High temperature drying of UK Sitka spruce

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31st January 2007

Client report number 228-853

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Executive Summary

This study was commissioned by the Forestry commission and Scottish Enterprise under contract number FG15/04 and investigates the high temperature drying of UK spruce. Previous trials undertaken on UK spruce by research organisations in France, Finland and the Netherlands have indicated that UK material can be dried to a moisture content of 18% in approximately 63 hours with a quality similar to, or better than that achieved using conventional drying methods.

Although the results from this previous work looked very promising, several areas of high temperature drying still required further investigation before the UK industry could be confident that the system had some commercially viability. These included:

- Investigating the possibility (using experimental trials) of further reducing drying times whilst retaining or improving final dried quality of UK material.
- Undertaking a full scale industrial trial with the most promising kiln schedule developed in the experimental phase, and assess the drying time and wood quality.
- Providing an indication of the construction costs of an industrial size high temperature kiln and a full breakdown of the energy requirements to dry spruce in such a facility.
- Undertaking a programme of bending and stiffness assessments on conventionally dried and high temperature dried spruce to clarify the situation on possible strength reductions due to subjecting timber to high temperature.

Four high temperature drying trials have been undertaken at the premises of HB Koeltechniek, in Almelo, the Netherlands. This kiln manufacturer has been constructing high temperature kilns for the timber industry for a number of years and produces a very high quality product. The drying times recorded from this set of trials range from 76 hours to 56 hours. After some discussion, it was felt that the drying times could be further reduced, although the variation in final moisture content of the charge would be likely to increase.

During distortional assessments on high temperature dried material, the average twist values were found to be either very similar too or lower than those exhibited by conventionally dried material. In comparison, bow and spring values tended to be slightly variable, although in all instances well within acceptable limits.

Results from strength and stiffness assessments undertaken on material from each of the trials were found to be quite variable. When compared to timber dried conventionally, certain batches of high temperature dried material showed significant reductions in strength and stiffness, whilst others remained fairly stable. These results indicate that the schedule type, and or length, may have a degrading influence on the structural properties of the timber being dried. In an attempt to clarify the variable reductions in strength from the first set of trials further assessments were undertaken on material dried using high temperatures in a separate project by the Windsor/Nardi group.

Results from strength and stiffness assessments on material dried by Windsor/Nardi again showed that high temperature drying resulted in reductions in strength and stiffness on UK spruce when compared to material dried conventionally.

In order to investigate how the strength and stiffness reductions recorded on high temperature dried material affected the machine and x-ray grading processes, material dried in the Windsor/Nardi drying programme were graded using both the x-ray grading system and the more traditional machine grading system. Results from machine grading assessments indicate that conventionally dried material returned a C16 yield of 100% and high temperature dried material a slightly lower yield of 96% and 98%.

If a sawmill was machine grading their material as a C16 standalone grade, material which had been high temperature dried would return a fairly respectable yield (96% and 98%). Considering that the Windsor/Nardi high temperature trials were drying spruce between 24 and 30 hours, this method of drying would enable material to be dried on a ‘just in time’ basis with fairly good yield returns.

The results generated by this project indicate that high temperature drying is a viable option for drying UK spruce although this statement must be viewed with a note of caution. High temperature drying does result in significant reductions in strength and stiffness of UK grown spruce. When machine graded, the highest structural grade which can possibly be produced (with any reasonable yield) is C16. Before purchasing any high temperature drying system, care must be exercised that the system fulfils all production requirements.

Contents

1. Introduction

This report presents the results from the current project since it's inception at the end of October 2005. The work was funded by the Forestry Commission and Scottish Enterprise under contract number FG15/04 and complements work already undertaken in both European and government funded Partners in Innovation projects. This report represents the final milestone of the contract, due at the end of January 2007.

During the last five years, BRE and 7 of the UK's largest softwood sawmillers have been partners in the European funded 'STRAIGHT' project. This project was initiated to investigate a number of new and novel drying techniques to improve softwood drying, reduce distortion and shorten drying times. Several of the techniques assessed within the project provided very encouraging results. One of the most promising methods was high temperature drying. After a series of trials on UK spruce by research organisations in France, Finland and the Netherlands, material was finally dried to a moisture content of 18% in approximately 63 hours with a quality similar, to or better than that achieved using conventional drying methods.

Although the results from this work have been very promising, the work to reach this point has required extensive assessment. Before the UK softwood sawmilling industry could be confident that the system was commercially viable, several areas of high temperature drying still required further investigation. These included:

- Investigating the possibility (using experimental trials) of further reducing drying times whilst retaining or improving the final dried quality of UK material.
- Undertaking a full scale industrial trial with the most promising kiln schedule developed in the experimental phase, and assessing the drying time and wood quality.
- Providing an indication of the construction costs of an industrial size high temperature kiln and a full breakdown of the energy requirements to dry spruce in such a facility.
- Undertaking a programme of bending and stiffness assessments on conventionally dried and high temperature dried spruce to clarify the situation on possible strength reductions due to subjecting timber to high temperature.

2. Description of the project

Initially, the project was organised into six work tasks covering a range of experimental trials culminating in a full scale industrial trial. Due to the unforeseen results from the structural testing assessments and the withdrawal of our Dutch partner (who undertook the high temperature drying), aspects of certain work tasks were curtailed.

At the dissemination meeting held at BRE on the 26th January 2006 and attended by project partners and funders, a number of difficulties were raised concerning the 'The high temperature drying of spruce' project. Firstly, the company (HB Koeltechniek) who have been drying the UK spruce using their experimental high temperature facility in Holland had 'lost interest in the project'. Michel Reipen who had been devising and overseeing the drying programme has, due to difficulties with HBK severed his working ties with the company. This resulted in the cessation of trials being undertaken in the Netherlands.

The initial chain of events has since been overtaken by the results recorded from strength and stiffness testing of the high temperature dried material. Results from the initial tests has indicated that severe reductions in the strength and stiffness of UK spruce can occur when dried using high temperatures. These results obviously raise considerable doubt about the future use of high temperature to dry UK spruce.

During the middle of last year, a separate BRE project was undertaken with the Windsor/Nardi group (kiln manufacturers from New Zealand and Italy) on the high temperature drying of spruce using their equipment. These company's use a slightly different form of drying technology than those used in Holland although both are very similar. One of the main differences between the different forms of drying is that the Windsor/Nardi group has shown that they are able to dry UK spruce in approximately 24 to 30 hours, whereas the shortest time achieved by the group in Holland was 56 hours. This reduction in drying time is impressive. Even so, further work is required to improve the distortional quality of the dried material, although the quality is not far removed from that achieved by conventional means.

At this moment in time, the Windsor/Nardi group are in discussion about their direction in the future. Among several ideas under discussion is to install a full size industrial unit at a sawmill in Scotland. This would allow further trials to be undertaken, although this would also require a considerable outlay for the company's involved.

Due to the poor strength and stiffness results of material dried in the Netherlands, it was decided that further strength and stiffness tests would be undertaken with the material dried in the Windsor/Nardi high temperature work. This would clarify whether the reduction in the structural properties of the material was due to the high temperatures used during the drying process (similar temperatures are reached by both systems) or whether the drying system itself is causing the reductions. Grading assessments would also be undertaken to assess how the material performs when graded. Alternatively, UK spruce may not be best suited to this type of drying due to its specific cellular structure.

3. Findings

3.1 High temperature drying assessments on UK spruce

Four high temperature drying trials have been undertaken at the premises of HB Koeltechniek, in Almelo, the Netherlands. Each of these high temperature trials was devised and supervised by Michel Reipen of the TNO Research Institute, Delft, the Netherlands. As this project is a continuation of the work first undertaken in the EU funded STRAIGHT project, the original coding for the trials has been continued on into this project. Therefore, the first high temperature trial within the project is suffixed 09, the second 10 and so on.

50 x 100 x 4800 mm spruce battens were selected from freshly processed material from two of the participating UK sawmills. Each pack was consecutively numbered, cut in half, a moisture content sample removed from the centre of each batten and the packs mixed to provide two identical packs. One pack was dried by the participating sawmill using a conventional drying schedule and the other pack sent to the Netherlands to be dried using high temperature. After drying, both the experimental (high temperature dried) and control packs (dried conventionally in the UK) were sent back to BRE for quality assessment measurements.

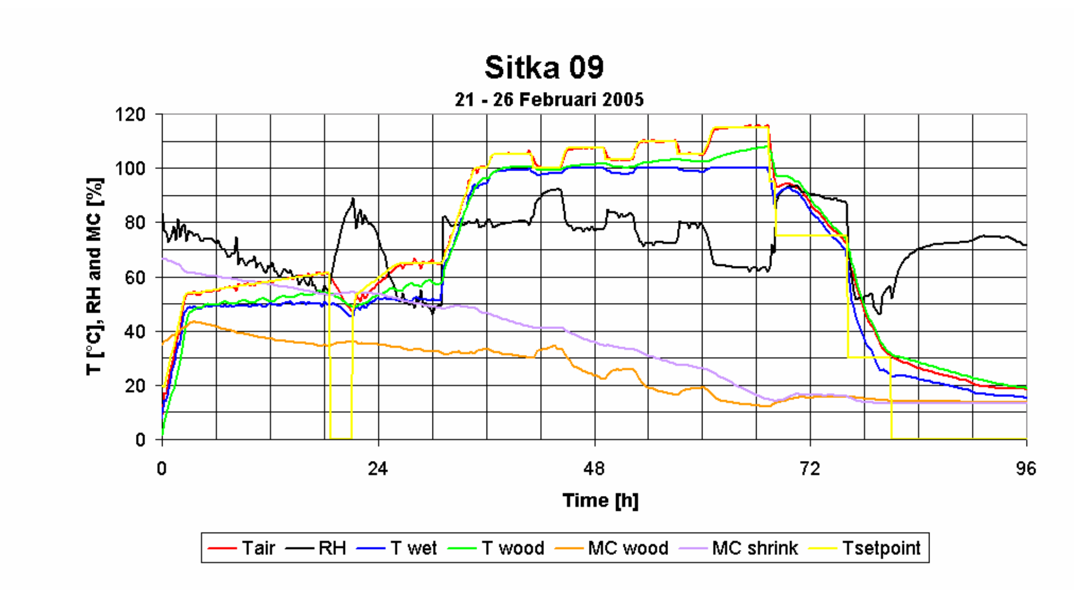

Figure 1. No 09 high temperature drying schedule (76 hours in length)

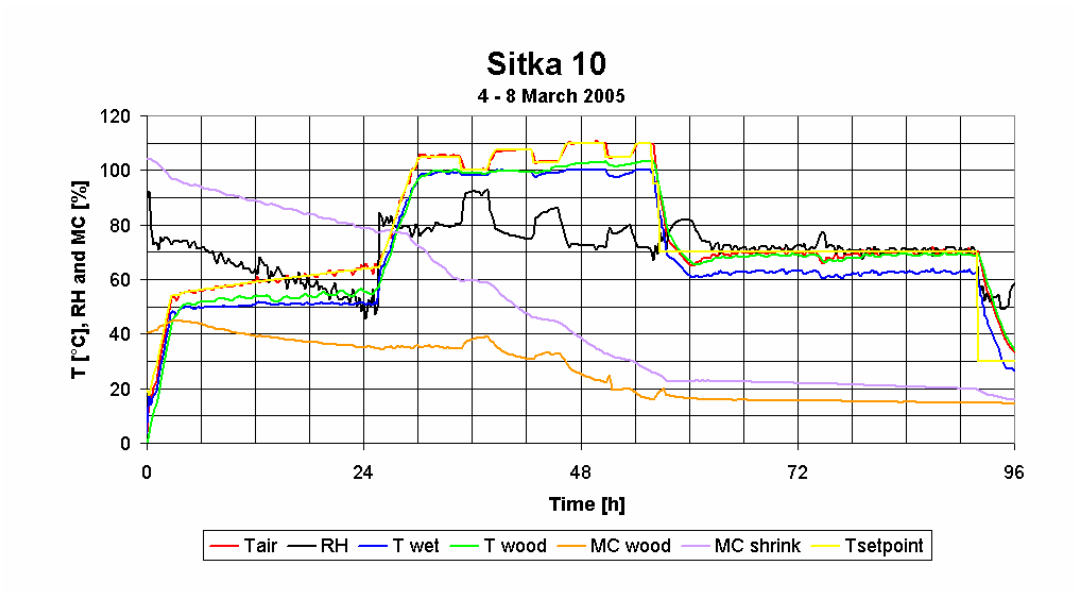

Figure 2. No 10 high temperature drying schedule (60 hours in length)

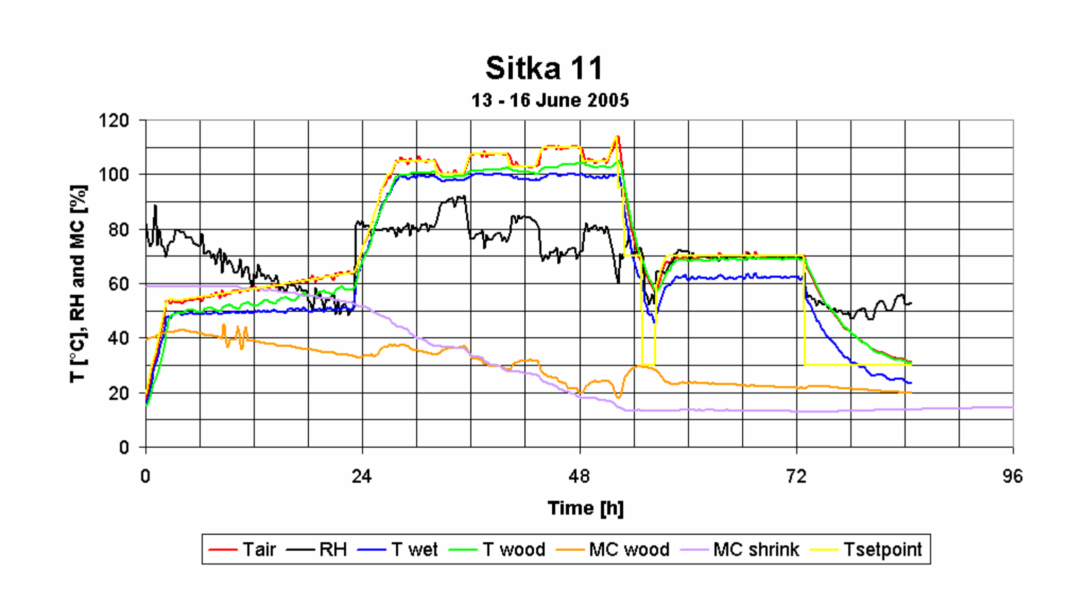

Figure 3. No 11 high temperature drying schedule (56 hours in length)

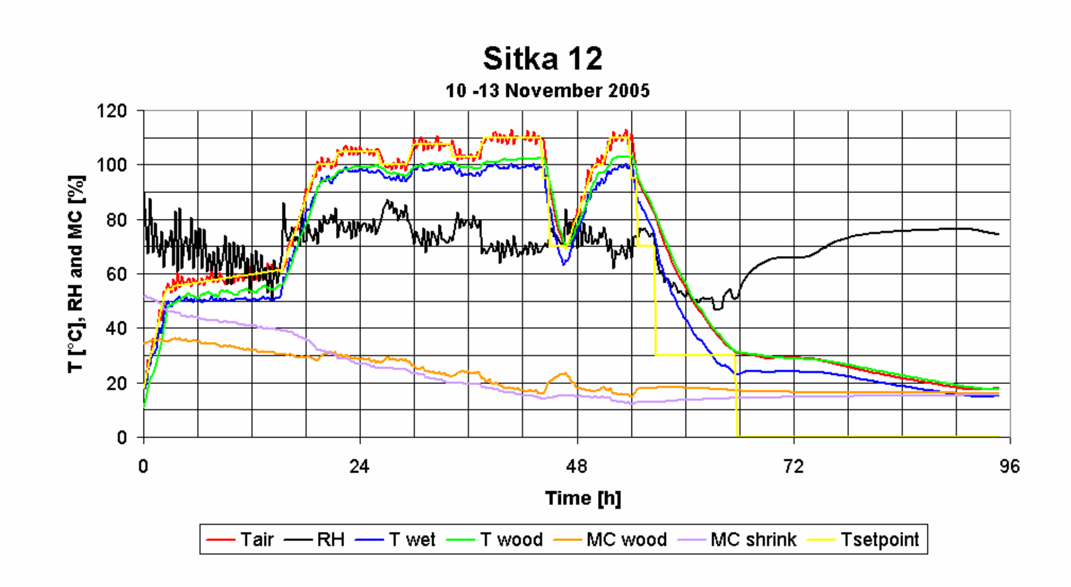

Figure 4. No 12 high temperature drying schedule (58 hours in length)

Figures 1, 2, 3 and 4 show the experimental high temperature schedules used to dry the four batches of experimental material sourced from the UK. The drying times recorded from these trials ranged from 76 hours to 56 hours. The associated control material for trial 09 and 10 was dried in 98 hours using conventional drying technology at the sawmill of Adam Wilson & Sons Ltd of Troon, using a maximum dry bulb temperature of 68°C. The associated control material for trial 11 and 12 was dried in 165 hours using conventional drying technology by BSW Timber Plc at their Boat of Garten sawmill, Scotland, using a maximum dry bulb temperature of 60°C. In discussion with Michel Reipen of the TNO Institute in Delft, it was felt that the high temperature drying times could be further reduced, although the variation in final moisture content of the charge would also increase from those exhibited (table 1). In reality, even charges dried using conventional means still exhibit a fairly wide variation in final moisture content (table 1). In a high temperature charge, this could be reduced by elongating the equalising phase of the schedule.

Table 1. Final moisture content variation

Trial	**Conventionally dried**		**High temperature dried**	
	Average M/C (%)	Standard Deviation	Average M/C (%)	Standard Deviation
09	14.3	1.3	15.6	2.4
10	14.0	0.9	17.1	2.5
11	19.1	2.5	18.0	3.7
12	19.2	2.4	17.9	2.0

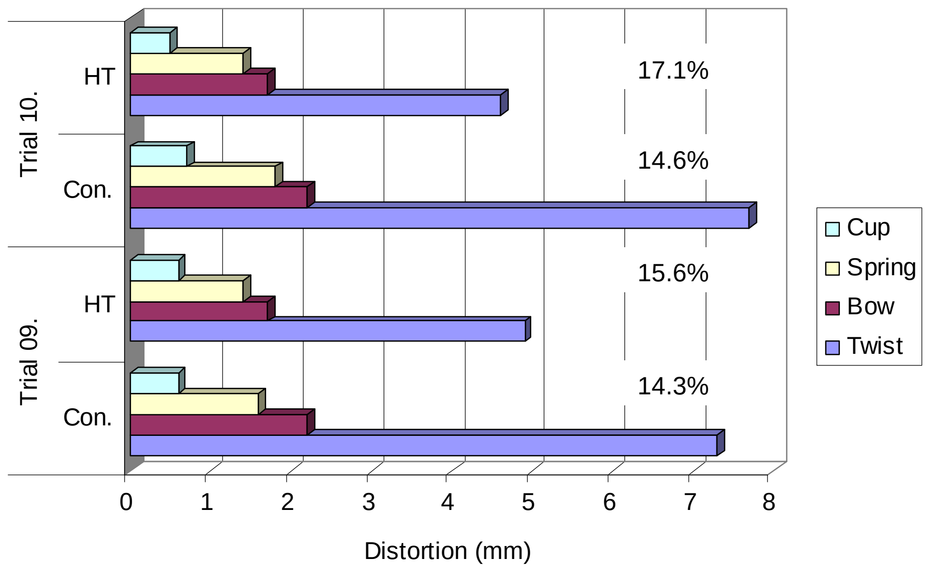

Figure 5. Average distortion & M/C values for experimental and control trials 09 & 10

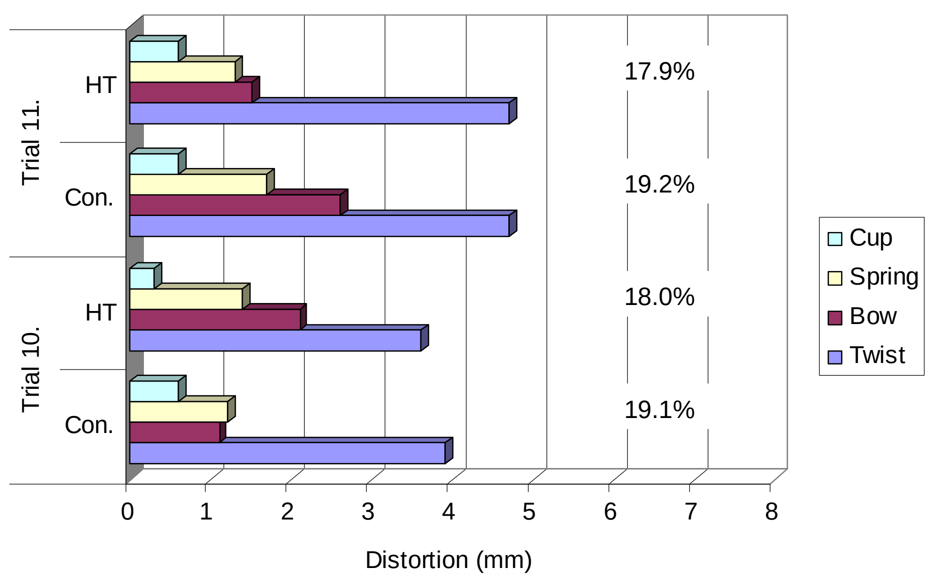

Figure 6. Average distortion & M/C values for experimental and control trials 11 & 12

3.2 Distortion assessments

Figures 5 and 6 show the average distortion values exhibited by each of the high temperature and associated control trials, with the average final moisture content of each batch shown to the left of each bar graph. Distortion measurements were recorded as per the specification in appendix A.

In all four instances, the average twist values of the high temperature dried material were either very similar, or lower than those exhibited by conventionally dried material. In comparison, bow and spring values tended to be slightly variable, although in all instances well within acceptable limits.

Attention is drawn to the final average moisture contents of conventionally dried material in trial 09 and 10. Due to a computer failure on the distortion measuring rig, this material required re-measurement after the initial data had been lost. This resulted in further drying of the material whilst in store, with an associated rise in distortion values. Even so, the average moisture contents are only differentiated by 1% between the sets of material within trial 09, although the twist values vary considerably.

These trials provide additional evidence to previous work that UK grown spruce can be effectively dried using high temperature in less than 60 hours. The recorded distortion levels of this material are similar to or better than those achieved by conventional drying means. As already mentioned, Michel Reipen of the TNO Institute in Delft felt that these drying times could be further reduced, although final average moisture contents would become more variable. The variation exhibited (table 1) in final moisture contents in the latest trials is similar to that of conventionally dried material. It should be noted that if the final average moisture content is reduced, the actual variation between final moisture contents will also be reduced.

3.3 Strength and stiffness assessments on high temperature dried spruce

As with many new drying techniques, high temperature drying has been researched quite extensively in Europe and many other parts of the world. It is documented in both Swedish[1] and American[2] timber research literature that timber subjected to high temperatures (above 100°C) have shown very small (5%) or no loss in strength or stiffness. Under task 5 of the project, battens dried using both high temperature and conventional drying schedules were assessed for possible variations in strength and stiffness. This work task investigated whether drying UK spruce under high temperature causes any significant loss in strength or stiffness, and if so, how this may affect subsequent machine grade settings.

Material from all four high temperature and conventional drying trials were tested in four point bending in accordance with EN 408: 1995 (Timber Structures – structural timber and glue laminated timber – Determination of some physical and mechanical properties) for the calculation of both the modulus of rupture, MOR (strength) and modulus of elasticity, MOE (stiffness).

The battens were assessed using a medium capacity Avery strength testing machine located in the timber centre at BRE. A linear voltage displacement transducer (LVDT) was placed in a central position under each specimen to measure the deflection of the beam as the load was applied. Data from the LVDT and load cell were transferred to a PC via a data acquisition programme which recorded both the applied load and the specimen deflection at 1 second intervals up to a specified deflection. The specimen was then tested to failure. After the tests were completed, the results were standardised for strength to a common batten depth of 150 mm and for stiffness at a moisture content of 12%.

Table 2. Results for modulus of elasticity (MOE) and modulus of rupture (MOR) on conventional and high temperature dried spruce

Trial	Conventionally dried		High temperature dried	
	MOE (N/mm^2)	MOR (N/mm^2)	MOE (N/mm^2)	MOR (N/mm^2)
09	10723.3	23.6	8257.6	18.4
10	9466.3	23.2	8964.23	15.28
11	8575.6	21.1	8851.5	21.8
12	9101.5	23.0	10212.6	19.3

MOR values adjusted to 5th percentile

Results from the strength and stiffness assessments (table 2) indicate quite variable results. In trial 09, both strength and stiffness of the high temperature dried material was reduced by approximately 22% when compared to values recorded on conventionally dried material. In trial 10, stiffness was reduced by 6% and strength by 32%. In trial 11, stiffness slightly increased and strength remained almost constant when the two types of drying were compared. In trial 13, stiffness again increased, although strength was reduced (approx. 15%).

Although the statistical sample is relatively small, the results from this piece of work do indicate that using high temperatures (110ºC+) to dry UK spruce generally results in a significant reduction in both strength and stiffness. The variability of the results recorded may be due to schedule type or possibly length.

3.4 Strength and stiffness assessments on spruce dried under the Windsor/Nardi high temperature drying programme

In order to clarify the results obtained under section 3.3, material which had been dried under the separate Windsor/Nardi high temperature drying programme was also assessed for strength and stiffness characteristics. Two packs (100 pieces of 47 x 100 x 2400 mm per pack) of high temperature dried spruce and two packs (156 pieces of 47 x 100 x 2400 mm per pack) of conventionally dried spruce were assessed using the same method as described in section 3.3.

As this material was dried under a private contract with Windsor/Nardi, it is not possible to describe the high temperature schedules specifically used, other than to say the maximum drying temperatures were in the region of a 110ºC+, with drying being completed between 24 and 30 hours. The control material was conventionally dried in the UK by James Jones at Aboyne and BSW, Boat of Garten using their normal spruce drying schedules.

Results from strength and stiffness assessments (table 3) on material dried by Windsor/Nardi again shows that high temperature drying of UK spruce does cause reductions in strength and stiffness when compared to material dried conventionally. In trial 1/6, both strength and stiffness of high temperature dried material was reduced by approximately 12% when compared to values recorded on conventionally dried material. In trial 2/7, stiffness was reduced by 8% and strength by 11% when compared to values recorded on conventionally dried material.

Table 3. Results for modulus of elasticity (MOE) and modulus of rupture (MOR) on conventional and high temperature dried spruce

Trial	Conventionally dried		High temperature dried	
	MOE (N/mm^2)	MOR (N/mm^2)	MOE (N/mm^2)	MOR (N/mm^2)
1/6	9298.8	23.1	8208.3	20.8
2/7	9132.8	20.91	8079.7	19.2

MOR values adjusted to 5th percentile

The reductions in strength and stiffness recorded on material from the latest Windsor/Nardi high temperature trials are generally lower than those recorded from the Dutch trials. This may be partly due to small statistical or drying schedule variations.

Without testing a very large number of high temperature dried samples, a precise figure cannot be provided on what reductions in strength and stiffness can be expected when this type of drying is undertaken. Even so, with the natural variation shown by UK spruce, even this type of trial may not provide a definitive answer. What the results do indicate is that significant reductions in strength and stiffness can be expected if high temperatures are used to dry home grown spruce. How these reductions affect the final strength grading of the material is covered in the following section (3.5).

3.5 The influence of high temperature drying on the machine grading and x-ray grading of UK grown spruce

Significant (but variable) reductions in strength and stiffness have been recorded on UK spruce dried using high temperatures (110ºC +). In order to investigate how this affects the machine and x-ray grading process, UK material high temperature dried in the Windsor/Nardi drying programme was graded using both the x-ray grading system and the more traditional machine grading system. Two packs of high temperature dried spruce and two packs of conventionally dried spruce were passed through both types of grading machine and the results recorded (grading was undertaken on the same two packs assessed under section 3.4). The x-ray grading was undertaken by James Jones at Aboyne in Scotland on a Microtec GoldenEye machine and machine grading undertaken at BRE in Watford on a Cooke Bollinder machine.

Table 4. Results from machine grading trials on conventional and high temperature dried spruce (material has been graded for C16 standalone grade and C16, C24 combination grade)

	Conventionally dried			**High temperature dried**		
Pack	**Single grade**	**Combination grade**		**Single grade**	**Combination grade**	
	C16	**C16**	**C24**	**C16**	**C16**	**C24**
1/6	100%	23%	53%	96%	23%	37%
2/7	100%	38%	36%	98%	33%	17%

The battens dried within each group (conventional and high temperature) were graded as a C16 standalone grade and a C16/C24 combination grade. The results in table 4 show that both packs of conventionally dried material returned a C16 yield of 100% and high temperature dried material a slightly lower yield of 96% and 98%.

Machine grading the same material using a C16/C24 combination grade setting returned yields of 23% C16 and 53% C24 for conventionally dried (pack 1/6) and 23% C16 and 37% C24 for the corresponding high temperature dried pack.

Pack 2/7 returned a combination grade yield of 38% C16 and 36% C24 for conventionally dried material and 33% C16 and 17% C24 for the corresponding high temperature dried pack.

If a sawmill was machine grading their material as a C16 standalone grade, material which had been high temperature dried would return a fairly respectable yield (96% and 98%). Considering that the Windsor/Nardi high temperature trials were drying material between 24 and 30 hours, this method of drying would enable material to be dried on a 'just in time' basis with fairly good yield returns.

In comparison, if a mill was using a combination C16/C24 grading setting and were drying using high temperature, the yields would be significantly reduced when compared to material which had been conventionally dried.

X-ray grading of high temperature dried material

The grading results from material both high temperature and conventionally dried using the Microtec GoldenEye grading system (table 5) indicates that no significant variation exists between materials from the two types of drying. The grading values shown in table 5 were derived from data (moisture content, density and F_{max}) generated by the x-ray grading machine at the premises of James Jones, Aboyne.

Table 5. Results from X-ray grading trials on conventional and high temperature dried spruce

	Conventionally dried		**High temperature dried**	
Pack	**% of each grade**		**% of each grade**	
	C16	**C24**	**C16**	**C24**
1/6	5%	95%	4%	96%
2/7	5%	95%	4%	96%

In order to x-ray grade material dried using high temperatures, a large set of data from strength and stiffness assessments would be required by the x-ray grader manufacturing company in order to derive the correct settings for this material. This would then allow the reductions in strength and stiffness caused by this type of drying to be incorporated into the grading model for the machine type.

4. Surface colour changes in high temperature dried material

The colour of freshly processed spruce is generally a bright creamy white. Conventional kiln drying has little effect on this colour, although this will darken naturally over time to a light tan. This will be accelerated if exposed to direct sunlight.

The colour differences between the timber dried using conventional, and high temperature schedules is fairly marked. Drying spruce using high temperature darkens the timber to a similar hue as that of aged conventionally dried spruce.

This definite colour variation may cause some concern to producers; especially if the colour change affects the customer perception of timber dried using this form of technology.

5. Energy costs associated with high temperature drying

Kiln drying is a necessary part of producing UK softwoods for the construction industry. This process is often a bottleneck in the production chain and also a serious consumer of energy.

The cost of drying timber for the UK markets consists of four main elements, capital investment, raw material cost, energy consumption and labour (load and un-load the kiln). The energy requirements can be further split into four components to:

- Generate heat
- Generate airflow
- Run the control unit and associated switch gear
- Run the forced extraction fans (if fitted)

All four can utilise electricity, although most UK softwood sawmills use a combination of energy types including, electricity, fuel oil, gas and sawmill waste residues to run their kilns. Because of the different sources and the variability of dimensions and moisture contents required from the final product, it can be very difficult to place a specific price on the cost of drying per m^3 of softwood.

A conventional wood drying kiln (batch kiln) is basically an insulated box with the facility to produce heat and to humidify and circulate air. These three variables (heat, humidity and airflow) are essential elements of the drying process and are controlled via sensors within the kiln to optimise the removal of moisture from wet timber at a controlled rate.

Most UK softwood producers have relatively modern wood drying kilns which have the main fans and heat exchangers situated above the kiln load in the roof space, above a false ceiling. Top and side flaps or rubber partitions reduce the size of gaps around the parcels of timber, ensuring the heated air is directed through the load as efficiently as possible. Several types of kilns have forced air extraction units to remove moisture laden air, whilst vents introduce fresh air. Most of the modern kilns used in the UK softwood industry have their operation controlled by computer.

On the whole, conventional wood drying kilns (batch) are not efficient users of heat energy. Essentially, wet timber is placed into the kiln and the air within heated and circulated through the stacked timber by a number of fans. In order to regulate the loss of moisture from the drying timber (to prevent drying degrade), the atmospheric conditions are regulated by the introduction of moisture (steam or atomised spray) to prevent the timber drying too rapidly (to prevent distortional problems and various types of drying degrade).

As the hot air is passed through the kiln, the wet timber absorbs heat, resulting in the movement of moisture to the surface where it is absorbed by the circulating air. When the circulating air becomes saturated with moisture, the vents, located on the kiln roof are opened and the saturated air is vented to the atmosphere. Fresh air is then drawn into the kiln, heated, and the wood drying process continues.

The high temperature drying system used in this project is better described as ‘super heated steam drying’, where the wet bulb temperature is set at 100°C and the dry bulb temperature may reach 120°C. This type of drying system uses the sealed chamber principle, whereby no exchange of air occurs between the atmosphere and drying charge during the drying cycle. Moisture given off from the timber during drying is vented as a natural overpressure from the system as drying occurs.

High temperature drying systems reduce drying times and have been calculated as being more energy efficient than conventional systems. The main reasons for this are:

- Drying occurs at a faster rate than with conventional systems (reducing energy consumption)
- High temperature kilns are sealed units and do not require an exchange of air with the atmosphere to expel the excessive moisture produced during the drying process

Table 6 provides a cost comparision[3] between a conventional batch kiln drying to a moisture content of 8%, a continuous kiln drying to 18%, and a high temperature (HTD) kiln drying to both 8% and 18%. The table shows that HT-drying is most economical when drying to low moisture contents. Shorter drying schedules cut capital and energy costs. In this example, normal construction timber is dried in a continuous kiln, which are common in Nordic countries. The use of a heat exchanger on this example makes it more energy efficient. Savings are higher (estimated €11m^3) when construction timber is produced using HT-drying compared with low temperature batch kiln drying.

Table 6. Comparison between HT drying and conventional kiln drying (batch kiln for joinery timber and one stage continuous drying kiln for shipping dry timber).

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

Conclusion and recommendations

This report presents the results from the project 'High temperature drying of UK spruce' since it's inception at the end of October 2005. To date, the work program has covered a number of work tasks including:

- Undertaking further high temperature trials to reduce drying times and improve timber quality
- The assessment of distortional characteristics
- Undertaking strength and stiffness assessments
- Undertaking machine and x-ray grading trials
- Providing an indication and comparison of the construction costs of an industrial size high temperature kiln and a breakdown of the energy requirements to dry spruce in such a facility.

Four high temperature drying trials have been undertaken at the premises of HB Koeltechniek, in Almelo, Holland. Each of these high temperature trials was devised and supervised by Michel Reipen of the TNO Research Institute, Delft, Holland. The drying times recorded from these trials ranged from 76 hours to 56 hours.

An assessment of distortional characteristics on high temperature dried material indicated that average twist values were either very similar, or lower than those exhibited by conventionally dried material. In comparison, bow and spring values tended to be slightly variable, although in all instances well within acceptable standard limits.

Material from the four high temperature and conventional drying trials were tested in four point bending in accordance with EN 408: 1995. In trial 09, both strength and stiffness of high temperature dried material was reduced by approximately 22% when compared to values recorded on conventionally dried material. In trial 10, stiffness was reduced by 6% and strength by 32%. In trial 11, stiffness was slightly increased and strength remained almost constant when the two types of drying were compared. In trial 13, stiffness again increased, although strength was reduced (approx. 15%).

Due to the poor strength and stiffness results recorded on material dried in the Netherlands. It was decided that further strength and stiffness assessments would be undertaken on material from the recent Windsor/Nardi high temperature drying work. This would hopefully clarify whether the reduction in the structural properties was due to the high temperatures used during the drying process (similar temperatures are reached by both systems) or whether the drying system itself is causing the reductions.

Results from strength and stiffness assessments on material dried by Windsor/Nardi again showed that high temperature drying resulted in reductions in strength and stiffness on UK spruce when compared to material dried conventionally. In trial 1/6, both strength and stiffness of high temperature dried material was reduced by approximately 12% when compared to conventionally dried material. In trial 2/7, stiffness was reduced by 8% and strength by approximately 11% when compared to values recorded on conventionally dried material.

In order to investigate how the strength and stiffness reductions recorded on high temperature dried material affect the machine and x-ray grading process, material dried in the Windsor/Nardi drying programme was graded using both the x-ray grading system and the more traditional machine grading system. Two packs of high temperature dried spruce and two packs of conventionally dried spruce were passed through both types of grading machine and the results recorded. The battens dried within each group (conventional and high temperature) were graded as a C16 standalone grade and a C16/C24 combination grade. The results indicate that both packs of conventionally dried material returned a C16 yield of 100% and high temperature dried material a slightly lower yield of 96% and 98%.

Machine grading the same material using a C16/C24 combination grade setting returned yields of 23% C16 and 53% C24 for conventionally dried (pack 1/6) and 23% C16 and 37% C24 for the corresponding high temperature dried pack.

Pack 2/7 returned a combination grade yield of 38% C16 and 36% C24 for conventionally dried material and 33% C16 and 17% C24 for the corresponding high temperature dried pack.

The grading results from material both high temperature and conventionally dried using the Microtec GoldenEye grading system indicates that no significant variation exists between materials from the two types of drying.

Data and literature supplied by Michel Reipen of the TNO Institute in Holland indicate that the building of a new high temperature drying kiln is more expensive, the running of the unit is more energy efficient and therefore more economical than conventional drying kilns.

The results generated by this project indicate that high temperature drying is a viable option for drying UK spruce although this statement must be viewed with a note of caution. High temperature drying does result in significant reductions in strength and stiffness of UK grown spruce. When machine graded, the highest structural grade which can possibly be produced (with any reasonable yield) is C16. Before purchasing any high temperature drying system, care must be exercised that the system fulfils the production requirements.

References

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Appendix A – Distortion measurement process

Twist

Twist measurements were recorded on a special rig using calibrated transducers. Each batten being measured over a distance of 2000 mm. The severity of twist exhibited by each piece was measured at a distance of 2000 mm from the clamped end, at a height or depth of 100 mm (fig. 7).

Bow

Bow measurements were recorded on a special rig using calibrated transducers. The central portion of each batten was clamped against the rig up-rights, 2000 mm apart. The deflection from parallel of the piece was measured at the central point, 1000 mm from either up-right (fig. 7).

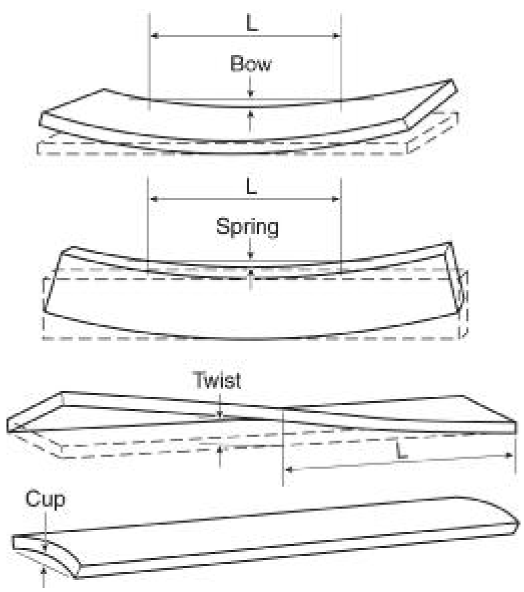

Figure 7. Distortion Types

Spring

The measurement of spring was similar to that of bow, except measurements were recorded on the narrow face only.

Cup

Cup was measured using a short straight edge and a digital dial gauge. The straight edge was positioned across the broad face of each piece, and the deflection of the piece from parallel measured in the centre of the section, in the centre portion of each batten.

Moisture Content Measurement

Moisture content was measured, using a calibrated electrical resistance type moisture meter at the central position of the board, a third in from one edge at a depth of 15 mm. The reading was calibrated against wood temperature at the time of measurement.