A Sensor to Measure Wood Stress During the Drying Process

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ABSTRACT

In order to quantify and control the internal stress and subsequent strain generated in wood during the process, different indirect and semi-direct techniques can be adopted such as the so called “flying wood” test, prong test and other: these semi-direct techniques provide measurement of the overall effects of stress as the combination of internal gradients. In order to specifically measure the internal stress at a given depth in the material, an in-situ measurement is required, by inserting a probe which can measure the local pressure of the wood along a specific axis. This system needs to be non destructive and minimize the interference of the measurement specimen with the material. Moreover, it has to be chemically inert towards the environment of the drying oven.

Innovative and patented in situ measurement of internal stress of wood during the drying process is presented. A custom sensor was designed based on a silicon micromachined pressure gauge inserted in a Teflon shell: Teflon provides protection, it works as a medium between the gauge and wood, and it makes it possible to handle the sensor. In this configuration the pressure gauge has directional sensitivity, and therefore axis-selective measurement is possible. An easy to use sensing device was realized, reducing the package dimension to the minimum.

The influence of the Teflon shell on the gauge sensitivity was studied by finite element simulation using ANSYSTM software. Measurements of internal stress during drying process were carried out and compared with results obtained by different measurement techniques. A first empirical confirmation of the theoretical models for wood stress was obtained. A series of verifications, required for the future implementation of the system at industrial level, are presented.

INTRODUCTION

During drying, sawn timber is exposed to high risks which can affect the integrity and quality of the material by generating internal damage coming from the stress induced by the physics of the process itself and the quality of drying has a strong effect on the behavior of wood during the end use phase.

Drying causes a non uniform reduction of the moisture content through the section of the wood, since the outer regions dry faster than the inner core of the material, thus inducing plastic strain and subsequent damage.

Up to now, in order to quantify and control the internal stress and subsequent strain quality of wooden products, only destructive tests at the end of the drying process were possible. These semi-direct techniques provide measurement of the overall effects of stress as the combination of internal gradients. They provide information about the quality of the dried wood but, being end-process measurements, they do not allow to control it.

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In order to specifically measure the internal stress at a given depth into the material, in situ measurement is required, by inserting a probe which can measure the local pressure of the wood along one specific axis.

Previous works in the past experimented different techniques to directly measure pressure in wood. The main problems were due to the dimension of sensor, to its stiffness influencing the quality of measure and to practical issues such as the problems of insertion of the probe into the wood.

This work, also based on such previous experiences, was focused to the solutions to such problems, working on new materials and on the last available transducer micro technologies.

**THE SENSOR FOR IN-SITU MEASUREMENT**

Among others, the requirements for the system are: “low cost” and “ease to use”. In addition, the measurement should be non destructive, chemically inert and capable of minimizing the interference of the sensor with the material. A simple and handy design was developed, adopting a pressure sensor inserted in a teflon casing: the device is inserted in the wood and Teflon works as a medium, transducing wood compression to the sensor.

In this configuration the pressure gauge has directional sensitivity, and therefore uniaxial measurement is possible: active components of the pressure (along Y axis) are transduced, while other components are symmetrically compensated by the geometry of the package.

Different prototype of sensors with different layout and configuration have been tested in laboratory conditions and in industrial kilns during several evolutive steps.

The last prototype is equipped with a pre-charge system. It allows to reduce the influence of the hole diameter in wood and, above all, to measure tensile stress.

**EXPERIMENTAL TESTS**

Characterization of sensor behavior has been performed in two different experimental configurations:

- Pure bending tests of sawn timber in transversal and longitudinal direction;
- Drying test at different drying condition of green sawn boards;

In both kind of test the influence of several factors, such as anatomic orientation of wood in respect to the sensor orientation, influence of drill-hole dimension, has been evaluated.

Longitudinal and transversal pure bending tests (four points loading) have been performed by means of a Metrocom© testing machine. In this configuration, a bending stress in Y direction produces tensile and compressive stress in X direction around the neutral axes. The output signal of the sensor ($\sigma_s$) at different depth has been compared with the theoretical stress at a given depth in Y direction ($\sigma_y$) calculated with:

$$\sigma_y = \frac{6M}{B \cdot y^2}$$

where $M$ is the bending moment, $y$ is the distance from the neutral axes along the Y axis (where the stress sensor is placed) and $B$ the dimension of beam in Z direction.

**FIGURE 1. schematic of the four point loading test**

Static and dinamic (time dependent) tests allows to estimate the dumping factor due to the interaction between the wood and the teflon package and the influence of time due to creep and relaxation phenomena.

$$c = \frac{\sigma_{bending}}{\sigma_s}$$
Drying tests have been performed on wet radial sawn boards of spruce and beech of different thicknesses.

During each test two boards with the same characteristics are dried in parallel: one with thickness \( s \) is equipped with the stress sensor; the second with thickness \( s/2 \) is insulated on 5 of the 6 faces in a non symmetrical way. The asymmetrical moisture profiles in such boards with five isolated faces produce a stress field whose torque is not equilibrated. This stress field bends the sample section whose curvature (together with the load variation) is collected during the process. The typical trend of deformation vs. time of the specimens (already described in previous papers as flying wood test or non symmetrical drying test) gives qualitative and quantitative information of stress trend along the thickness that can be compared with the data coming from the stress sensor.

**FIGURE 3.** Drying test at 65° C of a 50 mm beech sawn board. Radial and tangential stress measured by sensors in the core compared with the expected stress as estimated from the non symmetrical test. It could be observed that the sensors seems to successfully catch the stress reversal phenomena. (positive values = compression).

**SIMULATIONS**

The influence of the Teflon package on the gauge sensitivity was studied by finite element simulation using ANSYS™ software and results compared with experimental ones.

A section of the wood sample with the sensor in it was two-dimensionally simulated, considering the dynamic process of drying as a sequence of static equilibrium stages. Under this condition the portion of wood which contains the gauge has rigid constraints on its perimeter. The mechanical properties of teflon, steel (the sensor) and beech (the wood environment) have been applied to the model. Uniform axial stress was imposed in beech, both radial (R) and tangent (T), with a ratio T/R of about 1.4, as resulted by preliminary experiments. In figure 4 the interference in stress distribution due to the presence of the gauge is visible: on the left a blue area indicates no variation, while around the circular perimeter of the gauge a stress gradient is present up to a distance about as long as the diameter of the gauge itself.

**FIGURE 4.** plot of the stress along the Y axis, with a wood stress of 10MPa, for an 8x2cm cell.
FIGURE 5. plot of the stress along the Y axis, with a wood stress of 10MPa, for a 2x2cm cell.

Simulation showed a ratio between wood stress and stress at sensor’s surface along the Y axis, equal to 1.86, due to the package dumping effect.

This factor was then considered as a correction factor for experimental data.

FIGURE 6. stress values along Y axis for an 8x8cm cell, as a function of the distance from the sensor.

INDUSTRIAL APPLICATION IN A LARGE SCALE DRYING KILN

The industrial application of this system, patented by Nardi Srl,IVALSA, (Italian Tree and Timber Institute) and ITC/IRST (Centre for Scientific and Technological Research), in the typical average industrial drying kiln implies a series of verifications related to:

- number of sensors to be installed: this is of course related to the variability of the wood material loaded in the drying kiln. As stress is primarily related to MC distribution in the boards, the same stochastical order of sampling (number of MC probes) should be applied;
- species to be assessed: the specific visco-elastic and/or mechano-sorptive behaviour of different species has to be taken into account when stress is being monitored in a drying kiln. A series of dynamic calibrations are envisaged to assess the order of stress induced strain in different wood species;
- lumber thickness: stress distribution is determined by MC distribution along the section of the board (MC gradient); larger samples imply a greater difference in MC distribution, arising during the drying process; stresses are here normally higher, unless specific precautions (conditioning by high moisture) are taken;
- stack configuration: the way the lumber is loaded in the kiln, in separate packs or stacks, in different directions, with different size of stickers separating the boards, have been taken into account when designing the sensor. Of course, the industrial application will provoke a number of successive adjustments in the design of the system, simplifying it still to shorten time of installation;
- efficient models and algorithms for the transformation of the input data from the sensor in control procedures of the drying process.

BENEFITS IN DRYING

A series of benefits can be envisaged, by the introduction of this stress measurement system:

- duration of the conditioning phase: the duration of this phase is related to the stress relief effect, when a high level of moisture is applied to the surface of the boards causing a compressive creep strain which counteracts the previous mechano-sorptive deformation. In a conventional system, the duration of the conditioning phase is normally calculated according to experimental data and/or experience (e.g. rule of thumb methods prescribing: “1-2 hours for each centimeter thickness). The presence of a measurement device which can define precisely when and how the stress is being relieved is of course beneficial to avoid excessive duration of the process;
- assessment of risk levels of stress induced defects in lumber: the appearance of stress induced defects, like casehardening, surface checking and honeycombing, is detrimental in wood drying. The sensors will signal, to the electronic control of the drying kiln, the approach of stress levels (compression, tension) related to appearance of defects. This would, at a later stage of the project,
automatically induce a sequence of precautions (increase in air-moisture, decrease in temperature) to avoid them.

- the latter will of course induce a third and more important benefit allowing to dry at faster rates, by calculating, in real time the correct climatic configuration which most enhances water transport and evaporation, without damaging the lumber. We all know, in fact, that drying schedules stem from experimental research and experience and are generally much too cautious; a system which keeps under control the stresses present in the lumber, allows instead to increase temperature and decrease air-moisture settings in the kiln to the break-even point, where moisture extraction from wood is highest and stress remains at sustainable level.

CONCLUSIONS
A novel and patented in situ measurement system was realized and tested to monitor the internal stress of wood during the drying process.

The “qualitative” trend of the stress measured versus time and the amplitude of such values seems to fit the expected data according to literature and simulations, even if further work is needed on the design of the package in order to improve the response of the sensor to the stress of wood in operative conditions.

A set of experimental tests in laboratory and industrial conditions is still in progress in order to evaluate the influence of different variables such as the wood species, geometry (thickness) of lumber and the hygro-thermal drying air conditions. Such tests will lead to the full industrialization of the sensor, promoting better and faster drying conditions.

REFERENCES
Brandao A., Perrè P. The "flying wood" - a quick test to characterize the drying behavior of tropical woods, 5th iufro W.D.C. pp. 315-324, 1996, Quebec.
Ranta-Maunus A., Determination of drying stresses in wood when shrinkage is prevented: Test method and modelling. 3th IUFRO, pp. 139-144, 1992, Vienna (Austria)
Ugolev B.N., Skuratov., Wood hygrofatigue and its influence on strength and stiffness of dried lumber, Drevarsky Vyskum, pp.11-22, 1995 (4)