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

Work package 2.2
Effect of top loading on the deformation of sawn timber during kiln drying

Effekten av toppbelastning på deformasjoner av trelast i tørkeanlegg
Tiltak for forbedring av kvalitet og formstabilitet i skurlast ved tørking og driftsforhold

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Date: May 2005

Summary

Deformation during drying is one of the most important reasons for downgrading timber.

In this EU funded project, STRAIGHT, nine research institutes in eight European countries have studied different methods to minimise the distortion of sawn timber occurring during drying and service conditions. The study has been divided into several work packages with one to nine partners, each with one responsible institute.

This report presents the results from studies on top loading of timber during drying as a method of reducing distortion. Bundesforschungsanstalt für Forst- und Holzwirtschaft (BFH), Building Research Establishment (BRE), Technical Research Center of Finland (VTT) and Norsk Treteknisk Institutt (NTI) as coordinator, have taken part in the study.

The main goal of the study was to find the correlation between the level of top loading and the degree of deformation of sawn timber and to study new approaches for top loading.

Stikkord: Toppbelastning, deformasjoner, tørking
Keywords: Top loading, deformations, drying

All tests were run with 50 mm x 100 mm battens sawn from 150 mm - 170 mm diameter logs of Norway spruce (Picea abies) and Sitka spruce (Picea sitchensis). Due to the high amount of juvenile wood with large fibre angle in the centre of the log, this dimension is highly prone to distortions.

The tests were run under industrial conditions with full timber lengths and under laboratory conditions with shorter timber lengths. Totally, more than 50 tests were run with different top load levels and compared to the same number of reference tests with no top load.

The main conclusion from the tests is clear - the top load has considerable influence on all typical deformations in timber, i.e. twist, bow and spring, with twist as the most pronounced. The deformations were reduced down to about 30 % for twist and 40 % for bow and spring. This again can partly be reduced by the spring back effect, if the timber after drying is stored for longer periods without pressure.

For all these types of deformations, the optimal top load for the tested dimension 50 mm x 100 mm spruce was app. 600 kp/m^2 for the industrial tests, for the laboratory tests, a bit higher. Increasing the load above these levels had only marginal positive effect on the deformations.

The results also reveal the benefits of smaller sticker distances and the importance of proper alignment of the stickers.

The study finishes with a discussion on pros and cons of different methods of applying the top load, concluding with a preference for a pneumatic or hydraulic system, especially for larger compartment kilns with several packages in the height. In addition to the possibility of controlling the top load level, the "dynamic" top loading will also prevent tilting of packages by proper top load and stop the air leakage above the packages.

The results maintained in the tests are representative for Norway spruce and Sitka spruce of the dimension 50 mm x 100 mm. Other species, dimensions and timber with other sawing patterns will behave differently as to distortions and will have different optimal top loads.

Preface

The STRAIGHT project, "Measures for improving quality and shape stability of sawn softwood timber during drying and under service conditions" is part of the EU 5th framework programme (QLRT-2000-00276). The project was completed at the end of 2004. The contact person in EU was Dr. Norbert Winkler. The project participants are listed below.

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In the work package 2.2 "Novel top loading", the following research institutes took part:

- Norsk Treteknisk Institutt (NTI) (work package coordinator)
- Building Research Establishment (BRE)
- Bundesforschungsanstalt für Forst- und Holzwirtschaft (BFH)
- VTT Building and Transport (VTT)

In addition to the participants from the research institutes, major contributions to the project have come from sawmills in Finland (Honkalahti and Kotka sawmills, timber and hiring of kilns), Norway (Begna and Haslestad sawmills, timber, hiring of kilns and considerable work) and UK (AW, Balcas, BSW and Gordons sawmills, timber). Our thanks to all the sawmills. Without the help from these sawmills the project had not been possible.

This report presents the results from work package 2.2, which has studied the effect of top loading on the degree of distortion. The report has been written by Sverre Tronstad (editor) with the aid of the partners in the work package.

Major contributions to the report from the following persons are acknowledged:

Geoff Cooper (BRE) for Chapter 3, Hans Welling (BFH) for Chapter 4 and Veikko Tarvainen (VTT) for Chapter 5.

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

Oslo, May 2005

Sverre Tronstad

Contents

1. Introduction

Earlier studies have shown that top loading during drying has a positive effect on the straightness of timber after drying. This is due to the creep of wood, especially pronounced at higher temperatures.

The timber twists, bows and springs because the grain angle is not parallel to the length axis of the battens and because the longitudinal shrinkage of the battens is unhomogeneous. For example, higher shrinkage of compression wood located on one side of the batten affects bow on the face and spring on the edge. The main cause of twisting is that the grain direction differs from the direction of faces and edges. The spiral grain can be almost constant for a longer line on the timber face. Local spiral grain appears mainly around the knots. The total effect of knots on deformations depends on how the knots are located. If the timber is sawn so that the knots are located on one side of the face, spring can be expected.

The timber should be clamped during drying, so that it remains fully straight. In such a case, the variations in longitudinal shrinkage initiate longitudinal drying stresses. The loading or clamping of drying timber prevents free movements, and the wood begins to creep due to shrinkage stresses. The amount of creep depends on moisture content, drying schedule and properties of the wood. Despite the creep, some stress remains in the timber. When the battens are freed from restrictions after drying, they distort again, i.e. spring back.

Keeping the timber straight during drying, normally means dense stickering and a high enough top loading that can press the battens straight, also at low moisture contents towards the end of drying. This can not yet fully prevent the lateral movement, i.e. spring. Because of radial and tangential shrinkage of battens, gaps between them grow. This allows for some lateral movement. To prevent this, it is also necessary to have side pressing during drying. Another possibility is to generate high enough friction forces between stickers and timber, so that spring is not possible.

The aim of the project is:

- Develop new approaches for top loading kiln loads and determine the effects on deformation of sawn timber during drying.
- Provide the basis for the design of commercial systems for top loading in order to reduce deformation during drying.

2. NTI tests

2.1. Laboratory tests

2.1.1. Test material

The test material was 50 mm x 100 mm paired battens (2 x log) of Norway spruce for all laboratory and industrial tests. The battens were sawn from 15 cm - 16 cm diameter logs. The 50 mm x 100 mm battens are warp prone, due to normally high grain angle because of a high amount of juvenile wood. The loaded battens and the reference battens are always pair battens taken from the same log, as shown in Figure 2.1. (Two tests were run for BRE at the NTI laboratory kiln with 50 mm x 100 mm Sitka spruce. These battens were paired according to the procedure described under BRE tests.).

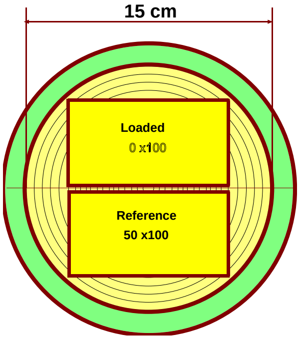
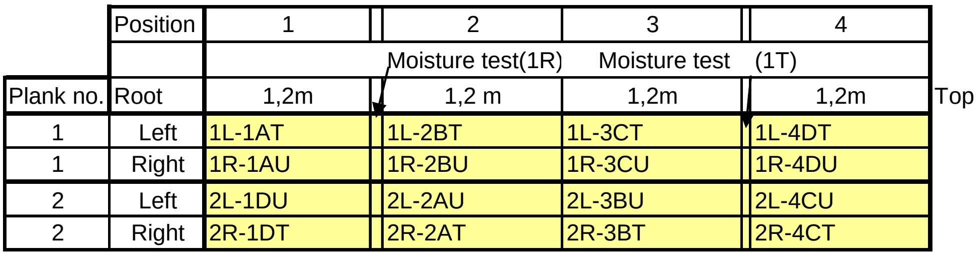


Figure 2.1. Sawing pattern for battens used at the NTI laboratory and industrial tests, with one batten loaded and the other unloaded as reference.

In the laboratory tests, where the length of the battens were limited to 1,2 m, four pairs of test battens were taken from each full length pair batten. The test battens for loading and reference were shifted between left battens and right battens and top and root end to avoid systematic errors. Totally, 64 pair battens were used in each laboratory test, with 32 battens loaded and 32 battens unloaded. To improve the accuracy in measurements, the battens were surfaced before drying.



	Position	1	2	3	4	
			Moisture test(1R)	Moisture test	(1T)	
Plank no.	Root	1,2m	1,2 m	1,2m	1,2m	Top
1	Left	1L-1AT	1L-2BT	1L-3CT	1L-4DT	
1	Right	1R-1AU	1R-2BU	1R-3CU	1R-4DU	
2	Left	2L-1DU	2L-2AU	2L-3BU	2L-4CU	
2	Right	2R-1DT	2R-2AT	2R-3BT	2R-4CT	

Figure 2.2. Cutting, position of moisture tests and marking of test battens for the laboratory test (L=left, R=Right, T=Treated (loaded), U=Untreated (unloaded)).

		Test A.		Test B		Test C.		Test D	
Plank no.		Position	Treatmen	Position	Treatmen	Position	Treatmen	Position	Treatment
1	L	1	T	2	T	3	T	4	T
1	R	1	U	2	U	3	U	4	U
2	L	2	U	3	U	4	U	1	U
2	R	2	T	3	T	4	T	1	T

Figure 2.3. Principle for the positioning of the test battens in the laboratory tests.

The moisture content of the battens was in average about 45 %.

2.1.2. Test procedure

For the laboratory tests, a pneumatic top loading system was constructed and installed in a laboratory kiln (Figure 2.4). The top load can be adjusted from zero to 3200 kg. The kiln allows timber lengths of 120 cm and package widths of 90 cm. The unloaded samples are located in the upper part of the kiln and are totally free to move.

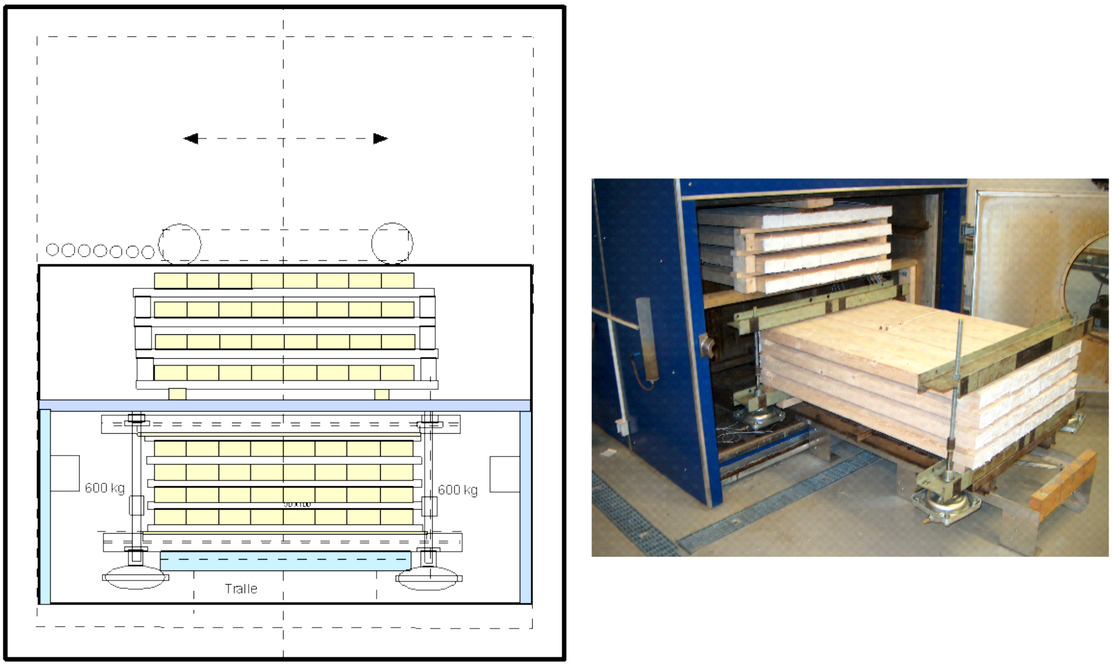


Figure 2.4. Pneumatic top loading system in laboratory kiln.
32 loaded and 32 unloaded samples.

In the NTI test program, four tests (A, B, C, D) with three levels of top load for each test depending on moisture content, were carried out (Figure 2.5).

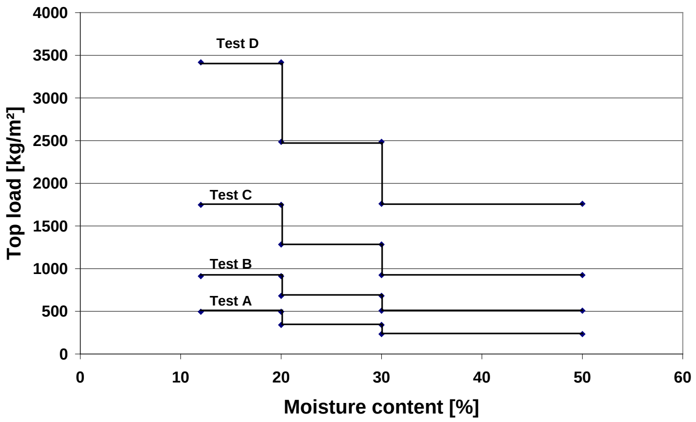


Figure 2.5. Top load at different moisture contents at the laboratory tests A, B, C and D.

For the Sitka tests carried out for BRE, two top load levels equal to A and B were used.

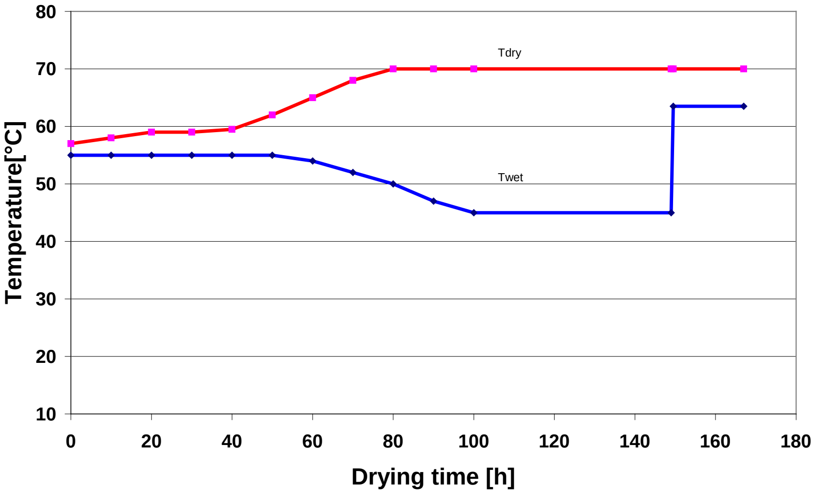


Figure 2.6. Drying schedule at the laboratory tests at NTI.

At all laboratory tests, the same kiln schedule (Figure 2.6) was used, and the timber was dried to the same target moisture content of 12 % for the NTI tests and to 15 % for the BRE tests.

Before drying, the grain angle, batten thickness and moisture content was measured. Immediately after drying and cooling down, moisture content, twist, spring, bow, sticker marks under stickers, cup under and midway between stickers and finally the batten thickness was measured. The grain angle was measured at the splint side opposite of the pith with an instrument developed at Chalmers University.

2.1.3. Results and discussion

Distortion

To get comparable results for the industrial tests, the deformations measured at 1,2 m was extrapolated linearly to 2 m, which is the normal observation length for most of the grading rules.

The twist is substantially influenced by the top load level as seen in Figure 2.7, where the average values of twist are shown for unloaded battens and for battens with four different top loads. The pneumatic top load was gradually increased as shown in Figure 2.5, and the loads shown in Figure 2.7 are at the highest towards the end of drying.

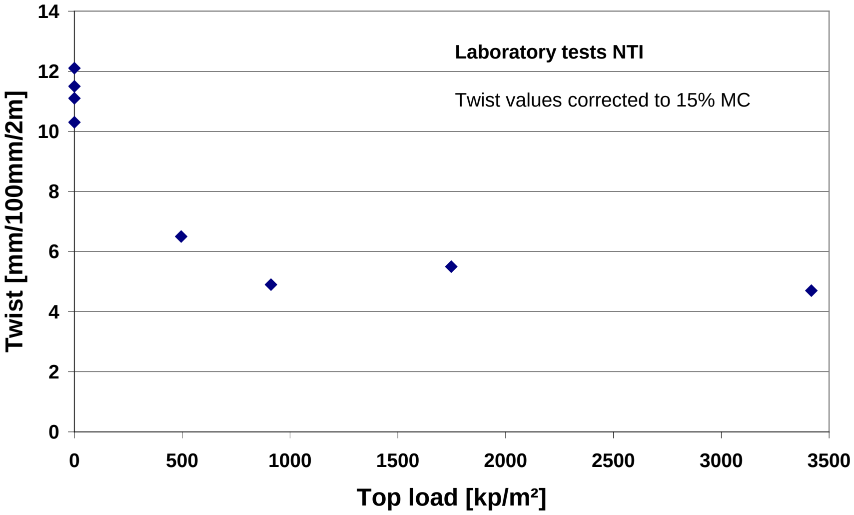


Figure 2.7. Average twist at different end top loads at laboratory tests.

The test results indicate that an optimal top load is reached just under 1000 kp/m², which indicates that this load is sufficient to keep the battens in position. Further increase in the top load seems to have no influence.

The influence of the top load can also be expressed as acceptance level in percent as to different requirements. There are a number of different methods for reduction of twist, and for the purpose of this the project, it was decided to use 4 mm over 100 mm batten width measured over 2 m as a threshold for comparing different methods. For bow and spring, the thresholds are set to 4 mm and 3 mm respectively. The threshold values are valid at 15 % moisture content. At moisture contents deviating from 15 %, a linear correction of deformations is made.

In Figure 2.8, the acceptance level of twist is given for the four tests. With only two stickers at the laboratory tests, the values for bow and spring have little relevance and will not be shown.

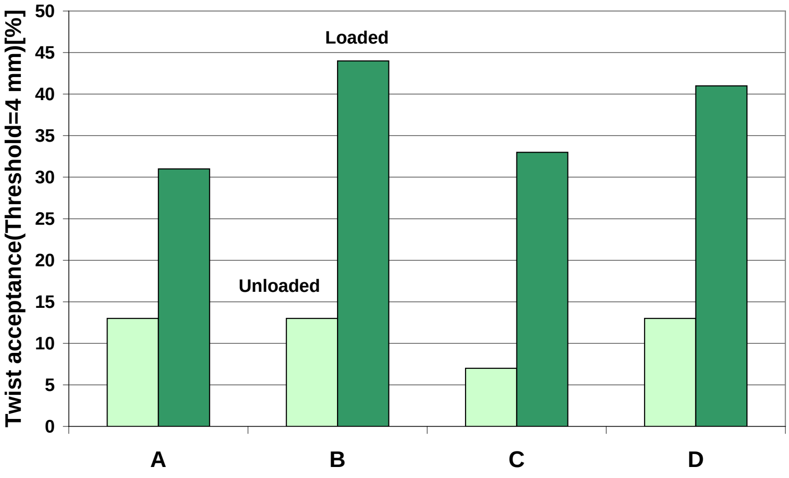


Figure 2.8. Acceptance percentage for twist at a threshold of 4 mm/100 mm /2 m at the four laboratory tests. The load levels can be taken from Figure 2.5.

At test B, C and D, with a top load above 900 kg/m², the acceptance percentage is nearly four times higher for loaded than for unloaded battens.

Grain angle

The grain angle seems to have substantial influence on the twist (Figure 2.9).

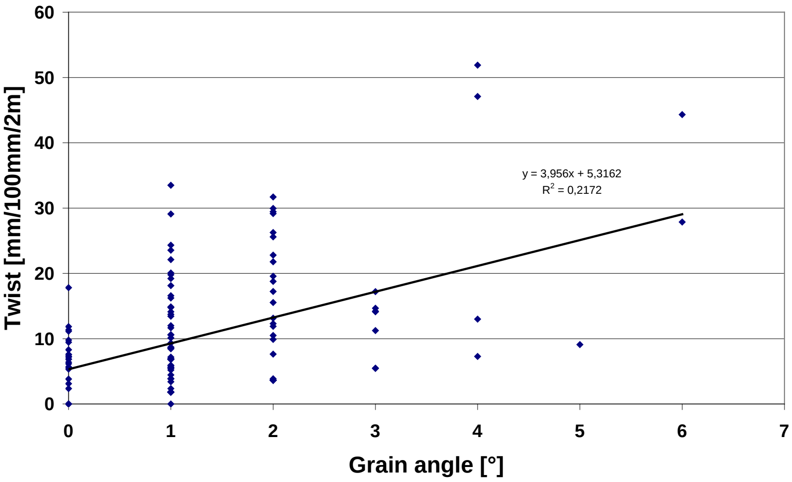


Figure 2.9. Influence of grain angle on the degree of twist (unloaded battens at laboratory test).

Cupping

Increased top load will also reduce the cupping of the battens, especially under and near the stickers. The influence of the top load, calculated as specific sticker pressure, on the cupping under the stickers and midway between the stickers, is shown in Figure 2.10.

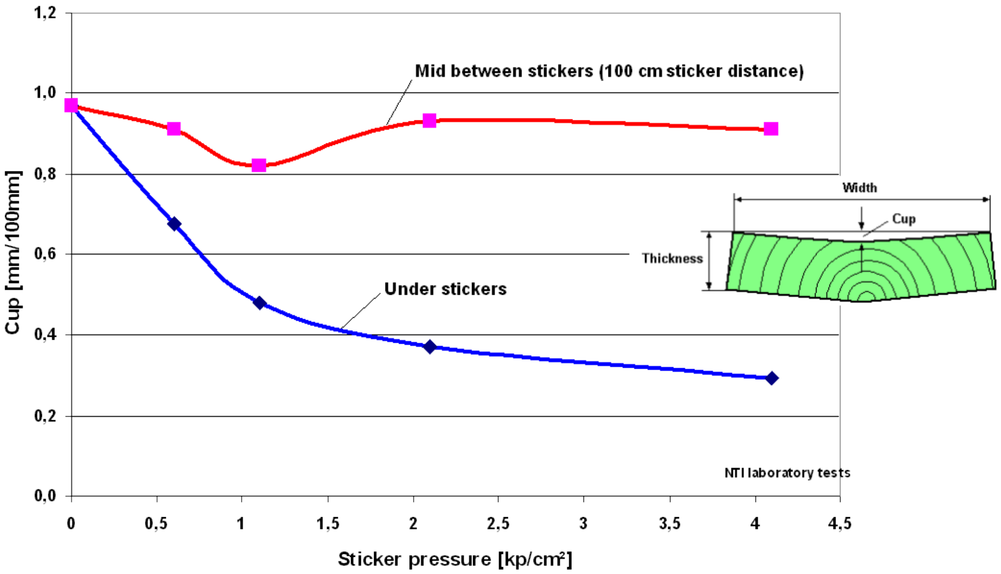


Figure 2.10. Influence of sticker pressure on the cupping under the stickers and midway between the stickers.

The measurements indicate that there is a considerable reduction in the cupping under the stickers with increased top load, but no influence at a distance of 50 cm from the stickers (sticker distance 100 cm). Earlier tests at NTI have shown that the influence of the sticker pressure diminishes gradually from under the stickers to about 20 cm, where the influence is almost zero, see Sandland and Tronstad [4]. To obtain a reduction of the cupping by top loading, the distance between the stickers must therefore be under 40 cm, which is unrealistic.

Sticker marks

The sticker marks were measured at the surfaced battens using a measuring gauge with a resolution of 1/100 mm. The average sticker marks were limited to about 0,25 mm, with maximum values up to 0,70 mm.

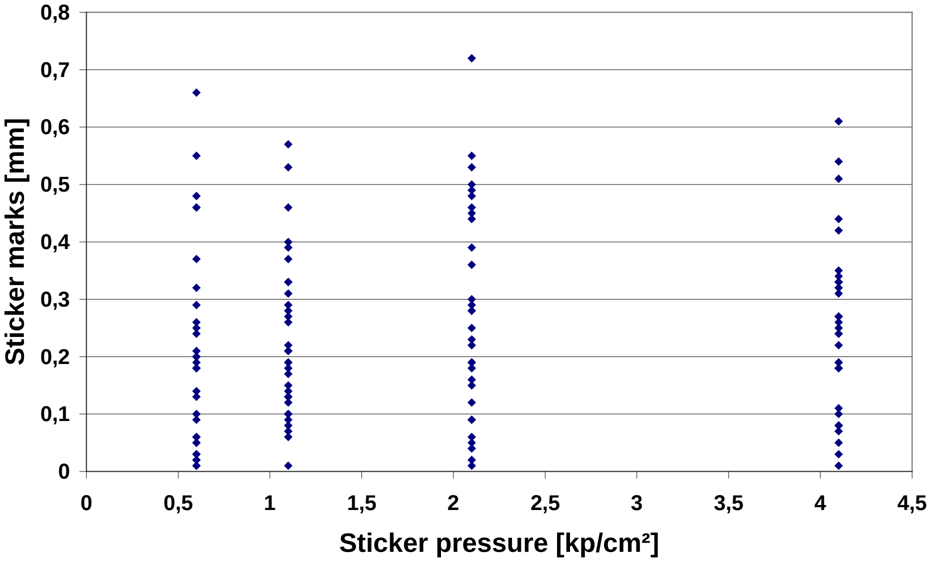


Figure 2.11. Influence of sticker pressure on sticker marks at laboratory tests.

2.2. Industrial tests

2.2.1. Test material

In the industrial tests, the battens (50 mm x 100 mm) of Norway spruce were sawn from 15 cm - 16 cm diameter logs with random lengths of 3 m - 6 m. The paired battens were marked directly after leaving the last machine in the sawmill line and led to a separate sorting bin for collection before the final marking for loaded (treated) and unloaded (untreated) battens. The battens were shifted between left pair battens and right pair battens to avoid systematic errors. Totally, 100 battens were used in each test, with 50 loaded and 50 unloaded. The test battens represent the most warp prone battens in the log distribution. The initial moisture content for the different industrial tests was in average 55 %, ranging from 38 % to 82 %.

2.2.2. Test procedure

The industrial tests were performed at the sawmills Begna Bruk AS and Haslestad Bruk AS. Both sawmills had recently installed pneumatic top loading in their new kilns, partly based on promising results from top loading tests carried out in the Norwegian Kiln Drying Club, see Tronstad [3].

To achieve a wide range of top load levels, the test packages were placed at different heights in the kilns, giving different starting levels of top loading, combined with gradually increasing pressure from the pneumatic top loading system. The top loading system consists of four frames of stainless steel, one for each package row. Each frame is operated with two pneumatic cylinders.

Between the frame and the fan roof, flexible flaps preventing air leakage above the top packages and the fan roof are installed. The two cylinders are able to give a maximum top load of 2000 kp at Haslestad Bruk AS and 2340 kp at Begna Bruk AS. The weight of the frames of app. 200 kg has to be added, giving a maximum top load of 2200 kp and 2540 kp respectively. The system with pneumatic cylinders allows for adjusting the top pressure in the whole range from zero to maximum load.

At each sawmill, four different top load levels were tested and compared to the unloaded reference battens. The reference battens were pair battens to the loaded battens. In each test, 100 battens were used, with 50 battens loaded and 50 battens as unloaded references. The reference battens were placed on protruding stickers on both sides of the kiln, as shown in Figures 2.12 and 2.13, and were completely free to move.

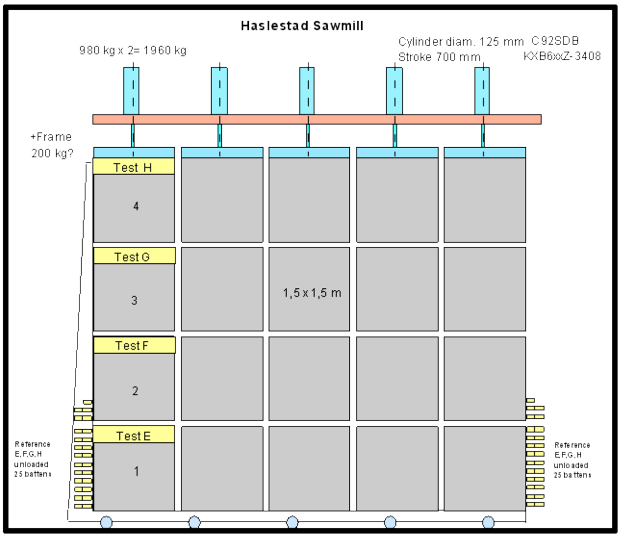


Figure 2.12. Drawing of the test arrangement at Haslestad Bruk AS.

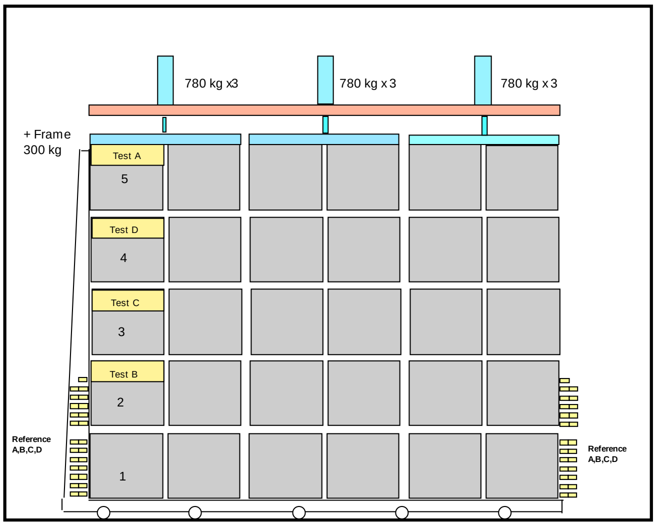


Figure 2.13. Drawing of the test arrangement at Begna Bruk AS.

The real load on each test package will be a combination of the applied pneumatic top load plus frame and the load of the timber, stickers and truck battens above the test package. Half of the test package is included in the calculated load. During drying, the load from the packages above the test package will gradually be reduced due to the weight loss caused by the drying. The actual top load will consequently be dependent on the applied top load and the moisture content of the battens, as shown in Figure 2.12 for Haslestad Bruk AS.

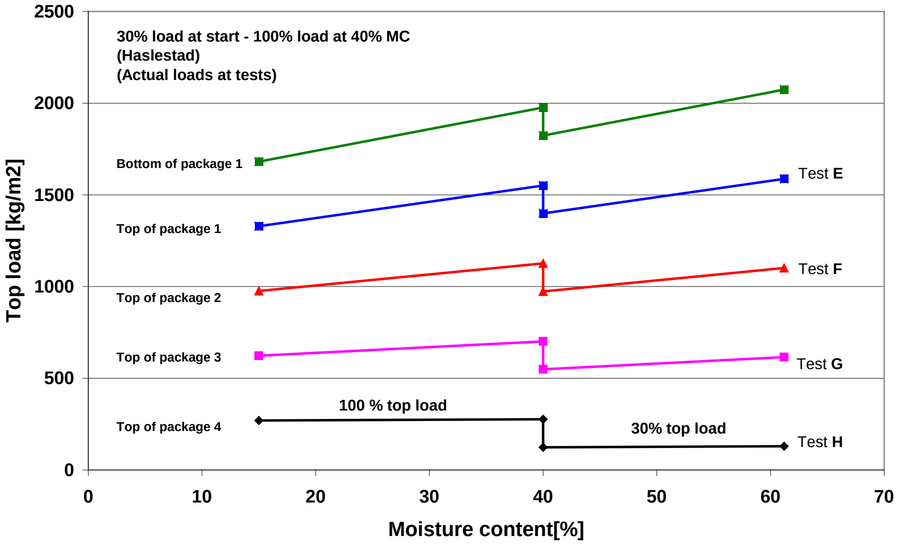


Figure 2.14. Specific top loads of the four tests at Haslestad Bruk AS.

As can be seen from Figure 2.14, the kiln operator set the top load to 30 % of maximum at start of drying and increased it to full load at about 40 % moisture content.

At Begna Bruk AS, only the weight of the frame was set from the start, and full top load was applied at 30 % moisture content, as shown in Figure 2.15.

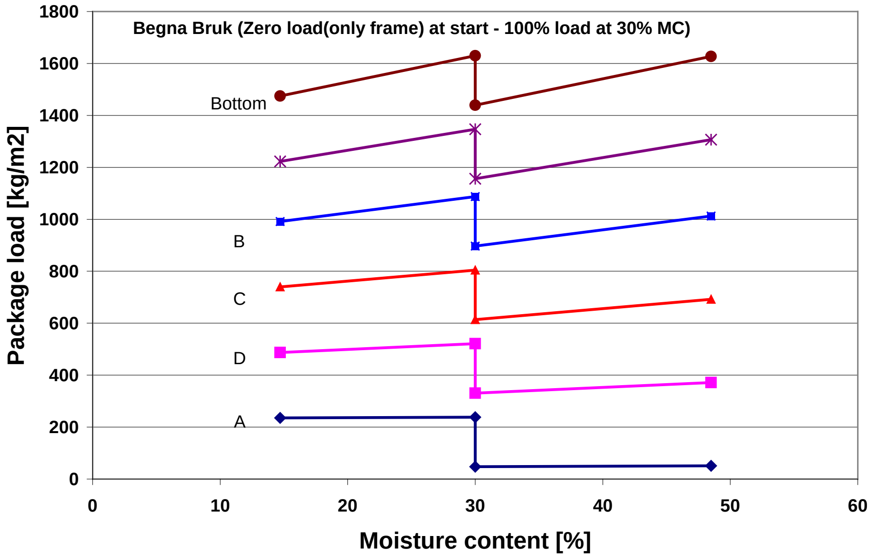


Figure 2.15. Specific top loads of the four tests at Begna Bruk AS.

The kiln schedules were the same for each test and were almost identical at the two sawmills.

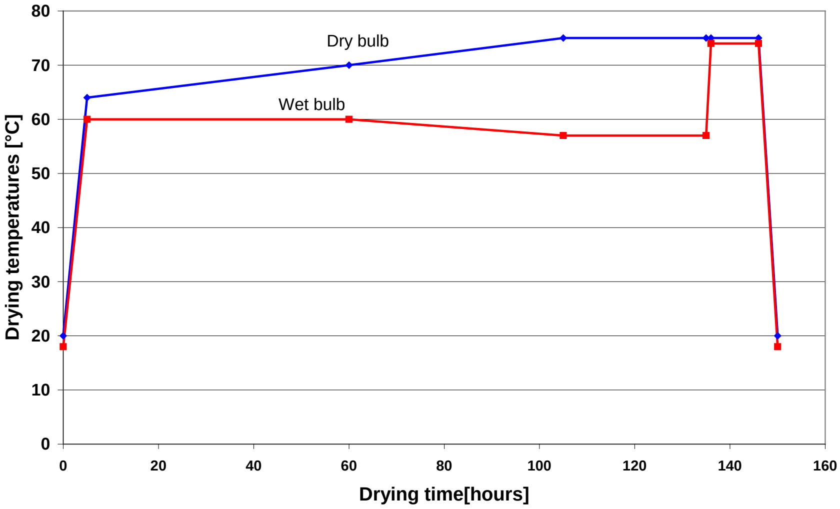


Figure 2.16. Drying schedule for the tests at Haslestad Bruk AS.

The target moisture content was 14 % for the test runs at Begna Bruk AS and 16 % for the test runs at Haslestad Bruk AS.

In the industrial tests, the grain angle, thickness and moisture content was measured before drying. After drying (within one to five days), the moisture content, twist, bow, spring, sticker marks and the length of the protruding end between the stickers were measured. For twist, bow and spring, the deformations were measured over 2 m from the last sticker and from the protruding end between the stickers (see Figure 2.17).

Before drying, the moisture content was measured according to the oven dry method, and after drying with resistance meter.

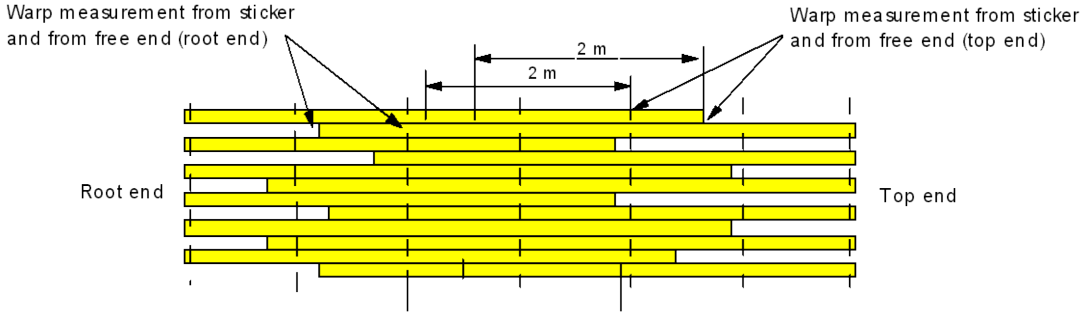


Figure 2.17. Measuring strategy for the industrial tests.

The deformations were measured over 2 m with an aluminium jig especially made for the project (Figure 2.18).

Figure 2.18. Test jig for the industrial tests.

The sticker marks were measured at the mid point of the pith side using a measuring gauge with a resolution of 1/100 mm and mainly in the middle part of the package where the sticker pressure is highest.

2.2.3. Results and discussion

Distortion

Twist, bow and spring were greatly influenced by the top load; and twist the most.

In Figure 2.19, the influence of the top load (at end of drying) on the level of *twist* is shown. Each point represents the mean value of twist for 50 battens. The diagram shows two series of measurements, one measured over 2 m from the last sticker and the other measured over 2 m from the free end.

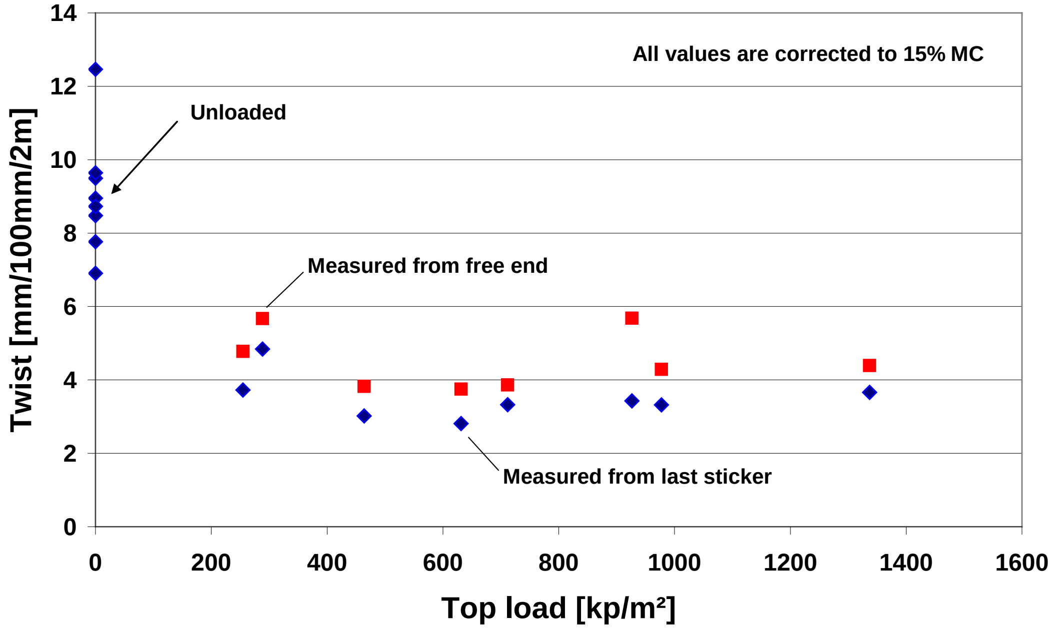


Figure 2.19. Influence of top load on average twist at the industrial tests. The twist is measured over 2 m from the last sticker and over 2 m from the free end between the stickers.

From the diagram one can conclude that the top load has substantial influence on the degree of twist. It can also be concluded from these tests that a specific top load of app. 600 kp/m² seems sufficient to keep the battens in position. Further increase in the top load gives only marginal decrease in the twist.

A curve estimation gave the following equation: $Twist = \frac{344{,}3}{Topload + 52{,}2} + 3{,}2$

The fact that the battens normally have free unsupported ends between the stickers, will lead to increased deformations when measured from the free end. The increase in twist for the free end measurements is app. 1 mm in average, or about 30 %, and will depend on the sticker distance.

The test results can also be evaluated by calculating the percentage of pieces that fall within certain deformation thresholds. These thresholds can be taken from existing quality requirements in different standards. As the limits in these standards vary between the "project countries", one has decided to use the same limits when evaluating the different methods in the Straight project. These limits, or thresholds, are stricter than what is found in the existing standards and are as follows: Calculated for 2 m length and 100 mm width for the twist at a reference moisture content of 1.

Twist:	4 mm (for 100 mm width and 2 m length)
Bow :	4 mm (for 2 m length)
Spring:	3 mm (for 2 m length)

For twist, the percentage acceptance at a threshold of 4 mm/100 mm/2 m at different top loads are shown in Figure 2.20.

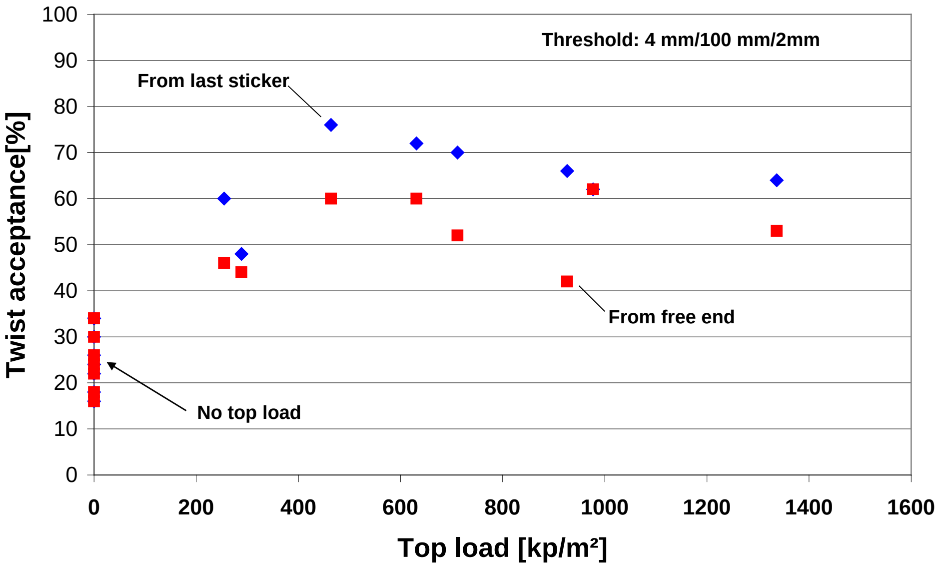


Figure 2.20. Influence of top load on acceptance percentage for twist at the industrial tests.

Presented this way, the same conclusion as above can be drawn as to the optimal top load; about 600 kp/m^2 seems enough to keep the battens in position. Additional load seems to have no influence on the contrary.

The influence of the top load (towards end of drying) on *bow* is shown in Figure 2.21. Each point represents the mean values for 50 battens.

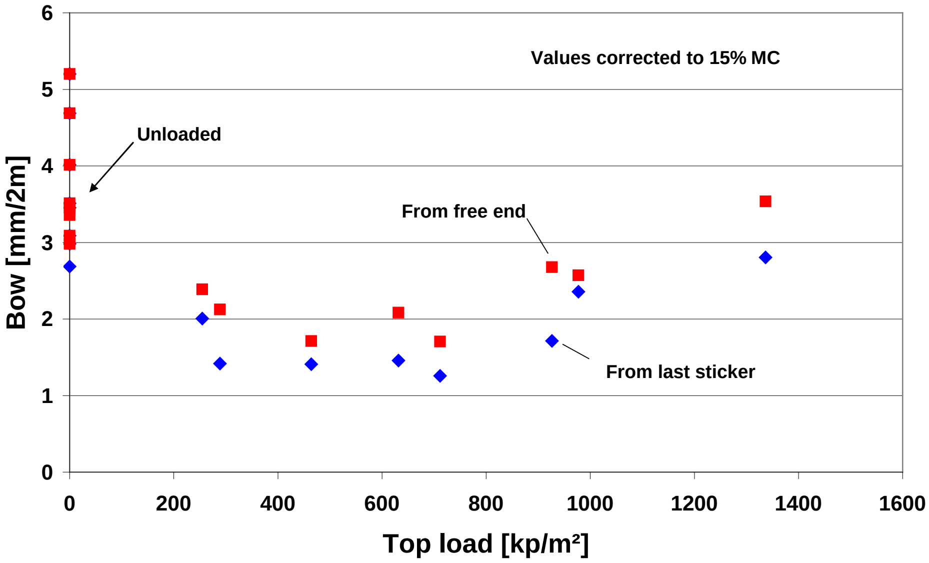


Figure 2.21. Influence of top load on the average bow at the industrial tests.

The bow is also greatly influenced by the top load, with an optimal top load at 500-600 kp/m². An increase in the load above this level seems to increase the bow. This may be caused by a bending moment on the battens if the stickers and truck battens are not completely aligned, which was observed at one of the sawmills.

The acceptance percentage with a threshold of 4 mm over 2 m is shown in Figure 2.22.

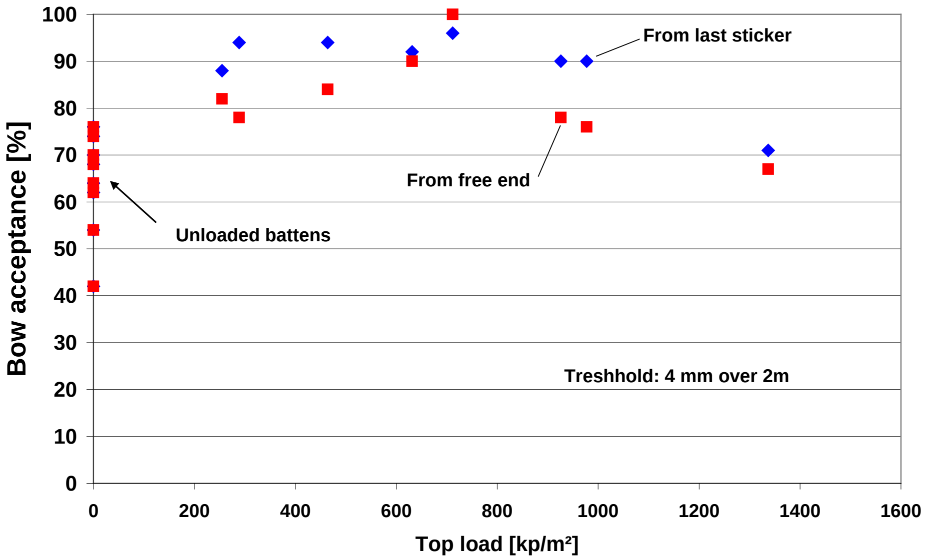


Figure 2.22. Influence of top load on the acceptance level of bow.

By increasing the top load to 600-700 kp/m², the acceptance percentage is increased from about 65 % to 95 %. Higher loads seem to reduce the acceptance percentage.

The influence of the top load on *spring* can be seen from Figure 2.23.

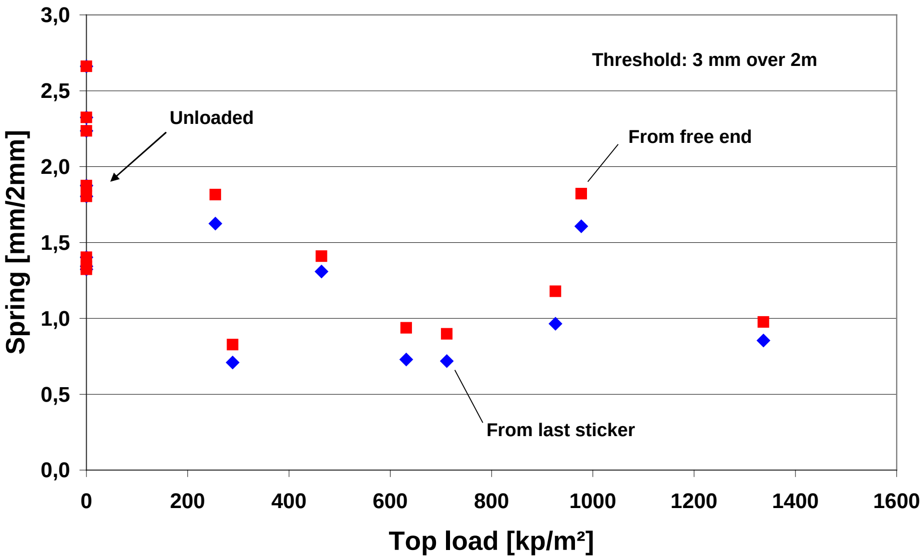


Figure 2.23. Influence of top load on the average spring at the industrial tests.

The influence of the top load on spring is clear, with a halving of the spring compared to unloaded battens. Again, a top load of about 600 kp/m² seems to be the optimal. Here too, we can observe the higher spring on the protruding ends between the stickers.

The percentage acceptance at a threshold of 3 mm over 2 m is shown in Figure 2.24.

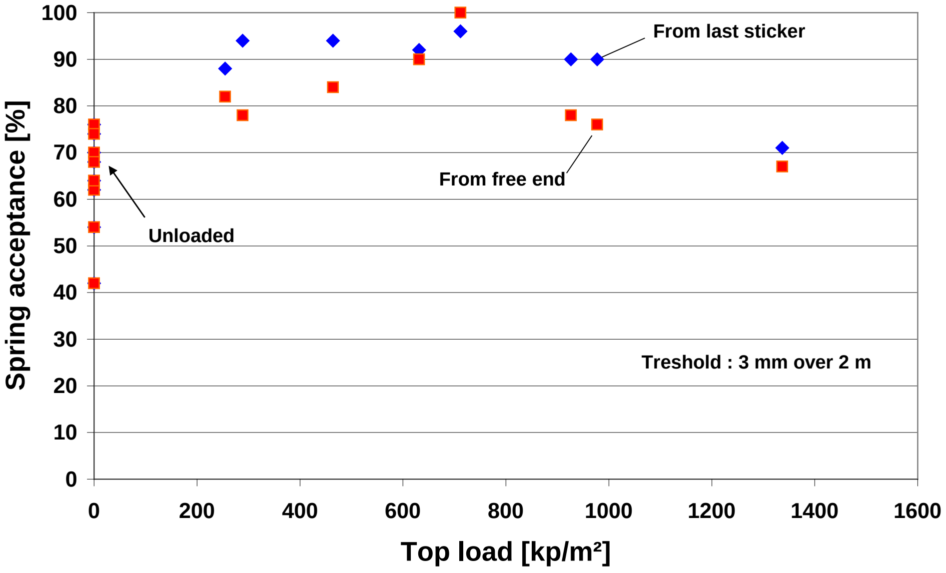


Figure 2.24. Influence of top load on the acceptance level of spring.

By applying a top load of 600-700 kp/m², the acceptance level is increased from about 65 % for unloaded battens to 95 % for the loaded ones.

As a conclusion for the industrial tests, the top loading has substantial influence on twist, bow and spring, with the highest influence on twist. As an example, the reduction on twist, bow and spring from one test run is shown in Figure 2.25, with a corresponding picture of the loaded and unloaded battens (Figure 2.26).

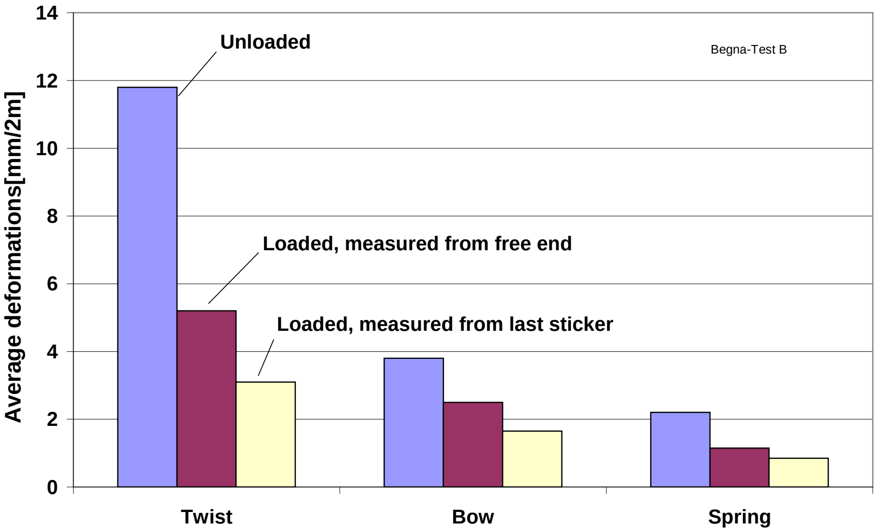


Figure 2.25. Influence of top load on twist, bow and spring for one of the industrial tests.

Figure 2.26. Loaded and unloaded battens after drying.

One should be aware that the top load will mainly influence the upper parts of the timber charge in the kiln. When the load of the timber itself, without top load, reaches the level at which the timber is clamped (at about 600 kp/m²), an additional top load will have no further influence on the distortion. This is illustrated for twist in Figure 2.27.

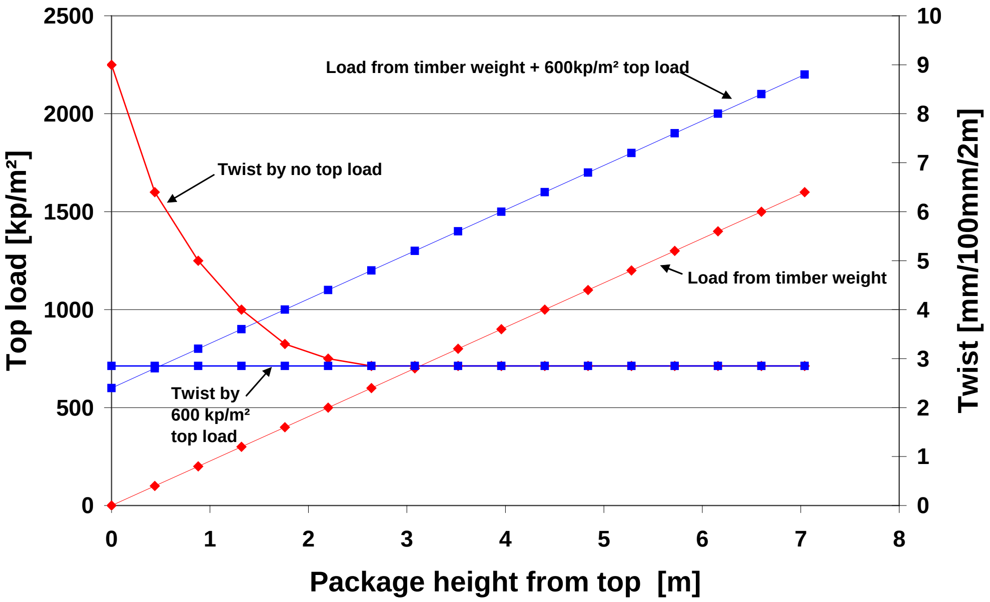


Figure 2.27. The influence of top loading and no top loading on the twist at different package heights from top.

In the diagram, where 600 kp/m² is set as the level where the timber is clamped, the influence of the "additional" top load will have a positive influence to about 2,6 m from the top of the timber charge compared to no top loading. In effect, this will be somewhere between one and a half and two packages from the top, depending on the package height.

The percentual gain in reduced distortion at top loading will therefore depend on the total package height. With only one package in a small kiln, the percentual gain will be very high. In a large kiln with package heights of 5-6 m, the percentual gain will be smaller. The absolute gain will, however, be almost similar for the two kilns.

Sticker distance

At all tests, the length of the free ends between the stickers was measured in order to get information on the importance of sticker distance on the degree of warping. In Figure 2.28 A, the average values of twist are plotted against the average length of the protruding (free) ends between the stickers and compared to the twist under the stickers (0 cm).

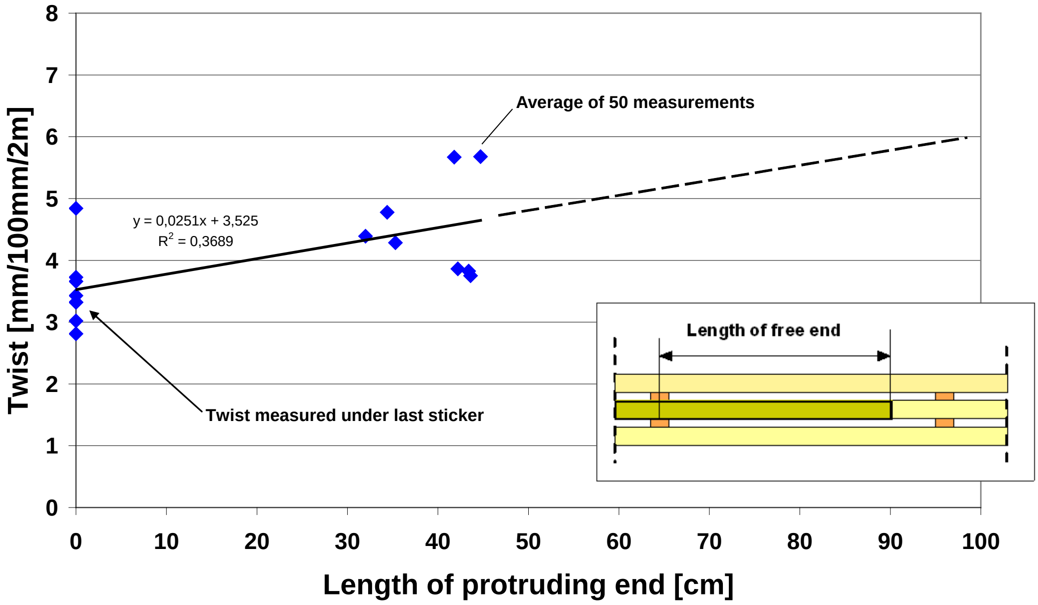


Figure 2.28 A. Influence of the length of free ends on twist (mean values).

In Figure 2.28 B, the individual values of twist is plotted against the length of free ends. The twist measured over 2 m, taken from the reference battens without loading, is also included in the diagram (statistically questionable, but gives additional information on what happens at very large sticker distances).

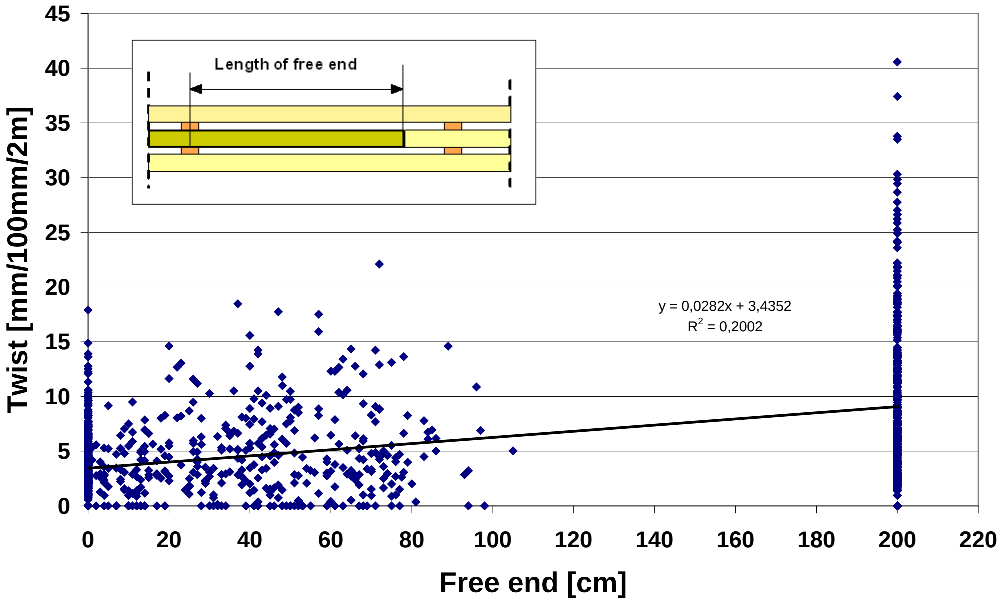


Figure 2.28 B. Influence of the length of free ends on twist. The values from unloaded battens with a theoretically free end of 200 cm are also included (individual values).

There seems to be a gradual increase in the twist with increasing length of the free end. The values are very scattered, due to all other parameters affecting the values. The twist of battens almost doubles at a free end of 1 m compared to being clamped between the stickers. A similar tendency was also obtained for bow and spring, but to a lower degree (Figure 2.29).

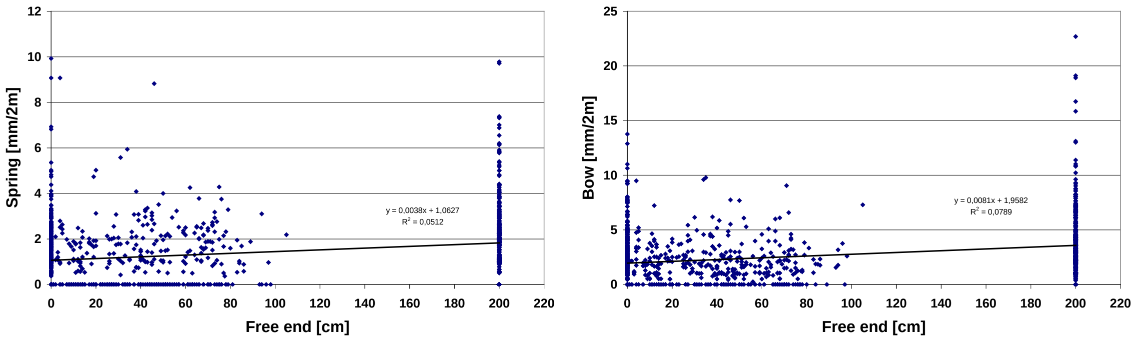


Figure 2.29. Influence of free end on the degree of bow and spring. The values from unloaded battens are also included with a theoretically free end of 200 cm (individual values).

Sticker marks

The influence of top load on the sticker marks is of interest, as the marks may limit the degree of top pressure (Figure 2.30).

Some influence was measured at the top loads used, but the observed sticker marks were not considered a problem at the two sawmills, even at the highest pressures.

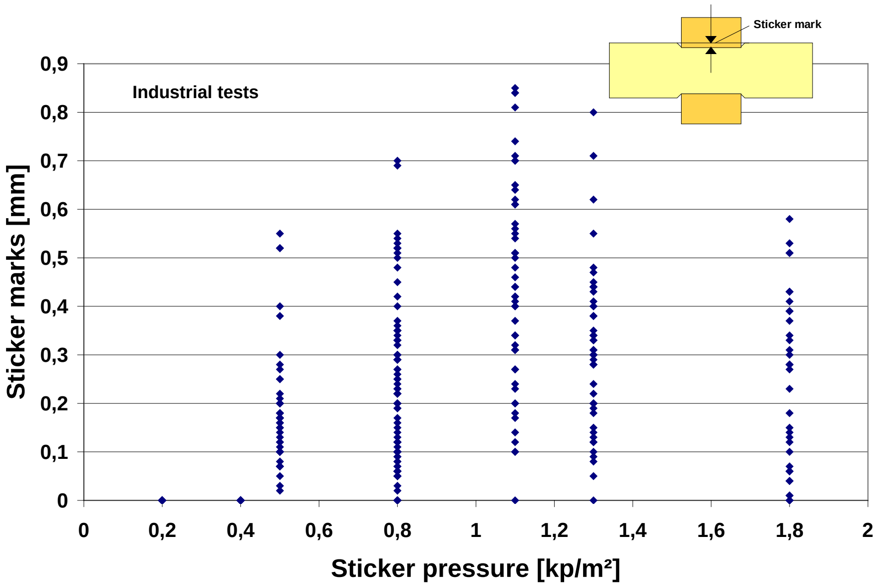


Figure 2.30. Influence of sticker pressure on sticker marks.

The sticker marks will also be most pronounced in the pith area and at the edges of the back side in battens due to shrinkage and cupping. These areas will mainly be planed away, and the sticker marks will therefore only to a little degree influence the rectangular yield. In thinner boards, these cupping forces will be too small to have a similar effect.

The thickness of all battens was also measured to find out whether there was any correlation between the thickness and the sticker marks. It is expected that the thicker battens are more exposed than the thinner ones when they are placed mixed in the same layer in the packages. In Figure 2.31, the sticker marks are plotted against the thickness of the battens.

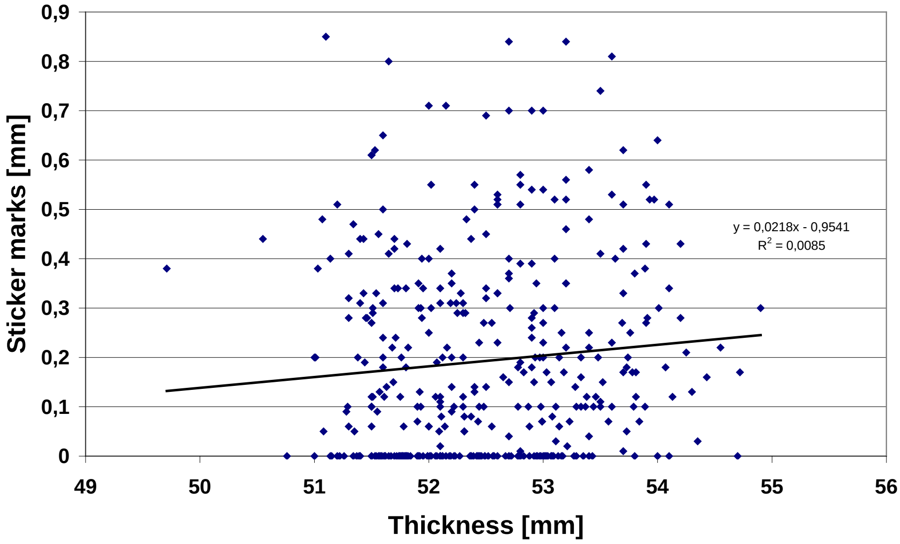


Figure 2.31. Influence of thickness of battens on sticker marks.

A statistical analysis shows only a slight linear correlation. The reason might be that the wooden stickers are relatively weak at the actual drying temperatures and will follow the timber thickness variation. The thickness of the battens above will also be random, helping to even out the total thickness in the height. If metal or plastic stickers were used, the effect might have been more evident.

Grain angle

Even if the correlation coefficient is low, the grain angle seems to have a considerable influence on the degree of twist, as expected. (Figure 2.32).

Analogous tests of grain angle and bow and spring showed no correlation.

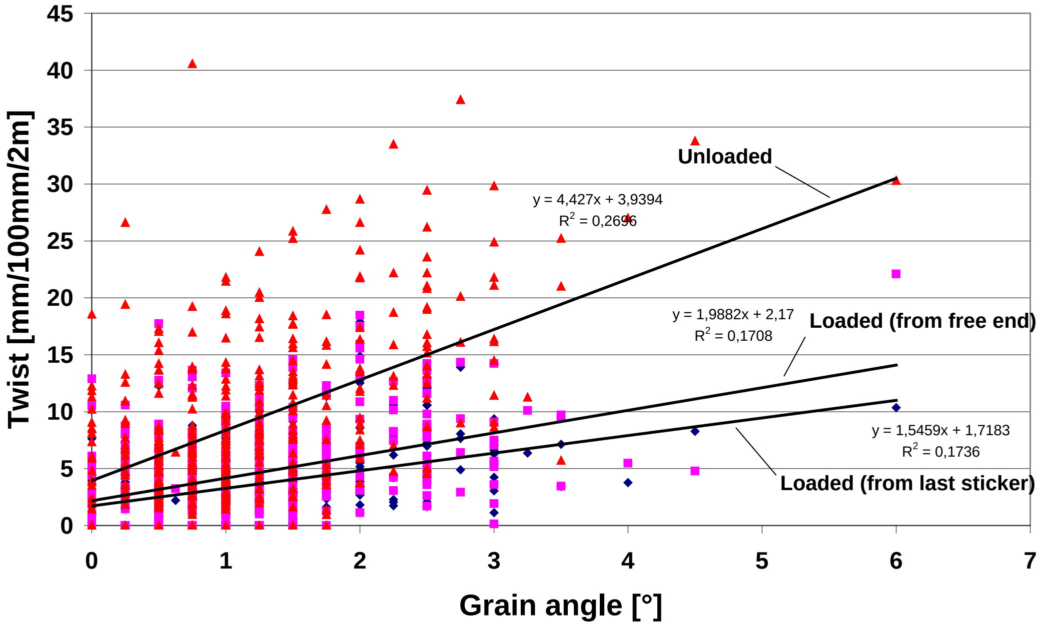


Figure 2.32. Influence of the grain angle on twist on unloaded and loaded battens measured from last sticker and from free end.

Regression analysis

The correlation between top load and distortion seems to be nearly exponential, following an equation like:

Distortion = A/(Top load + B) + C

For twist, the parameters for the industrial tests are estimated (Figure 2.33), giving the equation (top load in kp/m^2):

$$\text{Twist} = \frac{344{,}2}{Topload + 52{,}2} + 3{,}2 \text{ (mm/100 mm/2 m)}$$

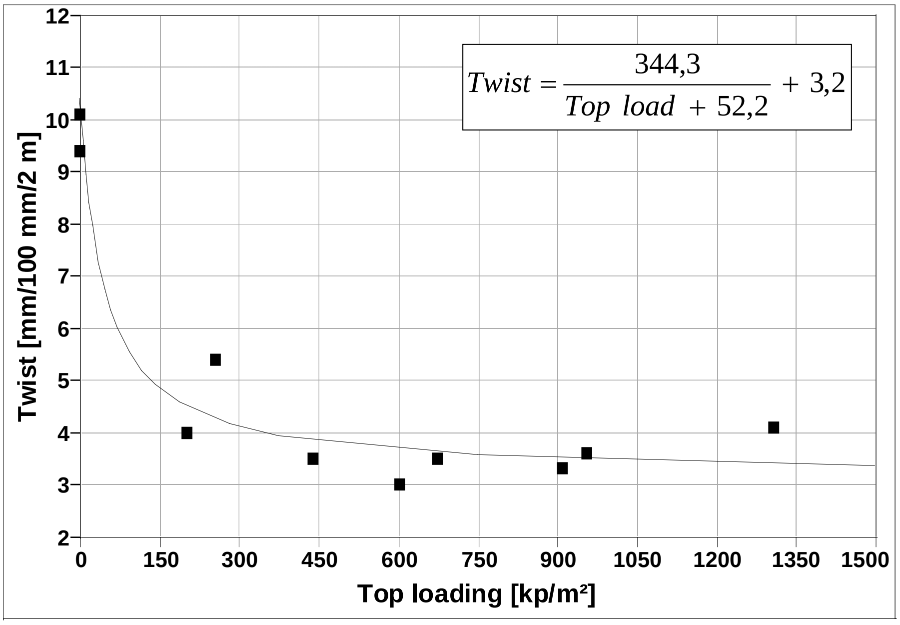


Figure 2.33. Exponential curve fit for twist as function of top load based on the industrial tests.

With the influence of the grain angle included, the formula for twist is estimated to:

Twist = 2,77 x grain angle – 0,0047 x top load + 4,64 (R^2 = 0,29)

The twisting of the free end is influenced by the length of the free end and the grain angle, as shown in the formula below:

Twist = 0,028 x free end + 2,645 x grain angle + 0,369 (R^2= 0,35)

(Free end in cm and grain angle in degrees).

2.3. Conclusion

The main objective of the laboratory and industrial tests was to find the influence of the top load on the degree of warp. In this connection, the results were clear – the top load had a considerable influence on all typical deformations in timber, such as twist, bow and spring, with twist as the most pronounced.

For all these types of deformations, the optimal top load, as to reduction in warp at the industrial tests, was at about 600 kp/m² for the dimension tested. At the laboratory tests, the optimal load was a bit higher, about 900 kp/m². The results from the industrial tests were based on 800 measurements compared to 256 measurements at the laboratory tests. One important observation is that the drop in deformation is very steep in the start, indicating that even a relative small top load has considerable influence on the deformations in the upper package.

Increasing the load above these levels had no further positive effect on the deformations. For bow, the deformations rather seemed to have a slight increase when exceeding the above mentioned loads. The influence of the top load was most pronounced for twist, with a reduction of the deformation down to about 30 % compared to unloaded battens. For bow and spring, the influence of the top load was also clear, with a reduction down to about 40 % at the optimal top load level.

Even if the optimal top loads for 50 mm x 100 mm battens were measured to be in the range of 600 kp/m^2 at the industrial tests, it is not obvious that the economic optimal top load is at that level. The economic optimal top load will depend on the benefits of the increasing load, compared to the extra costs of the equipment to raise the load. The economic optimal top load will surely be a bit lower than the measured optimal load. One should be aware that a top load of half the "optimal" gives app. 80 % of the maximum reduction in distortion.

The extra top load will only have a positive influence on the distortions where the load of the timber itself is below the optimal of about 600 kp/m^2. I.e. from the top layer to about 2,5 m down in the packages.

It is important to notice that the optimal top load proposed is for 50 mm x 100 mm battens. Thicker and more square battens will need higher loads, thinner and wider battens will need less load.

For large kilns with many packages in the height, it is extra important to align the stickers very precisely. Bad sticker alignment will lead to increased bow deformations when passing the optimal top load. It is also obvious that all sticker rows must be aligned with a support at the bottom of the kiln, securing that the forces will be led through the stickers to the ground without any bending moment. The optimal top load of about 600 kp/m^2 is set for the upper package, while the packages underneath will have gradually higher specific loads.

By using pneumatic or hydraulic top loading, it is possible to gradually increase the top load with reduced moisture content. In this way, the sticker pressure in the lower packages can be held at an acceptable level when the timber is wet and heavy. This can contribute to reduced sticker marks and avoid some of the excess bow in the lower packages by bad alignment of stickers. At the two test sawmills, the top load was set to 30 % of maximum at the start of the drying and increased to 100 % at 30 % and 40 % moisture content respectively.

With an acceptance level of 4 mm twist over 100 mm width at a length of 2 m, the acceptance percentage in the industrial tests increased from an average of 25 % for unloaded battens to 60 % for optimal loaded battens measured from the free end and to 75 % for battens measured from the last sticker. The same and even higher percentual increase in acceptance was observed at the laboratory tests.

For bow and spring, the acceptance level at a requirement of 4 mm and 3 mm respectively, over 2 m, increased from about 65 % for unloaded to 95 % for optimal loading.

The difference between warping of battens clamped between stickers (equals one length battens in the package) and battens with a combination of being clamped by the stickers and still having one end as a free protruding end between the stickers, was also measured. The results were statistically not very clear for the top loading, but indicated a 20 % reduction of twist by halving the sticker distance from e.g. 1,5 m to 0,75 m.

Increased top load will increase the sticker pressure and lead to sticker marks. The tests showed clearly that this will happen, but the level of sticker marks, even at the highest loads, was not reported as a problem at the sawmills.

The main reason for twisting, which is a grain angle different from zero, was clearly demonstrated in the tests, with a fairly good correlation between the grain angle and twist.

From the sawmills' and kiln operators' point of view, the installation of pneumatic top loading frames were reported as successful. This is mainly based on the results as to the reduced distortion, but also on the increased air flow due to almost zero air leakage above the packages. The securing of the packages against tilting was also reported as a clear benefit. However, the optimal load to avoid tilting has not been tested. Applying too high top pressure on kiln loads with several and badly aligned packages in the height, may lead to buckling.

The remanufacturing departments also reported a reduced downtime in the production line due to straighter battens.

The laboratory tests and industrial tests, with practical experience from daily running, all indicate a positive effect of applying top load to reduce distortion during drying.

3. BRE tests

3.1. Laboratory tests

Various pilot scale drying experiments were undertaken to assess the impact of top loading on drying quality, and in turn how this was affected by increases in drying temperature. Each test run consisted of one experimental trial and one control trial. Within each of these runs, half the load was top weighted, whilst the other half was unweighted.

3.1.1. Test material

The cutting patterns used in the UK differ slightly to those used in Northern Europe. Due to these differences, the sampling strategy was altered to ensure that battens dried experimentally could be compared to battens dried under control conditions. Each of the four trials utilised Sitka spruce (*Picea sitchensis*) from four different UK sawmills. In effect, this represents material from four different geographical regions of Scotland.

All the material was sourced from small diameter logs (160 cm - 180 cm top diameter) after having been sawn and stacked into parcels prior to kiln drying. A pack of "green" 50 mm x 100 mm x 4800 mm material was selected from the sawmill yard, and sequentially numbered plastic tags attached to both ends of each batten (different colours either end). The position of each batten remained the same during each set of tests. The parcel was then cross-cut into two equal lengths, and a moisture content sample (for green moisture content) removed from the central portion. The two packs of battens were then mixed (Figure 3.1) equally into two packs (this prevented all the "tops" or "butts" remaining in one parcel and affecting result comparability). This process involved exchanging or substituting every other set of battens between the two parcels. After this mixing process was complete, two almost identical packs of 50 mm x 100 mm x 235 mm material remained.

As already mentioned, each full size pack was then used to complete one trial. Each trial consisted of an experimental portion and a control portion.

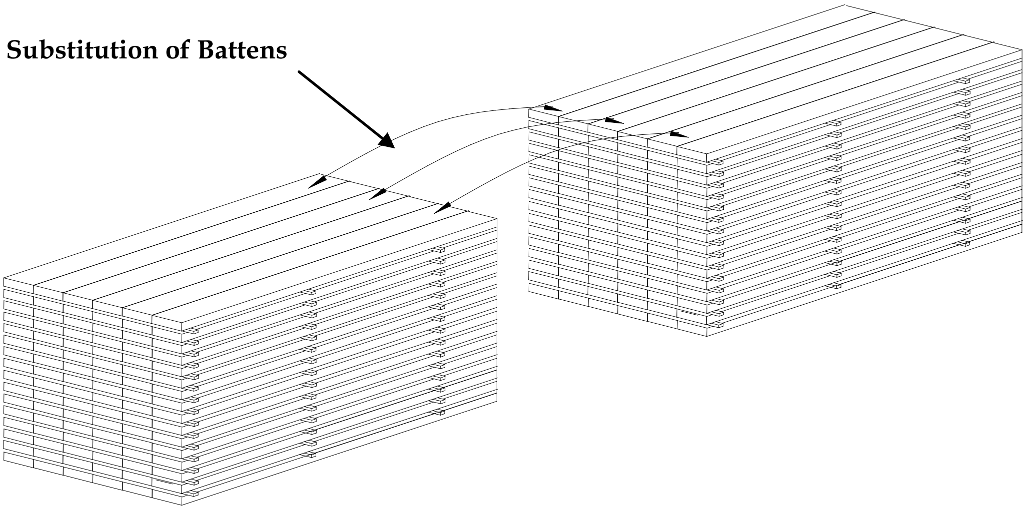


Figure 3.1. Batten substitution process. This prevented all the top or butt sections occurring in one pack and skewing results.

3.1.2. Test procedure

All eight kiln trials (four experimental and four control) were undertaken with between 100 and 154 battens (the number of battens occurring in a pack being dependent on the sawmill of origin).

Figure 3.2. Front view of kiln load, lower part loaded with 480 kg/m², upper section unloaded.

During each trial, the lower half of the kiln load was top loaded with concrete weights (480 kg/m²), and the upper layers were left unloaded. The weight on each upper layer of battens was considered negligible. *[Editors comment: With totally 6 layers of 50 mm battens in the "unloaded" kiln load, the top load on the underlying layers will gradually increase to a maximum of app. 160 kp/m² on the lower layer.]*

The amount of top weight used in these trials was decided after consideration of the initial results produced by NTI and practical considerations specific to UK industry. No pneumatic kilns are as yet, used by UK industry. Where top loading is used, this is generally provided by the application of concrete blocks. Due to the high levels of health and safety legislation present in the UK (and the risk of the stacks toppling due to concrete weights being placed on the top of drying stacks), the smallest optimal load to return the best reductions in distortion would be the preferred choice. Due to these considerations, a load of 480 kg/m² was selected.

Four sets of elevated drying temperature drying trials were completed. The first experimental trial was undertaken with a maximum dry bulb temperature of 67 °C. Each of the three subsequent experimental trials was increased by 5 °C, up to a maximum of 82 °C. For each experimental trial undertaken, a control pack was dried using a lower temperature control drying schedule (Figure 3.3). The maximum dry bulb temperature reached during this schedule was 57 °C. The control schedule utilised in this series of trials, closely follows that of a typical schedule used by one of the larger UK sawmills. The target moisture content for all the drying trials was set at 18 %.

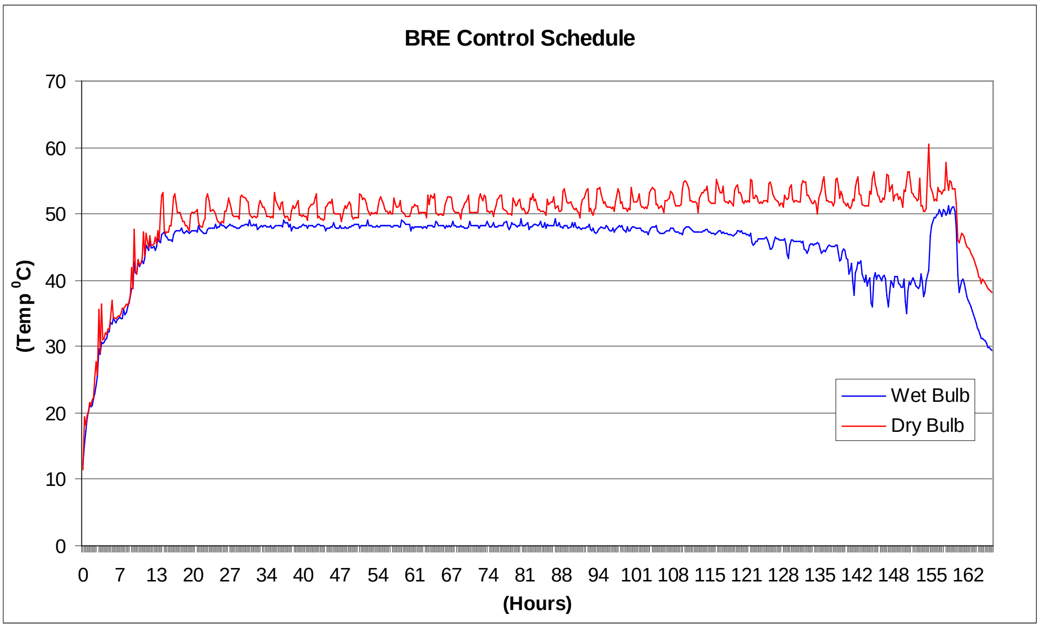


Figure 3.3. Control drying schedule.

During this and subsequent drying trials, all the drying parameters remained constant, whilst maintaining a similar schedule shape in accordance with the rise in dry bulb temperature. The drying parameters included:

- One pack of 50 mm x 100 mm x 4800 mm freshly cut UK grown spruce, split into two, to form one control pack and one experimental pack.
- Material used was taken, where possible, from small diameter logs.
- Each trial would further split the pack into two; half the pack would be top loaded and half left without load.
- Airflow velocity was maintained at 3,5 m/s throughout the schedule.
- Sticker thickness was: 22 mm x 38 mm and placed every 500 mm along the load.
- Airflow reversal time was set at 2 hour intervals.

After each kiln trial, twist, bow, spring, cup, moisture content, slope of grain and the position of piece in the log were measured on each individual piece. Throughout the kilning operation, the moisture content was monitored by using electrical resistance type measuring instruments.

Twist, bow and spring were measured on a specially designed aluminium distortion rig. Twist was measured over the central 2000 mm portion of each batten, at a height of 100 mm. Bow and spring were also measured on the central 2000 mm portion of each batten. Cup was measured using a special dial gauge jig, the measurement being taken from the centre of each batten, 50 mm from one edge. Twist, bow and spring were measured to an accuracy of 0,5 mm and cup to 0,1 mm. Oven dry samples (50 mm x 100 mm x 50 mm) were removed from battens during the cross-cutting stage to ascertain green moisture content.

3.1.3. Results and discussion

Comparison of moisture content and drying time

Each of the average moisture content values presented in Table 3.1 was calculated from results of the four trial packs. Initial moisture content was estimated using oven dry results from the green cross-sections removed during the initial cross-cutting stage. The final moisture contents were determined with an electrical resistance type moisture meter (1 measurement per batten, measuring depth 1/3 of board thickness).

Table 3.1. Average initial and final moisture contents of trial material.

Trial no.	**No. of battens in pack**	**"Green" average M/C (Std)**	**Control battens final average M/C (Std)**	**Experimental battens final average M/C (Std)**
1	142	74 % (25)	19,5 % (1,8)	21,0 % (2,7)
2	154	93 % (38)	19,7 % (3,9)	18,4 % (2,6)
3	100	78 % (44)	18,7 % (3,4)	18,5 % (3,0)
4	143	66 % (27)	20,0 % (2,7)	20,0 % (2,8)

Table 3.2 shows the drying times of the control and comparative experimental drying runs. The results indicate that the control schedule length varies between 167 hours and 182 hours, a maximum difference of 15 hours. The table also indicates that the longest control schedule does not always correspond to the highest initial "green" average moisture content.

Table 3.2. Drying time variation at different maximum dry bulb temperatures.

	Drying time (hrs)	Max. temp. (°C)	Drying time (hrs)	Max. temp. (°C)
Trial no.	Control		Experimental	
1	167	57	155	67
2	175	57	144	72
3	182	57	136	77
4	171	57	113	82

As expected, if the maximum dry bulb temperature is raised whilst keeping all other drying parameters constant, the drying time is reduced (Table 3.2 and Figure 3.4). This trend does not seem to be overly affected by quite large variations in initial moisture content, although further work would be required to verify these initial results and investigate how other drying parameters affect final wood quality.

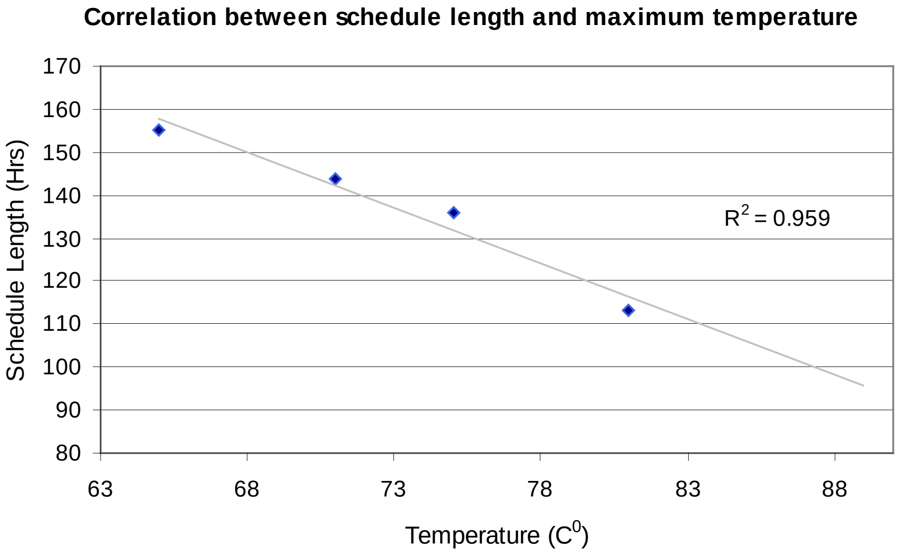


Figure 3.4. Correlation between maximum temperature and drying time.

The effects of top loading on the development of twist
Each of the four trials consisted of drying two packs of battens.

- One control set (half the pack dried under top load and half without top load).
- One experimental set (half the pack dried under top load and half without top load).

The control pack was dried using a set drying schedule (Figure 3.3), where the maximum dry bulb temperature was capped at 57 °C. Each of the experimental trials utilised a similar shaped schedule as that of the control schedule, but with an increase in maximum temperature from a target of 67 °C to 82 °C in 5 °C increments (Table 3.2).

The aim of the experimental procedure was to determine the effect of top loading in conjunction with the effects of raising the maximum drying temperature and how this affects the development or variation in drying distortion.

Figures 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 3.10 and 3.11 show the twist distribution frequency percentages for both control and experimental trials. Tables 3.3, 3.4, 3.5 and 3.6 show the percentage of battens falling within a 0-4 mm and 4-8 mm twist range, for both loaded and unloaded battens.

In both the control and experimental drying trials, the application of a top load was found to have a considerable influence on reducing the incidence of twist. The trials also provided firm evidence that top loading is more effective at reducing twist levels on battens which show a higher tendency to twist, when compared to those battens with a lower propensity to twist. The reduction in average twist values by the application of top weight can be extremely variable, being as much as 100 % or as little as 10 %. The reasons for this variation are still unclear.

With a twist acceptance level of 4 mm of over 100 mm width, by a 2000 mm length, the acceptance percentage in battens dried using control schedules increased from an average of 36 % in unloaded battens to 50 % for loaded battens. The acceptance percentage in battens dried using experimental schedules increased from an average of 31 % in unloaded battens to 53 % for loaded battens. These results indicate that the use of elevated drying temperatures and top loading seem to have a beneficial effect by increasing the percentage of battens falling into the 4 mm twist acceptance level. Even so, graphs shown later in this report, depicting the average values for all distortion parameters, show that higher values occur during the use of elevated temperatures and lower values occur using milder temperatures. These conflicting results indicate further work is necessary to validate initial results.

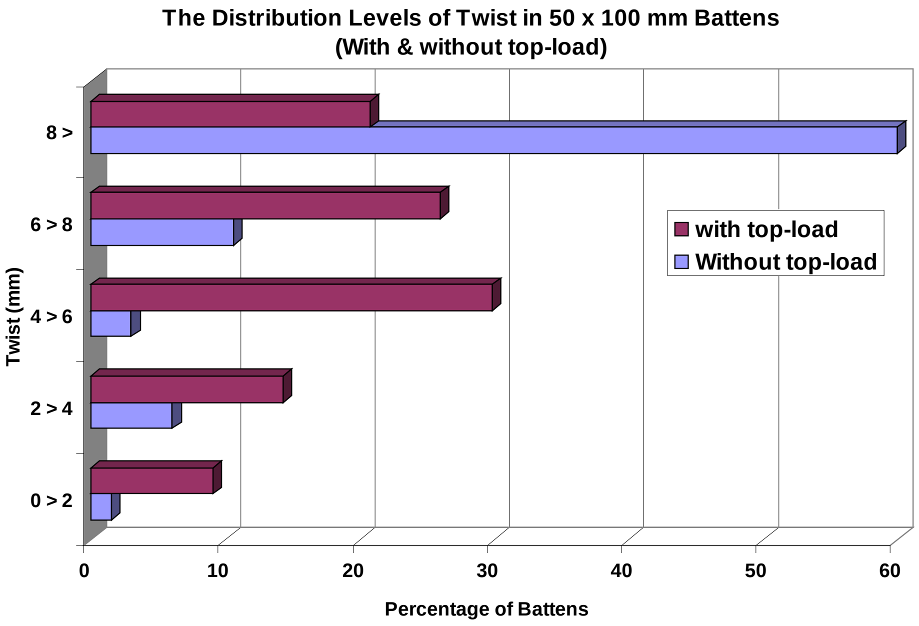


Figure 3.4. Distribution levels of twist in trial 1, control battens.

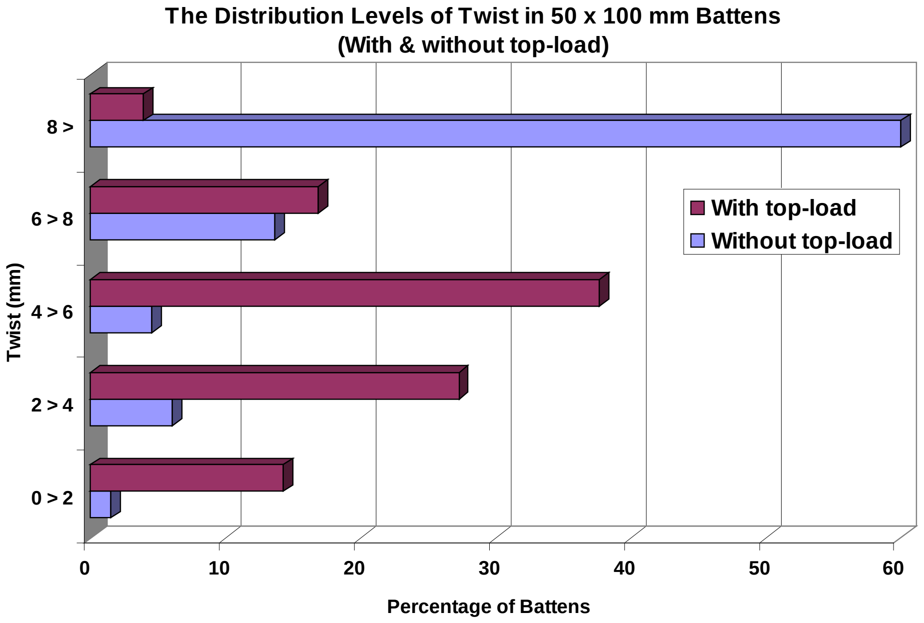


Figure 3.5. Distribution levels of twist in trial 1, experimental battens.

Table 3.3. Frequency distribution of twist within 0-4 mm and 4-8> mm (Trial 1).

	% of battens with twist levels within 0-4 mm range		% of battens with twist levels within 4-8> mm range	
	Top loaded	Unloaded	Top loaded	Unloaded
Control	23	8	77	92
Experimental	41	8	59	92

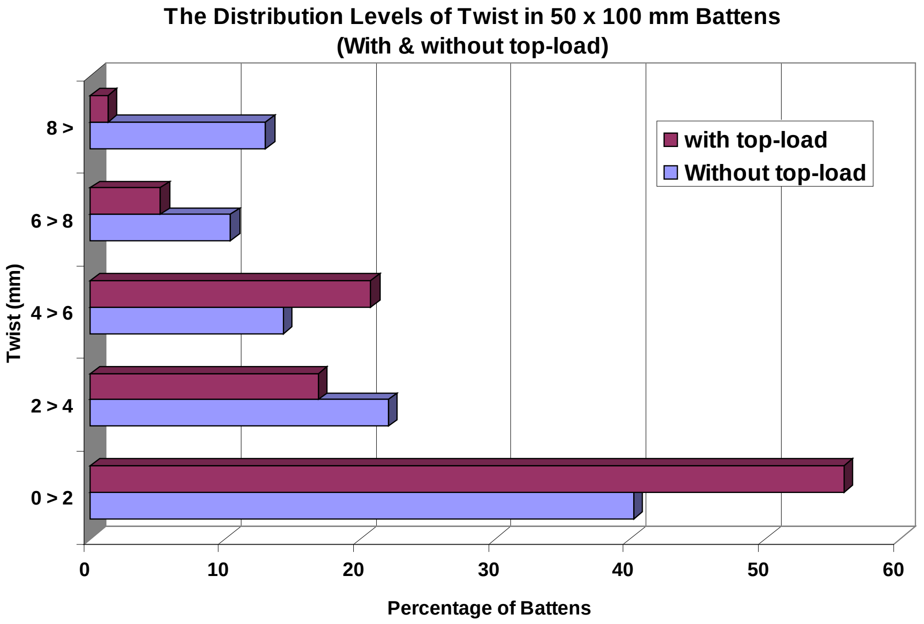


Figure 3.6. Distribution levels of twist in trial 2, control battens.

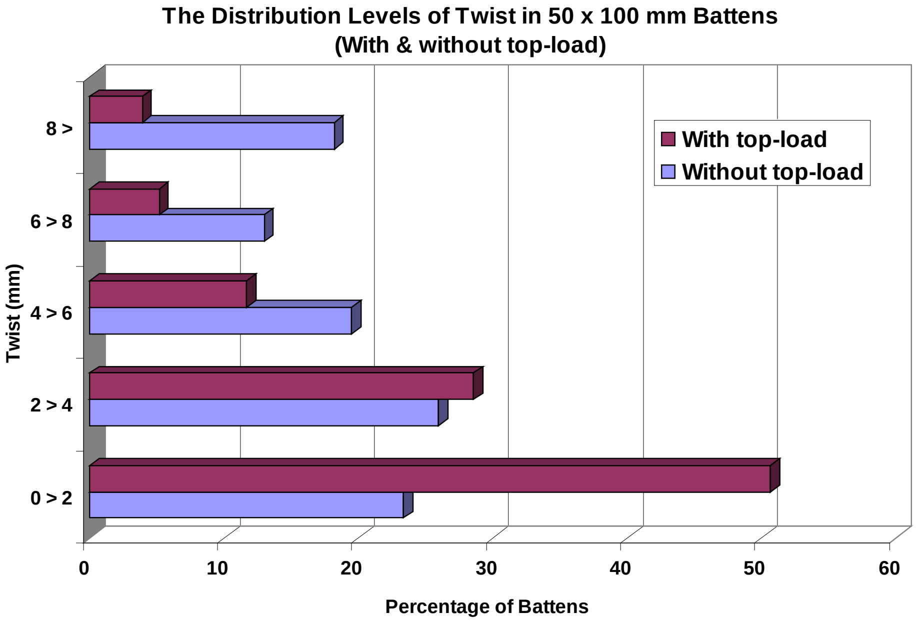


Figure 3.7. Distribution levels of twist in trial 2, experimental battens.

Table 3.4. Frequency distribution of twist within 0-4 mm and 4–8> mm (Trial 2).

	% of battens with twist levels within 0-4 mm range		% of battens with twist levels within 4-8> mm range	
	Top loaded	Unloaded	Top loaded	Unloaded
Control	73	62	27	38
Experimental	80	49	20	51

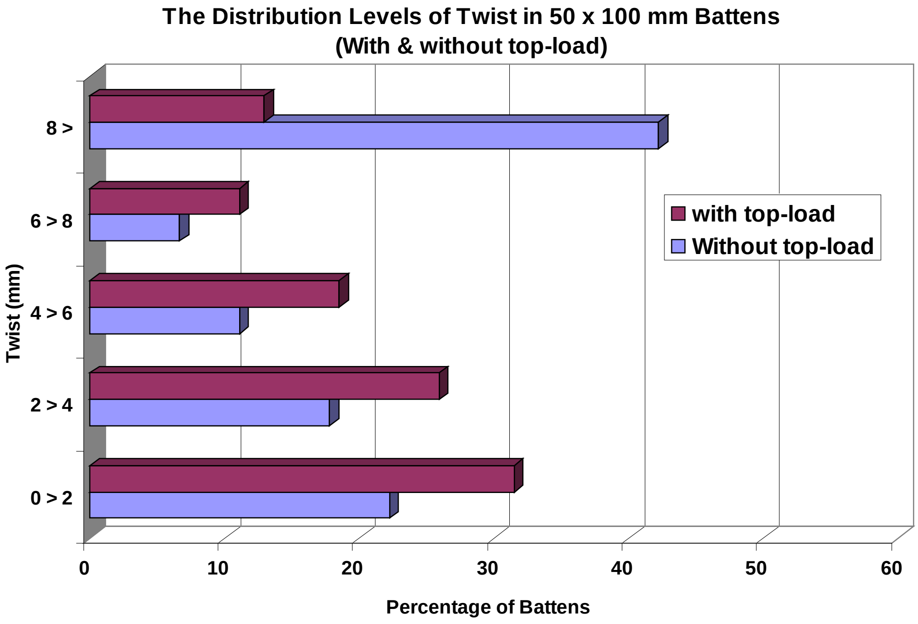


Figure 3.8. Distribution levels of twist in trial 3, control battens.

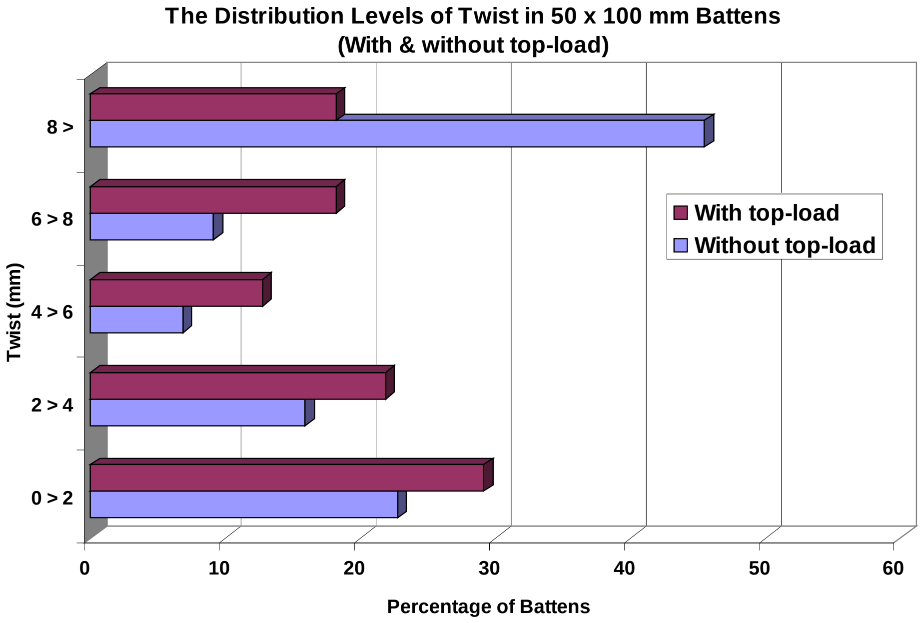


Figure 3.9. Distribution levels of twist in trial 3, experimental battens.

Table 3.5. Frequency distribution of twist within 0-4 mm and 4-8> mm (Trial 3).

	% of battens with twist levels within 0-4 mm range		% of battens with twist levels within 4-8> mm range	
	Top loaded	Unloaded	Top loaded	Unloaded
Control	57	40	43	60
Experimental	51	39	49	61

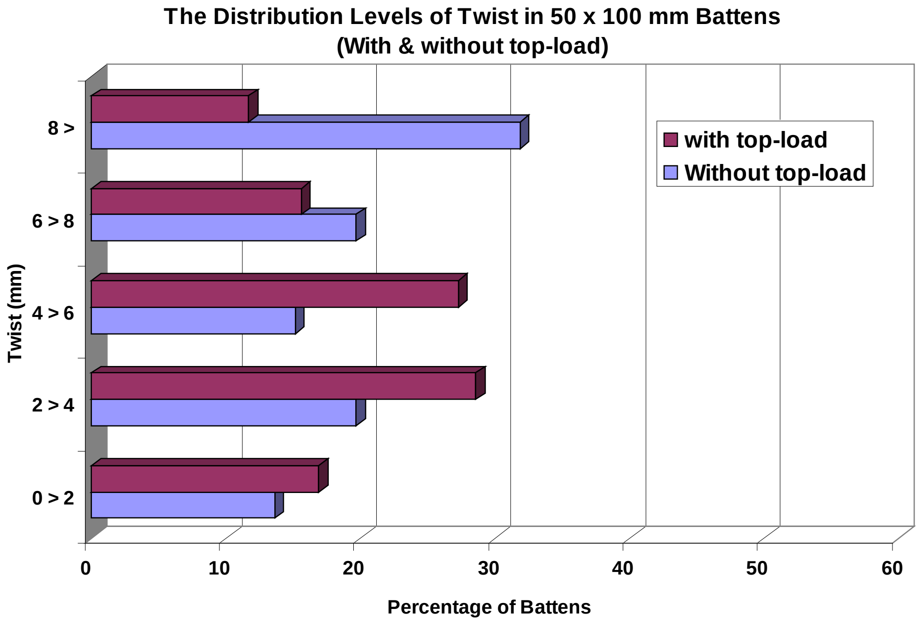


Figure 3.10. Distribution levels of twist in trial 4, control battens.

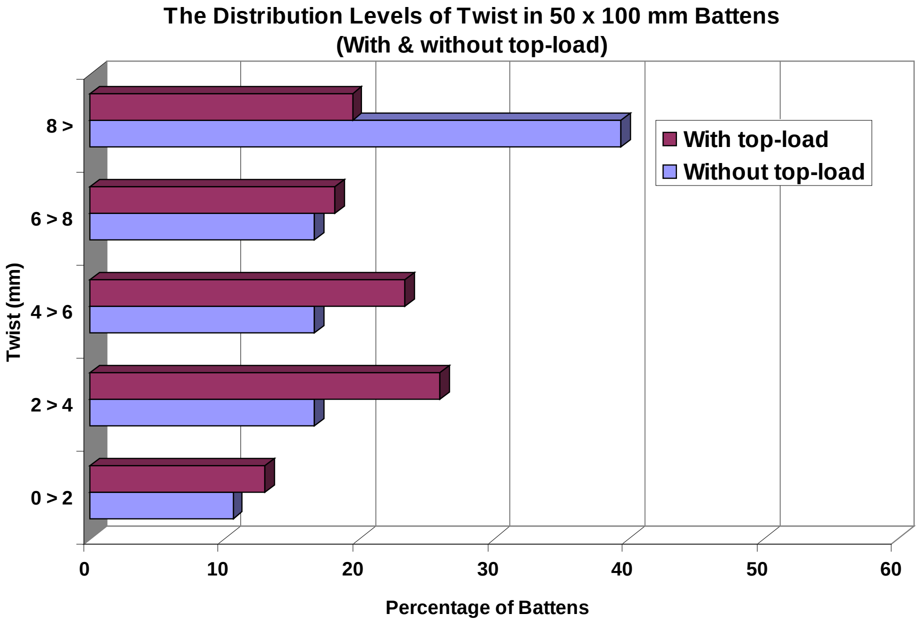


Figure 3.11. Distribution levels of twist in trial 4, experimental battens.

Table 3.6. Frequency distribution of twist within 0-4 mm and 4-8> mm (Trial 4).

	% of battens with twist levels within 0-4 mm range		% of battens with twist levels within 4-8> mm range	
	Top loaded	Unloaded	Top loaded	Unloaded
Control	46	34	54	66
Experimental	39	28	61	72

The effects of top loading on other forms of distortion

Figures 3.12, 3.13, 3.14 and 3.15 show the average values for all forms of distortion on material dried within the work programme. The graphs clearly show that the application of a top load significantly reduces the incidence of twist when compared to battens dried without any form of top loading. This trend is obvious in both control and experimentally dried material.

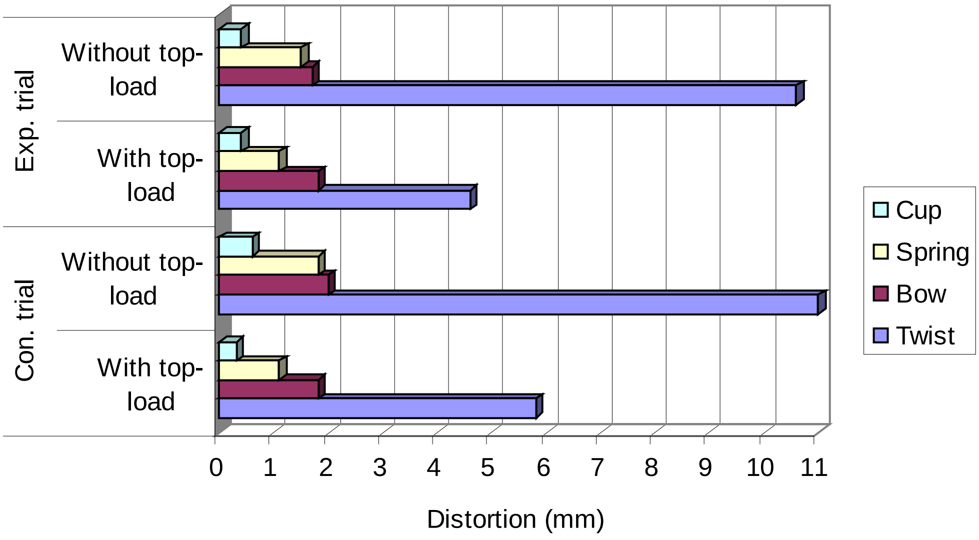


Figure 3.12. Average distortion values for trial 1 material, control and experimental.

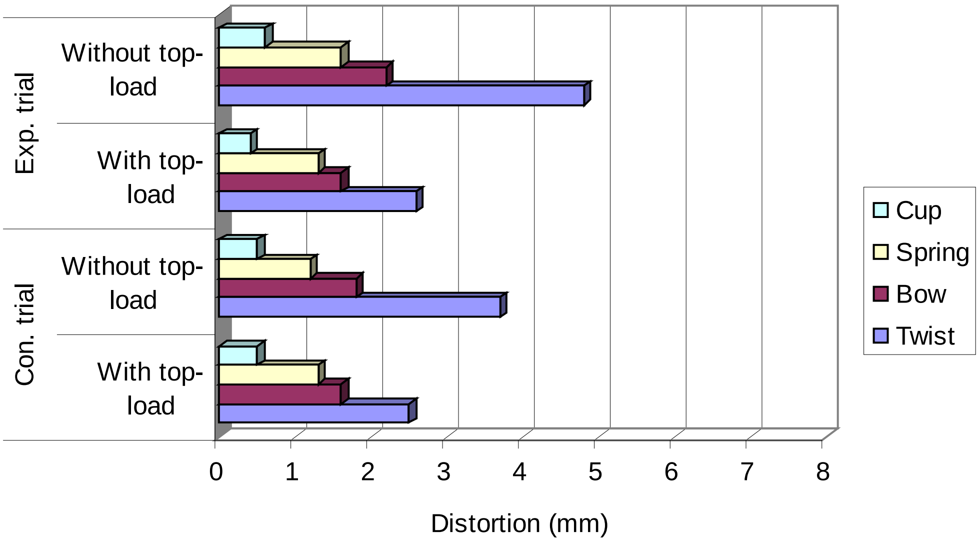


Figure 3.13. Average distortion values for trial 2 material, control and experimental.

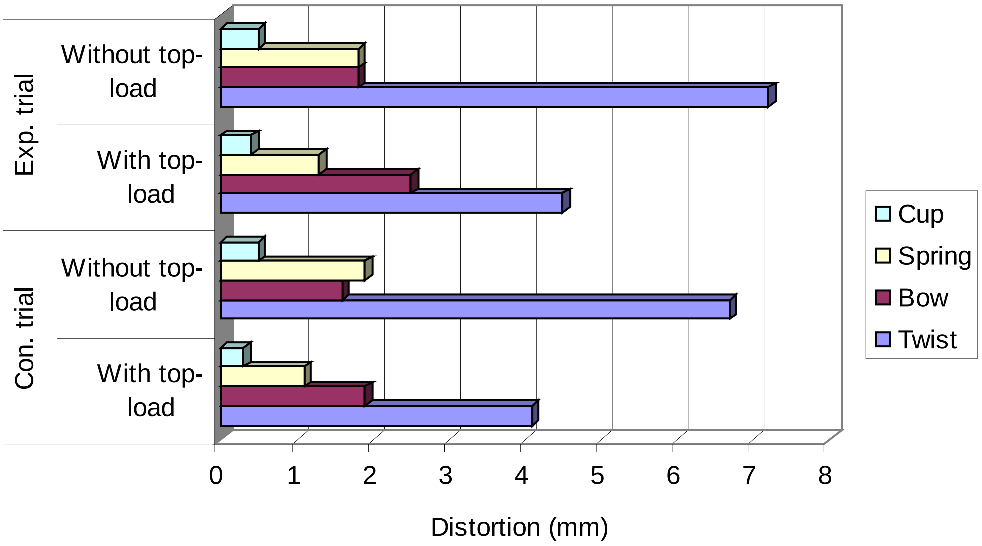


Figure 3.14. Average distortion values for trial 3 material, control and experimental.

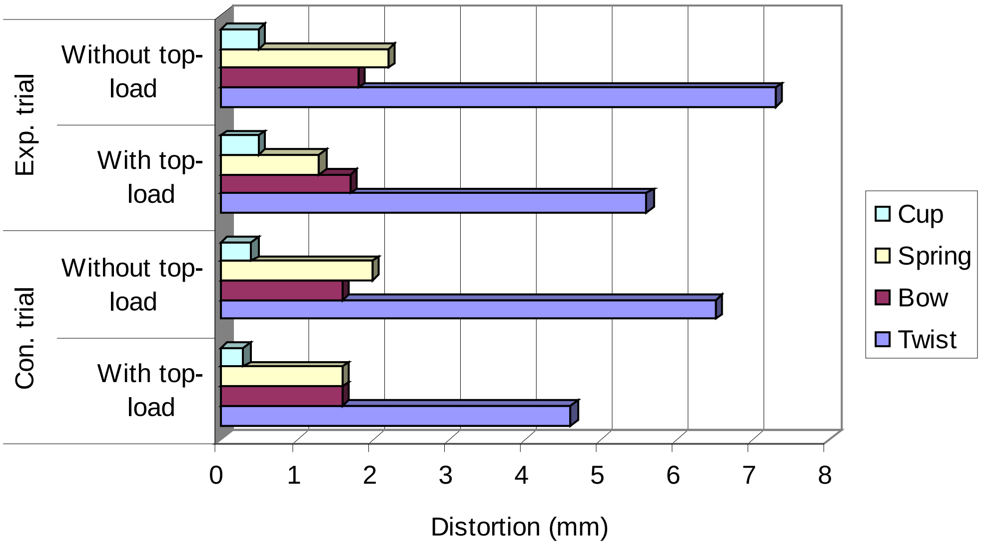


Figure 3.15. Average distortion values for trial 4 material, control and experimental.

The charts also show that the application of top weight, reduces the severity of bow spring and cup, although, not to the extent of twist. In general, the charts indicate that raising the maximum dry bulb temperature (experimental trials), causes the average twist values to increase slightly in comparison to material dried under lower control schedule temperatures. This trend is replicated in material both top loaded and unloaded. No explanation can be given for the values shown in Figure 3.12, where the figures show a complete reversal of this trend.

Slope of grain and its influence on distortion

Slope of grain measurements were recorded using the traditional scribing method. All the timber used in the experimental program was measured. Between three and six scribe marks were placed on each batten face (inner face, being the face closest to the centre of the tree and outer face being the face facing the outer part of the tree), and the average slope of grain angle calculated from the marks on that face. All battens with inconsistent slope of grain measurements were removed from the group before analysis. Figures 3.16 and 3.17 show the results recorded from trial 1 battens using twist values obtained from the control schedule program. The battens were dried to an average moisture content of 19,5 %. The results shown in both figures are very similar for all groups of battens used in this program.

The graphs indicate that there is a link (although weak) between the increase in slope of grain and the increase in twist after drying. This correlation is further enhanced by the application of top weight, which seems to reduce the variability of the twist values, in comparison with the large spread of results found in the battens without the application of top load. Although the graphs are not shown, the link shown between the increase in slope of grain and the increase in twist after drying is considerable worse when measurements recorded on the outer face of the same battens are used to form the graphs.

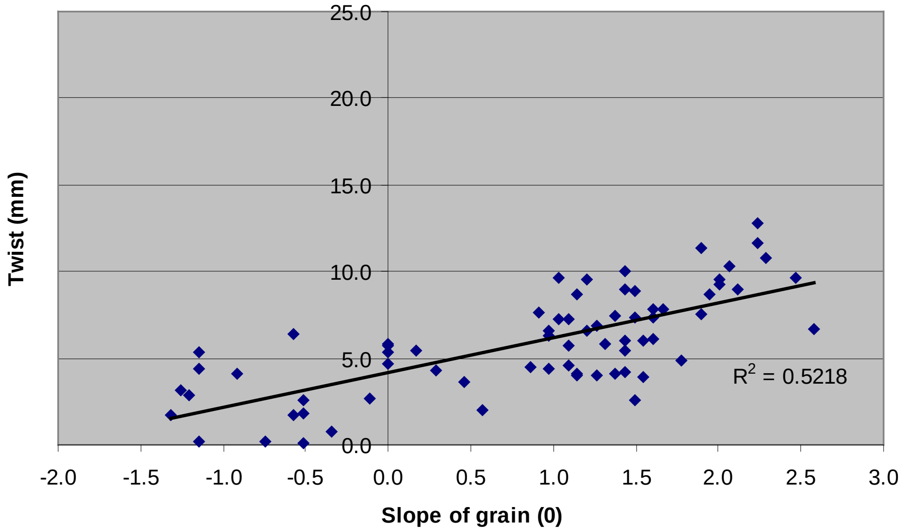


Figure 3.16. Correlation between slope of grain and twist on battens top weighted during drying (Trial 1 battens, inner face slope of grain measurements used).

A comparison between Figures 3.14 and 3.15 show that the application of top weight has a beneficial effect on the development and severity of twist, especially on those battens showing relatively high slope of grain. Figure 3.14 also shows that top loaded battens with a grain angle between -1,5° to 0,5° develop the lowest twist values within this group.

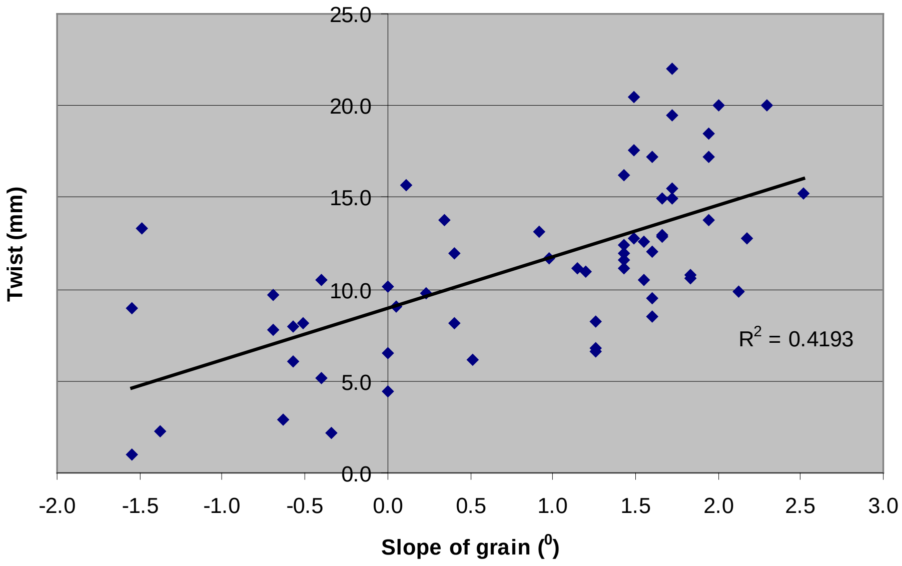


Figure 3.17. Correlation between slope of grain and twist on battens unweighted during drying (Trial 1 battens, inner face slope of grain measurements used).

No mention has been made so far regarding the relationship, if any, between slope of grain and log size. All the battens used in these trials have come from relatively small diameter logs (160–180 mm). Only small logs were used in this work. It is not known if the correlation between slope of grain and twist remains the same or improves with differences in log dimension. There may also be some differences between timber species from different countries.

3.2. Conclusion

The main objective of this series of drying trials was to assess the impact of top loading on the development of drying distortion, and if an increase in the maximum drying temperature affected drying quality and drying time.

Results from the four sets of trials clearly show that the application of top loading (480 kg/m^2) significantly reduces the incidence of twist when compared with battens without load. The trials also provided firm evidence that top loading is more effective at reducing twist levels on battens which show a higher tendency to twist, when compared to those battens with a lower propensity to twist. It should be noted that reductions in twist by the application of top loading can be very variable. Top loading has also been shown to reduce the incidence of bow, spring and cup, although not to the extent of twist.

With a twist acceptance level of 4 mm over 100 mm width, by a 2000 mm length, the acceptance percentage in battens dried using control schedules increased from an average of 36 % in unloaded battens to 50 % for loaded battens. The acceptance percentage in battens dried using experimental schedules increased from an average of 31 % in unloaded battens to 53 % for loaded battens. These results indicate that the use of elevated drying temperatures and top loading seem to have a beneficial effect by increasing the percentage of battens falling into the 4 mm twist acceptance level. Although, graphs depicting the average values for all distortion parameters show that the use of elevated temperatures results in higher distortion values and lower values occur using milder temperatures. These conflicting results indicate that further work is necessary to validate the initial results.

As expected, drying times were reduced when the maximum dry bulb temperature was increased (with all drying parameters remaining constant). Results from the experimental trials indicate that a good correlation existed between a stepwise increase in maximum dry bulb temperature and the reduction in drying time, even when quite large variations occur in initial moisture content. As explained previously, conflicting results exist on whether an increase in maximum dry bulb temperature increases or decreases the severity of twist.

Slope of grain measurements were recorded on all timber within this work program using the traditional scribing method. The results obtained indicate that there is a link (although weak) between the increase in slope of grain and the increase in twist after drying. This correlation is further enhanced by the application of top weight, which seems to reduce the variability of the twist values in comparison with the large spread of results found in the battens without the application of top load. The slope of grain/twist results obtained from UK Sitka spruce, do not seem to follow the good correlations exhibited by other species of spruce from partner countries.

In most UK softwood sawmills, drying is undertaken on standard length packs. Each pack consisting of processed material, which is all to the same length. This ensures that any problems associated with attempting to dry packs which consist of a number of different lengths (as seen in Sweden, Finland and Norway) is not encountered. Recommendations were also made a number of years ago relating to distances between stickers. Most, if not all, UK softwood mills now use sticker distances in the region of between 500-600 mm to reduce the incidence of distortion due to large sticker distances. For these reasons, problems associated with wide sticker spacing and uneven pack lengths are not encountered in the UK.

Overall, the results from these series of trials clearly show that top loading has a positive effect in reducing drying distortion, and that the softwood sawmilling industry would benefit greatly from top loading, whether static or pneumatic.

4. BFH tests

4.1. Laboratory tests

Various pilot scale drying experiments were carried out to analyse the impact of oscillating drying conditions on drying quality and drying time. The test runs were conducted with material that was top loaded. In each kiln load, unloaded material was used as control. All test runs were carried out with standard schedules. Drying temperatures ranged between 55 °C at the beginning and 70 °C towards the end. Climate oscillations in the standard heat and vent kiln were produced by controlling amplitude and frequency of the equilibrium moisture content (EMC). Temperature was kept constant during the climate oscillations.

4.1.1. Test material

Matched samples were used in four of the eight test runs to reduce the influence of material variation on the test results. 4500 mm long studs were cut in the middle. 50 % of the 2000 mm test pieces were dried with top loading, the remaining 50 % was dried unloaded (see Figure 4.3). Four of the kiln loads were Norway spruce from Northern Germany, whereas the other four kiln loads were UK grown Sitka spruce.

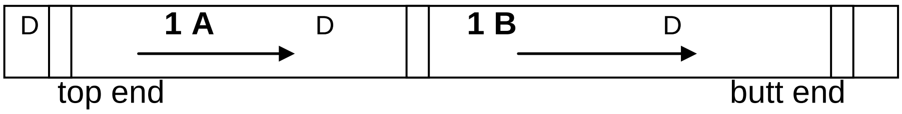


Figure 4.1. Cutting scheme for studs used in oscillation test runs with and without top loads.

The cutting scheme is presented in Figure 4.1. Cross section D next to the test material was used to determine initial moisture content of each board by means of the oven dry method. The progress of the kilning process (time when climate conditions are to be changed according to the drying schedule) was determined gravimetrically, which means that the actual moisture content of the kiln load was recalculated based on the weight of the pile and its initial moisture content.

Kiln runs 1-4 had to be carried out subsequently. It had to be ensured that the initial moisture content of the kiln loads did not change (no pre-drying). The first test series was carried out in January/February 2003. During this time, outdoor temperature was below 0 °C. Covered under plastic foil outdoors, moisture content of the studs hardly changed, which was proven by taking weight measurements occasionally. For the kiln runs st1a-st2b, initial moisture content was almost identical.

For the next four kiln runs, st3a-st4b, UK grown Sitka spruce material was used. For these kiln runs, matched samples could not be used, because the matching samples stayed in UK for industrial size tests.

Table 4.1. Coding of drying test runs with oscillation schedule.

Trial	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Code	st1a	st1b	st2a	st2b	st3a	st3b	st4a	st4b
Species	Norway spruce				Sitka spruce			

The studs were delivered with 2500 mm length. They were cut to 2000 mm length to fit into the pilot scale drier. Again, cross sections were taken to determine initial moisture content. End pieces were discarded (see Figure 4.2). The test material for runs st3a and st3b was delivered to BFH in June 2003. Due to ambient temperatures well above 20 °C, the material was partly pre-dried (see Table 4.2). Material for st4a and st4b was cut and delivered in January 2004. Due to the low temperatures, no pre-drying occurred. The loads for st4a and st4b had the highest initial moisture contents of all kiln runs.

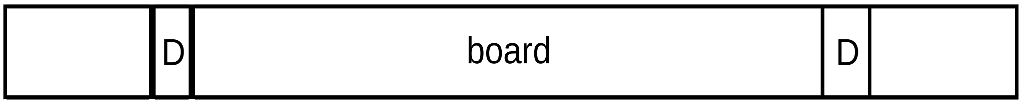


Figure 4.2. Cutting scheme for UK grown Sitka studs.

4.1.2. Test procedure

All eight test kiln runs were carried out with 108 studs (green dimensions 53 mm x 105 mm x 2000 mm). The lower half of the kiln load was top loaded with concrete weights (500 kg/m^2), whereas the upper half of the kiln load was unloaded. The weight of the studs in the upper layers was considered negligible. (*See editors comment in Chapter 3.1.2).* In order not to disturb the weight measurement and the controlling of the drying process based on the weight measurements, the weight of the top load was deducted before the kiln was loaded.

Figure 4.3. Front view of experimental stack, lower part loaded with 500 kg/m², upper part unloaded.

The drying schedules used for runs st1a-st2b (Norway spruce) and st3a-st4b (Sitka spruce) are presented in Tables 4.2 and 4.3.

Table 4.2. Drying schedules for Norway spruce.

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

Table 4.3. Drying schedules for Sitka spruce.

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

Throughout all test runs, the drying temperature in the consecutive drying steps was kept unchanged. Two types of climate oscillations were chosen for the first four test runs (st1a-st2b). In runs st1a and st2a, climate conditions were changed every 2,5 hours, whereas in st1b and st2b, conditions were changed every hour. In st1x runs, somewhat harder drying conditions were chosen compared to st2x runs.

Drying schedules st3x were modified based on the results of the first four runs. Oscillation time and amplitude of EMC oscillation were changed from short (1 h) and high (± 3 %) in the initial stages to long (3 h) and low (± 0 %) towards the end of the kiln run. In run st4a, the climate (EMC) was kept constant throughout each drying step.

The oscillation schedules used in this study try to simulate the climate conditions to which the outer packages of a kiln load are exposed in large industrial kilns. In a normal industrial kiln, the drying conditions on the air inlet side of the stack are equivalent to the set point values defined in the drying schedule, whereas the conditions on the air outlet side of the kiln are much softer. By changing the direction of the air flow, climate oscillations are unavoidable. Therefore, the "non-oscillating" conditions of test run st4a cannot be found in industrial batch kilns. But they are very similar to the conditions found in progressive kilns. Test run st4b simulates kiln runs, which have very short reversal intervals in early stages and rather long intervals towards the end.

After the kiln run, cup, bow, spring and twist of each individual stud were determined. In addition, all studs were assessed with respect to surface checking. Throughout the kilning operation, moisture content was calculated based on weight measurements. After the drying was terminated, average moisture content of individual studs was determined by using the electrical resistance type measuring instruments.

4.1.3. Results and discussion

Comparison of moisture content and drying time
Each of the average moisture content values presented in Table 4.4 were calculated from 108 studs. Initial moisture content was estimated by using the oven dry results from cross sections. The final moisture content was determined with electrical resistance type moisture meter (three measurements per stud, measuring depth, 1/3 of board thickness).

Table 4.4. Initial and final moisture content of test runs st1a-st4b.

Trial		MC %	Initial	Final
st1a		**Average**	73,6	16,8
		Standard deviation	33,9	2,3
	%	**Variation coefficient**	46	14
st1b		**Average**	76,2	14,2
		Standard deviation	28,3	1,9
	%	**Variation coefficient**	37	13
st2a		**Average**	79,6	15,9
		Standard deviation	29,5	2,1
	%	**Variation coefficient**	37	13
st2b		**Average**	76,8	15,6
		Standard deviation	31,4	2,3
	%	**Variation coefficient**	41	15
st3a		**Average**	66,1	14,6
		Standard deviation	18,1	1,8
	%	**Variation coefficient**	27	12
st3b		**Average**	63,0	16,0
		Standard deviation	20,1	2,9
	%	**Variation coefficient**	32	18
st4a		**Average**	88,2	15,9
		Standard deviation	30,5	3,1
	%	**Variation coefficient**	34	19
st4b		**Average**	90,3	15,3
		Standard deviation	30,7	3,1
	%	**Variation coefficient**	34	20

Because of the differing initial and final moisture contents between the test runs, the comparison of drying time is based on the time needed to dry the material from 63 % to 17 %. For run st3b, the time needed to dry from 57 % to 17 % was determined, because in this case, initial moisture content of 63 % was reduced to 57 % during the warming up period, which was not included in the evaluation. In order to be able to compare st3b with the other test results, the interval 57 % to 17 % was determined for all experiments.

Table 4.5. Drying time for different MC intervals.

	Drying time (h)	
	MC interval	
Trial	**63-17 %**	**54-17 %**
st1a	65	57
st1b	95	87
st2a	75	65
at2b	85	73
st3a	87	78
st3b	-	69
st4a	92	80
st4b	82	69

Results of runs st1a-st2b

As can be seen from Table 4.5, the time necessary to reduce moisture content varies considerably between the test runs. The most pronounced difference exists between the two hard drying schedules st1a and st1b. In case of st1b, 30 hours more are needed compared to st1a. For the mild schedules st2a and st2b, the difference is much smaller. High frequency of climate change (short air flow reversal times) results in longer drying times compared to longer air flow reversal times. Despite harder drying conditions, schedule st1b results in longer drying times as compared to the two mild schedules st2a and st2b. Standard deviation of final moisture content did not differ substantially between the test runs.

Pronounced differences were found with respect to surface checking. Table 4.6 shows the relative length of boards with checks (sum of all check length related to sum of board length in percent). The two schedules with harder conditions produced significantly more checks than the milder schedules. A clear effect of oscillation frequency on check development cannot be stated.

Table 4.6. Check development in tests st1a-st2b.

Trial	Board length with checks (%)
st1a	25,1
st1b	22,5
st2a	2,6
st2b	5,8

Results of runs st3a-st4b
Due to the high amount of studs that had developed checks during the two first trials, and due to the relatively long drying time for tests 3 (st2a) and 4 (st2b), the drying schedule used for st3a and st3b was modified. In st3a, the mild drying conditions of 14 % EMC (like in st2a and st2b) were kept until 40 % MC was reached. Below 40 % MC, conditions were intensified so that the conditions of st1a and st1b were reached. In addition, the amplitude of the oscillations was reduced. In test st3a, the reversal time was 2,5 hours throughout the whole duration of the test, whereas the reversal time in st3b was changed from short (1 h in the beginning) to long (2,5 h towards the end).

Results of st3a, st3b, st4a and st4b
In run st3b, 78 hours were needed to dry from 63 % to 17 %, which was 21 hours longer than in st1a and 13 hours longer than st2a. The reduction of the amplitude of the oscillations between 45 % and 30 % in test st3a, leads to a prolongation of drying time compared to st2a. Even the harder drying conditions towards the end could not make up for this.

In test st3b, the same drying time was needed as for st4b for the MC interval 54-17 %, which used the same initial conditions until 30 % MC. When one compares st3a and st3b with respect to drying time for the interval 54-17 %, a time save of 12 % has been achieved for st3b.

Test runs st3a and st3b show a lower amount of studs that exhibit surface checks compared to the st1 and st2 series. In st3a, only 1,7 % of the total stud length exhibited checks, whereas st3b had 3,2 %.

Table 4.7. Relative length of boards with checks.

Trial	Board length with checks (%)
st3a	1,7
st3b	3,2
st4a	0,6
st4b	0,5

In test st4a, 92 hours were needed to dry from 63 % to 17 % MC. This test run without climate oscillations showed the mildest drying conditions of all test runs. The oscillating run st4b needed 82 hours for the same MC interval, which is 10 % faster than st4b. Drying quality with respect to checking was approximately the same, but both runs, st4a and st4b, had lower checking tendency than all the other tests.

Results with respect to deformations

For all studs in all 8 test runs (st1a to st4b), deformation (twist, cup, bow and spring) was determined after completion of the drying experiment. Aim of the experimental procedure was to determine the effect of top loading in conjunction with oscillating conditions on development of deformations. For this purpose, each kiln was separated in two subsets, one of which was top loaded, whereas the other one was kept unloaded. Unloaded in this context means that the test boards are in effect exposed to the same conditions as the studs in the upper layer of the upper packages in a large industrial kiln.

Deformation twist

While assessing twist, 95 % of all studs examined showed positive twist. Only a very small percentage of all studs had negative twist, which was smaller than 1 mm/2000 mm. Positive twist ranged from 0,5 mm up to 17 mm/2000 mm. Both groups, with and without top loading, did not show a Gaussian normal distribution of twist values. For the top loaded group, either a left sided biased distribution or a distribution with two maxima was found. This showed that top loading has some effect on twist, but an efficient impact on all pieces for a package could not be achieved.

In the statistical evaluation, arithmetic means and standard deviation were not used, but rather median and confidence interval of median, as statistical parameters. Threshold level was set to 90 % for two-sided problems and to 95 % for one-sided problems.

Test runs st1a, st1b, st2a and st2b

In all four test runs, confidence levels for twist in unloaded and top loaded collectives overlap (see Table 4.8). From a statistical point of view, a very pronounced effect of top loading on twist cannot be established. Run st1a with very hard drying conditions showed the smallest deformation compared to the other test runs.

Table 4.8. Confidence interval of median for twist (values given in mm/2000 mm).

Twist [mm/2000 mm]	**Median confidence level**	
Trial	**Unloaded**	**Top load**
st1a	2,90 ≤ 4,89 ≥ 5,59	3,42 ≤ 4,06 ≥ 5,84
st1b	6,04 ≤ 6,93 ≥ 8,94	4,67 ≤ 5,70 ≥ 6,40
st2a	6,26 ≤ 7,39 ≥ 8,99	4,85 ≤ 5,68 ≥ 6,82
st2b	7,10 ≤ 9,11 ≥ 10,95	5,76 ≤ 7,10 ≥ 9,09

Considering the relative fraction of pieces with twist below threshold values of 4 mm and 10 mm, an absolute reduction of the number of pieces beyond these threshold values can be determined for the top loaded groups when compared to the unloaded groups. The positive effect is stronger for high twist values, which means that top loading is more effective on studs having a high tendency to twist, when compared to those with low propensity to twist.

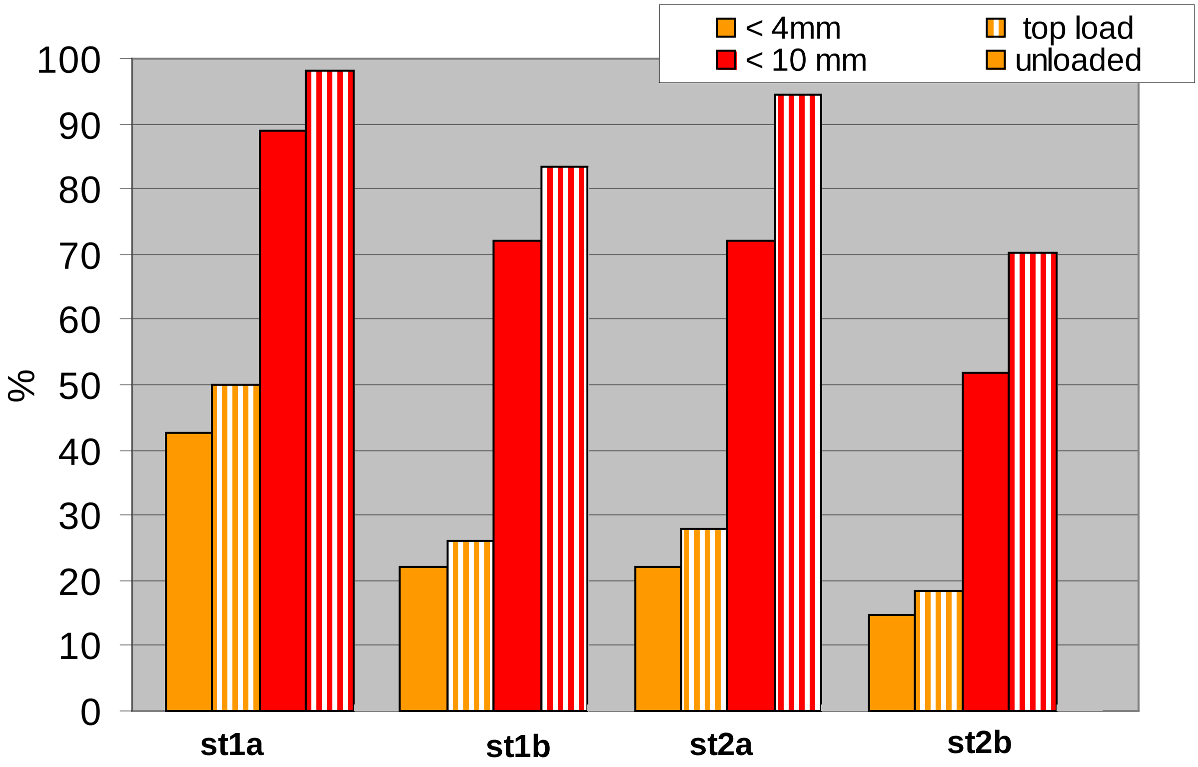


Figure 4.4. Reduction of twist by top loading in runs st1a, st1b, st2a and st2b.

Test runs st3a, st3b, st4a and st4b

In this group of four test runs, only st4a showed a significant reduction of twist affected by top loading. In all other test runs, no significant difference between top loaded and unloaded groups can be seen (see Table 4.9). This also means that an effect of climate oscillations on deformation behaviour could not be shown.

Table 4.9. Confidence interval of median for twist (values given in mm/2000 mm).

Twist [mm/2000 mm]	Median confidence level	
Trial	**Unloaded**	**Top load**
st3a	6,63 ≤ 8,42 ≥ 9,52	6,25 ≤ 7,91 ≥ 8,56
st3b	5,56 ≤ 7,25 ≥ 8,72	4,97 ≤ 5,62 ≥ 5,96
st4a	4,98 ≤ 5,92 ≥ 6,65	2,48 ≤ 2,87 ≥ 4,15
st4b	5,03 ≤ 7,04 ≥ 9,09	5,38 ≤ 6,75 ≥ 8,20

When comparing the two sets of test series, the hardest drying conditions (st1a in test series with Norway spruce) and the mildest conditions (st4a in test series with Sitka spruce) showed the lowest twist deformations. In the remaining 6 test runs, the oscillating conditions do not effect the deformation. Even between the two species, Sitka spruce and Norway spruce, no significant difference in deformation behaviour could be determined.

Deformations cup, bow and spring

For cup, bow and spring, a significant reduction by top loading was only observed in very rare cases. For cup, the median differences range from 0,05 to 0,1 mm/ 10 mm. Considering the very low variation, an effect of top loading on cup cannot be established. This missing effect might be due to the limited amount of top loading (500 kg/m^2).

Table 4.10. Confidence interval of median for cup (values given in mm/100 mm).

Cup [mm]	**Median confidence level**	
Trial	**Unloaded**	**Top load**
st1a	0,4 ≤ 0,5 ≥ 0,5	0,3 ≤ 0,4 ≥ 0,5
st1b	0,4 ≤ 0,5 ≥ 0,6	0,3 ≤ 0,5 ≥ 0,5
st2a	0,4 ≤ 0,5 ≥ 0,6	0,3 ≤ 0,4 ≥ 0,5
st2b	0,5 ≤ 0,5 ≥ 0,6	0,5 ≤ 0,6 ≥ 0,6
st3a	0,4 ≤ 0,5 ≥ 0,6	0,4 ≤ 0,5 ≥ 0,6
st3b	0,4 ≤ 0,5 ≥ 0,6	0,3 ≤ 0,4 ≥ 0,5
st4a	0,4 ≤ 0,5 ≥ 0,6	0,4 ≤ 0,5 ≥ 0,5
st4b	0,4 ≤ 0,6 ≥ 0,6	0,3 ≤ 0,4 ≥ 0,5

In the case of bow, an effect of top loading could only be established for two test runs. st2b and st4a showed reduced bow values.

Table 4.11. Confidence interval of median for bow (values given in mm/2000 mm).

Bow [mm/2000 mm]	**Median confidence level**	
Trial	**Unloaded**	**Top load**
st1a	2,1 ≤ 2,6 ≥ 3	2 ≤ 2,4 ≥ 2,7
st1b	0,9 ≤ 1,6 ≥ 2,3	2 ≤ 2,7 ≥ 3,2
st2a	1,8 ≤ 2,3 ≥ 2,9	2 ≤ 2,5 ≥ 2,8
st2b	1,8 ≤ 2,6 ≥ 3,4	1,2 ≤ 1,4 ≥ 1,6
st3a	1,3 ≤ 2,4 ≥ 3	0,9 ≤ 1,6≥ 2,2
st3b	1,5 ≤ 2,4 ≥ 3	1,5 ≤ 2 ≥ 2,4
st4a	2 ≤ 2,5 ≥ 3	1,2 ≤ 1,7 ≥ 2
st4b	1,8 ≤ 2,1≥ 2,8	1 ≤ 1,7 ≥ 2,1

For spring, no significant difference between the test runs could be established.

Table 4.12. Confidence interval of median for spring (values given in mm/2000 mm).

Spring [mm/2000 mm]	**Median confidence level**	
Trial	**Unloaded**	**Top load**
st1a	0,95 ≤ 1,43 ≥ 2,32	0,89 ≤ 1,45 ≥ 1,8
st1b	1,13 ≤ 1,66 ≥ 2,29	0,82 ≤ 1,08 ≥ 1,33
st2a	1,09 ≤ 1,35 ≥ 1,91	0,91 ≤ 1,4 ≥ 1,67
st2b	1,6 ≤ 2,19 ≥ 2,46	0,96 ≤ 1,75 ≥ 2,16
st3a	1,06 ≤ 1,54 ≥ 2,26	0,97 ≤ 1,4 ≥ 2,56
st3b	1,06 ≤ 1,58 ≥ 2,56	1,11 ≤ 1,43 ≥ 1,97
st4a	1,1 ≤ 1,44 ≥ 2,17	1,2 ≤ 1,32 ≥ 1,57
st4b	1,26 ≤ 1,59 ≥ 2,19	0,9 ≤ 1,2 ≥ 1,81

4.2. Conclusion

For Sitka spruce and Norway spruce, the level of the various types of deformation did not differ between the species. The fast grown Sitka spruce (st3a-st4b) did not show a more pronounced deformation propensity when compared to the more slowly grown Norway spruce (st1a-st2b). But results for all types of deformations were more evenly distributed for Sitka than for Norway spruce (compare Figures 4.4 and 4.5).

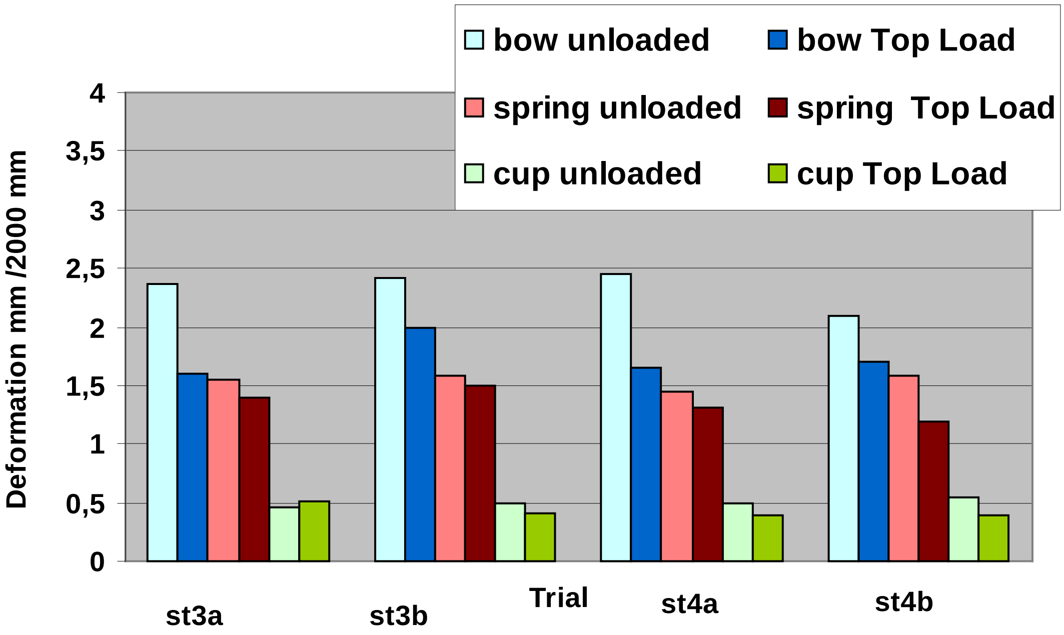


Figure 4.4. Median for deformation bow, spring und cup for Sitka spruce, st3a-st4b.

In the case of Norway spruce, bow increased under top loading in test runs st1b and st2a, which can be explained by the existence of bow before drying started. Initial deformation before drying was different for these groups. The average bow level for st1a and st2b was larger than 2,5 mm/2000 mm, whereas in the case of st1b and st2a, the average bow was below 2,5 mm/200 mm. With an average bow below 2,5 mm/200 mm, bow will increase during drying with and without top loading, whereas in the other case, bow is reduced. The greater the initial bow deformation, the more effectively bow is reduced by top loading.

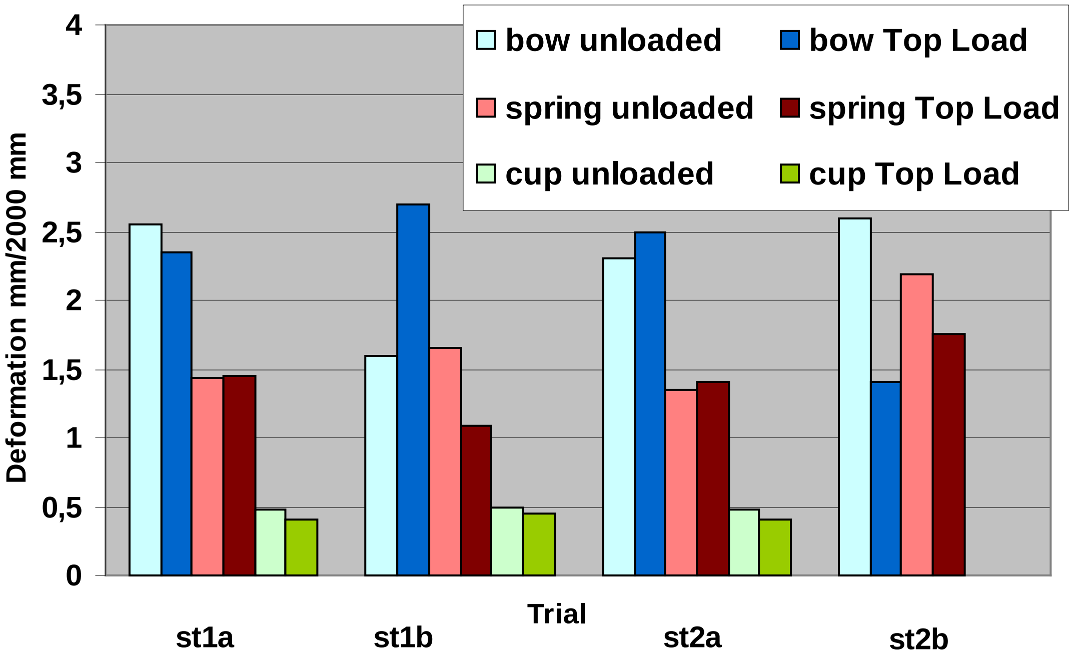


Figure 4.5. Median for deformation bow, spring und cup for Norway spruce, st1a-st2b.

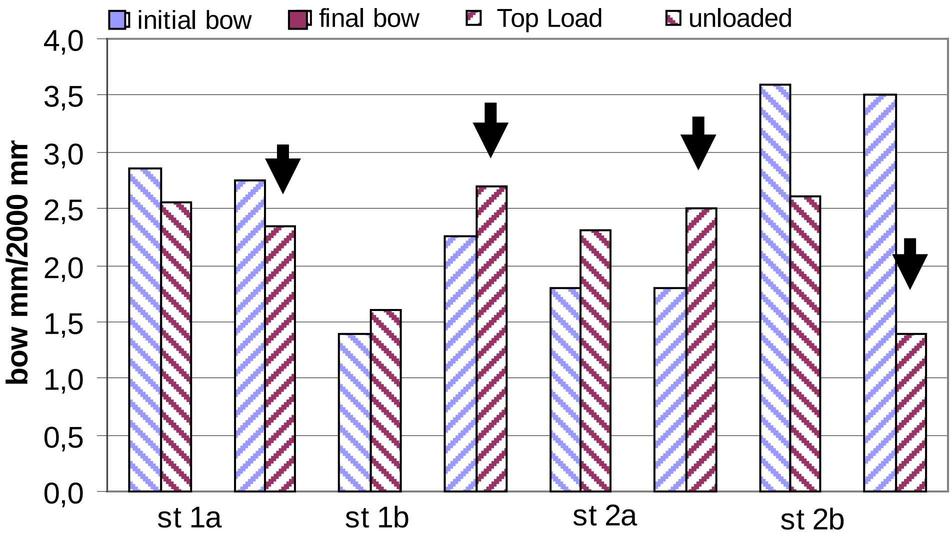


Figure 4.6. Median for initial and final deformation bow, st1a-st2b.

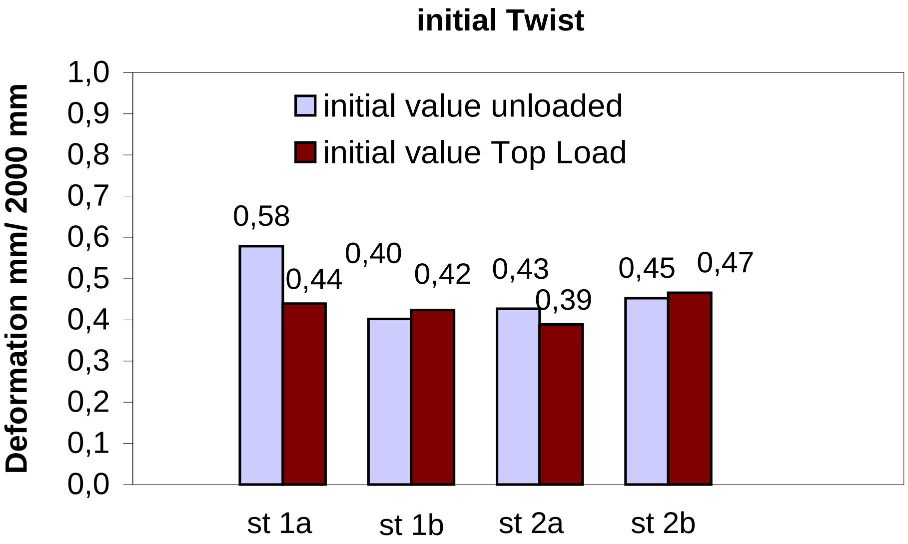


Figure 4.7. Median of initial twist for test runs st1a-st2b.

In the case of twist, only small differences regarding initial twist have been detected (see Figure 4.7). For this reason, a superposition of initial deformation and drying induced deformation can be neglected.

Due to oscillating climate conditions, a statistically proven positive or negative effect on development of deformation has not been found. But, considering the quite pronounced differences between the various schedules with different oscillation conditions, it can be shown that a considerable reduction of drying time can be achieved without any negative effect in terms of drying quality.

In the series of test runs with different oscillation conditions, an effect of top load on the development of deformations did exist, even though the differences between top loading und unloaded controls were not statistically significant. A possible reason for this can be seen in the quality of the test material, which already showed different levels of deformation in the green condition before drying. A considerable effect can be achieved with studs that already show deformations (twist and bow) before drying.

5. VTT tests

5.1. Laboratory tests

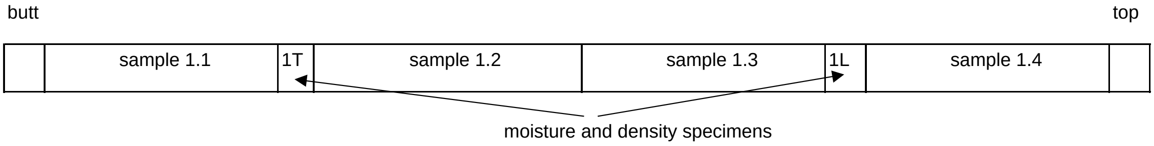
5.1.1. Test material

The test material for the laboratory tests was 50 mm x 100 mm Sitka spruce sent from BRE and Norway spruce from Finland.

All battens were cut in four 1,2 m long pieces to suit the length of the laboratory kiln.

The battens from BRE were labelled and divided into test and reference groups, using Batten Selection Process 2 in UK. After drying, the timber was sent to BRE for further measurements and analyses.

The Norway spruce battens were divided into four parallel groups (Figure 5.1). Initial MC and density was determined at two points in each long batten.



Dividing in drying groups

Pcs	Drying at 70 °C		HT-drying at 106 °C	
no	top loading	no loading	top loading	no loading
1	1,1	1,2	1,3	1,4
2	2,4	2,1	2,2	2,3
3	3,3	3,4	3,1	3,2
4	4,2	4,3	4,4	4,1
5	5,1	5,2	5,3	5,4
6	6,4	6,1	6,2	6,3
7	7,3	7,4	7,1	7,2
8	8,2	8,3	8,4	8,1
9	9,1	9,2	9,3	9,4
10	10,4	10,1	10,2	10,3
11	11,3	11,4	11,1	11,2
12	12,2	12,3	12,4	12,1
13	13,1	13,2	13,3	13,4
14	14,4	14,1	14,2	14,3
15	15,3	15,4	15,1	15,2
16	16,2	16,3	16,4	16,1
17	17,1	17,2	17,3	17,4
18	18,4	18,1	18,2	18,3
19	19,3	19,4	19,1	19,2

Pcs	Drying at 70 °C		HT-drying at 106 °C	
no	top loading	no loading	top loading	no loading
20	20,2	20	20	20
21	21,1	21	21	21
22	22,4	22	22	22
23	23,3	23	23	23
24	24,2	24	24	24
25	25,1	25	25	25
26	26,4	26	26	26
27	27,3	27	27	27
28	28,2	28	28	28
29	29,1	29	29	29
30	30,4	30	30	30
31	31,3	31	31	31
32	32,2	32	32	32
33	33,1	33	33	33
34	34,4	34	34	34
35	35,3	35	35	35

Figure 5.1. Dividing the battens into test groups in laboratory tests.

Average initial moisture content was 76 %, and the standard deviation was 23 %. Density (abs. dry mass/green volume) was 357 kg/m^3 and standard deviation was 38 kg/m^3.

5.1.2. Test procedure

Six high temperature dryings (105 °C and 120 °C) and two reference dryings at 70 °C were performed with Sitka spruce. In this report, only the drying schedules for the BRE battens are presented.

Two laboratory dryings, one at 105 °C, and a reference drying at 70 °C with Finnish Norway spruce were performed and analysed. These are reported further below.

The laboratory tests were performed at VTT in a Vanicek laboratory HT-kiln. The bottom part of the kiln charge was top loaded, and the upper part of the charge was without additional loading, i.e. the upper layer was totally unloaded while the lower layers were loaded with the layers above. (*See editors comment in Chapter 3.1.2*). Figure 5.2 shows a load of Sitka spruce in the kiln.

Figure 5.2. Drying charge in laboratory kiln. The bottom layer of timber is top loaded with aid of pneumatic cylinders. Species shown is Sitka spruce timber from UK.

The recorded drying schedules for Norway spruce are presented in Figures 5.3 and 5.4. In both schedules, there was a relatively long conditioning phase for reducing the MC deviation and gradient. To achieve an effective conditioning after HT drying, the timber was first cooled down. The condensation of steam on wood surface speeds up the conditioning.

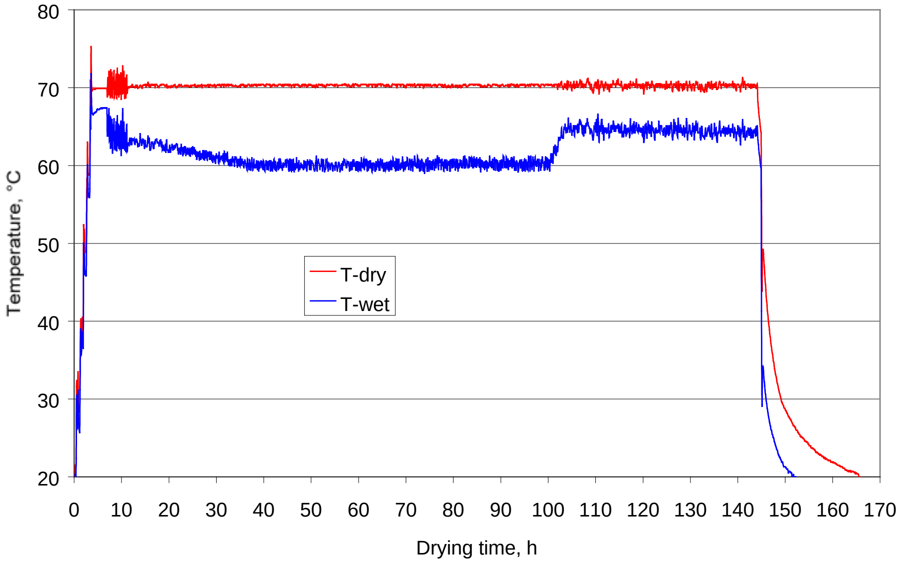


Figure 5.3. The measured low temperature drying schedule for Norway spruce.

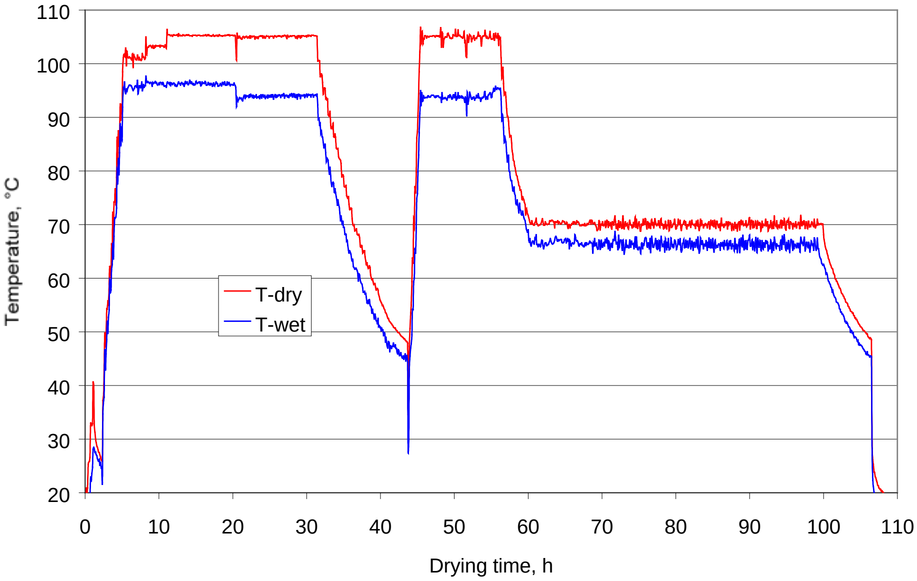


Figure 5.4. The measured high temperature drying schedule for Norway spruce.

Altogether 8 drying tests, 3 HT drying tests at 105 °C and 3 at 120 °C, with two reference tests at 70 °C, were run at VTT with Sitka spruce from UK. 3 different main drying schedules were used. Figure 5.5 presents the HT drying schedule at 105 °C. Figure 5.8 presents the reference drying schedule at 70 °C.

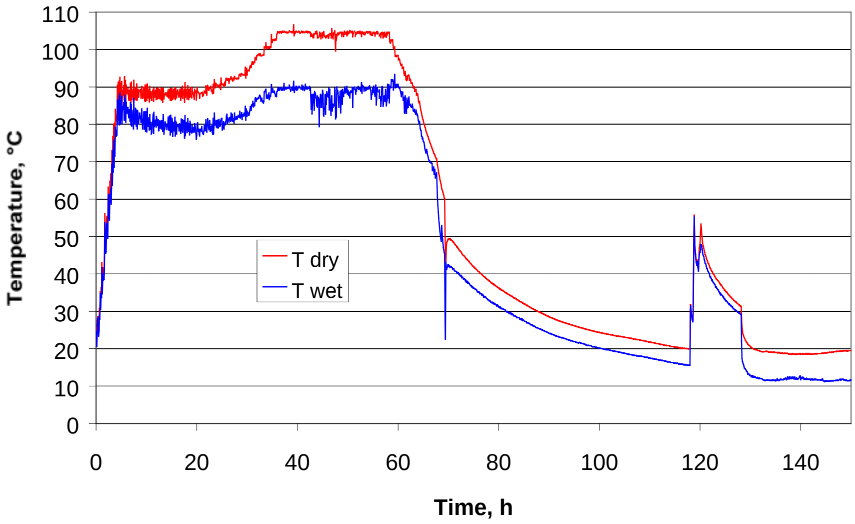


Figure 5.5. Drying schedule for Sitka spruce from UK. The first drying period at 90 °C is for avoiding collapse. A short conditioning after cooling down is added to reduce case hardening. The average air speed was 4,5 m/s. The second drying at 105 °C was quite similar, despite higher temperature (max. 90 °C) in the conditioning phase.

Figures 5.6 and 5.7 show how the timber was dried at 120 °C. The wood temperatures in the middle of the cross section can also be seen.

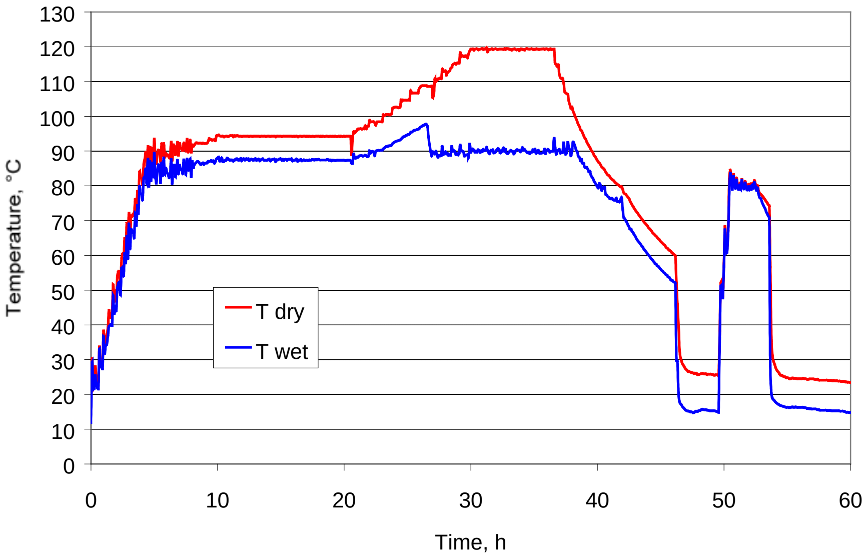


Figure 5.6. Drying schedule HT3 for Sitka spruce from UK. The first drying period at 95 °C is for avoiding collapse. A short conditioning after cooling down is added to reduce case hardening. The average air speed was 4,5 m/s.

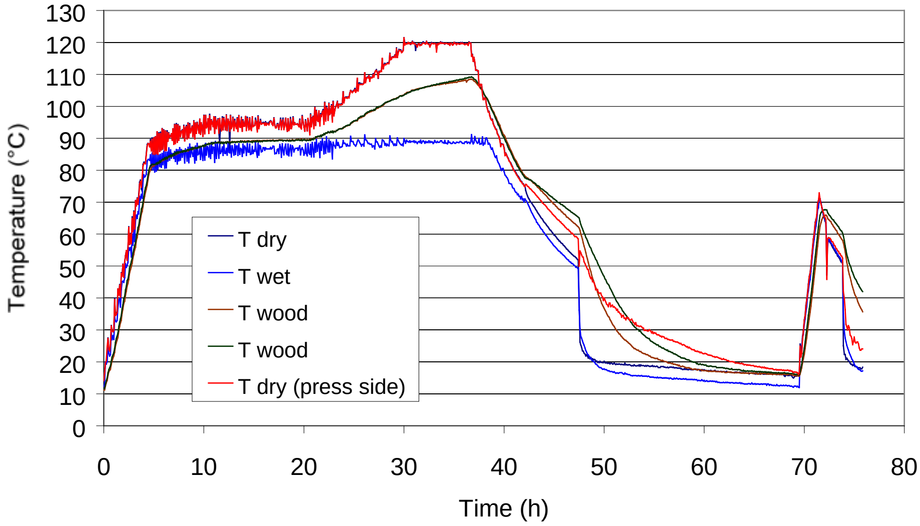


Figure 5.7. The measured dry and wet bulb temperatures and wood inside temperature in drying HT5 for Sitka spruce. The first drying period at 95 °C is for avoiding collapse. A short conditioning after cooling down is added to reduce case hardening. The average air speed was 3,6 m/s.

The reference drying schedule LT2 is presented in figure 5.8.

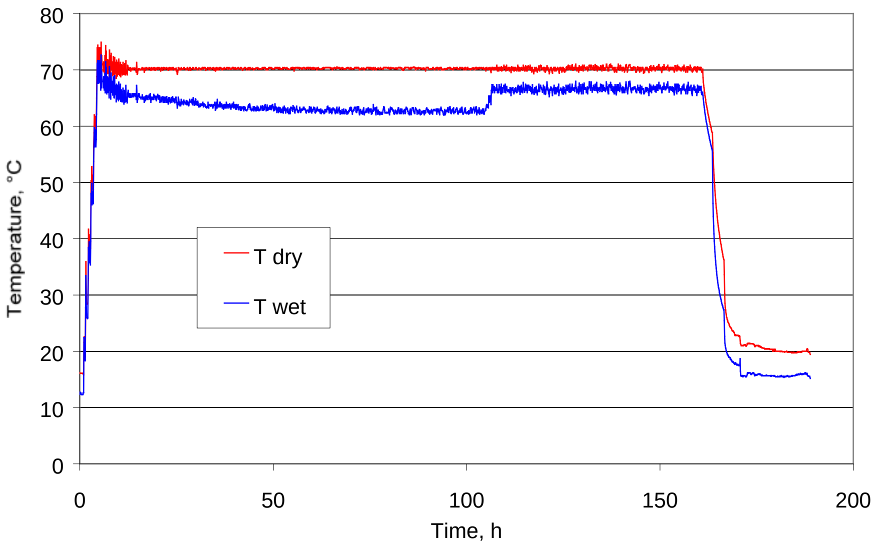


Figure 5.8. The measured reference drying schedule for Sitka spruce. Average air speed was 3,8 m/s.

The effect of different drying schedules and wood parameters on deformations for Sitka spruce is presented by BRE.

Deformations (twist, bow, spring and cup) and moisture content were measured after drying. Figure 5.9 presents the measuring of twist with aid of a deformation test jig. The data was transferred directly to a computer.

Figure 5.9. Jig for measuring deformations. Determination of twist.

The moisture content was measured after deformation measurements with the oven dry method.

The top loading was 5,2 kN/70 cm x 120 cm (stickers 1 m apart), which corresponds to 620 kp/m^2.

5.1.3. Results and discussion

Figures 5.10 and 5.11 present the average values of deformations, end moisture content and density of the drying groups. The figures show that the moisture content varies between groups. This has to be taken into consideration when comparing the results with each other.

Drying T$_d$ / top load	End MC %	Stdev %	Twist mm/1m	Stdev mm/1m	Bow mm/1m	Stdev mm/1m	Spring mm/1m	Stdev mm/1m	GA °	Stdev °
70 / no	11,2	0,6	5	3	1,4	1,1	0,6	0,7	3	1,3
70 / yes	10,9	0,6	3,7	2,1	1,5	1	0,8	0,7	2,2	1,1
106 / no	13,9	1,5	4,2	2,1	1,1	1	0,6	0,4	1,8	1,3
106 / yes	12,7	1	2,8	1,5	0,9	0,8	0,7	0,5	1,7	1,2

Figure 5.10. Average end moisture content, grain angle (GA) and deformations with standard deviations after dryings at 70 °C and 106 °C, with and without top loading of 620 kg/m^2.

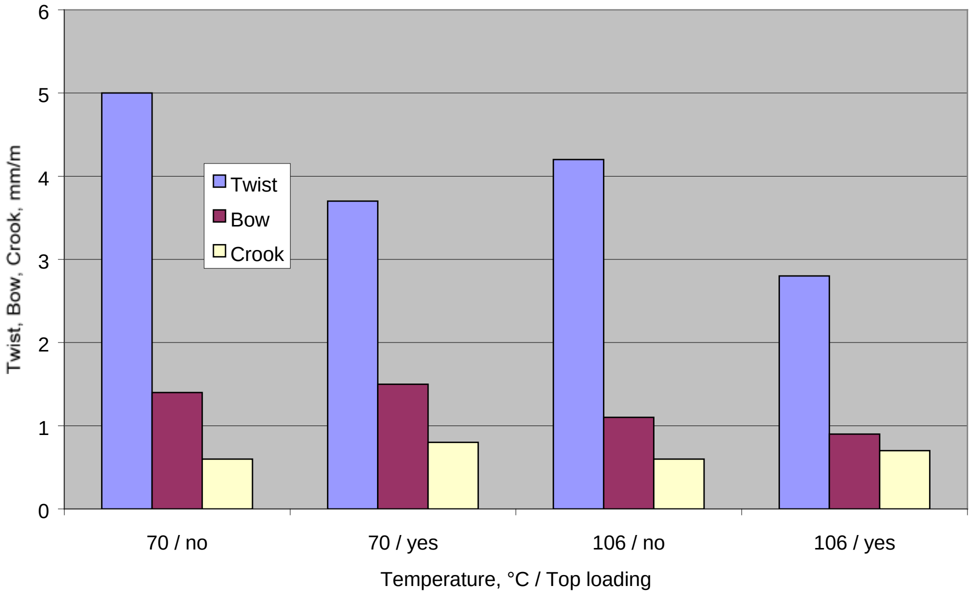


Figure 5.11. The effect of drying temperature and top loading on average distortion values. Norway spruce 50 mm x 100 mm. Average density 357 kg/m³ and stdv. 38 kg/m³. End moisture contents from left to right: 11,2 %, 10,9 %, 13,9 % and 12,7 %.

The differences in moisture content complicates the comparison of deformations. But the top loading seems to have a diminishing effect on twist as expected. The effect on bow and spring is not clear. Analysis of variance will give a better expression of the effects of variables.

Analysis of twist shows that the grain angle (GA) explains 45 % of the twisting, and GA together with top loading (TL) gives an explanation of 53 %. The grain angle is an average value on the middle part of the outer face. Top loading is expressed with 1 and no top loading with 0. The equation for twist is as follows (formula 1).

$$\text{Twist (mm/m/100 mm)} = 1{,}25 \times GA - 1{,}35 \times TL + 1{,}44 \qquad (R^2 = 0{,}45) \qquad (1)$$

where GA = grain angle (°)
TL = top loading, (1 = 620 kp/m²; 0 = no top loading)

According to formula 1, the twisting of timber with GA = 5 ° is on average 6,3 mm/m/100 mm and without top loading 7,7 mm/m/100 mm. Thus, a reduction of 18 % due top loading.

Adding the temperature to the regression formula increases the explanation only by 2 %. The regression formula is as follows (equation 2).

$$\text{Twist} = 1{,}25 \times GA - 1{,}38 \times TL - 0{,}012 \times T + 3{,}18 \qquad (2)$$

where T = temperature (°C)

The previous example calculated with formula 2 at 70 °C would give 8,6 mm/m/100 mm without top loading and 7,2 mm/m/100 mm when loaded. At 105 °C, the corresponding values are 8,2 mm/m/100 mm and 6,8 mm/m/100 mm.

According to these results, the effect of temperature is quite small, but showing that increasing temperature decreases deformations.

An other interesting result of the variance analysis is that the end moisture content had no significant effect on the twisting. Adding end MC to the model did not change the explanation percentage.

5.2. Industrial tests

5.2.1. Test material

Norway spruce was sawn with 2 x log from top diameter class 150-160 mm. Nominal timber dimension was 50 mm x 100 mm. From each log, only the upper batten was selected for test drying. It was assumed that the timber material does not vary very much during the sawing period.

The selection of only one batten from each log is explained with a larger population of battens in the variance analysis and therefore better reliability of the results.

The test material was collected in four sorting boxes, 50 pcs. in each for one drying. Every fourth batten was directed to one box. When the boxes had 200 battens in all, they were fed to the sticking machine and then on to drying charges.

5.2.2. Test procedure

The timber groups were placed in four positions in the kiln (Figure 5.13). Only 48 battens (three layers, 16 pcs. in each) were analysed after drying. The two extra battens were kept in reserve for unexpected situations.

After sticking the timber for HT drying, the procedure was repeated with battens drying at 70 °C. Figure 5.13 presents the arrangement in a batch type kiln for LT drying.

Two high temperature industrial drying tests (at 120 °C and 105 °C) with reference dryings (at 70 °C) were performed at Stora Enso Timber, Kotka Sawmill. A Thermowood plant (Figure 5.12) was used for HT drying. Reference dryings were done in a normal batch type kiln.

Figure 5.12. Timber in the Thermowood plant after drying at 120 °C at Stora Enso Timber, Kotka Sawmill.

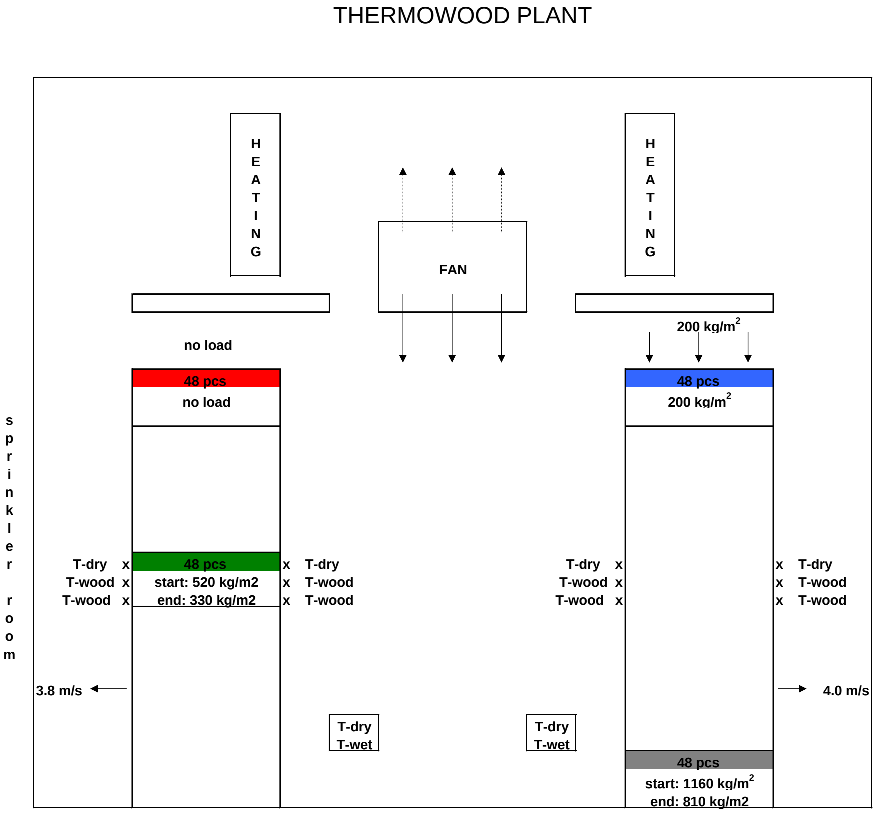


Figure 5.13. Location of test groups in the Thermowood plant. The app. top loading when the timber was wet and dry is presented. The location of temperature sensors is also marked.

Two HT dryings with reference dryings at 70 °C were performed. The realised drying schedules are found in Figures 5.14-5.17.

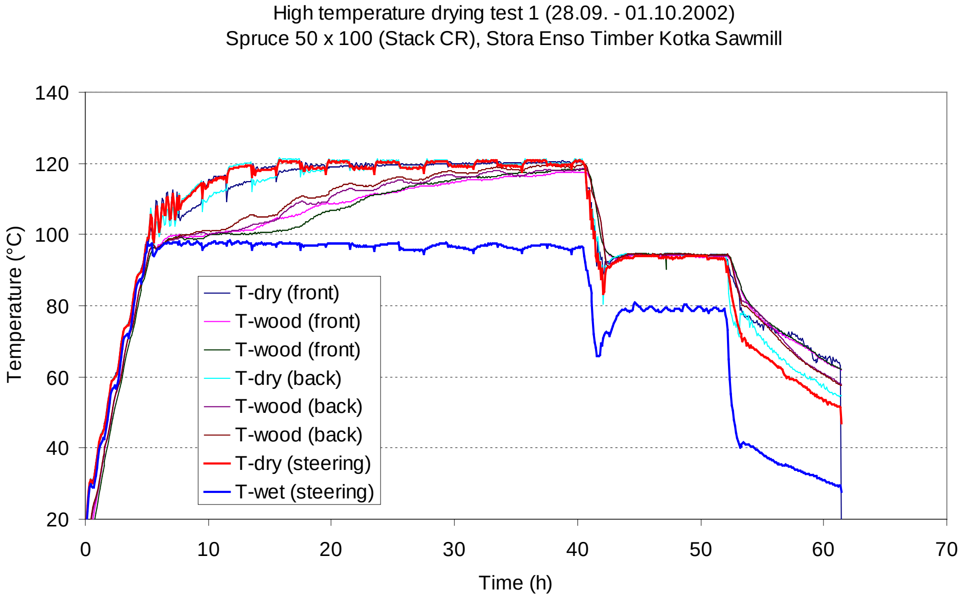


Figure 5.14. Measured dry and wet bulb temperatures and wood temperatures in the middle of the wood in the first HT drying (120 °C) at Kotka sawmill.

The drying ran very good according to the given schedule. The wood temperature curves show that the wood is quite dry before conditioning, because its inside temperature has nearly reached the dry bulb temperature.

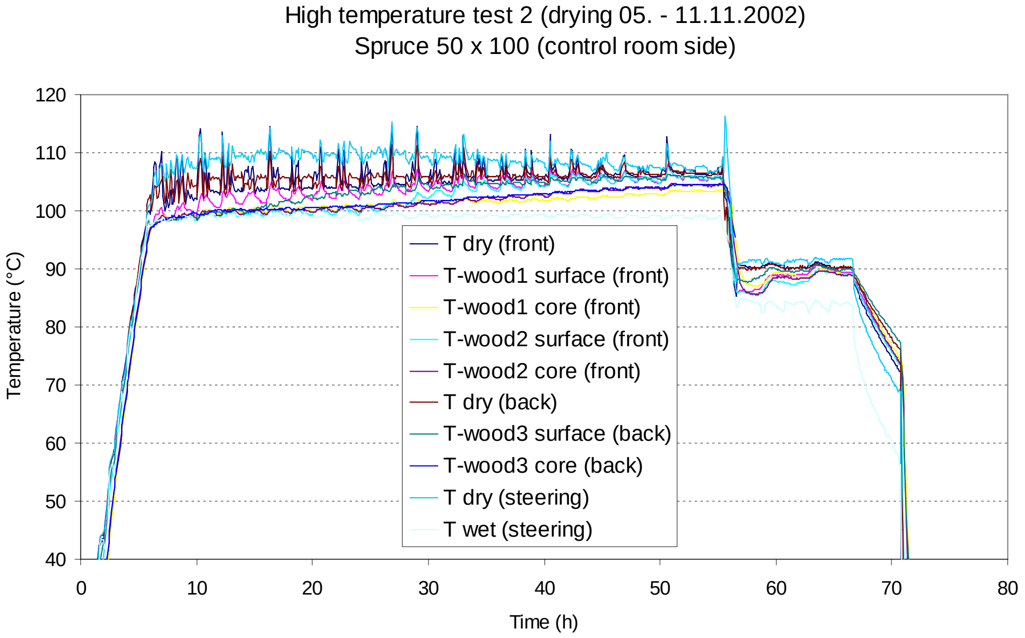


Figure 5.15. Measured dry and wet bulb temperatures and wood temperatures in the middle of the wood in the second HT drying at Kotka sawmill.

The target dry bulb temperature was 105 °C, but for some reason the realised temperature was 2-5 °C higher. The wet bulb was nearly 100 °C, as wanted. Thus, the drying should have been faster than planned.

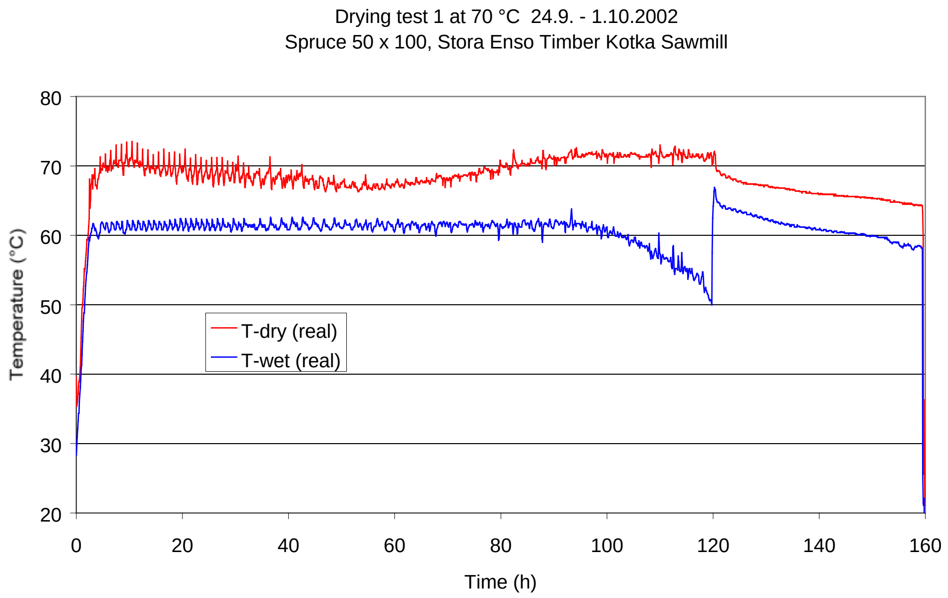


Figure 5.16. Measured dry and wet bulb temperatures in the first reference drying at 70 °C.

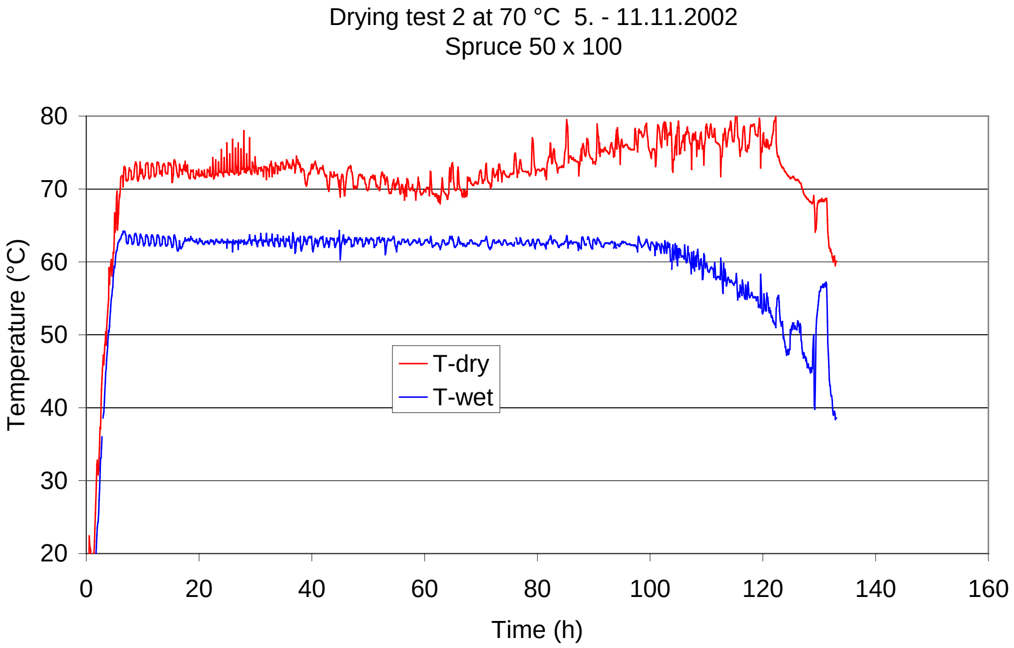


Figure 5.17. Measured dry and wet bulb temperatures in the second reference drying at 70 °C.

The reference dryings were run with the sawmill's own schedules. The temperature rose a bit higher in the second reference drying than in the first one.

After drying, the test pieces were numbered and the places of the last stickers were marked. The deformations were measured 2 m from the free end inwards and also from the last sticker inwards. The principle is presented by NTI.

After marking, the timber was packaged and sent to VTT. The material was stored in laboratory condition for 0,5-1,5 months before measurements.

The grain angle was measured at three places on the inside end of the battens. The average value of GA was marked in a spreadsheet. The grain angle turning left was marked as positive, and the grain slope to the right was marked with a negative sign. Twist, bow and spring were measured with test jig, first from the last sticker and then from the free end, if it was longer than 10 cm. Bow and spring were always measured from the concave side. Thus, the values were always positive. Twisting to the left was marked positive, and when the battens were twisted to the right, the sign was negative.

After deformation measurements, the battens were tested with Finnomoist moisture and density meter. Finnomoist gives values every 10 cm. It is advantages compared to normal oven dry method, where normally only one measurement/ batten is performed. Especially at high temperature drying, there might be quite big longitudinal MC variations in the battens. Finnomoist gives the average value for every batten.

The sawing machine centralises the logs, so that the centre saw blade runs quite near the pith. Thus, the distance between outer face of the batten and the pith did not vary significantly. Therefore, it was not measured. The effect of this distance and the effect of the ratio grain angle/distance was not stated and analysed.

5.2.3. Results and discussion

The average values of all industrial tests are collected in Figures 5.18-5.21. There were quite large variations in moisture content between the groups. It is important to point out, however, that the end moisture contents in these tables are different from the end MC just after drying. This may have some effect on the results compared to the situation that the wood moisture does not change after drying and the releasing of drying charges from top loading. The “spring back” effect and the additional drying in storage after kiln drying, may result in higher deformations than there were immediately after drying.

Distortion levels
Figures 5.18-5.21 present the average values and standard deviations of deformations, grain angle, moisture content, density and the length of free end in each top loading group in the industrial drying tests at Kotka sawmill.

STRAIGHT, WP 2.2		SET	Test no.	HT1	Treatment	HTD 120°C		Date 1	1.10.2002	Date 2		
Load		Measurements(deformations measured over 2 m from splint side) **after** drying						1) Under sticker 2) From free end. Bow and spring (+ for concave, - for convex)				
		Grain angle	MC el	Density	Twist 1)	Twist 2)	Bow 1)	Bow 2)	Spring 1)	Spring 2)	Sticker marks	Length, free end
		°(left+, right-)	%	kg/m^3	mm/2m	mm/2m	mm/2m	mm/2m	mm/2m	mm/2m	mm	cm
no	Aver	1,8	7,5	449	7,2	8,3	1,5	2,0	1,4	1,1		25
	Stdev	1,1	1,6	33	4,8	5,5	1,2	2,0	1,1	1,0		22
1/2 stack	Aver	1,8	7,3	443	5,2	5,0	1,6	1,1	1,1	1,2	minor	22
	Stdev	1,1	1,6	69	3,5	3,0	1,3	0,9	0,9	0,9		21
200 kg/m2	Aver	1,9	6,2	447	3,4	4,3	1,7	2,3	1,2	1,5		28
	Stdev	1,1	1,1	33	2,7	3,3	1,3	1,6	1,0	1,0		23
200kg/m2+Stac	Aver	2,2	5,9	445	4,6	6,6	2,2	2,6	1,0	1,0	1,4	28
	Stdev	0,9	1,0	31	3,7	4,3	1,4	1,5	0,8	0,9	0,6	22

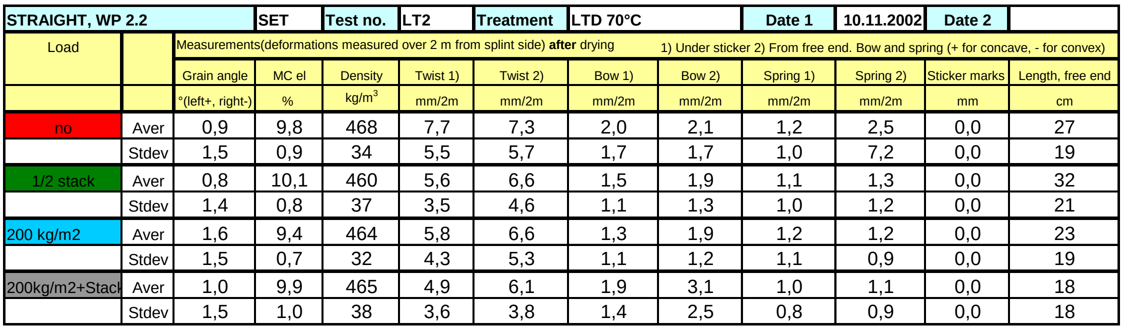
Figure 5.18. High temperature drying 1 at 120 °C. Average values and standard deviations in the different top loading groups. See text.

STRAIGHT, WP 2.2		SET	Test no.	HT2	Treatment	HTD 105°C		Date 1	8.11.2002	Date 2		
Top loading		Measurements(deformations measured over 2 m from splint side) **after** drying						1) Under sticker 2) From free end. Bow and spring (+ for concave, - for convex)				
		Grain angle	MC el	Density	Twist 1)	Twist 2)	Bow 1)	Bow 2)	Spring 1)	Spring 2)	Sticker marks	Length, free end
		°(left+, right-)	%	kg/m^3	mm/2m	mm/2m	mm/2m	mm/2m	mm/2m	mm/2m	mm	cm
no	Aver	1,0	11,4	462	6,2	7,2	1,8	2,2	1,2	1,3		28
	Stdev	1,2	2,1	38	5,1	5,4	1,6	1,9	0,8	0,9		18
1/2 stack	Aver	1,8	8,7	468	6,5	8,8	1,7	3,2	1,3	2,8		37
	Stdev	1,3	1,1	27	4,3	5,4	1,0	3,7	1,0	3,7		20
200 kg/m2	Aver	1,1	10,0	457	5,6	7,4	1,8	1,7	1,1	1,0		27
	Stdev	1,2	1,4	35	4,8	6,0	1,6	1,5	0,8	0,9		18
200kg/m2+Stac	Aver	1,7	10,2	466	5,6	6,6	1,5	1,9	1,2	1,7	0,7	31
	Stdev	1,4	1,6	37	3,7	5,2	1,3	1,3	1,1	1,4	0,2	18

Figure 5.19. High temperature drying 2 at 105 °C. Average values and standard deviations in the different top loading groups. See text.

STRAIGHT, WP 2.2		SET	Test no.	LT1	Treatment	LTD 70°C		Date 1	29.9.2002	Date 2		
Load		Measurements(deformations measured over 2 m from splint side) **after** drying						1) Under sticker 2) From free end. Bow and spring (+ for concave, - for convex)				
		Grain angle	MC el	Density	Twist 1)	Twist 2)	Bow 1)	Bow 2)	Spring 1)	Spring 2)	Sticker marks	Length, free end
		°(left+, right-)	%	kg/m^3	mm/2m	mm/2m	mm/2m	mm/2m	mm/2m	mm/2m	mm	cm
no	Aver	1,0	9,9	451	7,0	7,1	2,2	2,4	1,5	1,4		28
	Stdev	1,5	0,7	32	5,5	6,2	1,4	1,7	1,2	1,2		21
1/2 stack	Aver	2,0	10,3	455	6,9	7,6	2,3	2,2	1,4	1,3		27
	Stdev	1,4	0,7	30	4,7	4,7	1,9	2,0	1,2	1,1		23
200 kg/m2	Aver	1,5	10,1	455	7,3	8,9	1,9	2,4	1,1	1,4		28
	Stdev	1,3	0,9	33	5,3	5,8	1,5	1,9	1,2	1,6		22
200kg/m2+Stack	Aver	1,3	9,9	464	4,4	4,6	2,1	2,1	1,3	1,1	0,5	34
	Stdev	1,2	1,0	33	2,8	3,3	1,7	2,4	1,0	1,1	0,2	27

Figure 5.20. Reference drying 1 at 70 °C. Average values and standard deviations in the different top loading groups. See text.



STRAIGHT, WP 2.2			SET	Test no.	LT2	Treatment	LTD 70°C		Date 1	10.11.2002	Date 2	
Load		Measurements(deformations measured over 2 m from splint side) **after** drying					1) Under sticker 2) From free end. Bow and spring (+ for concave, - for convex)					
		Grain angle	MC el	Density	Twist 1)	Twist 2)	Bow 1)	Bow 2)	Spring 1)	Spring 2)	Sticker marks	Length, free end
		°(left+, right-)	%	kg/m^3	mm/2m	mm/2m	mm/2m	mm/2m	mm/2m	mm/2m	mm	cm
no	Aver	0,9	9,8	468	7,7	7,3	2,0	2,1	1,2	2,5	0,0	27
	Stdev	1,5	0,9	34	5,5	5,7	1,7	1,7	1,0	7,2	0,0	19
1/2 stack	Aver	0,8	10,1	460	5,6	6,6	1,5	1,9	1,1	1,3	0,0	32
	Stdev	1,4	0,8	37	3,5	4,6	1,1	1,3	1,0	1,2	0,0	21
200 kg/m2	Aver	1,6	9,4	464	5,8	6,6	1,3	1,9	1,2	1,2	0,0	23
	Stdev	1,5	0,7	32	4,3	5,3	1,1	1,2	1,1	0,9	0,0	19
200kg/m2+Stack	Aver	1,0	9,9	465	4,9	6,1	1,9	3,1	1,0	1,1	0,0	18
	Stdev	1,5	1,0	38	3,6	3,8	1,4	2,5	0,8	0,9	0,0	18

Figure 5.21. Reference drying 2 at 70 °C. Average values and standard deviations in the different top loading groups. See text.

The MC after drying at 120 °C was lower than in the other cases. The drying at 120 °C was very hard. Many battens developed inner cracks. The drying at 105 °C was much milder, but there occurred some inner cracks here as well.

The variation of grain angle is quite high between loading groups and also between different dryings.

In most cases, the deformations are higher when they are measured from the free end. In some battens, the free end was very short, less than 10 cm. In those cases, the deformations were measured only once, i.e. from the last sticker. Direct comparison can lead to false conclusions, because the free end measurements are made only for some of the battens, and the average deformations from last sticker include all the battens.

Some problems that affect the results a little were noted in sticking and stacking. In some cases, the stickered layers were not vertically in line with each other. Normally, the timber ends of drying stacks are in vertical columns at both ends. When this is not the case, the stick can be loaded by timber without support underneath it. This might affect the deformations, especially at high temperatures at the bottom of a stack (high top load). The lack of support of the wagon also causes problems. There were less support beams under the stack than sticker rows in the charge.

Influence of grain angle and top load on twist

Because of many variations of data, the effect of different factors can be seen only with statistical analysis. To start, we have studied the regression between grain angle and deformations, mainly twist under different top loading (Figures 5.22-5.25).

To reduce the effect of different moisture contents of the test specimens on distortion values and on the regression between twist and grain angle, the distortion values are reduced to 15 % moisture content. Linear correlation between distortion and MC has been used.

Figures 5.22 a-5.25 a present regression lines without MC reduction. Figures 5.22 b-5.25 b present regression lines calculated with twist values reduced to 15 % moisture content.

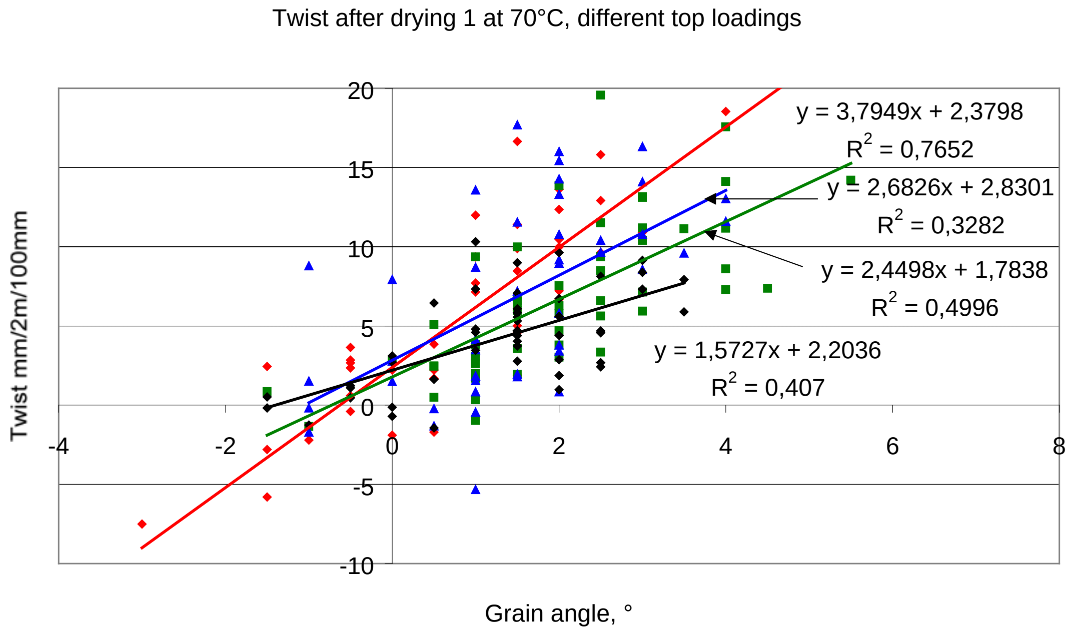


Figure 5.22 a. The effect of grain angle and top loading on twist. Reference drying at 70 °C. More data can be seen in Figure 5.20. Location of the groups in the kiln is presented in Figure 5.13. See colour code.

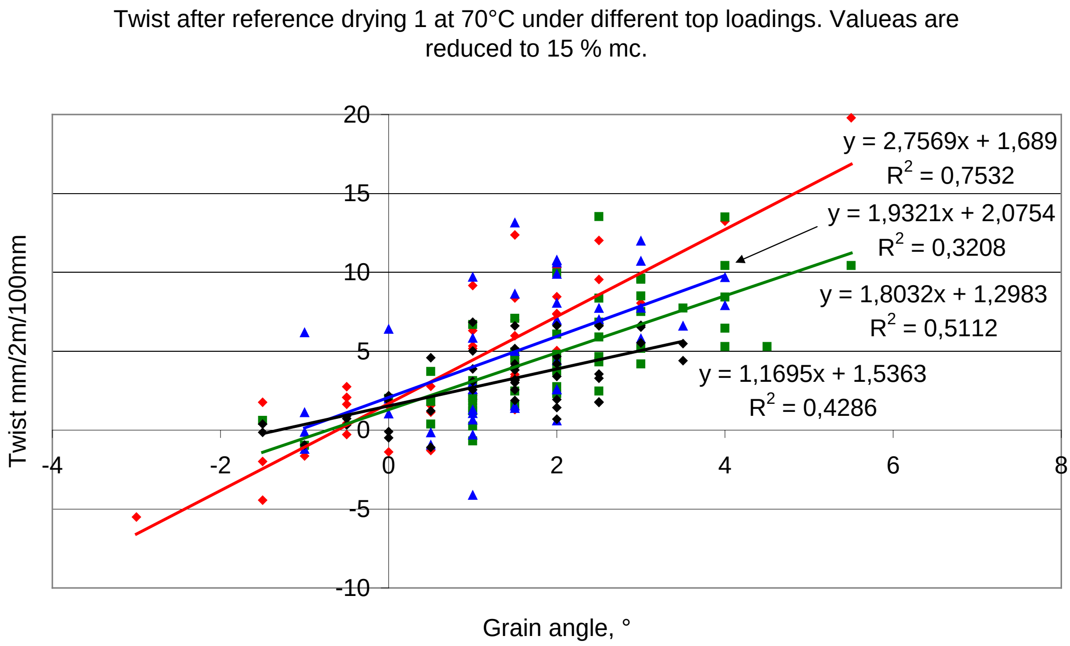


Figure 5.22 b. The effect of grain angle and top loading on twist. Twist values are reduced to 15 % moisture content. Reference drying at 70 °C. More data can be seen in Figure 5.20. Location of the groups in the kiln is presented in Figure 5.13. See colour code.

Because the moisture content at distortion measurements was lower than 15 %, the reduced twist values are smaller than without reduction. However, the main result in the drying at 70 °C has not been changed. With increasing top loading the twist diminishes.

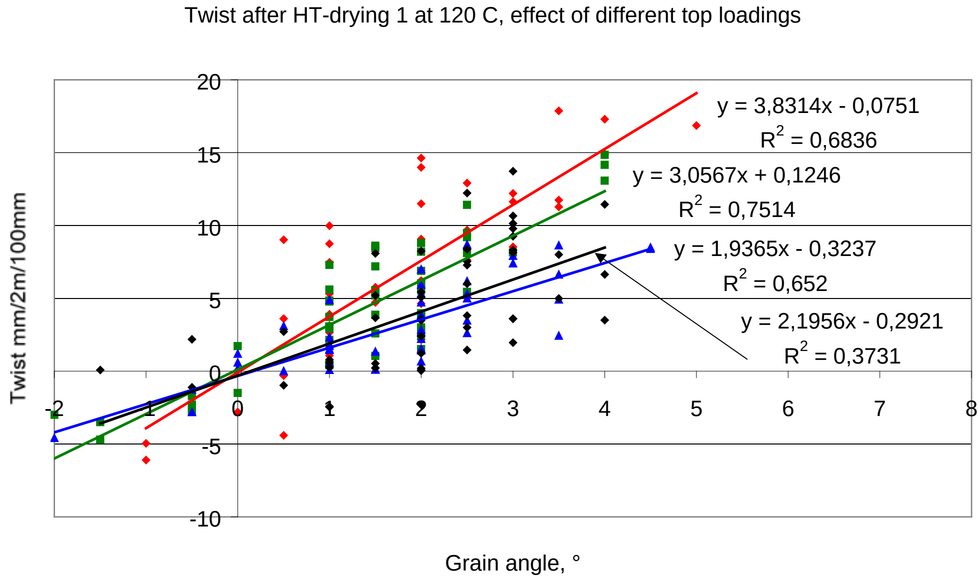


Figure 5.23 a. The effect of grain angle and top loading on twist. High temperature drying at 120 °C. More data can be seen in Figure 5.18. Location of the groups in the kiln is presented in Figure 5.13. See colour code.

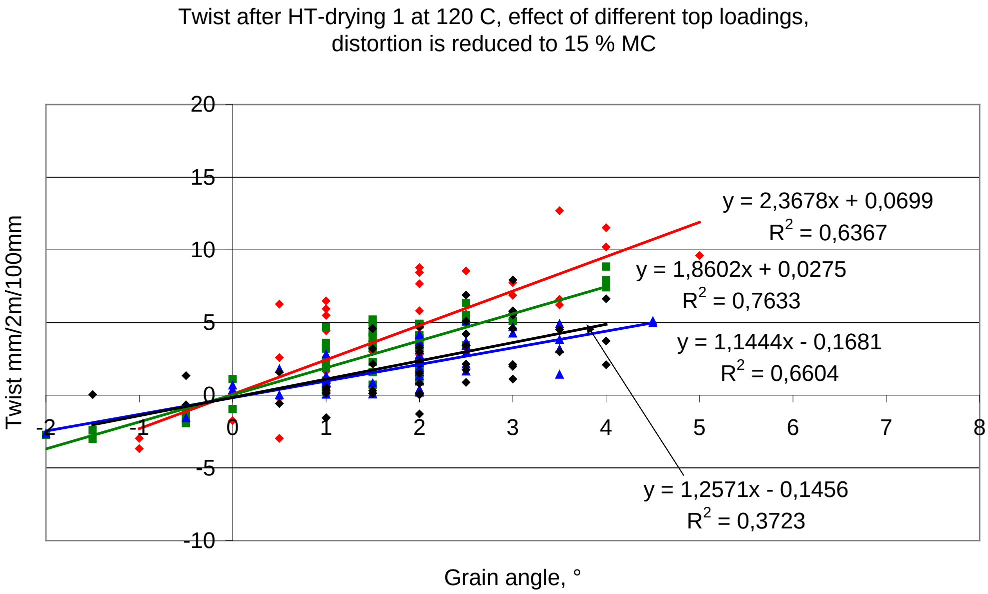
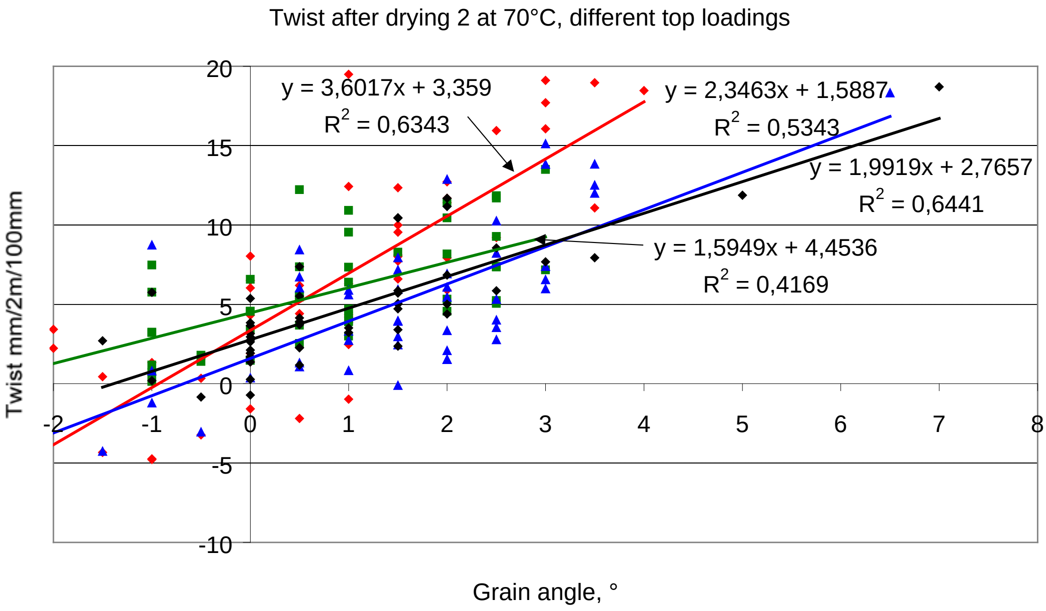
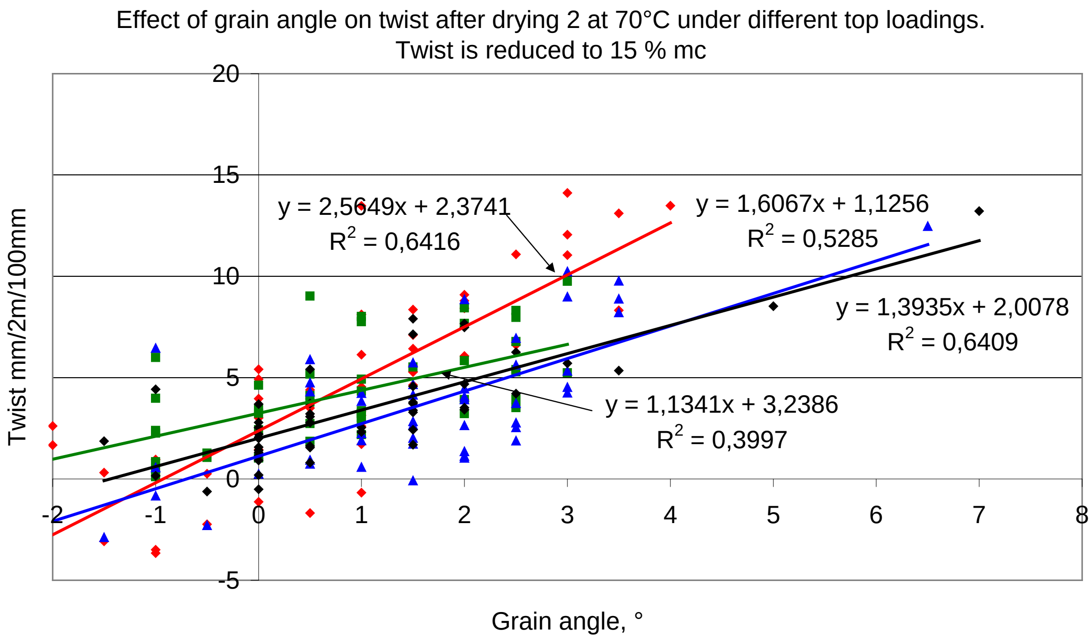


Figure 5.23 b. The effect of grain angle and top loading on twist. Twist values are reduced to 15 % moisture content. High temperature drying at 120 °C. More data can be seen in Figure 5.18. Location of the groups in the kiln is presented in Figure 5.13. See colour code.



Twist after drying 2 at 70°C, different top loadings

Figure 5.24 a. The effect of grain angle and top loading on twist. Reference drying 2 at 70 °C. More data can be seen in Figure 5.21. Location of the groups in the kiln is presented in Figure 5.13. See colour code.



Effect of grain angle on twist after drying 2 at 70°C under different top loadings.
Twist is reduced to 15 % mc

Figure 5.24 b. The effect of grain angle and top loading on twist. Twist values are reduced to 15 % moisture content. Reference drying 2 at 70 °C. More data can be seen in Figure 5.21. Location of the groups in the kiln is presented in Figure 5.13. See colour code.

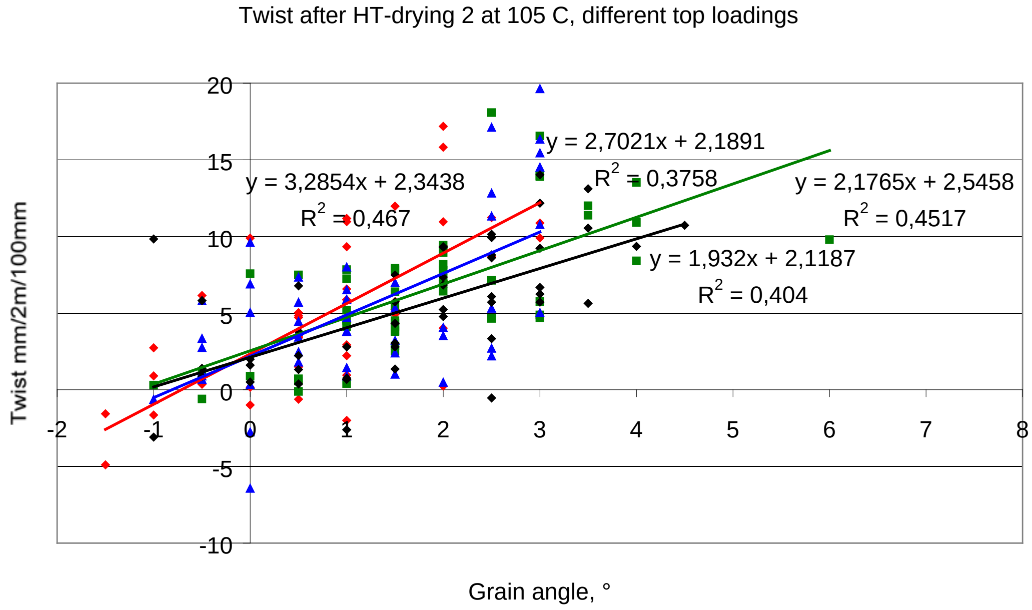


Figure 5.25 a. The effect of grain angle and top loading on twist. High temperature drying at 105 °C. More data can be seen in Figure 5.19. Location of the groups in the kiln is presented in Figure 5.13. See colour code.

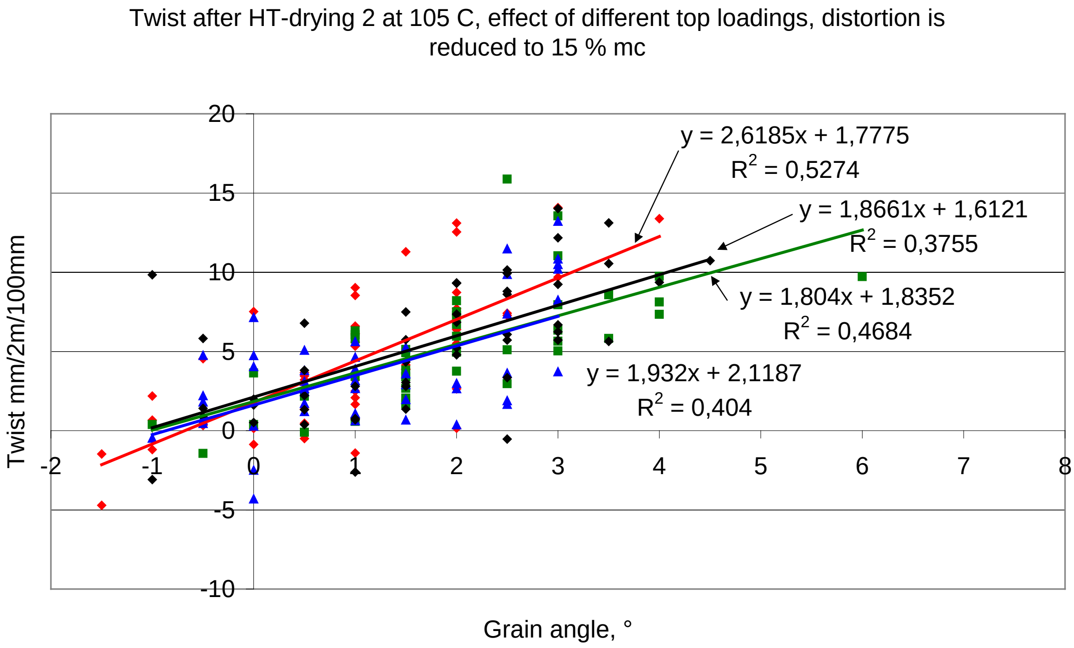


Figure 5.25 b. The effect of grain angle and top loading on twist. Twist values are reduced to 15 % moisture content. High temperature drying at 105 °C. More data can be seen in Figure 5.19. Location of the groups in the kiln is presented in Figure 5.13. See colour code.

Figures 5.20-5.25 show that the unloaded specimens in every drying have twisted most. However, the effect of the amount of top loading is not quite clear. The coefficient of determination is in most cases quite high. This means that the grain angle explains very much of the twisting.

Acceptance level
Nordic Timber grading rules gives limits for deformations in different quality classes at the moisture content of 20 %. The Straight project group has decided their own distortion thresholds, which are at 15 % moisture content.

Deformation	**Quality class A1, A2**	**Quality class A3, A4**	**Quality class Straight (15 %)**	**Unit**
Twist	4	6	4	mm/2 m/100 mm
Spring	3	4	4	mm/2000 mm
Bow	5	10	3	mm/2000 mm
Cup	2	2		mm/100 mm

Figure 5.26. Maximum allowed distortions in quality classes A1-A2 and A3-A4 according to Nordic Timber grading rules at a moisture content of 20 % and respective distortion thresholds at 15 % MC set in the Straight project. The deformations are measured over 2000 mm length and 100 mm width.

In figure 5.27, the acceptance of battens due to measured twist and spring are analysed in industrial dryings at Kotka sawmill according to Nordic Timber grading rules, quality class A1-A2. No moisture content reduction has been made.

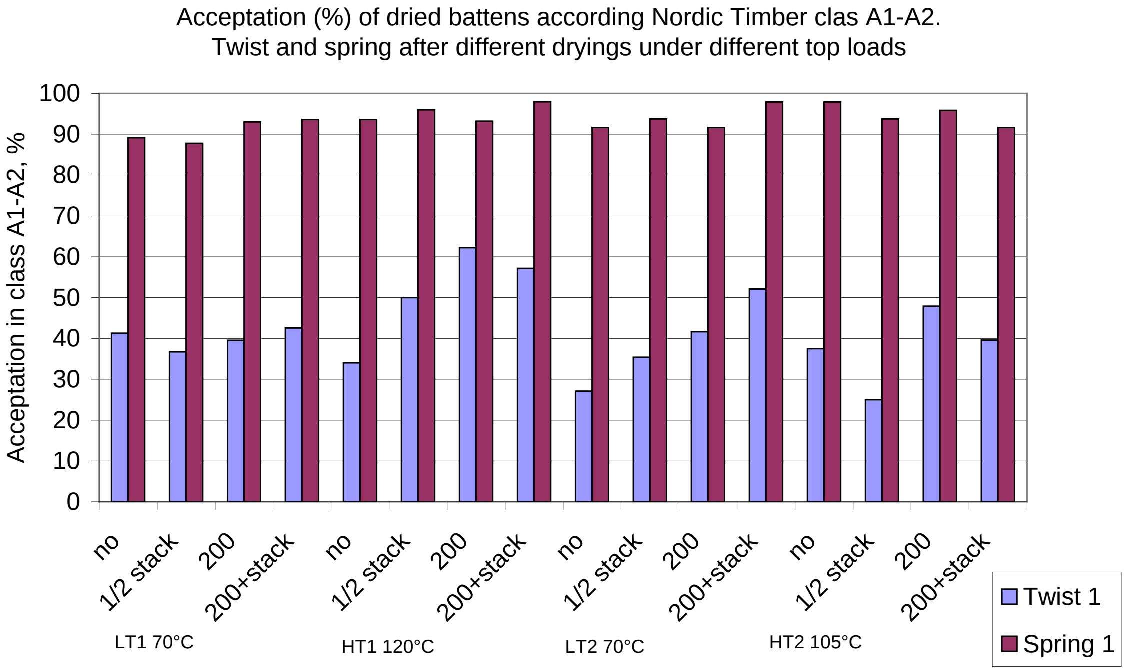


Figure 5.27. Acceptance (%) of dried battens according to Nordic Timber grading rules, quality class A1-A2. Twist and spring after different dryings under different top loads.

Figure 5.28 presents the acceptance percentages according to thresholds set in the Straight project (see Figure 5.26). Industrial dryings under different top loads at Kotka sawmill.

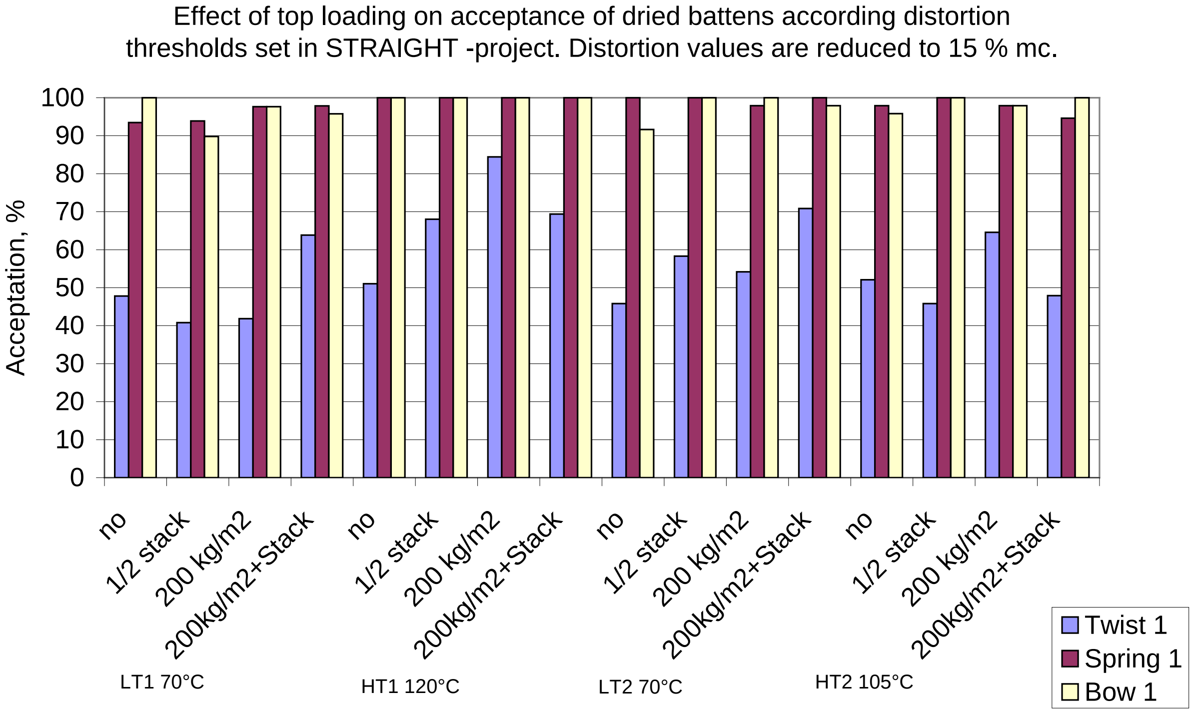


Figure 5.28. Acceptance (%) of dried battens according to thresholds set in the Straight project. Distortion values are reduced linearly to 15 % moisture content.

It is obvious that the spring and bow seldom bring problems. Over 90 % of the battens are accepted according to the Nordic Timber grading rules to the best quality class, despite much lower wood moisture content than given in Nordic Timber. However, due to the twist, less than half of the material is accepted. According to Straight, thresholds over 50 % of the material are accepted.

Variance analysis
The results were studied with variance analysis to establish the effect of different variables on deformations. The significance level of variables was 95 %. Since twisting is the most harmful distortion we have, the analysis focused on this.

It was assumed that the effect of top loading and temperature is not dependent on the direction of the twisting. That is why we have analysed the absolute values of GA and twisting. The results are presented in equations 3-5.

$$TW_{abs} = 2{,}30 \times GA_{abs} + 2{,}05 \qquad R^2 = 0{,}34 \tag{3}$$

$$TW_{abs} = 2{,}33 \times GA_{abs} - 0{,}0021 \times TL + 2{,}80 \qquad R^2 = 0{,}37 \tag{4}$$

$$TW_{abs} = 2{,}39 \times GA_{abs} - 0{,}0021 \times TL - 0{,}030 \times T + 5{,}45 \qquad R^2 = 0{,}39 \tag{5}$$

Where:

TW_{abs} = absolute value of twisting (mm/100 mm/2000 mm)

GA_{abs} = absolute value of grain angle (°)

TL = Top load (kg/m^2)

T = drying temperature (°C)

R^2 = coefficient of determination

The grain angle explains 34 % of the twisting under the stickers. Top loading and increasing temperature diminishes the twisting. However, these factors increase the coefficient of determination only a little.

In some earlier studies, the end moisture content also had significant effect on deformation. Including it in the model does not increase the coefficient of determination (equation 6 and 7).

$$TW_{abs} = 2{,}39 \times GA_{abs} - 0{,}0020 \times TL + 0{,}19 \times MC + 0{,}91 \qquad R^2 = 0{,}38 \tag{6}$$

$$TW_{abs} = 2{,}40 \times GA_{abs} - 0{,}0021 \times TL + 0{,}018 \times MC - 0{,}030 \times T + 5{,}2 \qquad R^2 = 0{,}39 \tag{7}$$

In equation 6, the effect of moisture content is especially unrealistic. The variation of MC is perhaps so small that other factors have covered its effect.

The effect of free end length is added to the model. The effect of GA and top loading with different exponents is also analysed. The effect of different variables on maximum twisting (free end) is found in equation 8.

$$TW_{absmax} = 1{,}9 \times GA^{1{,}2} - 0{,}21 \times TL^{0{,}35} + 0{,}013 \times FE - 0{,}024 \times T + 6{,}1 \qquad R^2 = 0{,}40 \quad (8)$$

Where:

FE = length of free end (cm).

TW_{absmax} = Maximum value of the twisting measured from the last sticker or from the free end.

Adding combined factors to the analysis, the coefficient of determination can be increased a little (equation 9).

$$TW_{abs} = 1{,}02 \times GA^{1{,}2} - 0{,}25 \times TL^{0{,}35} + 0{,}11 \times (MC \times GA) + 4{,}0 \qquad R^2 = 0{,}43 \qquad (9)$$

Equation 9 is like equation 7 not plausible because of the increasing effect of MC on twisting.

To summarize, the equations 3, 4 and 5 show the most useful results of the analysis. The coefficient of determination is not very high (R^2 = ~0,4). Therefore, other factors like local grain angle variations due to knots, compression wood and juvenile wood should have effect on the twisting.

The same kind of analysis for bow and spring did not give satisfactory explanations. The coefficient of determination was in the analysis with the measured variables (GA, MC, T, free end length, top load) much less than 10 %.

5.3. Semi-industrial tests at Stora Enso Timber, Honkalahti Sawmill

5.3.1. Test material

The test material was 50 mm x 100 mm Norway spruce sawn from logs with top diameter of 150 mm - 160 mm.

5.3.2. Test procedure

Honkalahti Sawmill, Stora Enso Timber has a semi-industrial high temperature and heat treatment kiln. Its capacity is about 10 m^3. Drying temperature of 115 °C was chosen on the basis of laboratory tests and dryings at Kotka Sawmill. Target MC was 8-10 %. A conditioning period was added to ensure low moisture gradient. The timber was stacked at the bottom part with 7 stickers/6 m and with 13 stickers at the top part of the charge. Top loading was 200 kg/m² (framework made of iron rail).

In earlier tests at Kotka, the timber had a lot of inner cracks, especially when drying at 120 °C. Now the planned schedule was mild at the beginning, and the maximum temperature of 115 °C was reached quite late. The average air velocity in the stack was 3,8 m/s.

The kiln load and stickering is presented in Figure 5.29. Top loading is 200 kg/m². The average additional top load/timber layer is about 20 kg/m². The top loading of the test groups is thus roughly ~260 kg/m² (13 stickers) and ~450 kg/m² (7 stickers).

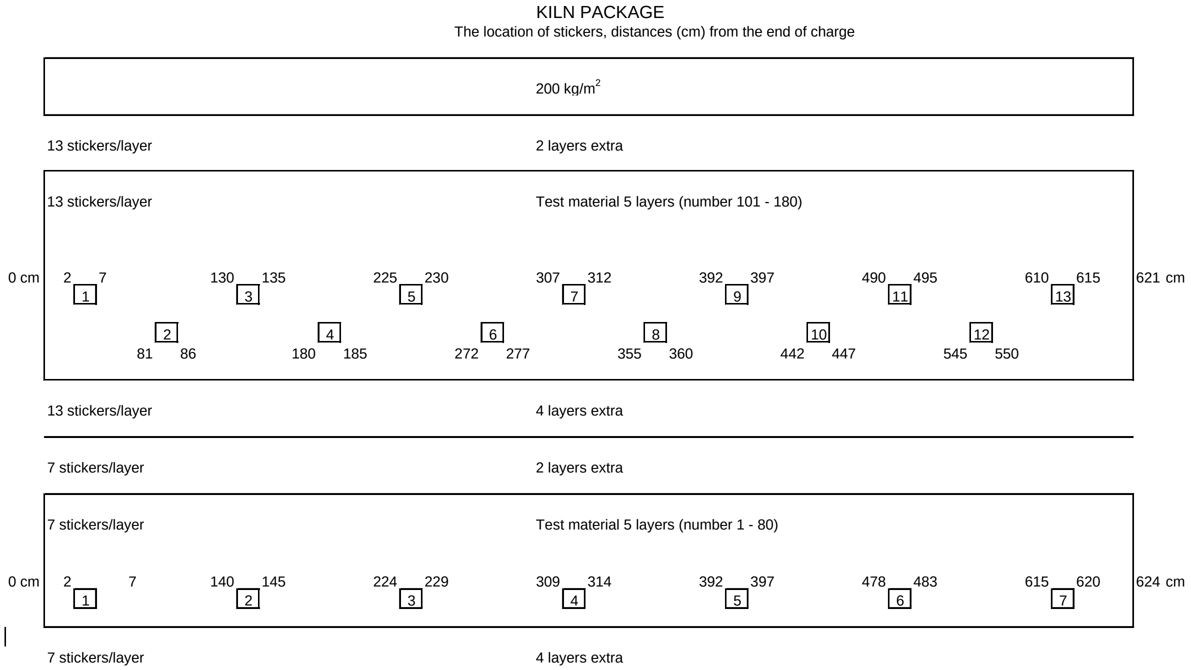


Figure 5.29. Location of test battens and stickers in the kiln load. Top loading 200 kg/m² + 20 kg/m²/layer when wet and 13 kg/m²/layer when dry. Stickering 7 and 13 pcs./~6 m length.

5.3.3. Results and discussion

The timber was sent to VTT and measured within ten days after drying. The measurements were the same as presented in Chapter 3.3.

Summary of average values is found in Figure 5.30.

STRAIGHT, WP 2.2			SET	Test no.	HT3	Treatment	HTD 115°C		Date 1	9.6.2003	Date 2	17.6.2003
Top load and stickers		Measurements(deformations measured over 2 m from splint side) **after** drying					1) Under sticker 2) From free end. Bow and spring (+ for concave, - for convex)					
		Grain angle °(left+, right-)	MC el %	Density kg/m^3	Twist 1) mm/2m	Twist 2) mm/2m	Bow 1) mm/2m	Bow 2) mm/2m	Spring 1) mm/2m	Spring 2) mm/2m	Sticker marks mm	Length, free end cm
200kg/m2+ 4 layers	Aver	1,4	6,8	456	4,1	5,0	1,7	1,8	1,7	2,4	-	13
13 stickers	Stdev	1,1	1,0	39	3,2	4,3	1,2	1,5	1,4	1,5	-	12
200kg/m2+ 15 layer	Aver	1,3	6,8	450	3,2	4,3	1,5	1,9	1,1	1,3	-	34
7 stickers	Stdev	1,4	0,8	36	2,7	3,9	1,2	1,7	1,0	1,1	-	26

Figure 5.30. Average values and standard deviations of grain angle, deformations, moisture content, density and length of free end. MC and density is measured with Finnomoist moisture meter. The moisture content and stdv. with oven dry method were 8,7 % and 0,7 % for bottom layers and 8,5 % and 0,7 % for upper layers respectively.

Average end moisture content (oven dry method) was 8,7 %. Standard deviation was 0,7 %. Average MC gradient was 0,7 %. There were very few surface and inner cracks. Thus, the drying quality was very good.

The effect of grain angle on twist in both groups can be seen in Figure 5.31. The regression lines show that the increase of the top loading has a diminishing effect on the twist. Top loading seems to be more important than the amount of stickers. Top loading of 200 kg/m^2 iron bars is not enough to keep the 50 mm x 100 mm Spruce timber straight during drying.

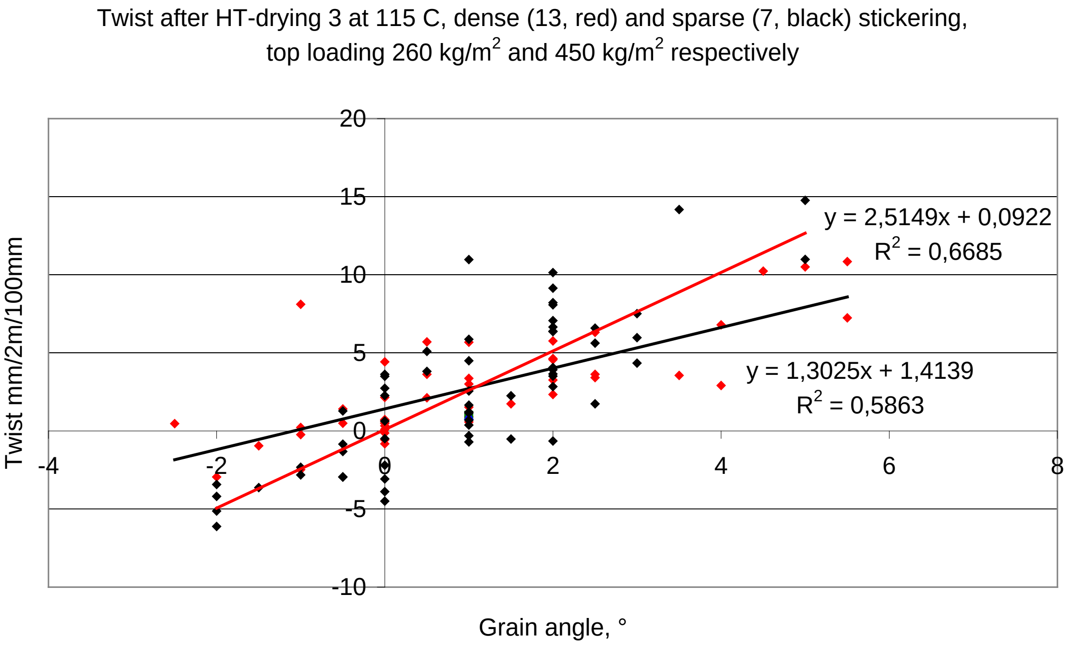


Figure 5.31. The effect of grain angle, stickering and top loading on twist. Red line: Top loading 250 kg/m², 13 stickers/layer. Black line: 450 kg/m², 7 stickers/layer.

Figure 5.32 presents the distortion values, which are reduced to 15 % moisture content.

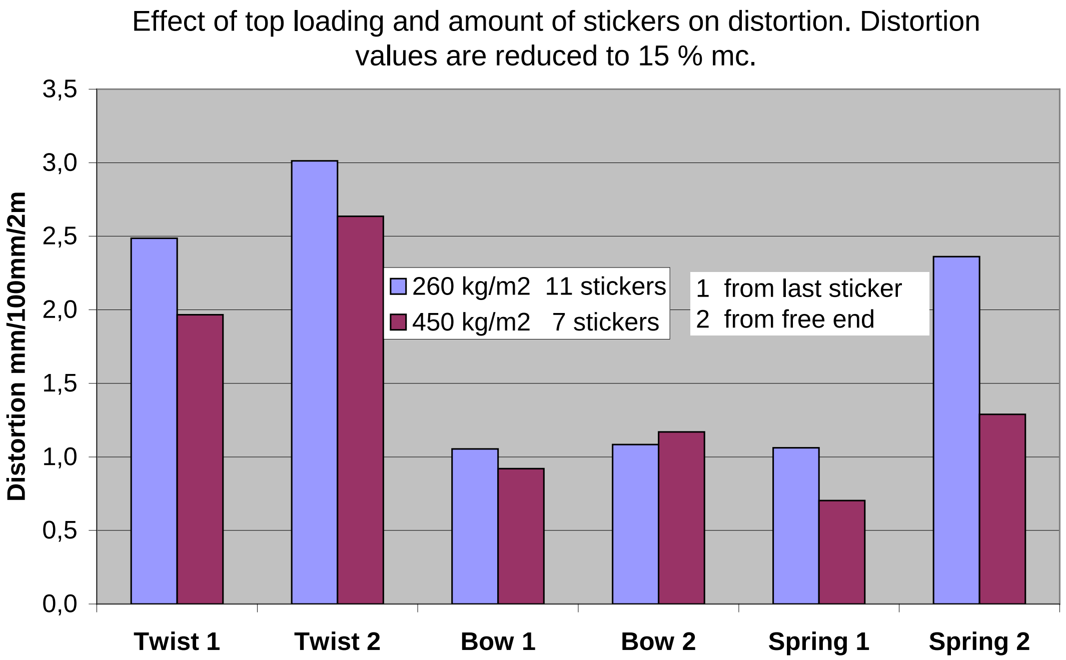


Figure 5.32. Effect of top loading and amount of stickers on distortion after HT drying at 115 °C.

In Figure 5.33, the acceptance percentages are according to quality rules adopted in the Straight project.

Drying	Temp	Load	Stickers	Class	Twist 1	Twist 2	Bow 1	Bow 2	Spring 1	Spring 2
HT3	115	200+4layers	13	Straight	80	74	100	100	96	89
HT3	115	200 + 15layers	7	Straight	89	80	100	97	100	100

Figure 5.33. Acceptance percentages according to the quality rules adopted in the Straight project: Twist < 4 mm/2000 mm/100 mm, bow < 4 mm/2000 mm and spring < 3 mm/2000 mm at 15 % MC. Deformation 1 is measured from last sticker and deformation 2 from free end.

For twist and spring, sufficient top loading is more important than the amount of stickers. In case of bow, the shortening of free end due to dense stickering increases the acceptance percentage a little. To summarize, the top loading have to be high enough to keep the timber straight during drying, and increasing the amount of stickers ensures straight ends of the battens.

If the amount of stickers is limited, it might be feasible to disperse them, so that in the region of batten ends, the stickers are closer to each other. In the middle part of the stack, the distance can be larger.

5.4. Conclusion

The distortion of sawn timber was studied after laboratory dryings at 70 °C and 106 °C and after industrial dryings at 70 °C, 105 °C, 115 °C and 120 °C under different top loads.

In laboratory dryings, parallel groups and fixed specimen length were used. The effect of disturbing factors was minimised. In industrial scale, the variation of the raw material was higher. One batten per log was used. The variations in stickering and for example small variations of drying schedule in different parts of the drying charges may affect variations in end results. The basic deviation in the variance analysis is thus higher than in the laboratory tests.

According to the laboratory tests, the grain angle alone explains 45 % of the twisting. When top loading is added to the model, the coefficient of determination is 53 %. In the industrial tests, GA explains only 34 % of twisting, and the best regression model gives a coefficient of determination of 42 %.

Top loading is an effective measure to reduce twisting. However, the increase of top loading from a quite low level (200 - 400 kg/m^2) decreases the twisting only a little.

According to the industrial tests, the temperature increase has a slight positive effect on twisting.

To obtain straight timber, it is very important to keep it straight during drying. This means dense stickering, so that the free end is short. It also means that the support under the stickered drying charges has to keep the timber straight, i.e. under every vertical sticker row there should be support.

6. All tests

More than 50 different industrial and laboratory tests with combined loaded and unloaded battens were carried out by the four participants. In spite of partly different sampling and test procedures, all data on top loading and distortion has been collected in one spreadsheet for analysis.

The reference battens were completely unloaded only in the NTI tests. In the other tests, the "unloaded" battens were completely unloaded only in the top layer in the reference packages. In the spreadsheet, the real top load in these reference packages have been recalculated to the average load in the mid-height of the packages.

To reduce the effect of different end moisture contents, the distortion values have been recalculated linearly to 15 % moisture.

6.1. Results and discussion

The main objective of this work package was to find the correlation between top load and distortion. The work has therefore been concentrated on testing distortion at different top loads. The top load in all these tests have ranged from specific loads from zero to an extreme load of 3418 kg/m^2.

In Figure 6.1, the results from all 107 tests are shown in one diagram, showing the influence of top load on twist. The large spread in the values indicates that the results are largely dependent on other parameters, such as grain angle and other growth characteristics.

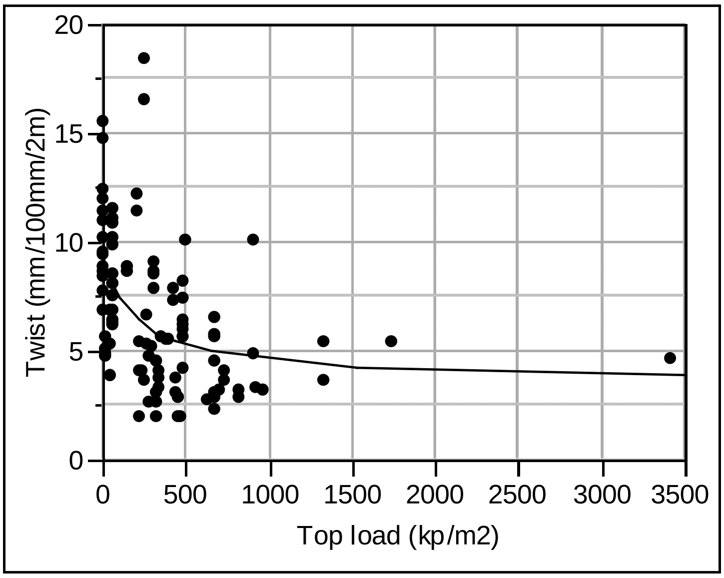


Figure 6.1. Influence of top load on average twist for all tests.

As can be seen from the curve estimation, the largest effect of the top load is from zero to 600 kp/m², but compared to the NTI results, it still seems to be an effect of the top load up to 1500 kp/m². However, the number of tests above 1000 kp/m² is low, making the curve fit in this range more uncertain.

The formula for the influence of top load on twist for all tests is:

$$Twist = \frac{1180}{Topload + 195} + 3{,}63$$

Even if there is a small difference between this formula and the formulas obtained by the different institutes, the main influence of top load is clear, with a marked and steep reduction in the distortions when increasing the top load from zero to app. 600 kp/m². From that level, the gain is marginal and surely not economically justifiable.

The grain angle has a substantial effect on the degree of twist, and the combined effect of top load and grain angle on the twist can be calculated from the formulas in Chapters 2.2.3 and 5.2.3

For spring, as shown in Figure 6.2, one can also see a trend towards lower values at very high loads, though not significant, when the results from BRE, NTI and VTT are analysed in the same diagram.

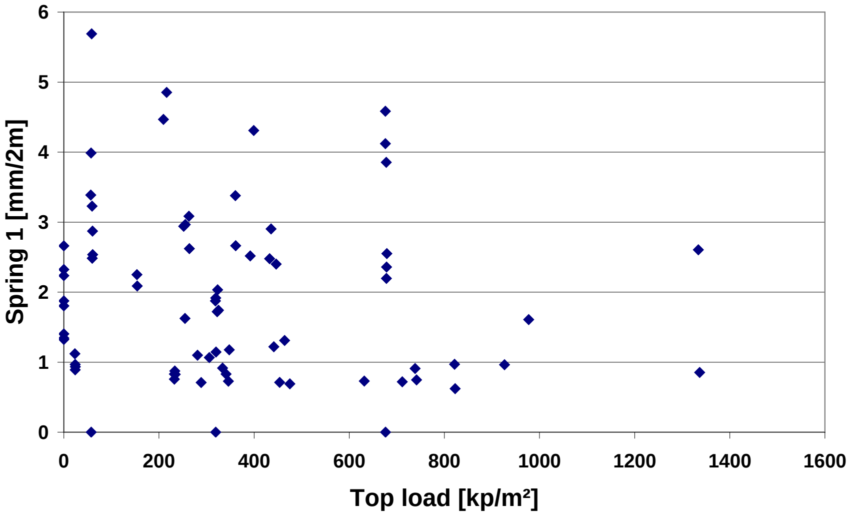


Figure 6.2. Influence of top load on average spring (BRE, NTI, VTT).

For bow measured from the free end, as shown in Figure 6.3, the average plots from the tests at BRE, VTT and NTI seem to show a reduction with increased load up to app. 400 kp/m². From that level, the bow seems to increase again. This coincides with the separate results at NTI and will probably have the same explanation as discussed in Chapter 2.2.3.

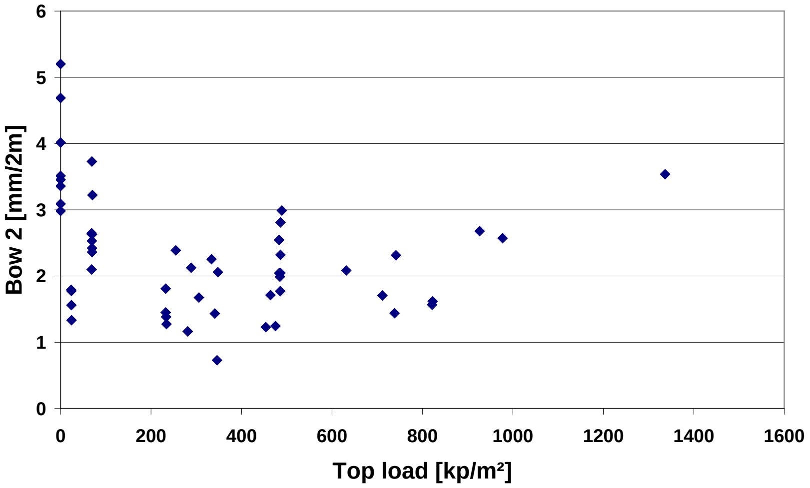


Figure 6.3. Influence of top load on average bow (BRE, NTI, VTT).

6.2. Conclusion

The overall conclusion from the analyses of all the tests in work package 2.2, is the positive effect of top loading to reduce twist, bow and spring, with the effect on twist as the most pronounced.

As to top loads, the tests indicate that a top load of app. 600 kp/m² seems sufficient to keep the battens (50 mm x 100 mm) straight during drying. An increase in the top load above that level seems to have an influence, although marginal, on the reduction of the distortions. For bow, a further increase of the top load in combination with inaccurate sticker and support positioning can reduce some of the positive effect. Precise alignment of the stickers and supports will contribute to a reduction of this effect at the higher top loads.

One important observation for all tests is the steep drop in deformation at the start of applying load, indicating that even a relative small top load has considerable influence on the deformations. At a top load of only half the "optimal" of 600 kp/m², 80 % of the distortion reduction effect is already obtained. The economical optimal top load for 50 mm x 100 mm is therefore surely a bit lower than the technically observed optimal.

Due to lack of data from all partners, no further analyses have been done on sticker marks, free end influence and grain angle influence. These data can be taken from Chapters 2 and 5.

The results maintained in the tests are representative for Norway spruce and Sitka spruce of dimension 50 mm x 100 mm. Other species, dimensions and timber with other sawing patterns will behave differently as to distortions and will have different optimal top loads.

7. Recommendations

7.1. Top loading design

There are two different ways of applying the top load:

- Concrete (or other material) blocks on top of the upper packages.
- Pneumatic or hydraulic operated frames acting on the top packages.

By using concrete blocks, the weight of each block must for example be 5400 kg at a package width of 1,5 m and package length of 6,0 m to achieve a top load of 600 kg/m². The height of the concrete blocks will be app. 250 mm at a specific weight of 2400 kg/m³ for the concrete.

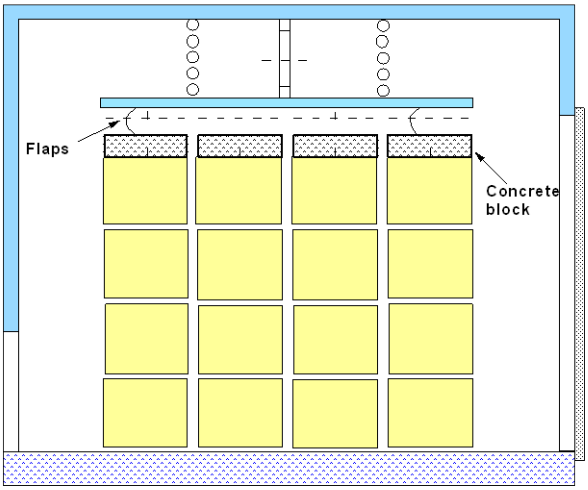


Figure 7.1. Compartment kiln with concrete blocks as top loading.

Depending on the fork lift capacity, the concrete blocks will either be lifted together with the top package or be placed on the top package after the top package is put in place. The latter method can be difficult for normal forklifts with tower, because the tower might hit the intermediate roof between the fans and the timber before the forks are at a sufficient height.

At large kilns with many packages in the height, the stability of the package piles must be secured in some way. This can be difficult due to the height.

One other problem, which is the same at kilns without top loading, is how to stop the air leakage above the packages. By the sinking of the packages and the concrete blocks during drying, the distance between the intermediate roof and the blocks will increase, making it more difficult to stop the air leakage. By using rubber/plastic flaps they have a sufficient height to take the sinking. However, this additional height often leads to breakage when loading the kiln.

An other disadvantage with concrete blocks, compared to the use of pneumatic load, is that the full load is applied from start, which can give too high sticker pressure in the lower packages at the start of the drying, when the packages are wet and heavy.

One benefit by using concrete blocks is the lower investment compared to pneumatic top loading. This benefit must be weighed against the extra costs of the work of placing the blocks and securing them against tilting. Due to the higher building height of the concrete blocks compared to the steel frames of the pneumatic system, one must also calculate with a smaller kiln capacity.

An alternative to concrete blocks are frames made of steel, which have a specific weight of 7800 kg per m³ compared to about 2400 kg/m³ for concrete. Depending on the compactness of the frames, the building height of the top loading elements can be reduced compared to concrete blocks.

By using pneumatic or hydraulic cylinders for applying the top load via steel frames (Figure 7.2), also called dynamic top loading, a lot of benefits can be achieved compared to the concrete blocks.

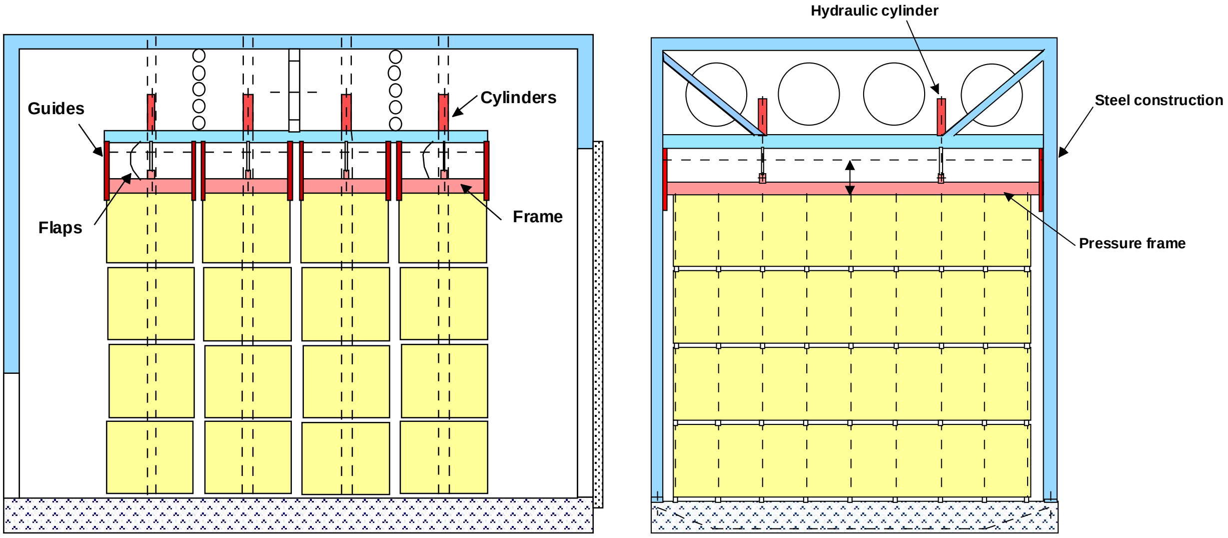


Figure 7.2. Drawing of compartment kiln with hydraulic/pneumatic top loading.

There are different ways of constructing compartment kilns with dynamic top loading. The most common way untill now is using two or three pneumatic cylinders connected to a steel frame covering the area of the top package of each package row. Due to slightly different package heights, it is not feasible to use one common frame for all package rows.

The normal industrial air pressure is about 8-10 bar. With a cylinder diameter of 12,5 cm, the maximal force per cylinder will be 981-1227 kp. Two cylinders, which is the minimum number, will give a frame load of maximum 2454 kp. With a package size of 1,5 m x 6 m, the specific load will be 273 kp/m². To achieve the maximum benefit of the top load as to warp reduction, the number of pneumatic cylinders should be increased to four, giving a specific top load of 546 kp/m².

An alternative to pneumatic cylinders is water hydraulic cylinders, where the water pressure can be at least 10 times higher than in air cylinders. This opens the possibility for using less cylinders, even with smaller cylinder diameters. With a water pressure of for example 80 bar, the necessary diameter when using only two water cylinders will be only 6,3 cm for applying a specific pressure of 546 kp/m². In addition to the benefits of fewer cylinders, the use of high pressure water hydraulics opens for the possibility of using the same water for controlling the relative humidity in the drying air, especially at the heating up period and in the conditioning period. Pressurized water mist can also be used as an effective fire extinguisher.

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

One important benefit by using dynamic top loading is the possibility to install flexible air flaps between the frame and the intermediate floor. This will almost completely reduce the air leakage above the packages.

The use of dynamic top loading will also reduce the risk of package tilting, if the construction is correctly designed for taking up horizontal forces. By using heavy pneumatic cylinders with large piston rod diameters, the forces might be taken up in the rods. By smaller cylinders with smaller rods, the horizontal forces must be taken up in the frames by means of guides between the frames and the kiln wall, as shown in Figure 7.2. Another solution is to have separate, heavy and guided rods between the frame and the cylinder rod. The optimal load to avoid tilting has not been tested. Very high loads combined with many narrow and incorrect aligned packages in the height should be avoided.

A top load of nearly 5 tons per row will give a total top load of nearly 20 tons with four package rows. Such a load must be taken up by the kiln construction, either by the weight of the kiln itself or with a combination of kiln weight and a transfer of the load through the walls to the ground, as indicated in Figure 7.2. The intermediate wall between the timber and the fans must also be rigid enough to take up the loads from the cylinders.

At new kilns, the maximal forces on the kiln construction can be calculated and taken into account when dimensioning the kiln, securing that the forces are balanced for example by leading the forces to the base of the kiln.

In existing kilns, the top load can exceed the weight capacity of the kiln, forcing the sawmill to invest in extra internal reinforcements to take up the load. Sometimes the only solution is to use loose concrete blocks or steel frames for top loading the timber.

7.2. Practical application

The use of dynamic top loading is now spreading to almost all new compartment kilns at sawmills in the Nordic countries. This is an indication that the sawmills and the kiln operators have given positive feed-back as to the benefits of the equipment.

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

In the test period, which ran for one and a half year, the test team could share the experience with the kiln operators and the technical administration.

At both sawmills, the equipment was completely new for the kiln operators, and the problem discussed was how much pressure should be applied at the different stages of the drying. Both sawmills ended up with applying 30 % of the maximum load at the start of the drying and increasing to full load at a calculated moisture content of 40 % respective 30 % for the two sawmills. In the test period, there were no problems with the equipment.

After the installation of the top loaded kilns, there was an immediate reaction from the remanufacturing departments that the timber was straighter and caused less problems in handling before and after the machines.

At one of the sawmills, the number of stickers were increased from seven to nine. This led to reduced twisting of the free ends between the stickers. When increasing the number of stickers, it is very important to follow up with lined up supports in the top frame and in the bottom. Otherwise, the effect of the reduced sticker distance will not be fully utilized.

For both sawmills, a side effect was that they have not had any tilting of packages in the new kilns with dynamic top loading of about 250 kp/m^2. In the older kilns, they had at least one serious package tilt, which caused more than one month stop. Luckily no one was injured. The optimal top load to avoid tilting has not been tested. High top pressure on kiln loads with many narrow and incorrect aligned packages in the height is, however, no guarantee for avoiding tilting.

With the high drying temperatures in the kilns, combined with humid climate and low pH, all constructions inside the kiln are exposed to a highly corrosive environment. The cylinders, pipelines and pressure frames must therefore be made of non-corrosive materials.

8. Participants list

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Heikki Murto	*Technician*
Soili Takala	*Technician*
Pirjo Kari	*Clerk*
Jaana Nurmi	*Clerk*

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