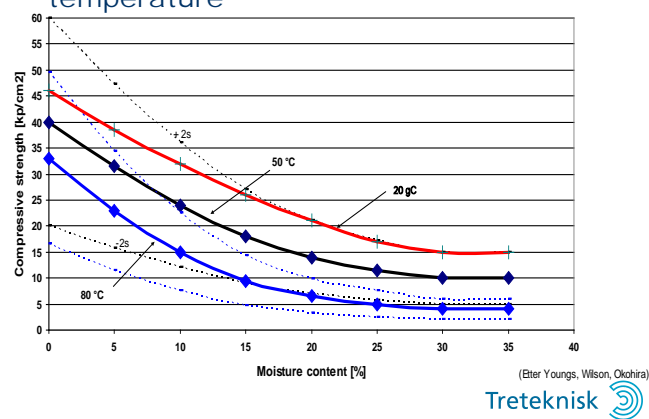


Which package do you want to buy
(or sell)?



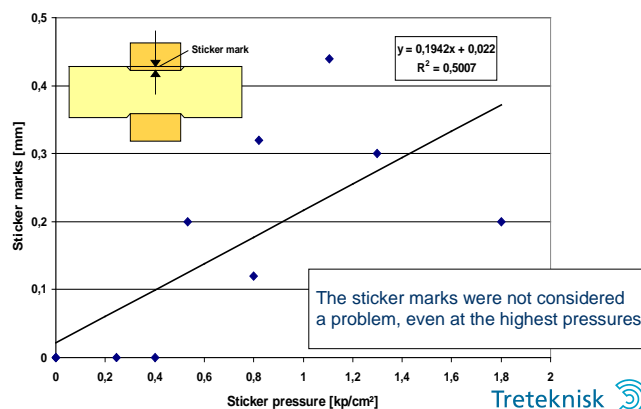
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The compression strength of wood depends on moisture content and temperature



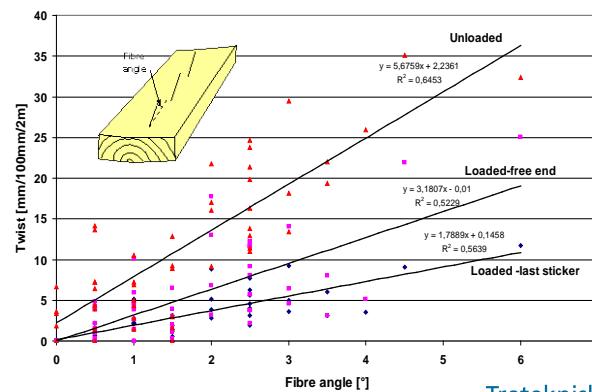
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Sticker marks as function of specific sticker pressure (industrial kilns)

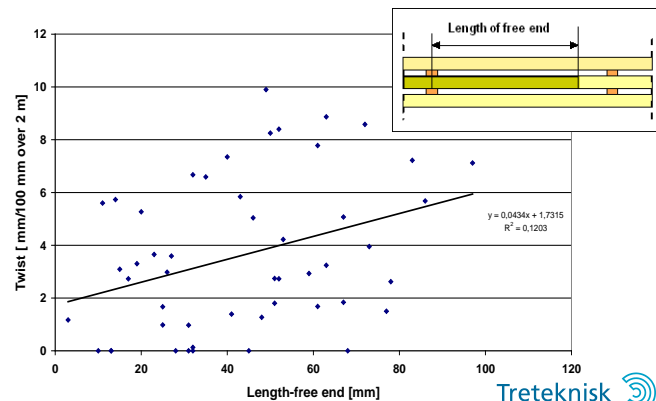


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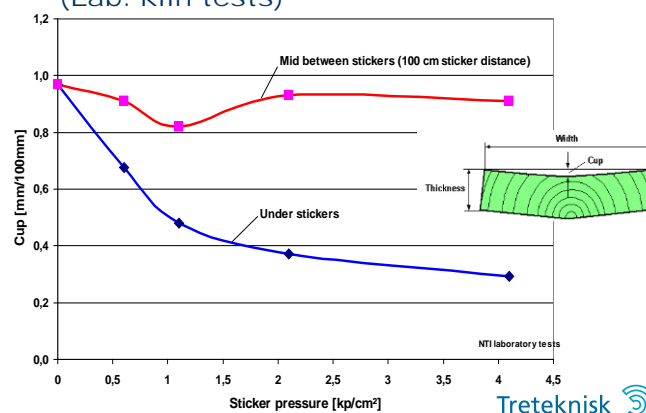
The fibre angle is the main cause of twisting



The sticker distance has a considerable influence on the twist (data from one test)

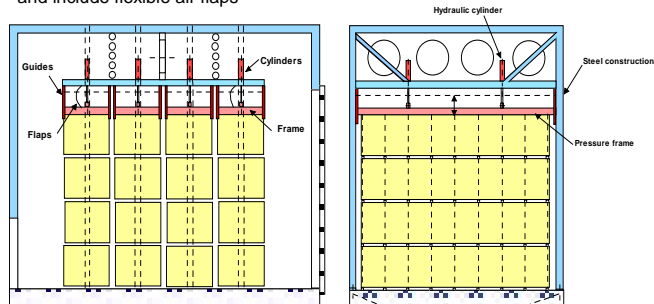


Cup under stickers is greatly influenced by the sticker pressure (Lab. kiln tests)



New kilns with dynamic top loading should be especially designed to take up the extra loads

The top loading equipment must withstand tilting forces and include flexible air flaps



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Conclusions

- Top loading leads to a considerable reduction in all deformations – 500-600 kp/m² seems sufficient
- The sticker distance has a great influence on the deformations. Short distances or equal timber lengths in the kiln is recommended
- The fibre angle is the main cause of twisting
- Sticker (pressure) marks seems to be a minor problem with the top loadings used
- Cupping is reduced to 1/3 under stickers by the loading, but negligible between stickers



Top loading reduces all deformations.
Dynamic loading also hinders package vault
and air leakage above the packages and
eliminates extra handling
RECOMMENDED!

Treteknisk 

6. Various wood properties influencing the development of checks in knots during drying

Kjersti Folvik and Knut Magnar Sandland

Abstract

Wood from Norway spruce (*Picea abies*) is very well suited for constructive purposes, but in many cases it is also desirable to process it into added value products, such as wood panelling for indoor use and other interior wood products. A considerable problem with using wood from Norway spruce in these products is the extent of checks and damages in the knots after drying and planing, which will result in a lower surface quality.

The aim of the present work has been to determine the effect of some of the fundamental wood properties on the occurrence of checks in knots during drying.

To uncover the effect of the difference in shrinkage between knot wood and the enclosing stem, half of the knots in the material were released from the surrounding wood and dried individually. The other half was dried enclosed in plank sections. All the knots were photographed before and after drying. There were obvious qualitative differences in the extent of checking.

An important property is the equilibrium moisture content (EMC) of the material. The aim of these experiments was therefore to determine the difference in EMC of the knots compared to that of the stem wood material. The EMC at 25 °C was measured for 20 released knots and 20 pieces of the corresponding stem wood, spread across three different climates with various relative humidity. Both the desorption and adsorption EMCs were determined. The results showed a lower EMC for knots than for the surrounding wood.

Introduction

Norway spruce (*Picea abies*) is an important species in the production of various wood products. The wood is very well suited for constructive purposes, but in many cases it is also desirable to process it into added value products, such as wood panelling for indoor use and other interior wood products, due to its light and homogenous visual impression. Besides, the resin content is low, which is preferable for surface treatments. A considerable problem using wood from Norway spruce in these products is the extent of checks and damages in the knots after drying and planing, which results in a lower surface quality. In general, knots in wood have a high risk of checking during drying, because the cross sectional shrinkage in the knots acts in the transverse direction of the small longitudinal shrinkage in wood. However, the knots of Scots pine (*Pinus sylvestris*)

are much easier to dry and plane without high amounts of checks and damages than Norway spruce. A reasonable explanation for this is that knots of Scots pine shrink less than knots of Norway spruce during drying. A study by Boutelje (1966) shows that the knots of Norway spruce shrink considerably more than knots of Scots pine, and that the shrinkage variations within the knots are much higher in Norway spruce than Scots pine, with higher internal stresses and check risk as a result.

Previous work (Folvik and Sandland 2003) has shown that it is possible to influence the severity of knot checking by varying the drying schedule, with low drying rate and high temperature as the most important factors.

The aim of the present work was to study some of the basic properties that might influence the occurrence of checks in knots during drying. It is expected that the orientation of the knots perpendicular to the stem wood is a very important factor. To determine the effect of tension due to differences in shrinkage, some knots were separated from the planks and dried individually. A second property that is expected to influence the checking is the EMC of the knot compared to that of the wood. To determine any differences in EMC, released knots were placed in three different climates along with the corresponding wood samples.

Material and methods

Drying of released knots

Ten different planks were used in this experiment. Two knots from each plank were selected; one was released from the surrounding wood and the other was left enclosed. The samples were divided in two and dried in the laboratory kiln following the drying schedules shown in Fig. 1 and 2. The first schedule is a conventional drying schedule with moderate temperature level and drying rate. The second schedule has a constant dry bulb temperature at 80 °C and the drying time is half of drying schedule one. The circumference of the knots were sealed with silicone rubber to simulate the knot's enclosure in the wood, and thus restrict drying to the end face of the knots. The ends of the wood samples were also sealed to avoid end effects. The samples were photographed before and after drying to detect any differences in checking between the released and the enclosed knots. The evaluation was performed as qualitative analysis based on visual impressions.

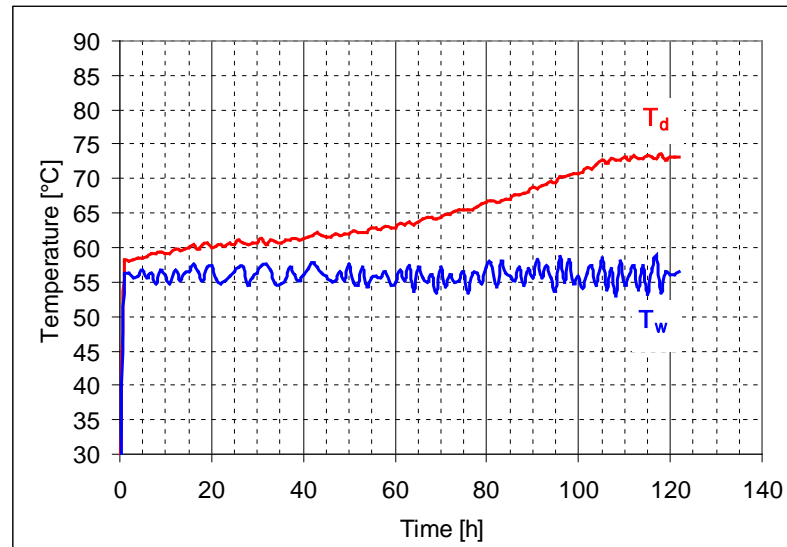


Fig. 1. Drying schedule 1.

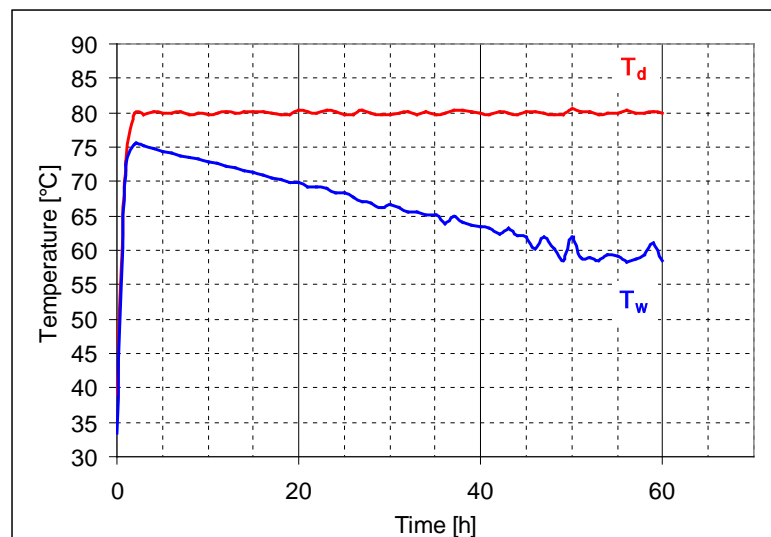


Fig. 2. Drying schedule 2.

Equilibrium moisture content

Twenty knots, four knots from each of five different planks, were selected for this experiment. The knots were all released from the wood. Samples of the surrounding stem wood of all the knots were also prepared. A picture of the samples can be seen in Fig. 3.

The samples (in green condition) were soaked in water for two days and then placed in a climate chamber at 25 °C in three different relative humidities until they reached the equilibrium moisture content (EMC). This would be the desorption EMC. The climates were established by using three different saturated

salt solutions as described in table 1. There were eight samples in climate 1 and four samples in climates 2 and 3 respectively.

Table 1. Saturated salt solutions and the corresponding relative humidities.

Climate no.	Salt	Relative humidity
1	Magnesium Chloride	$33,1 \pm 0,2$
2	Sodium Chloride	$75,5 \pm 0,2$
3	Potassium Sulfate	$97,6 \pm 0,6$

After reaching equilibrium, the samples were taken out and weighed. They were then placed over silica gel (at 20 °C), to be dried to a low moisture content. After drying, the same material was placed in the same three climates as before to determine the adsorption EMC and the hysteresis.

The oven-dry method was used to determine the moisture content in the material.



Fig. 3. Knot and wood samples for the EMC-experiments.

Results

Drying of released knots

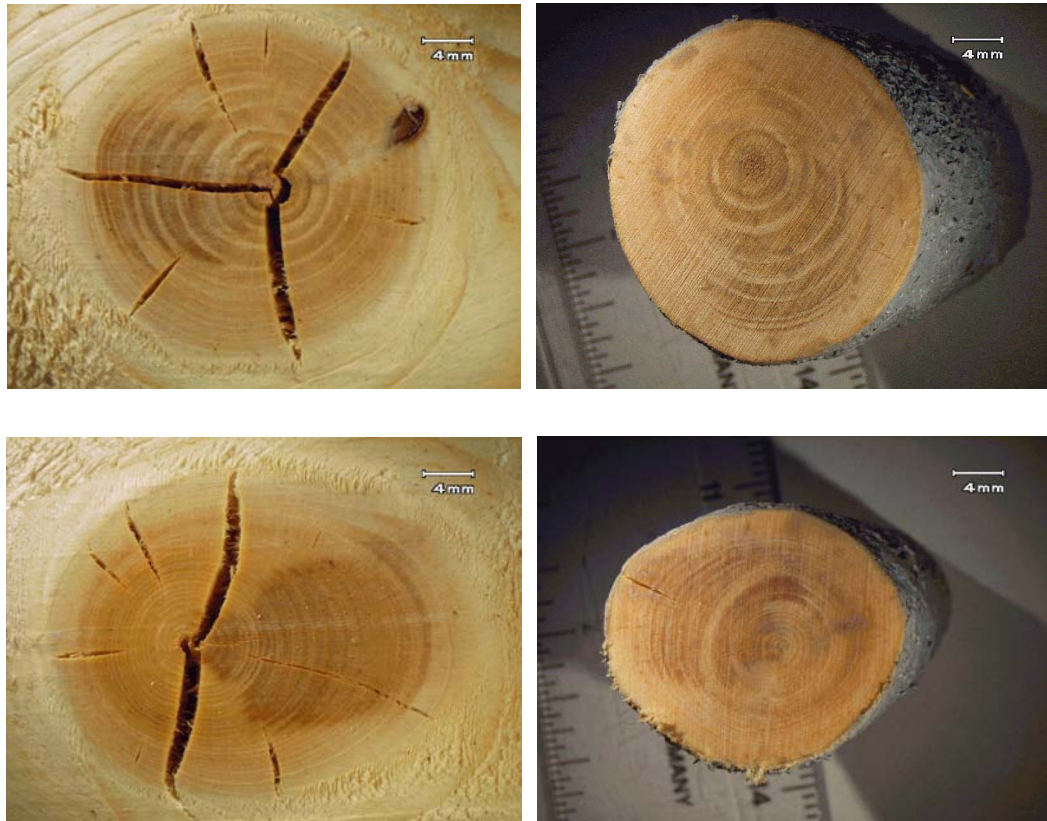


Fig. 4. Examples of knots dried according to drying schedule 1. The ones enclosed in the wood are seen to the left, and those released to the right.

There were obvious qualitative differences between the released knots and the ones enclosed in the wood. The enclosed knots were checked as usual with the dominating check perpendicular to the direction of the fibres. The released knots, on the other hand, were just barely checked at all, and the ones that were, were checked from the surface towards the pith, as can be seen for round timber. Some examples are shown in Fig. 4 and 5.

There were some slight differences between the two drying schedules, as might be expected according to the results of previous experiments (Folvik and Sandland 2003). The checks in the material dried at the highest temperature seemed to have the smallest checks, as can be seen in Fig. 5.

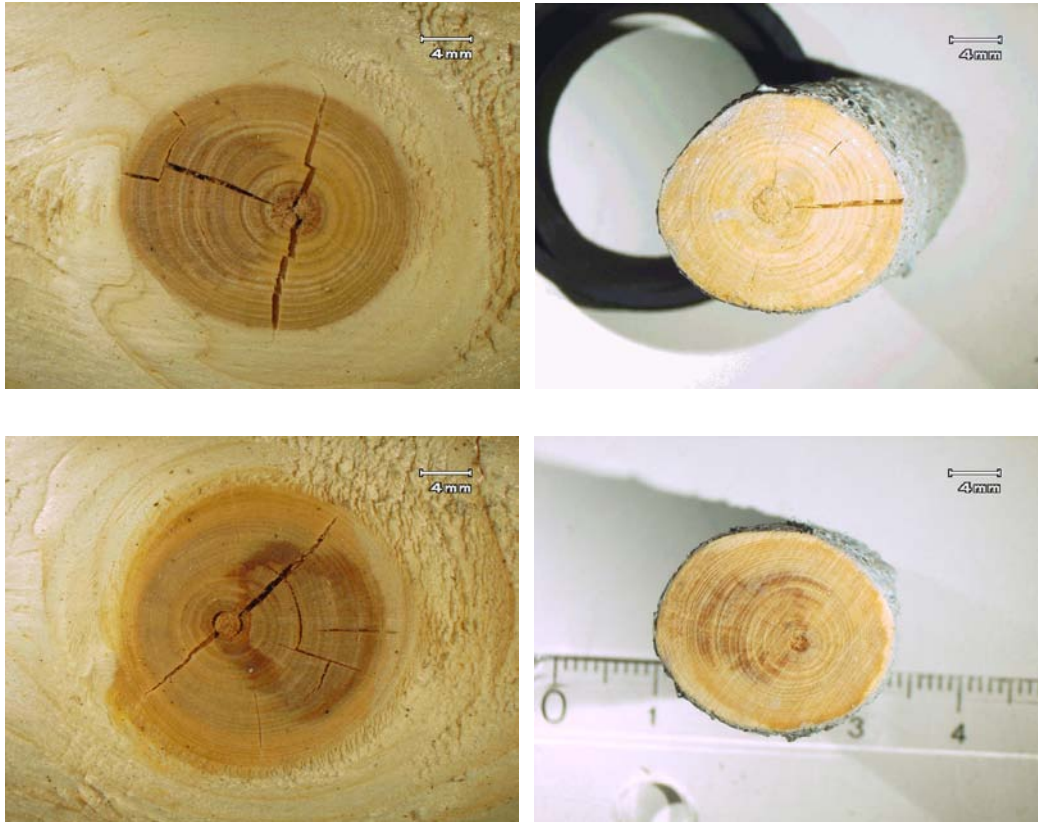


Fig. 5. Examples of knots dried according to drying schedule 2. The ones enclosed in the wood are seen to the left, and those released to the right.

Equilibrium moisture content

These experiments showed that EMC of the knots was somewhat lower than that of the surrounding wood, as can be seen in Table 2 and Fig. 6.

Table 2. Equilibrium moisture content of knots and stem wood at certain relative humidities (mean values of the eight observations in climate 1 and the four in climates 2 and 3).

Salt	RH	Knot		Stem wood	
		desorption	adsorption	desorption	adsorption
Magnesium Chloride	33,1 %	7,3 %	5,6 %	8,1 %	6,7 %
Sodium Chloride	75,5 %	15,4 %	12,6 %	17,7 %	14,5 %
Potassium Sulfate	97,6 %	23,1 %	21,6 %	27,7 %	25,4 %

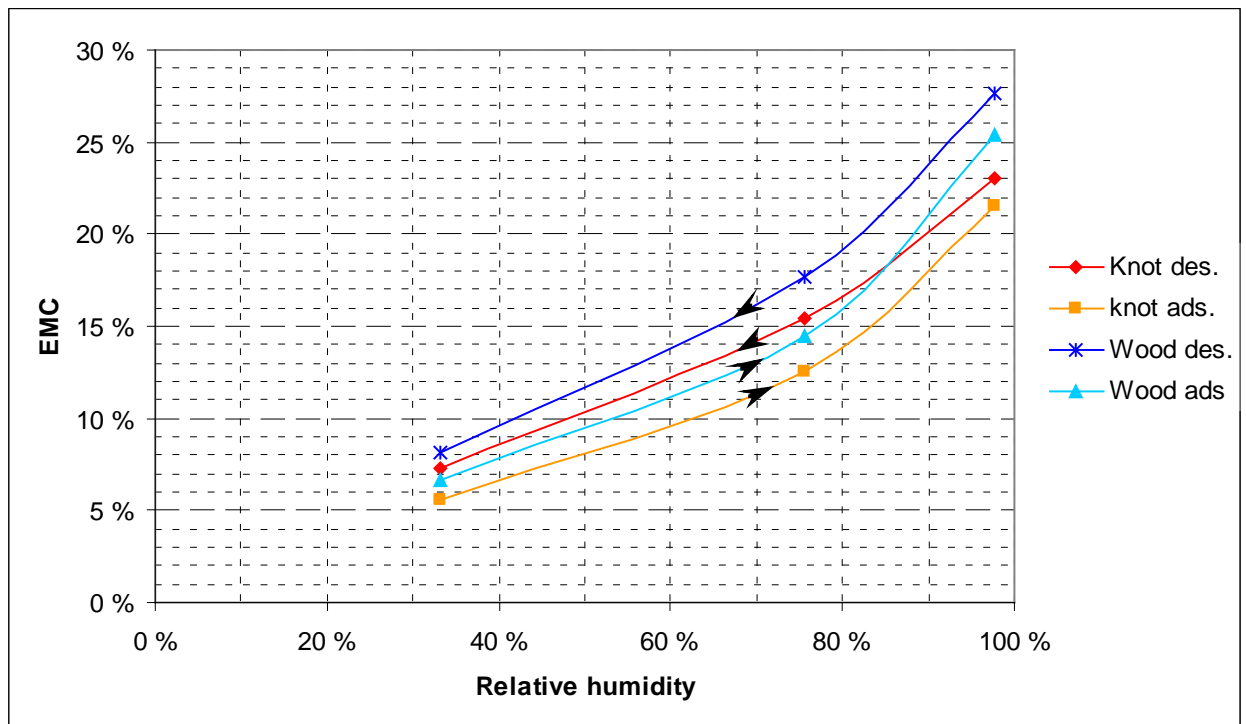


Fig. 6. Equilibrium moisture content of knots and stem wood. Both desorption and adsorption curves are shown.

Discussion and conclusions

The drying of released knots proved that the difference in shrinkage in the longitudinal direction of the stem wood and the radial direction of the knot has major influence on the checking of knots. The radial shrinkage in the knots is considerably higher than the longitudinal shrinkage of the stem wood. The knot will therefore in most cases check due to the great tension induced by shrinkage of the knot. This explains the dominant check perpendicular to the wood fibre direction. The results of these experiments are only qualitative observations, but the pictures show obvious differences.

The enclosed knot samples dried at the higher temperature showed a slightly smaller amount of checking. This corresponds with the results from previous studies (Folvik and Sandland 2003), and is explained by the increased plasticity at higher temperatures.

The knot material showed a lower EMC than the surrounding wood. This is most likely explained by the higher density of the knot, and that the wood substance is somewhat different in the knots compared to the stem. The lower EMC will cause the knot to dry more than the adjacent wood material and therefore further increase the check risk.

It is important to note that these are all preliminary experiments. The sample size is not satisfactory to draw positive conclusions. The trends, however, are quite clear, but will need further verification to establish more sure results.

Acknowledgements

The project is performed in cooperation with the sawmill company Moelven Soknabruket AS. The planing mill Bjertnæs Sag AS has participated in some parts of the investigations. The work is financed by The Research Council of Norway.

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7. Quality control in kiln drying

Håkon Toverød and Sverre Tronstad

Abstract

In order to meet the timber moisture requirements as specified in standards and contracts, a tightly controlled kiln drying process is necessary. This is especially important at lower moisture contents where the requirements may be quite stringent. The Norwegian Drying Club developed and tested a quality control scheme for kiln drying in 2000. The system uses a spreadsheet to log and present results, and the control work was kept at a minimum by using few observations for each kiln charge. Stable results were found even at as low as three observations per charge. The initial process control limits are calculated based on 30 observations and may be compared to tolerance limits from the selected product standard. The control system keeps the inspection work at a minimum and at the same time secures the stability of the drying processes.

Developing the process control scheme

1999 to 2000, the Norwegian Drying Club developed and tested a quality control scheme for kiln drying. The goal of the system was to ensure that the kiln drying processes were delivering a consistent moisture content well within the requirements specified in standards and contracts. The first attempt in 1999 was a quality control system using 30 observations per kiln charge to determine moisture content using the electric resistance method. The sample size amounted to a full inspection for batches according to INSTA 141. This system was tested by several sawmills in the Kiln Drying Club. For several reasons, it did not work.

- The work load was too high for the kiln operator and resulted in excessive costs.
- Charge to charge variations were not systematically recorded, giving no indication of the process variability over time.
- The electric resistance method was too inaccurate for low moisture contents, where the requirements in standards normally are stringent.

Based on these experiences, we repeated the task in 2000 with a number of changes.

- The number of measurement points per charge was reduced from 30 to 3-6.
- All charges were inspected and the history of charges recorded.
- The oven-dry method was preferred for lower moisture contents.

The system consisted of inspection procedures and a spreadsheet program for calculating, presenting and storing results. This also contained tolerance limits according to relevant standards and moisture classes, allowing the user to test if processes were capable of delivering products with the required moisture content.

Measuring method

No observation technique is totally accurate. It is associated with an uncertainty that can be expressed as a systematic bias, which is the average deviation between observed result and its true value: \bar{U} , and a standard deviation, S_U . Calibrated and adjusted instruments have the effect of minimizing the bias, but the variation, which is caused by several components of uncertainty, remains and has the effect of expanding the variability observed.

prEN 14 298 allows using the electrical resistance method for measuring moisture content, but at the same time specifies the oven-dry method as a reference method to be used in case of dispute.

The difference between the two methods has been a subject for several studies. Forsén & Tarvainen (2000) tested a broad range of hand held wood moisture content meters. The tests were conducted on well conditioned materials and compared to the “true” moisture content determined by the oven-dry method. This test was referred to as “laboratory conditions”. Another test was done on unconditioned materials and referred to as “industrial conditions”, although the measurements were done under comparable conditions to the laboratory case. From table 8 in the study we picked out a few results as shown in Table 1.

Table 1. Confidence intervals for MC-meters. Species: Nordic pine and spruce. MC-level 9-17 % for laboratory conditions and 7-25 % for industrial conditions.

Confidence intervals for MC-meters, Nordic pine and spruce	Resistance moisture meter				Capacitance moisture meters			
	Laboratory conditions		Industrial conditions		Laboratory conditions		Industrial conditions	
	95 % conf. interval % units	Average reading-true	95 % conf. interval % units	Average reading-true	95 % conf. interval % units	Average reading-true	95 % conf. interval % units	Average reading-true
Most accurate	±1,2	0,7	±1,7	-1	±2,5	-0,5	±1,6	-3,7
Least accurate	±2,1	-1,3	±4,5	2	±4,2	0,3	±4,7	-2,8
Mean	±1,7	-0,3	±3,1	0,5	±3,4	-0,1	±3,2	-3,25
Uncertainty= S_U	0,84		1,58		1,71		1,61	

The uncertainty of the instrument is the standard deviation of the measurement variation, in this case half the confidence interval divided by 1,96. The observed standard deviation when measuring samples from a lot, is going to be a combination of the true standard deviation in the material, and the uncertainty of the measurement method:

$$S_{obs} = \sqrt{S_{mc}^2 + S_U^2} \quad (1)$$

For example: If the true standard deviation in the moisture content is 1,4 %, the uncertainty of the instrument is 1,58, and we are going to observe a standard deviation of 2,1. It must be noted that the result was obtained in laboratory conditions where the inaccuracy of the oven-dry method may be considered negligible.

In true industry conditions, when the sampling and measurements are done by kiln operators, we introduce another element of uncertainty in the measurements. In a Kiln Drying Club study, a number of mills reported MC-data obtained by resistance meters and the oven-dry method. A few of them actually observed higher standard deviations using the oven-dry method than with the resistance method. This is contrary to the expectation, as the variation contributed by the method itself is much larger for the resistance method. What happened was that the observer contributed to the observed variation in addition to method- and the MC-variation. The most common causes for inaccurate results using the oven-dry method were:

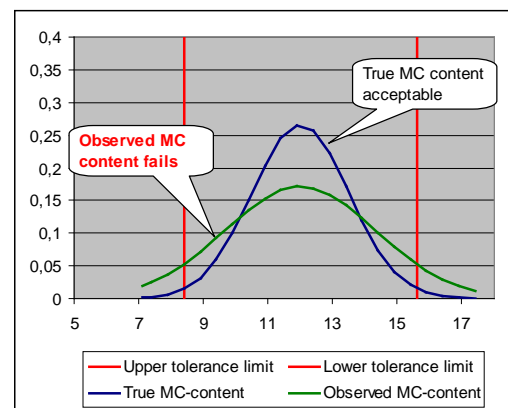
- Inaccurate scale and rounding off errors when reading scale.
- Too long time from cutting to weighing samples.

The oven-dry method is dependent on care in every detail in order to give accurate results. Under real industrial conditions, its uncertainty is no longer negligible. Table 2 shows the data with the obviously faulty observations removed. The difference between the two methods is calculated in terms of mean value and standard deviation. The results are roughly in agreement with Forsén & Tarvainen. It can be concluded that given correct use and careful implementation, the oven-dry method will give significantly less variation in observed values than the resistance method, even in industrial conditions.

Table 2. Measuring methods compared under industrial conditions.

Mill	Oven-dry method		Resistance method		Difference	
	MC _{mean}	S _{mc}	MC _{mean}	S _{mc}	Mean	Stdv.
A	16,4	1,4	17,3	1,8	0,9	1,1
A	15,0	1,1	16,3	1,6	1,3	1,2
B	18,0	0,6	20,1	1,7	2,1	1,6
B	11,7	0,7	10,9	1,7	-0,7	1,6
C	17,5	0,6	18,2	0,8	0,6	0,5
C	19,2	0,5	19,8	0,6	0,6	0,4
D	16,3	0,6	18,2	1,2	1,9	1,1
E	16,7	0,3	17,6	0,6	0,9	0,5
E	17,1	1,0	18,1	1,1	0,9	0,4
F	16,2	0,8	17,0	1,1	0,8	0,7
G	17,8	1,4	20,2	1,7	2,5	0,9
H	11,5	0,7	12,5	1,3	1,0	1,1
I	15,9	1,1	18,7	1,2	2,7	0,4
Mean					1,2	0,9
Standard deviation					0,9	0,4

The inaccuracy for moisture meters may result in the situation illustrated on the left. Here, a kiln charge has a true MC-content that satisfies the requirements in prEN 14 298 as indicated by the tolerance limits. When the moisture content is observed using a resistance meter with a standard deviation in measurement accuracy of 1,8 % however, this is impossible to prove, resulting in erroneously discarding the charge. For an instrument to be acceptable in general terms, its uncertainty variation must be less than 20 % of the parameter variation. None of the instruments in the VTT-study meet this requirement.



We can now solve formula 1) with respect to true moisture content. For observed standard deviation we insert maximum allowed standard deviation from prEN 14 298 which is $0,3 \cdot \sigma_{tar} / 1,85$. The uncertainties of measurements are listed in Table 1. We calculate the remaining maximum allowed true variation in moisture content:

$$S_{mc} = \sqrt{0,162^2 \cdot \sigma_{tar}^2 - S_U^2}. \text{ The result is shown in Table 2.}$$

Table 3. Allowable true standard deviation in moisture content according to prEN 14 298 when the measurement method has a significant influence on the observed variation.

MC-class U_{tar}	prEN 14 298			Allowable true variation S_{obs}			
	Tolerance		Max. variation	Resistance		Capacitance	
	LTL	UTL	S_{max}	Lab	Industry	Lab	Industry
From table 1: $S_u \rightarrow$				0,84	1,58	1,71	1,61
7	3,5	10,5	1,16	0,80	-	-	-
8	4,0	12,0	1,32	1,02	-	-	-
9	4,5	13,5	1,49	1,23	-	-	-
10	5,0	15,0	1,66	1,43	0,49	-	0,39
11	5,5	16,5	1,82	1,62	0,91	0,63	0,85
12	6,0	18,0	1,99	1,80	1,20	1,01	1,16
13	6,5	19,5	2,15	1,98	1,46	1,31	1,43
14	7,0	21,0	2,32	2,16	1,70	1,56	1,67
15	7,5	22,5	2,48	2,34	1,92	1,80	1,89
16	8,1	23,9	2,65	2,51	2,13	2,02	2,10
17	8,6	25,4	2,81	2,69	2,33	2,24	2,31
18	9,1	26,9	2,98	2,86	2,53	2,44	2,51

Instruments with uncertainty of measurements (S_u) in excess of 50 % of the allowed maximum variation (S_{max}) should not be used for quality control purposes, as the variation of the instrument will mask process variability. We recommend that the oven-dry method is used throughout.

Control chart

Control charts were adapted from *The Quality Toolbox*, Nancy R Tague (1995). A couple of definitions are in order:

- Observation: A measurement value from a specimen drawn randomly from a kiln charge.
- Sample: A collection of observations from one kiln charge (= Spot test).
- Sample size: Number of observations in each sample.
- Sample mean: The mean value of all observations in the sample.
- Sample range: The absolute difference between maximum and minimum observation.

The control chart is used to analyze process variation over time. By comparing data to historically determined control limits, we can determine if the process is stable (under control) or being affected by special causes for variation (out of control). There are several types of control charts designed for specific kinds of process data. For our control scheme we chose the \bar{X} and R charts, where \bar{X} is sample mean and R is the sample range. This method is appropriate when:

- Process data are measured on a continuous scale.
- Process data are not necessarily normally distributed.
- We want to detect small process changes.
- Data are generated frequently.
- In discrete manufacturing, where a sample of four or five observations may be used to represent production of several hundred or thousand pieces.

Sample size

The \bar{X} - R charts do not require normally distributed observations, but they do require that the sample means are normally distributed for our statistics to be valid. The sample size (n) is chosen as large as necessary for the sample means to become normally distributed. We can do this by collecting at least 3n samples and check if the sample means form a normal distribution using the normal probability plot or the Kolmogorov-Smirnov test. If data are not normally distributed, the sample size must be increased. (A normal probability plot is a comparison between a histogram for the mean values and the normal frequency distribution for the same data).

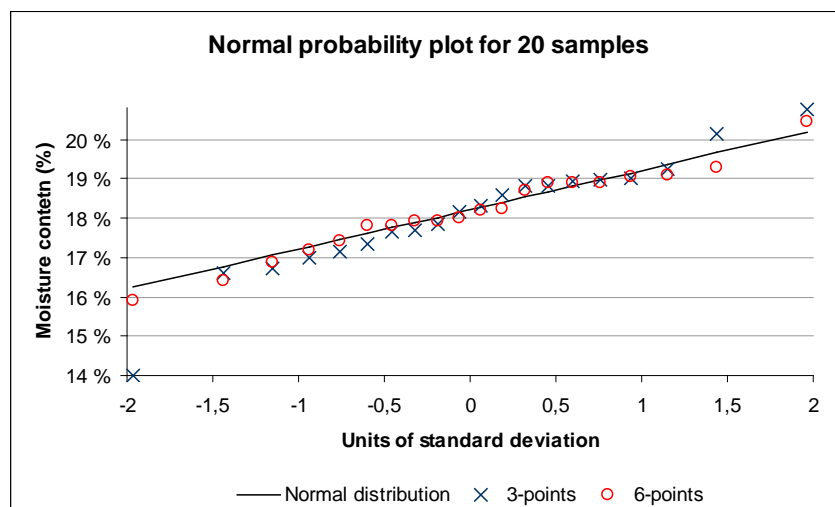


Fig. 1. Normal probability plot for sample means for a sample size of 3 (blue) and 6 (red).

Taken from a random data set of quality control data, the normal probability plots above show that even for 3 observations in each sample, the mean values approach a normal distribution. For six samples per subgroup, there is no doubt. As might be expected, for kiln drying, relatively small samples will do, as the moisture content tends to be normally distributed. On this basis, we expect that a sample size of three will be sufficient for tightly controlled processes.

Sampling frequency

The really large variations in drying quality is caused by break downs and abnormal behaviour in the production processes. In a kiln, this could be

substantial change in input moisture content, power failure, control system break downs or lack of fuel to the boiler to mention some. An important task of the quality control is to capture abnormal variations as they occur, securing that appropriate actions will be taken to avoid delivery of timber with wrong quality.

Since kiln drying is a long process, the probability of sporadic failures is relatively high. For this reason, it is good practice to sample all kiln charges rather than only a few of them. (For continuous kilns, sample once a day).

Constructing the control chart

When starting a new control chart, we need to collect 20-25 samples before we can calculate the control limits. In kiln drying, that could mean months of production before the chart is established. In the mean time, use a so-called Run-chart, which is the control chart without control limits. Use this time to reduce variation and to centre the process around the target moisture content. For each sample of size n , calculate \bar{X} and R and plot in the diagram together with the target moisture content.

Control limits are calculated from the first 20 samples. Calculate: $\bar{\bar{X}}$ = average of averages and \bar{R} = average of ranges. Estimate $3\hat{\sigma} = A_2 \bar{R}$ where A_2 is dependent on sample size.

Table 4. Statistical factors for calculating the \bar{X} - R-charts (99,7 % confidence).

N	2	3	4	5	6	7
A_2	1,880	1,023	0,729	0,577	0,483	0,419
D_3	-	-	-	-	-	0,076
D_4	3,267	2,574	2,282	2,114	2,004	1,924

Table 5. Formulas for control limits in the \bar{X} - R-charts.

Control limits	Upper	Lower
\bar{X} chart	$UCL_{\bar{X}} = \bar{\bar{X}} + 3\hat{\sigma}$	$LCL_{\bar{X}} = \bar{\bar{X}} - 3\hat{\sigma}$
R chart	$UCL_R = D_4 \times \bar{R}$	$LCL_R = D_3 \times \bar{R}$

If the process is out of control when the limits are calculated, bring it under control and recalculate control limits when it has been stable and under control for 20 samples. Control limits are not to be recalculated on a regular basis. Only when the process has changed, and the change is thoroughly understood, the control limits may be recalculated.

Considerations for implementation

One product dried in one particular kiln to one specification may be controlled using one chart. This would lead to as many control charts as there are products x

specifications x kiln types, and most of them would never contain sufficient data to establish control limits. In reality it is not quite that complicated. Unless the kilns are significantly different, several kilns may be considered to give statistically similar results, and consequently they can be treated as one process. Furthermore, products of the same species and thickness behave similarly in the kiln and can be treated as one product.

It is necessary to analyze products and processes in order to decide how many different processes we need to control, and then establish control charts for each of them.

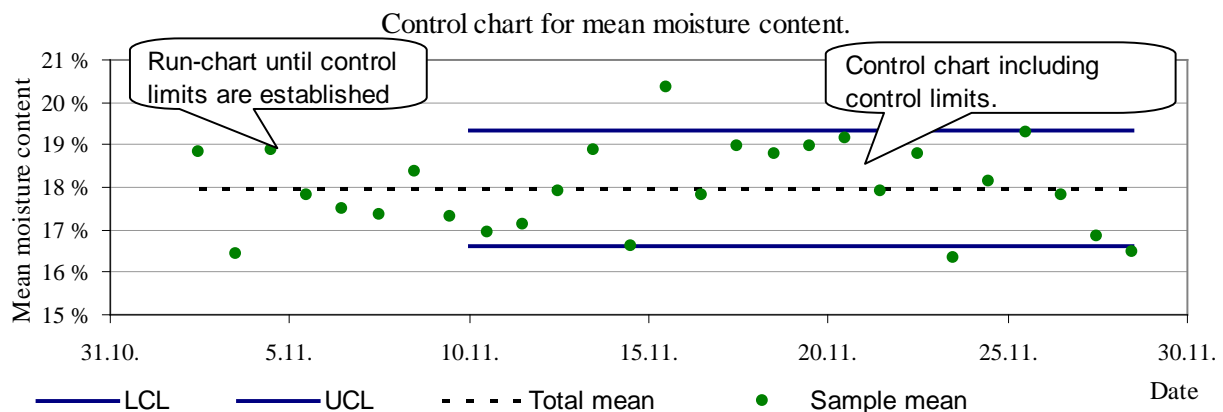


Fig. 2. A control chart for mean values. Here 38 mm spruce dried to 18 % MC.

Fig. 2 shows an example of a control chart being established. Until 20 samples have been collected, it is used as a Run-chart for the first 20 samples. After that time, control limits are calculated for the \bar{X} control chart. The chart must be continuously monitored and analyzed in order to tell if the process is under control. The example shows a few points (14, 22 and 27) outside of the control limits. That means the process is out of statistical control. This is normal after establishing a new control chart. Bring the process under control by adjusting the process, and if this is not possible, recalculate the process limits. When the process is under statistical control, we are able to predict its future outcome. Otherwise, we can only tell its historical performance.

In the chart, point 14 is well outside the process limits, marking a charge that might be affected by some unexpected variation. The corresponding kiln charge should be examined closer.

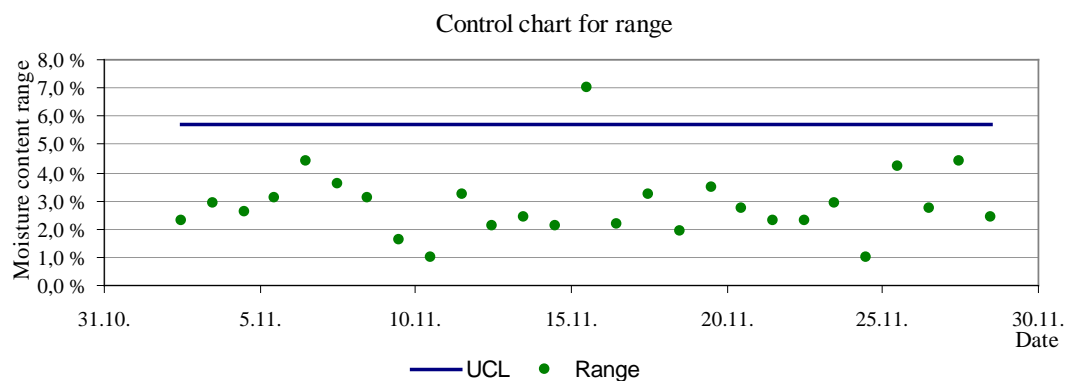


Fig. 3. Control chart for range. Spruce 38 mm, 18 % MC.

For kiln drying, a one-sided control limit for the range is used. The chart above shows the control limit and the sample ranges as points in time. Over all, the range is well below the limit for all points, except point 14, which is also out of control in the mean chart. This information is used to single out charge 14 for inspection and possible further processing. High mean value and large variation could for instance indicate premature ending of the drying program, loss of energy input, wrong drying program or a number of other causes. The benefit of the quality control is that it allows us to isolate such problems as they occur.

Tolerance limits

The purpose of the control chart is to determine if a process is under control. I.e., if its outcome is predictable. The next question is to determine if it is also able to produce a marketable product. In general terms, our customer expects the product to be “suitable for use”, nothing less. This broad concept is normally broken down into a product specification, which typically consists of tolerance limits and assessment procedures for attributes that characterize the functionality of the product. Such specifications are stated in contracts, which often refer to a standard. Let us take a look at the new drying quality standard prEN 14 298, to see how we can test if our process is capable of delivering products that meet its requirements.

prEN 14 298, Sawn timber – Assessment of drying quality

The standard defines a number of target moisture classes in the range from 7 to 18 % called target moisture content ω_{tar} . For each class, an allowable range of the average moisture content ω_m around the target is given. In addition, tolerance limits for individual pieces are given as $\omega_{tar} \pm 0,3 \times \omega_{tar}$ at the 93,5 % confidence level.

Table 6. Moisture classes and tolerance limits given according to prEN 14 298.

Target moisture content, U_{tar} %.	Allowable range of average moisture content around target moisture content %.	Lower limit for individual pieces: $0,7 U_{tar}$	Upper limit for individual pieces: $1,3 U_{tar}$
7	-1/ +1	4,9	9,1
8	-1/ +1	5,6	10,4
9	-1/ +1	6,3	11,7
10	-1,5/ +1,5	7	13
11	-1,5/ +1,5	7,7	14,3
12	-1,5/ +1,5	8,4	15,6
13	-2,0/ +1,5	9,1	16,9
14	-2,0/ +1,5	9,8	18,2
15	-2,0/ +1,5	10,5	19,5
16	-2,5/ +2,0	11,2	20,8
17	-2,5/ +2,0	11,9	22,1
18	-2,5/ +2,0	12,6	23,4

The assessment of drying quality is done on a per lot basis, sampled according to ENV 12 169, with the exception that pieces from the outer layers (top, bottom and sides) shall not be included, and that "the moisture content shall be estimated according to EN 13 183-2 (Electrical resistance method). In case of dispute, EN 13 183-1 (Oven-dry method) shall be used."

To check if our drying process is able to deliver a product that meets the requirements, the process control limits are tested against the tolerance limits of the specification.

Calculating tolerance limits from prEN 14 298

Extracting tolerance limits from prEN 14 298 is relatively straight forward, as they are already given for individual pieces at the 93,5 % confidence level. In our quality control scheme, we have chosen to use the 99,7 % confidence level, corresponding to $\pm 3S$ (S = standard deviation); so we need to recalculate.

prEN 14 298 is unusual in that tolerance limits are given for mean as well as for individual pieces. The values can be taken directly from Table 6. In the standard, the individual control limits are given at the 93,5 % confidence level, while we need them at the $3S = 99,7$ confidence level. The 93,5 % confidence level corresponds to $1,85 \times S$. Our tolerance limits for individual pieces becomes: $TL_i = \omega_{tar} \pm 0,3 \times 3 / 1,85 \times \omega_{tar} = \omega_{tar} \pm 0,49 \omega_{tar}$. Our control limits are calculated based on mean values, and before we can compare them to tolerances given for averages, we need to multiply the control offset with \sqrt{n} (n =sample size).

Mathematically this is equivalent to dividing tolerance offset with \sqrt{n} . Our tolerance limits then become:

$$UTL_{\bar{X}} = \bar{\omega}_{tar} + \frac{0,49}{\sqrt{n}} \bar{\omega}_{tar} \text{ and } LTL_{\bar{X}} = \bar{\omega}_{tar} - \frac{0,49}{\sqrt{n}} \bar{\omega}_{tar}$$

The tolerance limit for the range is calculated in the same manner as: $UTL_R = \frac{\bar{R}}{\sqrt{n}}$

Before we use the given tolerance limits in prEn 12 298 as yet another set of tolerances, let us see if they are really necessary at all. Assuming that MC-observations are normally distributed, we can calculate the confidence limits for the mean values based on the tolerance limits for individuals. The confidence limits for the mean is calculated by:

$$\bar{\omega}_m - t_{\alpha/2, N} \cdot \frac{s}{\sqrt{N-1}} < \mu < \bar{\omega}_m + t_{\alpha/2, N} \cdot \frac{s}{\sqrt{N-1}}$$

where

$\bar{\omega}_m$ = observation mean

s = observation standard deviation

N = number of observations

$t_{\alpha/2, N}$ = the critical value in a Students T-distribution at probability level $\alpha/2$

N-1 = degrees of freedom

$\alpha/2 = (1-\text{Confidence level})/2$

We estimate the maximum standard deviation as $S_{\max} = (UTL_i - LTL_i)/6$ and calculate the lower and upper limit for the mean at the 99,7 % confidence level. (See Fig. 4). Our sample size is 3, and we use at least 20 sample groups to calculate the control limits. We get $(3-1)*20-1=39$ degrees of freedom. It is clearly visible in the diagram, that when the individual pieces are within tolerances, the mean values are always within tolerances as well. This simplifies our control scheme, as we only need to take into account the individual tolerances in the standard.

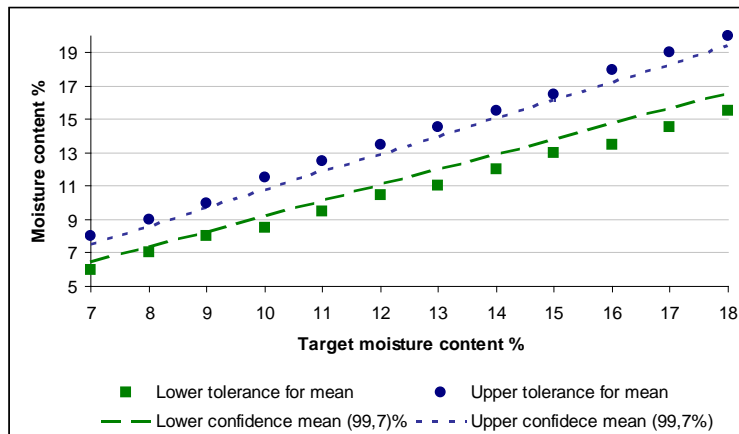


Fig. 4. 99,9 % confidence limits for the mean value when the individual pieces are within tolerance limits in prEn 14 298 at sample size 60.

Fig. 5 shows our control chart with the tolerance limits from prEN 14 298 added. The control limits are well within tolerances, and nicely centered. However, the process is at the moment out of control, so all we can say, is that the historical performances are within tolerances. As soon as the process is brought under statistical control, we will be able to predict its future outcome with reasonable certainty.

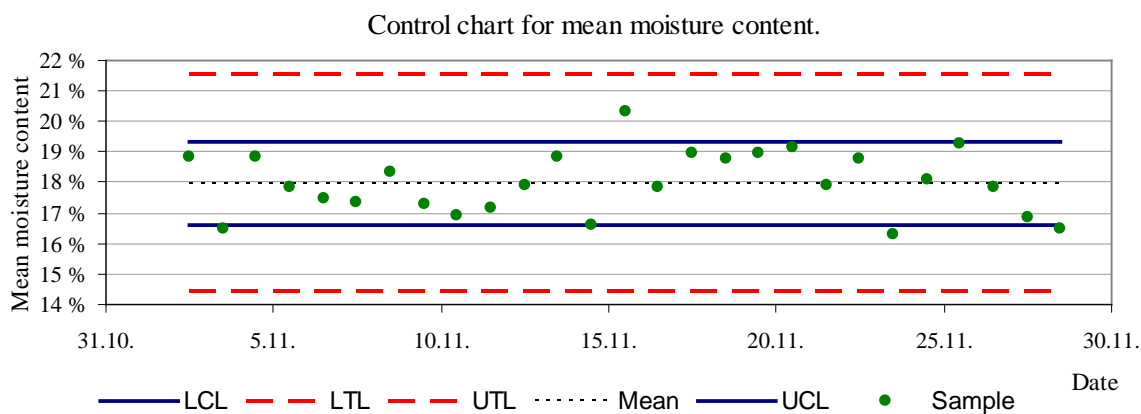


Fig. 5. The control chart with the tolerance limits for prEN 14 298 added.

Conclusions

In this paper we have discussed some experiences from developing and implementing statistical quality control for kiln drying in the Norwegian Kiln Drying Club. The system, more or less in its initial form, is in use by a number of mills.

- The inaccuracy contribution from measurement is a significant contribution to the total variance in moisture content data when electric resistance and capacitance moisture meters are used. For quality control purposes, the measuring uncertainty of the instruments should never exceed 50 % of true variation in moisture content. Even then, a 70 % increase in variation may be observed.
- We recommend using the oven-dry method for quality control. However, care must be taken to its implementation and execution in order to reduce measurement error.
- Due to the fact that moisture content data are normally distributed, a sample size of three observations or more may be used to determine if the process is under control. However, larger sample sizes (4-6), yield better control in the shape of tighter control limits and better sensitivity to change.
- A high sampling frequency should be used. Every charge should be sampled in compartment kilns. Once a day for continuous kilns.
- The common \bar{X} -R charts were used, as they are easy to implement and understand.
- One chart only covers processes that can all be said to belong to the same statistical population. For kiln drying, grouping products according to species thickness and target moisture content level, is mandatory. Kilns of different makes and models can be considered to be one process only if they behave similarly in statistical terms.
- Setting tolerance limits from prEN 12 498, only individual piece tolerances need to be considered. The requirements for mean values are fulfilled with 99,7 % confidence when the individual pieces are within tolerances.

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Teague, N. R. 1995. The Quality Toolbox, 1995, ISBN 0-87389-314-X.

Forsén, H. & Tarvainen, V. 2000. Accuracy and functionality of hand held wood moisture content meters, VTT 2000, ISBN 951-38-5581-3.

prEN 14 298. Sawn timber – Assessment of drying quality.

prENV 12 169. Criteria for the assessment of conformity of a lot of sawn timber.

8. After drying service

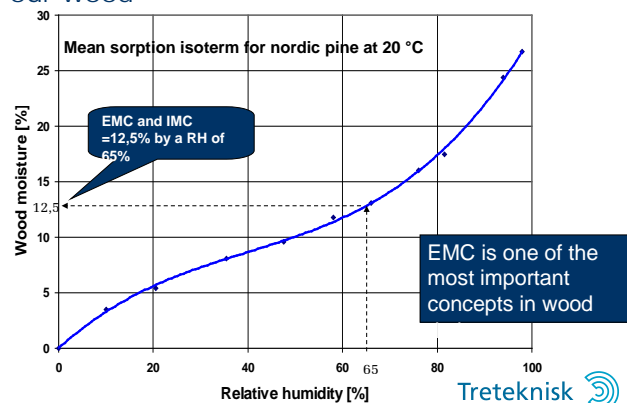


Discussion themes

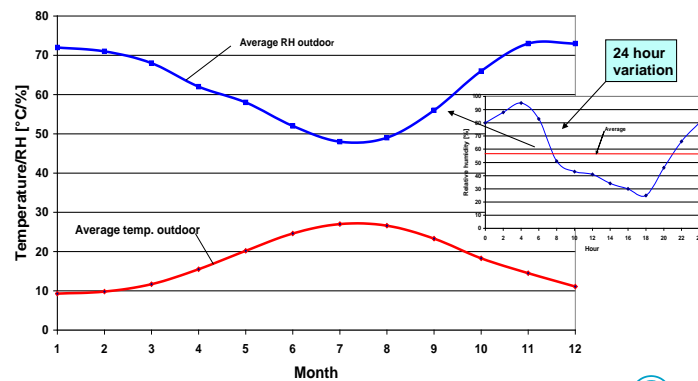
1. Which wood moisture content is the ideal for different end use purposes ?
2. How to keep the ideal wood moisture content in the chain from kiln to end purpose.
3. Shortly about how to avoid rewetting of the timber in use.

Treteknisk

As a basis for all discussions about ideal end use moisture content (IMC), we must know the equilibrium moisture content (EMC) curves for our wood

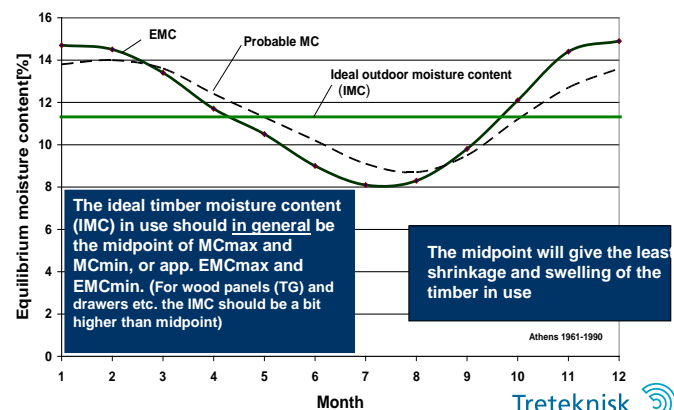


The outdoor RH and temp. will normally vary considerably over the year (Athens 1961-1990)



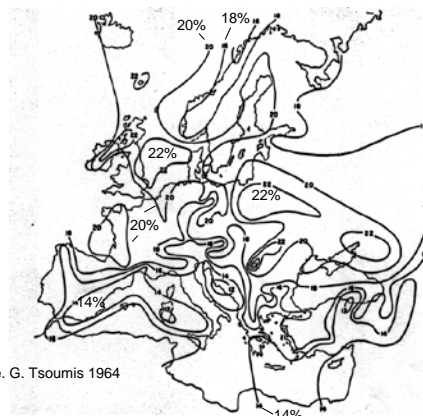
Treteknisk

Corresponding variation in the EMC for wood in the Athens region (1961-1990) and ideal outdoor MC



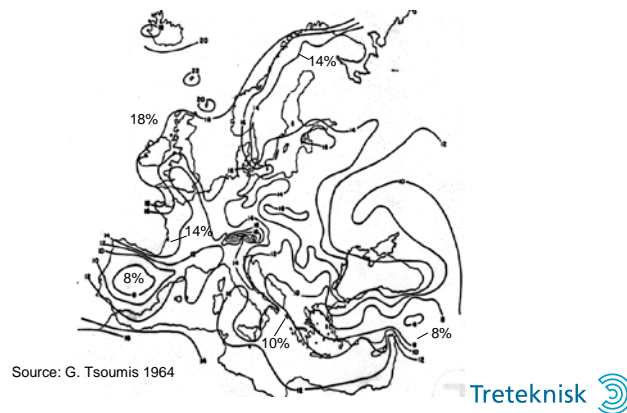
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There are considerable differences in the EMC in Europe (January)

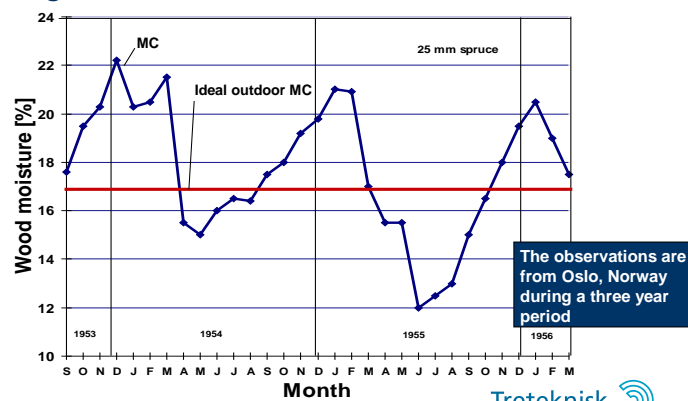


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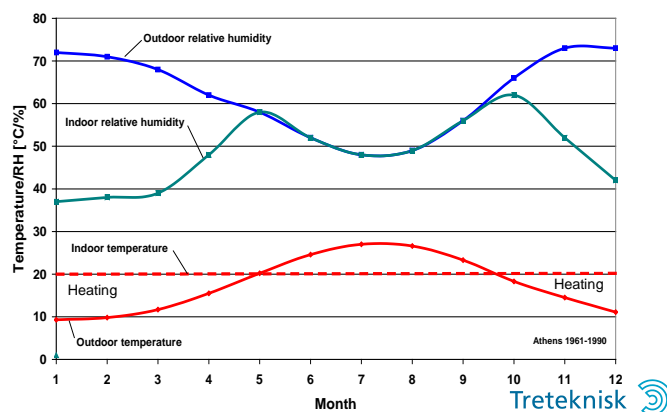
Equilibrium moisture content (EMC) for Europe in July



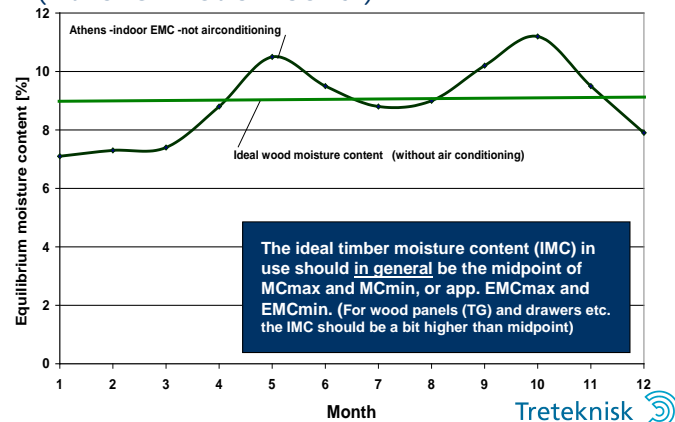
Observations from Oslo show greater variation, higher MC levels and consequently higher ideal outdoor MC than Athens



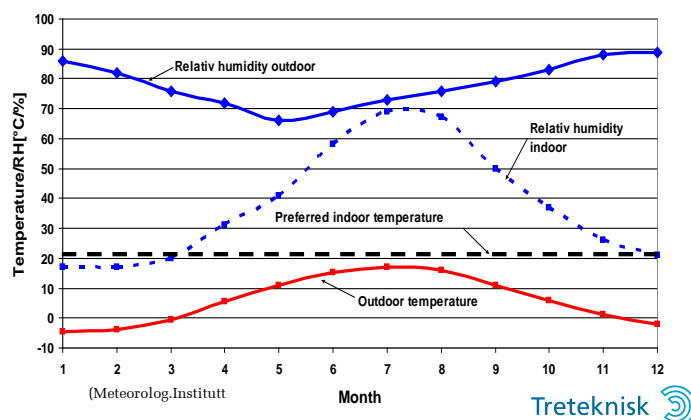
The indoor RH will in the heating period be quite different from the outdoor RH (Athens)



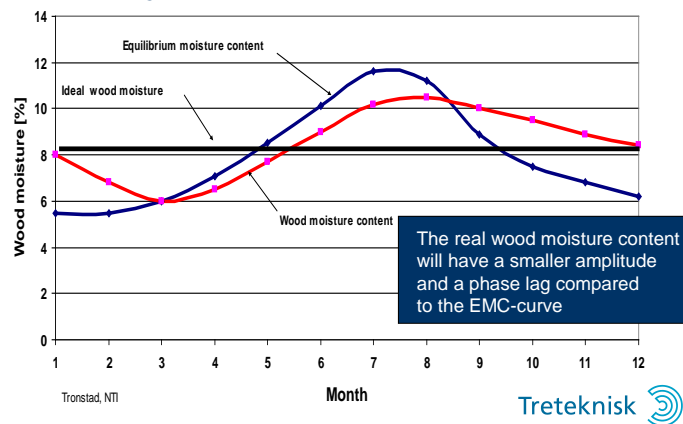
Indoor equilibrium moisture content and ideal indoor wood moisture content (Athens - not air cond.)



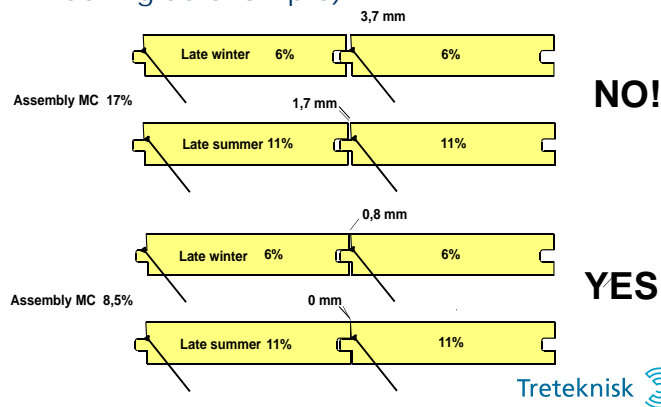
Example of outdoor and indoor climate in the Oslo area of Norway



Indoor EMC and wood moisture and corresponding ideal target wood moisture (Norway)



Drying to the ideal moisture content will give the least movement of the the timber and the most satisfied end users (Wood flooring as example)

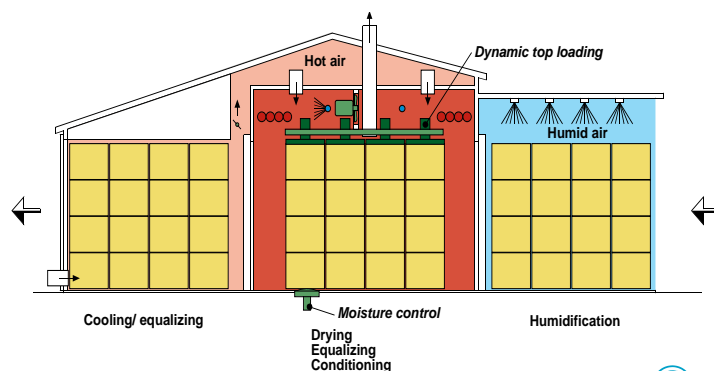


Summary no. 1

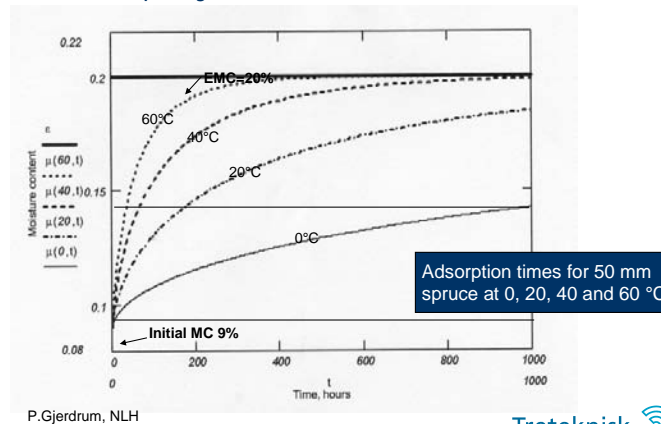
- The wood moisture content is strongly dependant on the relative humidity and temp. in the surrounding air.
- To find the ideal moisture content of a timber product, the RH and temperature data over the year in the end user environment must be known.
- The RH data will, via EMC tables, give the variation in equilibrium wood moisture content during the year.
- The **ideal moisture content (IMC)**, which should be the target MC for the drying, is in general the midpoint between the highest and lowest EMC during the year at the user environment. (A bit higher for some products).

Treteknisk

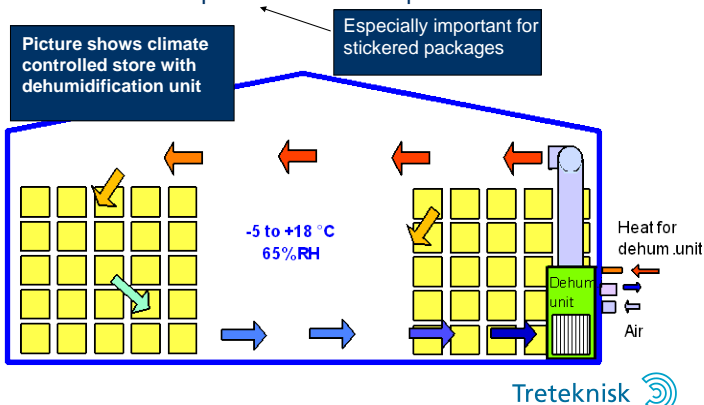
Theme 2. How to maintain the ideal moisture content from kiln to end user?



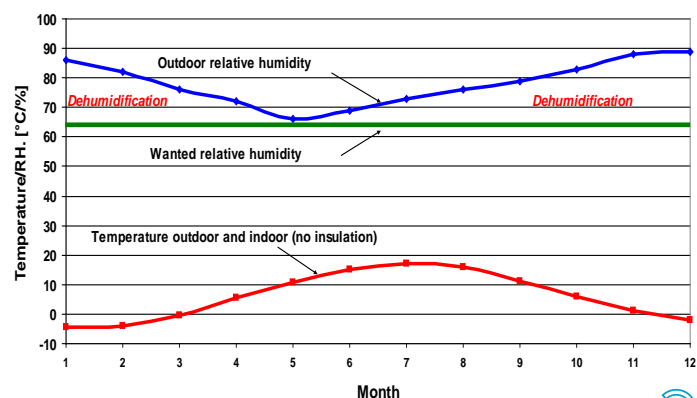
In humid conditions, the dried timber will rapidly absorb moisture from the air



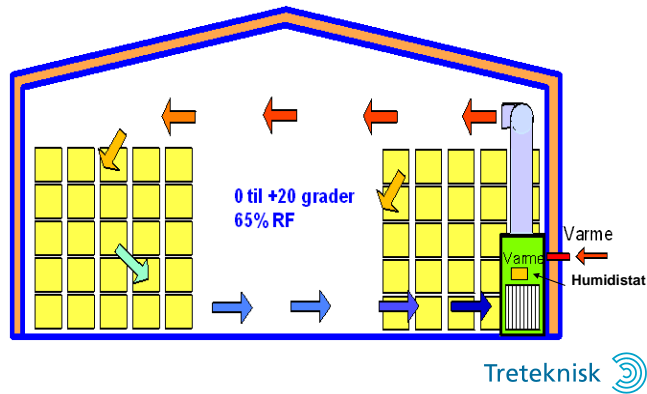
Timber dried to lower moisture contents must be stored in climate controlled rooms, or go directly to climate controlled production departments



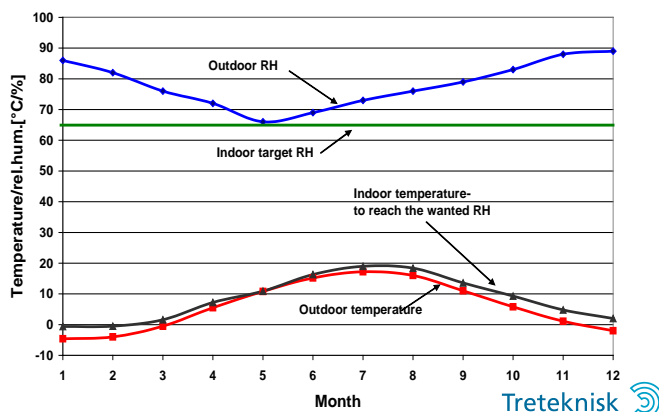
Unheated timber stores with dehumidification units for climatic control is a much used solution



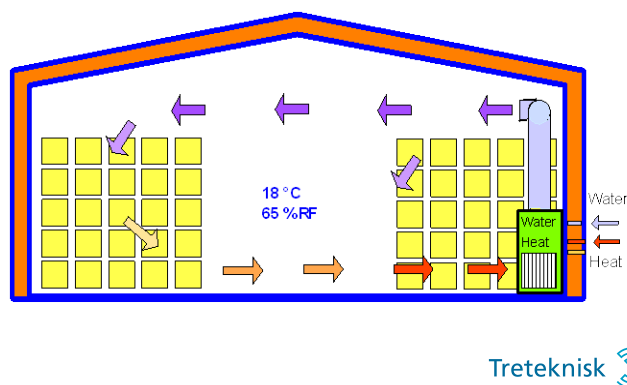
Moderately isolated timber store with temperature control of the RH via humidistat



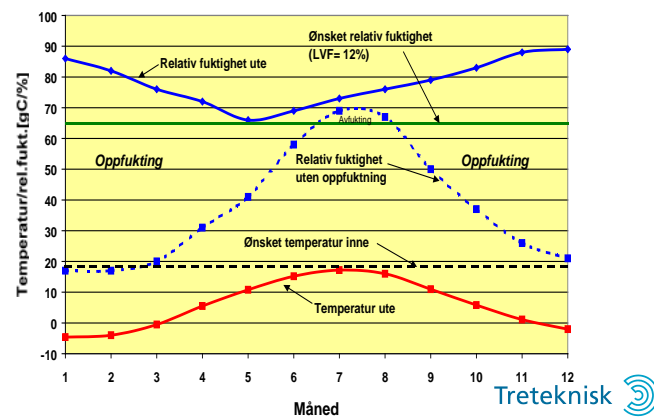
Indoor and outdoor temperature and RH in a temperature controlled timber store



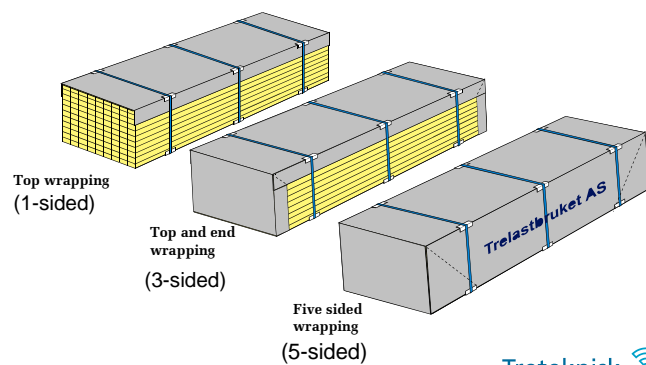
Isolated airconditioned timber store with heating, humidification and dehumidification



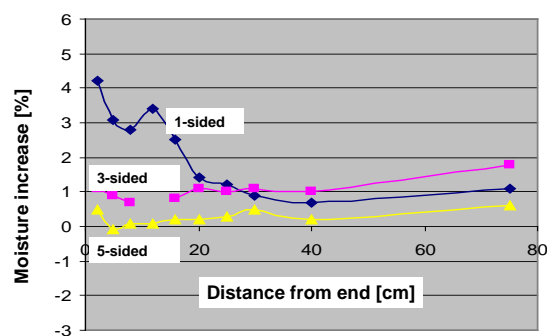
Indoor and outdoor temperature and RH in a heated timber store (18 °C)



By open transport and outdoor storing, the timber must be wrapped in different ways dependant on the moisture content

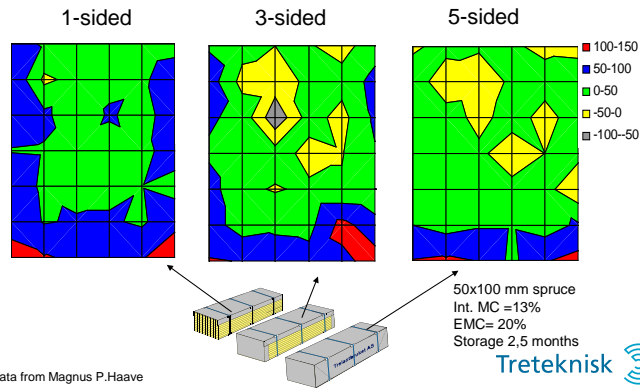


Moisture uptake from the end of packages will be considerable by 1-sided (top) wrapping



Data from Magnus P. Haave

Moisture increase in the cross-section by the three different wrapping methods

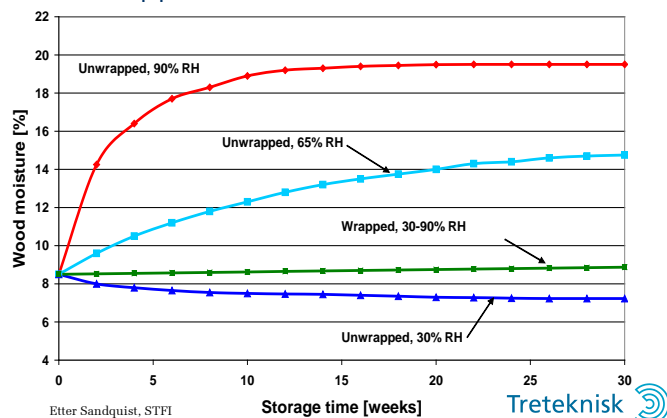


Only 6-sided (complete) wrapping will prevent moisture change in the timber

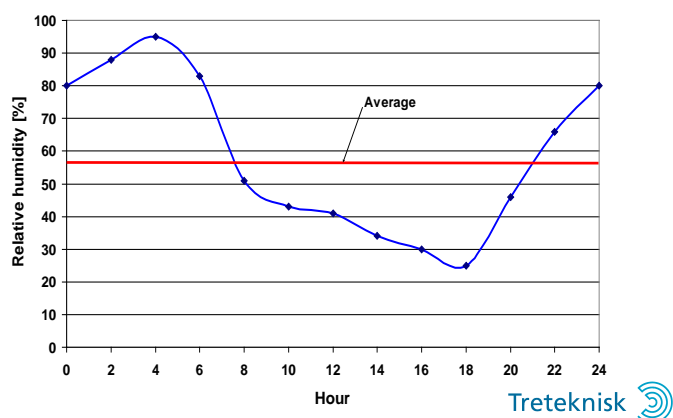


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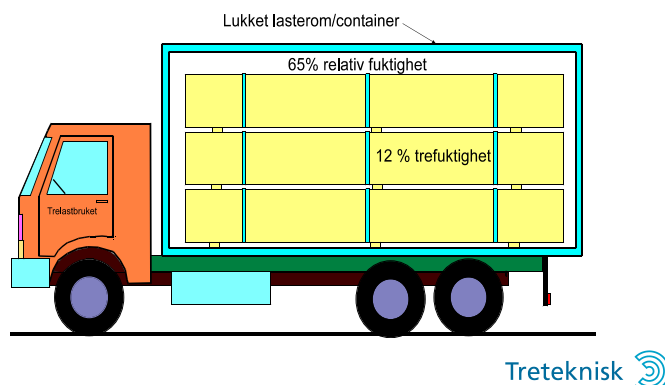
Moisture change in 6-sided plastic wrapped timber compared with unwrapped timber at different RH



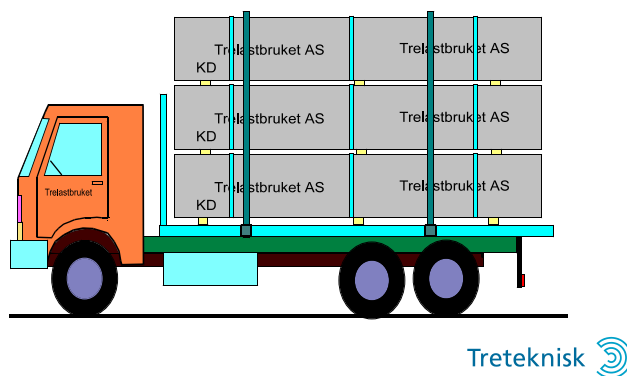
Actual and average relative humidity during 24 hours (Example Oslo - August)



The wrapping costs can be avoided by storing the timber in climate controlled rooms combined with transporting in sealed containers



Truck transport with wrapped packages



The timber merchant is important in the wood chain and must not forget to have control with the moisture content



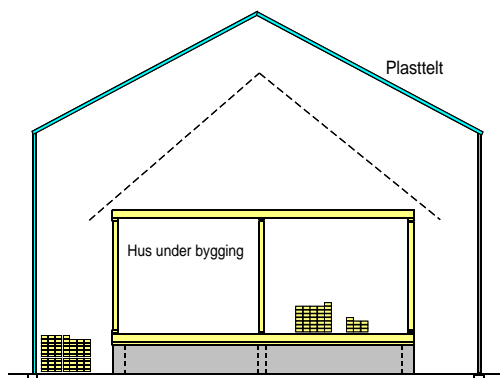
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Rewetting is often a problem at the erection of buildings



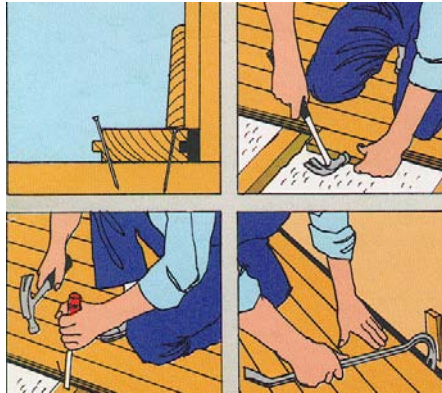
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In rainy seasons, the (timber) houses should preferably be built under plastic tents



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The relative humidity should also be within acceptable limits when installing (especially) flooring



The RH is often very high during erection due to concrete work

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Drying timber to correct MC, moisture controlled storing, transport and erection, combined with proper building design, will secure satisfied users of timber houses in many, many years



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"Dry timber lasts forever"

1000 year old
stavechurch
from Norway



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