ANALYSIS OF CASE HARDENING

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ABSTRACT

In this paper "case hardening" is defined based on an interview of scientists: it is seen primarily as tendency of dried wood to deform after re-sawing from larger cross-sections. This tendency after various drying schedules has been simulated by the use of FE program PEO which has been developed for analysis of moisture transport and stresses during drying. Also the draft CEN-standard method has been analysed.

1. INTRODUCTION

Case hardening is a term, which is often used to describe the quality of dried wood. In this study we made a survey to find out whether there is a unified international understanding what is meant with this term. Secondly, we used our drying simulation software to analyse not only drying and stresses during kiln drying, but also deformations after drying when the case hardening test is made in accordance with the draft CEN standard. Results are reported in this paper.

2. DEFINITION OF CASE HARDENING

2.1 Survey

The survey was conducted by sending questions via email to internationally known experts. 14 of them replied (see acknowledgement). The questions were asked as follows:

- How do you define the case hardening
- Which are the disadvantages of case hardening to the end users
- Do you have measured results to describe the phenomena at case hardening

A common feature in the answers was that case hardening is seen to be related to drying stresses and it causes deformations after the original dried cross section has been resawn or otherwise machined. The harm is caused by the deformed surface of the final product, by the wasted material when working the resawn surface back to a plane form or by the problems in woodworking because of the immediate deformation of the cross-section during planing or sawing.

It was also stated that case hardening is caused by the mechano-sorptive creep deformation during the early part of drying when the surface is under tensile stress. This strain is not recoverable under dry service conditions, but can be counteracted by conditioning wood at drying temperature: the compressive stress causes compressive creep strain making the total elongation of the outer surface smaller.

Residual stresses after drying, at the time of wood working, is considered to be part of ”case hardening”, but it could also be left out of the definition, and seen as a separate phenomenon.

The term case hardening is used often more loosely, including other meanings than those described above. On the other hand, the term case hardening does not describe the phenomena. Therefore, it would be better to use distinct well defined terms for different phenomena, such as:
- residual stress meaning the physical state of stress after drying, causing deformation immediately when resawed or planed.
- stretched surface, elongated during drying resulting in cupping when resawn and equalised.
- dry shell, dry and nutrition filled cells at surface, which can slow down the drying process which may explain the origin of term “case hardening”. Hardening may refer also to high hardness of surface because it is dry.

2.2 Definition

As result of the survey it is proposed that case hardening is defined as follows:

> **Case hardening is a feature of dried wood to deform (cup) after re-sawing and equalising of the moisture content.**

This phenomenon could be called ”surface stretching” in accordance with the reason of the phenomenon or ”cupping tendency” as to the harmful result of it.

2.3 Physical and chemical changes in wood

An interesting question is how mechano-sorptive strain or compression in direction perpendicular to grain affects the cell wall structure of wood. There are indications that tensile deformation means cracking in cell walls and compression set means local crushing (Sehlstedt-Persson 1998).

There are some other features which can also be considered as case hardening: hard surface because it is dry, lowered permeability of the surface because of dryness or because the sugars fill the cells close to the dry surface of sapwood.

3. ANALYSIS OF CEN TEST SPECIMEN

3.1 Method of analysis

The draft CEN standard gives a method which can be used to measure the tendency of cupping when the product is manufactured by resawing dried sawn timber. This method is illustrated in Appendix 1, figures 1 - 4.

The calculation of the ”case hardening” has been made by the use of PEO programme. PEO calculates moisture transport and development of stresses during drying. After cooling down the central line element connections are freed and cupping of the two pieces is summed after equalising the moisture.

In this programme the calculation of moisture changes in the cross-section is made using a two-dimensional isotropic model for the moisture transfer in the transverse (RT) plane of wood. The model uses a reduced approach that considers all the different flow components with a single, diffusion-type differential equation. This simplified model uses the diffusion coefficient and the surface emission coefficient as effective model parameters, which take into consideration the variation of flow properties and whose values are obtained through a comprehensive empirical fit to experimental data. The model has been introduced in more detail in refs. Hukka (1996) and Ranta-Maunus (1994). The spatial discretisation is done by the control volume method using rectangular calculation mesh. Basics of the calculation method are presented in this workshop by Hanhijärvi and Helnwein (2001).

The material used for simulations is 50 x 150 mm Scots pine heartwood timber. The logs are sawn with 2 ex-log. Thus the pitch is on inside face of the studs. The used FE mesh is presented in Figure 1.

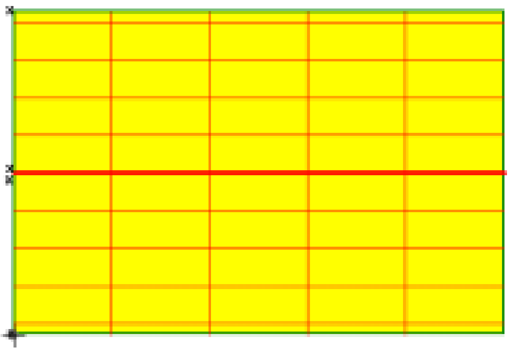

Figure 1. FE mesh used in drying simulations with PEO program. This is the right half of the specimen, y-axis being the axis of symmetry. The pith of the stud is in origo. Displacements in points denoted by x are shown in Fig. 2. Vertical position of lower right corner is fixed.

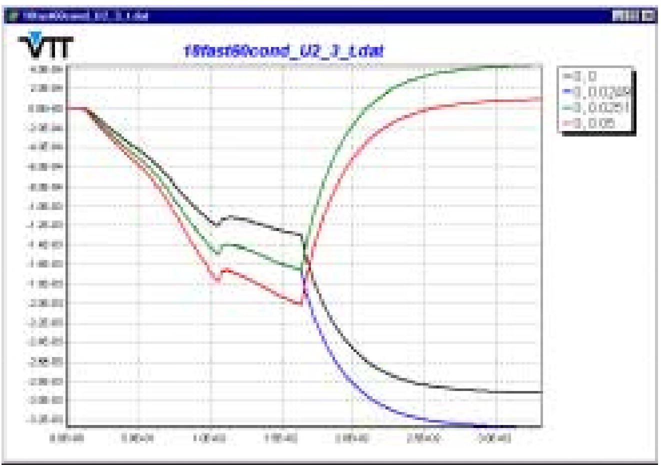

Figure 2. Vertical displacements of points on the symmetry axis: on both surfaces and on both sides of the slicing line (see Fig.2). Width of the specimen is 150 mm. Casehardening value is the distance of the center points at the end of the test, if the width of the specimen would be

100 mm. According the CEN-test the casehardening is seen as value measured after 24 hours of the slicing.

Figure 2 presents the displacements of mesh points in the middle of the surfaces and just beneath and over the centerline (slicing line, see Fig. 1). In drying and conditioning phase the displacements are due to cupping of the cross-section as one piece. After slicing the upper and lower part of the specimen are cupping in opposite directions when moisture is equalised. The calculation indicates that moisture content gradient disappears in one week when conditioning in plastic bag. The time scale of the calculation of moisture transport of test specimen in plastic bag may be inaccurate and is not verified by tests.

3.2 Drying schedules

Drying schedules are selected based on the calculations with simulation software Laatukamari. Fast and slow drying schedules are selected with following criterion:
- Only minor checking is allowed
- Wet bulb depression is in fast schedule higher than in slow schedule

Fast and slow schedules are in the beginning about the same for avoiding checking. In the fast schedules the end phase is speeded up by increasing the wet bulb depression more than in slow schedules. Schedules with additional conditioning were also simulated. The basic schedule was shortened so that after the conditioning phase the end moisture content was same as after drying without conditioning. Target moisture contents were 18 and 8 %. Drying schedules are specified in Table 1.

An example of drying curve and tangential stress (relative) development on the surface of outside face during drying schedule 18fast60 is illustrated in Fig. 3.

Table 1. Drying schedules used in PEO-simulations and moisture content gradient after drying, MC_{grad}. Schedules are specified with target moisture content MC_{target}, drying temperature T_{drying}, maximum wet bulb depression, WBD_{max}, and conditioning.

Drying schedule	MC_{target}	T_{drying}	WBD_{max}	Conditioning	t_{drying}	$t_{cond.}$	t_{tot}	$MC_{gradient}$
	%	°C	°C	yes / no	h	h	h	%
18fast60	18	60	14	no	117		117	5,7
18fast60cond	18	60	14	yes	107	33	140	3
18slow60	18	60	7	no	157		157	3,9
18slow60cond	18	60	7	yes	122	66	188	2,1
18fast80	18	80	14	no	78		78	6,5
18fast80cond	18	80	14	yes	72	17	89	3,8
18slow80	18	80	7	no	96		96	4,6
18slow80cond	18	80	7	yes	66	54	120	2,2
8fast60	8	60	22	no	256		256	1,8
8fast60cond	8	60	22	yes	240	65	305	0,7
8slow60	8	60	18	no	309		309	1,4
8slow60cond	8	60	18	yes	292	69	361	0,5
8fast80	8	80	25	no	150		150	2,1
8fast80cond	8	80	25	yes	142	38	180	0,7
8slow80	8	80	18	no	180		180	1,4
8slow80cond	8	80	18	yes	177	23	200	0,6

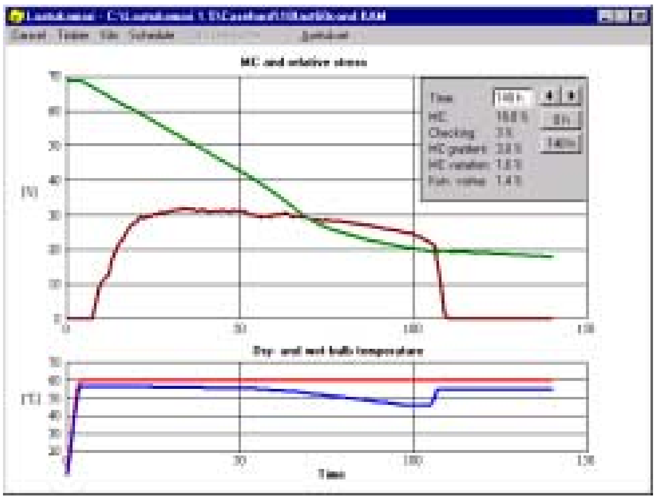

Figure 3. Drying schedule 18fast60cond. Moisture content and drying stress curves according to Laatukamari simulation model.

3.3 Simulated case hardening results

An example of the results of PEO simulation is presented in Figures 4a - 4d. Calculated ”case hardening” values are compiled in Table 2. Simulated case hardening values are compared to the cupping caused by equalisation of the moisture distribution at the moment of splitting the specimen. The values are shown also in Figure 5.

As expected, calculated gaps are largest after fast drying without conditioning, smaller when conditioned and about equal after slow drying without conditioning and after fast drying with conditioning. When drying to 18% without conditioning, the case hardening gap is nearly the same as the gap caused by equalising of the moisture content. After conditioning, the gap is smaller but not much different from the pure moisture gradient effect.

When dried to 8% final MC, simulated CEN case hardening gaps are about 50% larger than pure cupping after slicing due to moisture gradient, when conditioning is not part of drying. CEN gap is twice the cupping effect after schedules with conditioning.

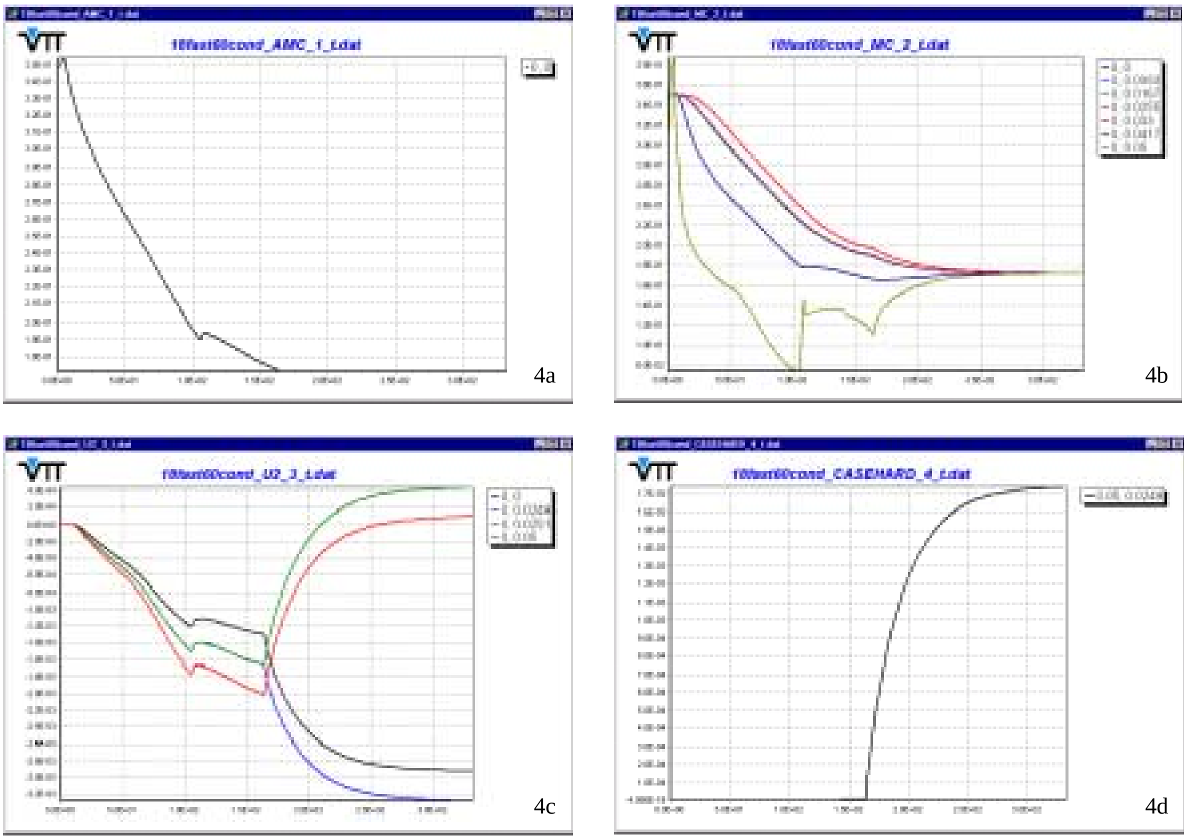

Figure 4. Average moisture content (4a), moisture content on the surfaces and inside the board (4b), vertical displacements of the mesh points, see fig 1 (4c) and case hardening opening (4d) in drying phase and after slicing of test specimen.

Table 2.CEN-gap and gap due to equalising MC-gradient without prior creep history, according to PEO -simulations.

Drying schedule	CEN-gap mm	Gap due MC-grad., mm
18fast60	2,5	2,5
18fast60cond	1,8	1,7
18slow60	1,8	1,8
18slow60cond	1,3	1,4
18fast80	2,5	2,4
18fast80cond	1,7	1,7
18slow80	1,9	1,9
18slow80cond	1,2	1,4
8fast60	2,1	1,4
8fast60cond	1,7	0,8
8slow60	1,8	1,1
8slow60cond	1,4	0,7
8fast80	2,1	1,5
8fast80cond	1,7	0,9
8slow80	1,7	1,1
8slow80cond	1,4	0,8

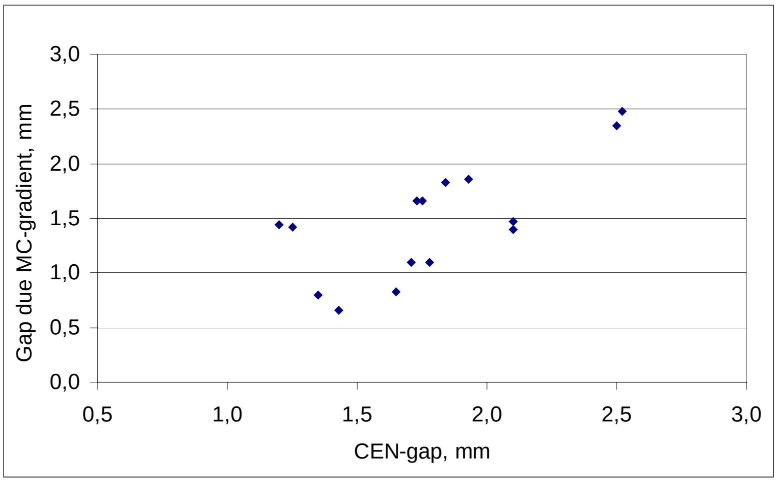

Figure 5. Same information as in Table 2.

In an experimental research work commissioned by Finnish Wood Research Ltd the correlation between MC-gradient and EDG-gap (like CEN-gap but measured after 24 hours in room conditions) was measured (Fig. 6). The cupping of the test specimens and cupping of panels resawn in three parts from 47 x 100 mm spruce timber was studied. Also the relationship between cupping of the test specimen and MC-gradient was analysed.

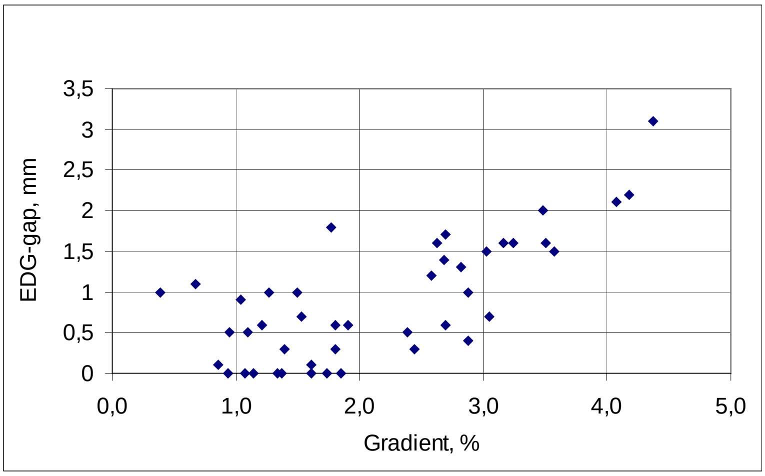

Figure 6. Correlation between the gap of the slicing test specimen and the moisture gradient after drying of 47 x 100 mm Norway spruce timber. Gap was measured according EDG after 24 hours conditioning of sliced specimens in 20 °C / 45 - 55 % RH.

These simulated and experimental data show that casehardening test results and MC gradients are correlated but obviously two different measurements which cannot replace each other.

3.4 Effect of the equalising time

In a study test specimens were prepared from 20 spruce studs dried in progressive kiln. From each stud one casehardening test specimen was kept after the slicing in a plastic bag and one parallel specimen in a room atmosphere. Figure 7 shows average values of the cupping in both cases. The result show that the equalisation in plastic bags is slower than in open space. Please notice that the total cupping is in room conditions higher due to lower EMC.

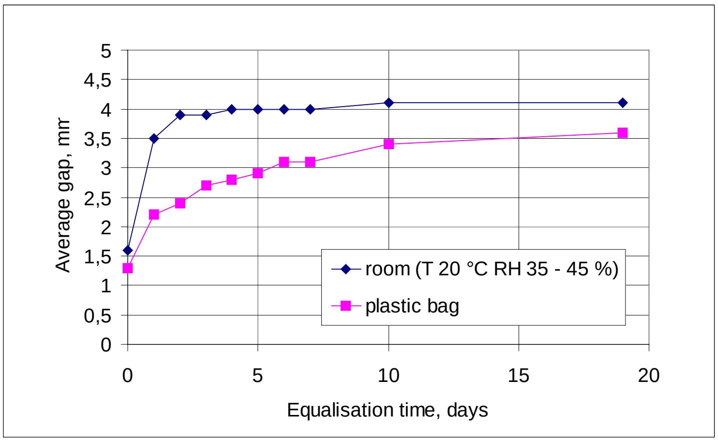

Figure 7. Cupping of sliced specimens in plastic bags and in room conditions. Spruce 32 x 125 mm dried in progressive kiln 72 hours (t_{dry} = 64 °C, t_{wet} = 52 °C). The points are average values of 20 specimen.

4. CONCLUSIONS

As conclusion of expert interview the casehardening is defined as follows: Case hardening is a feature of dried wood to deform (cup) after resawing and equalising of the moisture content.

Analysis with FE program PEO has shown that casehardening is not only the cupping due to equalisation of moisture content gradient after slicing the specimen. The experimental results give the same conclusion. However, the case hardening gap after drying to high final moisture content 18% is nearly identical to the gap caused by cupping when moisture gradients of the two halves of the test piece are equalised.

According to simulations and experiments, the proposed time (24 hours) to keep the sliced specimens in plastic bag is too short to show the total cupping. Thus the test doesn't show the whole cupping tendency for example of panels when the moisture content is equalised after resawing of studs and planing the billets.

The PEO programme is a suitable tool for analysing also the effect of other wood working cases. For example the effect of planing depth on deformations. This work will continue.

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Draft CEN test procedure for case hardening measurement

The test slice will be separated into 2 pieces (Fig. 3), stored in a plastic bag 24 hours and the gap is measured over the span of 100 mm.

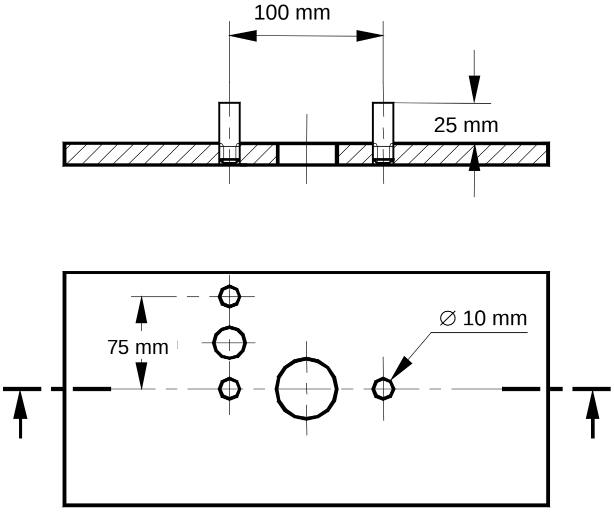

Figure 1: Test jig for assessment of case-hardening

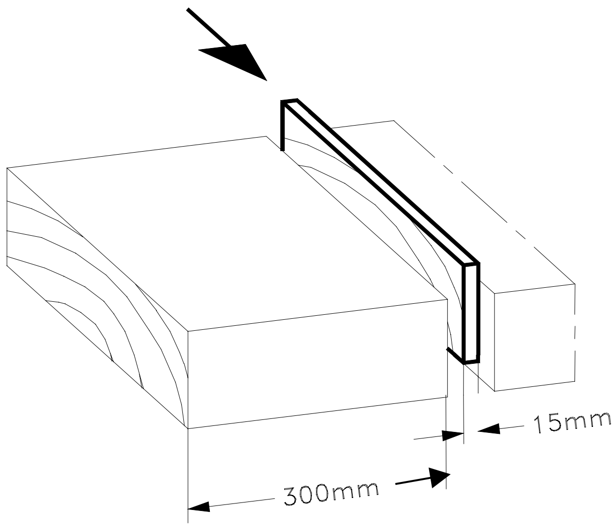

Figure 2: Preparation of test slice

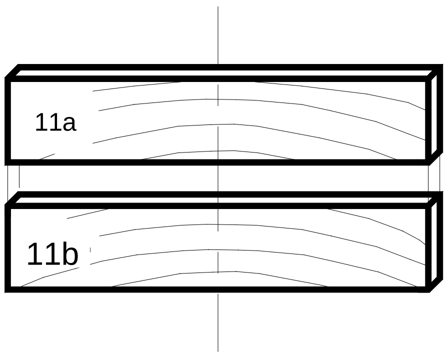

Figure 3: Separation and marking of test slice

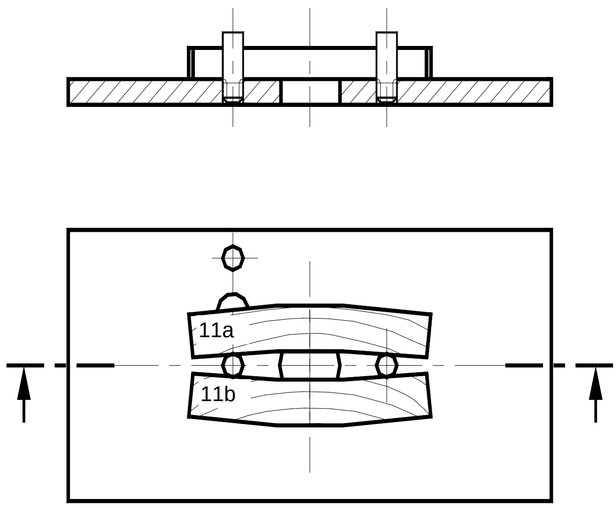

Figure 4: Evaluation of case-hardening with test jig