

# Reducing shrinkage defaults and/or drying time thanks to oscillating drying conditions

*Mariella De La Cruz – Lefevre<sup>(1,2,3)</sup>, Daniel Aleon<sup>(1)</sup>,  
Romain Rémond<sup>(2,3)</sup>, Patrick Perre<sup>(2,3)</sup>*

<sup>1</sup> *Institut Technologique FCBA  
10 Avenue de Saint Mandé 75012 Paris, France*

<sup>2</sup> *AgroParisTech, ENGREF, UMR 1092, LERFoB, Bois Biomatérial Biomasse Team  
14 rue Girardet F-54052 Nancy Cedex, France*

<sup>3</sup> *INRA, UMR 1092, LERFoB, Bois Biomatérial Biomasse Team  
14 rue Girardet F-54052 Nancy Cedex, France*

## **Abstract**

Wood drying is an essential process in wood industry. During drying, the stress field developed in the boards can produce several defaults such as deformations and cracks. The main objective of this work is to assess the potential of oscillating drying conditions to reduce the stress level through the activation of mechanosorption. With the oscillation of the equilibrium moisture content in the peripheral part of the board, mechanosorptive creep is activated continuously during the process. Beech wood, the second kiln dried hardwood after oak in France, has been chosen for this study. Beech wood has elevated shrinkage coefficients and thus an elevated risk of drying defaults. In this paper, we present some results concerning the use of oscillating drying conditions on the quality of the dried wood, specially its effect on case-hardening. Matched boards were kiln dried following a conventional schedule and two different oscillating schedules. The final moisture content, its distribution, the deformations and the residual stresses (case-hardening) were measured. Our results prove that oscillating drying schedules are able to reduce significantly the internal stresses. Therefore, oscillating schedules seemed to be an interesting option to improve the quality of kiln dried wood. Notice that such schedules can be applied to conventional kilns with little modifications.

This research is developed in partnership between a fundamental public research laboratory, LERFoB – Bois Biomatérial Biomasse Team, and Institut Technologique FCBA. The association of fundamental and applied research allows both a better understanding of the wood mechanosorptive behaviour and the improvement of wood drying.

*Keywords: wood kiln drying, oscillating conditions, drying stresses, slicing test, case-hardening*

## **Introduction**

Wood drying is an essential operation in wood industry to remove a large proportion of water from the freshly cut wood. During drying, a non-uniform moisture field develops in the board section because of the heat and mass resistance between air and wood and within wood. A moisture gradient appears within the board allowing the moisture migration but also a non-uniform shrinkage field generating stress and deformations. Internal stresses are responsible for several drying defaults that are unacceptable for an industrial production.

In order to reduce drying defaults, like deformations, checking and collapse, drying schedules should consider the mechanical behaviour of wood. Schedules are expected to

provide both a process duration as short as possible and a good product quality. This means a narrow scattering of the final moisture content (MC) among boards, small final MC gradients across the boards section, small deformations, few checking and imperceptible collapse. Several technical publications propose drying schedules based on the empirical knowledge for the most common commercial woods (Aléon et al., 2001; Boone et al., 1993; Joly and More-Chevalier, 1980). Despite all the efforts to provide convenient schedules, some species are still very difficult to dry. That is the case for several temperate hardwoods, for instance oak (*Quercus sp*) and beech (*Fagus sylvatica*).

Drying stresses can be reduced, in convective drying, by the activation of viscoelasticity. With both a high temperature level and a high equilibrium moisture content (EMC), the stresses are efficiently relaxed by the activated viscoelastic creep. This procedure has been successfully applied on tropical species in Aguiar and Perré (2000). Nevertheless, this strategy can not be applied in most of the existing industrial kilns. Moreover, some hardwoods have to be dried below 70°C to avoid discolorations and collapse. This temperature level becomes quickly lower than the glass transition temperature of wood components, as soon as the product enters the hygroscopic domain.

Hence, the idea to activate mechanosorption, which is possible even at low temperature, as a way to reduce the drying stresses.

In the industry, the drying stresses relief is commonly called case-hardening. Some recent simulations found that case-hardening decreases with increasing conditioning time and air humidity (Tarvainen, 2006). Kiln drying operators use to apply effective conditioning at the drying temperature or steaming after cooling to reduce or even remove the case-hardening. But, this strategy, when it works, fixes the consequence of the problem (stress relief) rather than the cause of the problem (stress itself). It would be better to reduce drying stresses using an accurate strategy, such as the activation of the mechanosorption throughout the process.

Oscillating drying conditions are a way to activate the mechanosorptive effect during the process. The continuous cycling of the EMC releases an additional deformation that can not be attributed to the superposition of elastic deformation, free shrinkage and viscoelastic creep at constant humidity (Muszynski et al., 2005). During an oscillating drying, the continuous change of MC at the peripheral zones of the boards activates the mechanosorptive effect. Mechanosorption leads to a reduction of internal stresses of the boards.

To our knowledge, the first literature reference concerning the use of oscillating drying conditions is described by Haygreen (1965). He reported the use of “part-time drying” in Florida (USA) for thick pecan and hickory boards. At regular intervals, the steam was cut off, kiln doors were opened and the fans were operated to cool the lumber. He also reported the use of schedules employing oscillating conditions of heating and humidification, in India. It was found that these methods could accelerate the drying and could also reduce the energy consumption.

Over recent years, many works were dedicated to the subject (Chadwick and Langrish, 1996; Vansteenkiste et al, 1997; Terziev et al, 2002; Sackey et al, 2004; Welling, 2004; Herritsch, 2008 and Milic, 2008). According to the results founded on literature, oscillating drying schedules do not necessarily improve the quality of the dried product nor shorten the drying time. Actually, results are disparate but it seems clear that adequate periods and intensities of oscillations are essential to obtain significant improvements.

## **Materials and methods**

### *Wood Material*

Beech wood was used on this study for two main reasons. First, it is the second dried hardwood in France, so there is a real interest from industrials to improve the quality and, if possible, the time of drying. The second reason is related to the physical characteristics of the species. With a

shrinkage coefficient of 6% in the radial direction and 12% in the tangential direction, beech wood is considered as a “high shrinkable wood” according to the French standard NF 51002. Thus, it has an elevated risk of drying defects. Moreover, US Forest Product Laboratory considers beech as a refractory species, so careful handling and drying is required. End-coating of boards is highly recommended for conventional kiln drying. High-temperature drying is impossible for this species.

42 freshly cut flatsawn boards of 300 cm length, 10 cm width and 3 cm thickness were used for these tests. The 32 boards showing the most homogeneous sawing pattern were selected and cut in three parts of 100 cm of length. The centre part was dried using a conventional schedule, and the two other parts were dried following oscillating schedules. Considering the high variability of wood, we thought that it would be more accurate to compare two consecutive boards; thus the centre part was chosen for the conventional drying. Boards were wrapped with a plastic sheet to limit moisture loss before the test.

### *The Semi-Industrial Kiln drying*

Kiln dryings were held in the FCBA dryer. This conventional kiln of 0.1m<sup>3</sup> of capacity is controlled by a double loop controller. Control parameters are the dry bulb temperature and the wet bulb temperature. The kiln has a cooling system which allows a fast decrease of the wet bulb temperature, which is suitable for oscillating schedules.

For all schedules, the dry bulb temperature was 55.0°C until the fibre saturation point (FSP) and then was progressively increased to 70°C. For the conventional schedule, the dew point was 51.5°C until the FSP, then increased progressively to 56.0°C, and when wood reached 20% MC it decreased to 47.6°C. Oscillations concerned only the dew point. The intensity was 3°C above or below the dew point for the conventional schedule. Periods were 3 hours for the oscillating schedule n°1 and 12 hours for the oscillating schedule n°2. By multiplying the

periods by four, we intended to extend the mechanosorptive creep activation into deepest layers of the boards from the exchange surface (indeed, the thickness would be exactly doubled for pure diffusive mechanism). All tests lasted 237 h. Table 1 shows the schedules and the  $\Delta$ EMC for the oscillating schedules.

Table 1. Drying conditions for the three schedules and  $\Delta$ EMC for the oscillating schedules.

Step	Time <sup>1</sup> (h)	DBT <sup>2</sup> (°C)	Conventional DP <sup>3</sup> (°C)	EMC (%)	Oscillating $\Delta$ DP (°C)	$\Delta$ EMC <sup>4</sup> (%)
1	185	55.0	51.5	15.0	$\pm 3.0$	+ 4.0/-5.0
2	190	60.0	52.4	11.0	$\pm 3.0$	+ 2.7/-2.1
3	212	65.0	54.2	9.0	$\pm 3.0$	+1.4/-1.7
4	218	70.0	56.0	7.0	$\pm 3.0$	+1.3/-0.8
5	237	70.0	47.6	5.0	$\pm 3.0$	$\pm 0.6$

<sup>1</sup> Accumulated time

<sup>2</sup> Dry bulb temperature

<sup>3</sup> Dew point

<sup>4</sup> Value estimated without considering hysteresis

### *Board instrumentation and measurements*

Twenty boards were randomly chosen to monitor the drying kinetics using an electrical moisture meter. Electrodes were inserted to the core of the boards. Mass of the boards and deformations (bow, spring, twist and cup) were measured before and after every kiln drying. Also, the slicing test was applied on each board at the end of kiln drying. This method consists in dividing in two slices a sample 15mm thick and cut at 300 mm at least from the extremity of the board. The samples are then stored in an impervious plastic bag. The sample must be free of bark, knots, resin pockets and reaction wood. According to the Standard XP ENV 14464, slices have to be stored during 24h for softwoods and 48h for hardwoods at ambient temperature. Then, the gap between the two slices is measured. For this study, a longer stocked period gap is used (at least 1 week after the end of kiln drying) to allow the homogenization of MC into the sample

(Tarvainen, 2006) and consequently, remove any differential shrinkage in the sample.

As case-hardening is an ambiguous term, on this work we rather called the drying stresses relief as revealed by the slicing test results.

## Results

### Final moisture content homogeneity

After 237 hours of drying, boards reached a similar average final MC: 9.62% (conventional), 9.05% (oscillating 1) and 8.89% (oscillating 2).

Final MC homogeneity and MC gradient between the surface and the core of the board are some of the most important criteria to evaluate the quality of wood kiln dried. Figure 1 depicts the final MC distribution for the schedules tested. The average final MC has significantly less dispersion for the oscillating schedules, especially for the oscillating schedule n°2.

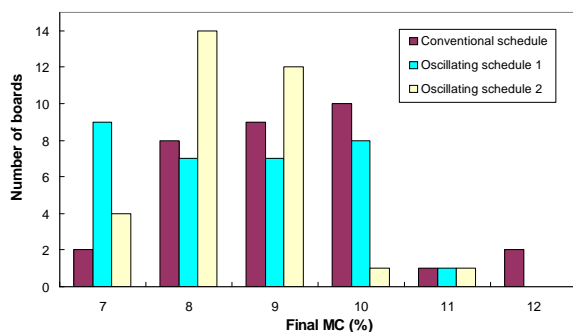


Figure 1. Distribution of final MC for oscillating and conventional drying schedules.

Table 2. Final MC (%) gradient between the core and the surface of the boards for the three schedules. Values between brackets are the standard deviation.

Schedule	Average MC	Core MC	Surface MC	Gradient
Conventional	9.62 (1.20)	12.82 (3.75)	8.51 (1.57)	4.31
Oscillating 1	9.05 (1.26)	11.20 (2.47)	6.86 (3.50)	4.34
Oscillating 2	8.89 (0.80)	11.18 (2.55)	7.55 (0.72)	3.63

Table 2 depicts the MC gradient between the surface and the core. Oscillating schedule n°1 did not improve the final MC gradient, but oscillating schedule n°2 led to 16% of gradient reduction. Note that the final EMC for all drying tests were set at 5%.

### Deformations

Important deformations are unacceptable defaults for an industrial use of kiln-dried wood. The most common deformations (bow, spring, twist and cup) were measured before and after the kiln drying. Both sawing pattern of the board and the anisotropy of shrinkage are the main reasons for these deformations which express during drying. Figure 2 depicts the deformations after drying. The deformations appearing during the oscillating schedules are always smaller or equal to those obtained with the conventional schedule. This is especially interesting for twist, significantly reduced with oscillations, as it is a particularly annoying deformation for wood transformation.

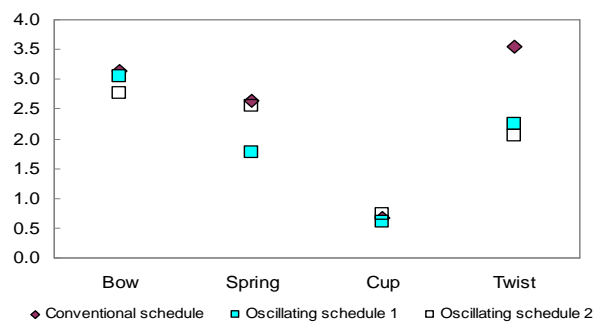


Figure 2. Average deformations produced during drying (mm) for all schedules tested.

This result could be explained by a more important relaxation of stress inside the board by mechanosorptive creep. This one is activated during all the process by the continuous change of MC at the peripheral part of the board under stress.

These results proved that convenient oscillations can reduce the board deformations appearing during drying through shrinkage.

## Slicing test

The slicing test allows visualizing and quantifying the internal stresses by measuring the gap appearing between the two slices of the transverse board section. The slicing converts one part of internal stress at the end of drying into section deformation. As a consequence of the memory effect of wood, boards presenting higher internal stresses during drying developed a higher gap. Figure 3 represented the slicing test results obtained for the three schedules studied 48h and 1 week or more after the end of kiln drying.

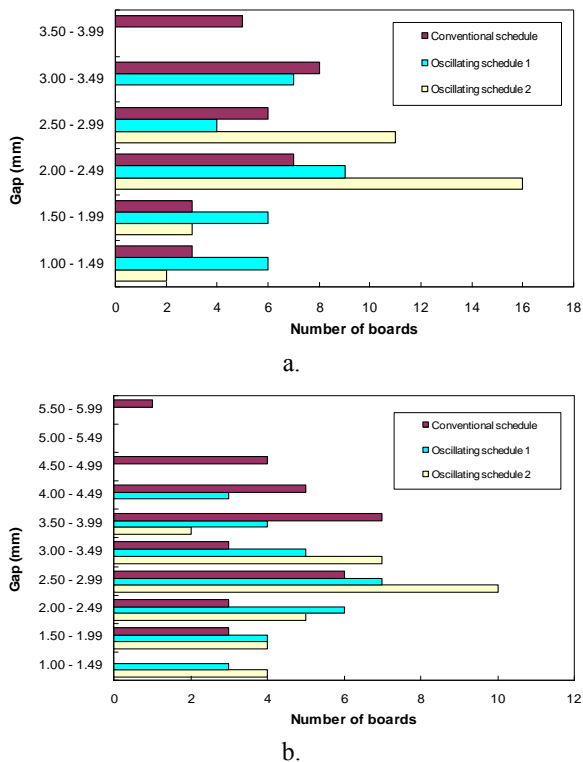


Figure 3. Slicing tests results expressed as gap (mm) for the three schedules: a. 48h after the end of kiln drying, and b. 1 week or more after the end of kiln drying. Values without the correction factor (1.78) preconized by standard XP ENV 14464 for boards 100 mm width or less.

48h after the end of process, gap is considerably lower for the oscillating schedules. Gap for the oscillating schedule n°2 is the lowest one. This measured gap is induced both by final MC gradient, which is smaller for the oscillating schedule n°2, and the memory effect.

After 1 week or more, final MC is supposed homogeneous inside each slice. These measured gaps, caused by the memory effect, gave the same tendency that 48h after the end of process (Fig. 3-b). Gap does increase but this is especially true for the conventional schedule. From 3.99mm of maximum gap after 48h, it increases to 5.99mm. Oscillating schedules gap raised from 3.49 and 2.99mm to 4.49 and 3.99mm respectively. Considering that gap is the expression of internal stresses in the boards, results showed a significant reduction of internal stresses for the oscillating schedules.

Oscillations, by the activation of the mechanosorptive creep, induced then a significant improvement of the kiln-dried product quality, since internal stresses are responsible for several defaults. The differences between the two oscillating schedules evidenced also the effect of periods. Thus, relevant periods for oscillations are essential to obtain some improvement. In particular, the relevant period will depend on species and thickness.

## Conclusions

The results of this study prove the potential of using oscillating conditions to improve the drying quality of wood. Oscillating schedules tested on this study showed an improvement in the final MC homogeneity, final MC gradient and residual stresses inside the board. Oscillating schedules seem to be also effective in reducing the global deformations of the board.

The influence of amplitude of the oscillations was not studied on this work. It would be interesting to study that and also the combined influence of amplitude and periods in final MC homogeneity. We intend to use a comprehensive drying model as a first step in the difficult task of tuning these parameters, namely as a function of species and thickness.

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