# Preliminary Tests for Optically Measuring Drying Strains and Check Formation in Wood

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# Preliminary Tests for Optically Measuring Drying Strains and Check Formation in Wood

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This study deals with the visualization of deformation during wood drying by Digital Image Correlation method using an Optical Measurement System. By this measurement, localized deformation by drying stress can be observed in naked eye. Estimation of displacement maps of willow tree disks and Oregon oak planks provided the strain distribution during drying of wood. And the stress concentration in the Oregon oak plank was successfully visualized.

It is considered that the use of a DIC system in wood drying can more accurately visualize strain changes of wood surface and using of DIC may provide more appropriate drying schedule preparation for unknown species or refractory wood species.

**Keywords**: drying strain, check formation, optical measurement, DIC (digital image correlation) system

## INTRODUCTION

Wood is a porous hygroscopic material whose moisture content changes with variations in the circumferential moisture conditions. These moisture changes can cause dimensional and physical property changes in wood. To assure the structural and physical stabilities of wood, its moisture content should be controlled through drying.

Wood shrinkage during the drying process causes deformation. This deformation originates in a localized position and is non–uniform. Wood scientists, therefore, have been interested in analyzing the wood deformation processes during drying. There are many models for predicting wood deformation and stress changes during drying (Ormarsson *et al*., 1999; Carlsson, 2001; Pang *et al*., 2001; Kang and Lee, 2002; Svensson and Martensson, 2002); however, these mathematical models have not been adequately confirmed through experiments.

Wood drying stress can be measured using various methods, such as a prong test, a slice test or a dissection test. However, these methods are destructive, discrete and retrospective. One non–destructive method is the sound radiation or acoustic emission method, which uses an AE transducer to detect the stress waves that occur due to drying. This method is effective for continuous detection of local microscopic observations during wood drying, but it is not available for wide–ranging strain observation because the stress wave sounds originate in localized positions (Breese *et al*., 1995; Krug *et al*., 1995; Lee *et al*., 1995; Kim *et al*., 2005). In addition, shrinkage and microcrack of wood during drying were visualized in microscopic level by in–situ observation using CLSM (confocal laser scanning microscopy). (Sakagami *et al*., 2007; Sakagami *et al*., 2009a; Sakagami *et al*., 2009b)

Therefore, we hypothesized that an optical measurement technique which takes advantage of Digital Image Correlation (DIC) could visualize strain deformation during wood drying. DIC is usually performed by determining the maximum of the correlation between original and deformed images. The cross correlation coefficient is defined as pixel intensity or the gray scale value at original point and deformed image. In this study, applying paint to the surface of non–dried wood, two cameras track the wood surface movement resulted from speckle pattern changes by drying stress occurred by locally originated strain. This technology has been used since the late 1980s to investigate the displacement of material loaded under stress (Ranson *et al*., 1987; Bruck *et al*., 1989; Vendroux and Knauss, 1998). It has been used successfully to detect deformations in wood fiber, paper, wood and wood–based materials because it can measure deformations in material surfaces ranging in size from a micron to a meter (Sutton and Chao, 1988; Zink *et al*., 1995; Mott *et al*., 1996; Choi and Shah, 1997; Muszy'n ski *et al*., 2006; Sinha *et al*., 2006). Concerning the relationship between wood deformation and drying stress, Danvind and Synnergren reported (2001) that the deformation during drying can be understood using displacement detection because wood deformation during drying causes stress concentration and drying check. In the late 90s, more accurate deformation measurement became possible as more advanced DIC systems were developed

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(Schmidt *et al.*, 2002a, b).

We adopted this advanced technology in wood drying to understand the wood deformation mechanisms. We applied a DIC system for both fast–drying and typical refractory species, measured the three–dimensional strain distribution of the wood, and investigated the possibility of drying check detection using an optical measurement method. These efforts can reduce the cost and aid in the time optimization of the wood drying schedule, in addition to possibly elucidating the appropriate drying schedule for a refractory wood species.

## MATERIALS AND METHODS

The experimental apparatus was established as shown in Fig. 1. The optical measurement system consisted of two lenses, a digital image capture board and a trigger. A lighting device was adopted so as to produce a bright and clear image.

Two different tree species were used; the fast–drying willow tree species was used for the three–dimensional deformation image, while the other, Oregon oak, a typical refractory wood, was used to observe check generation during wood drying. Wood sample specimens from 17–mm–thick and 8–mm–thick tree disks with 60–mm diameters were prepared from a freshly–cut willow tree. Willow specimens of 17–mm–thickness were used to compare the contour images of free and restrained deformations. A free deformation specimen was made by cutting it cone–shaped. Oak sample specimens with 70–mm widths, 80–mm lengths and 15–mm thicknesses were prepared from quarter sawn lumber in the longitudinal–tangential plane to ease drying check observation, as the drying check of oak usually originates in a region of ray tissue on the tangential plane. Subsequently, oak sample specimens were immersed into water prior to the experiment, because part of the sample specimen had already dried. All of the experiments were conducted at room temperature.

The side of the sample specimen that was turned toward the measuring lens was covered with black paint spots in order to atomize the sample surface. These spots unintentionally caused the formation of various grey scales that elevated the degree of correctness of the DIC system, which recognizes displacement according to subset movement. A DIC system can be reiterated and creates a subset composed of tens to hundreds of pixels in a single image. Displacement can be used to compare and calculate the locations of many subsets in a serial image. If the two subsets become close, then it shrink, swell if it becomes get away. Great care was needed to keep the specimens and camera stable, as any movement would negatively affect the image. The DIC system used in this research was VIC3D (USA Correlated Solutions Company).

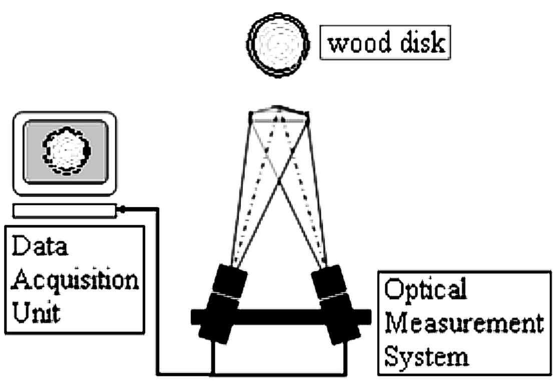


**Fig. 1.** Simplified diagram of the experimental apparatus, which consists of two cameras and a high–speed computer.

## RESULTS AND DISCUSSION

The DIC program materializes and enables the quantitative analysis of all of the elements of the local surface strain tensors and local displacement vectors. Furthermore, z represents the displacement between the lens and the sample specimen as a horizontal displacement change.

The contour maps in Fig. 2 show the deformation discrepancy between the disk and cone–shaped specimen looks uniform regardless of drying time. It implies that it shrank freely and is of less stress during drying. In contrast there are variable colors within the disk specimen. It shows that the core shrinks more than the outer, which develops drying stress within the specimen. This experiment confirmed that DIC method would be used to monitor the deformation of the specimen during drying. Furthermore, It could be reduced the possibility of crack or split caused by drying stress in tree disk by early adjustment of drying schedule.

Fig. 3 shows a displacement map of the willow disks according to drying time. The major displacement elements e1 and e2 closely agreed with each radial direction and tangential direction displacement.

Both strain maps of the radial and tangential directions showed that the pith region of the willow disk contracted faster than did the other regions. It is generally recognized that the contraction ratio in the tangential direction is greater than that in the radial direction. This tendency was also observed in this experiment (refer to Figure 3). In addition, the overall radial direction (e1) contraction surface was comparatively even over time, while that of the tangential direction (e2) was random. These observations could have not been made without the DIC system. Additionally, during drying, the willow disk is divided into several regions and shrinks or swells, and the dimension is illustrated in Fig. 3.

We compared the digital image of the Oregon oak sample specimen and the strain map of the displacement produced by the DIC system (Fig. 4). No check was found in the Digital Images after 9 and 12 hours, there were very minute drying check vestiges in the Digital Image at 15 hours, and the drying check looked very clear in the Digital Image at 42 hours. Conversely, the drying check seemed to take place in the first nine hours in the displacement map of the painted wood. Thus, we determined that the DIC system can detect drying checks due to drying stress more sensitively than can the digital image. As seen in the results shown in Fig. 4, this image system uses the color red to indicate expansion and the color blue to represent contraction. The contraction and expansion occurred simultaneously in the narrow areas. Therefore, the red color points and the blue color points

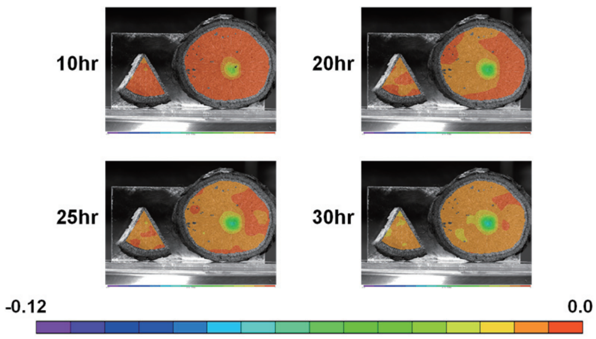


**Fig. 2.** Comparison of free and restrained strains of willow species tree disks prepared with 60–mm in diameter and 17–mm in thickness. The color bar at bottom is a deformation scale. A negative value represents the proportion of wood contraction.

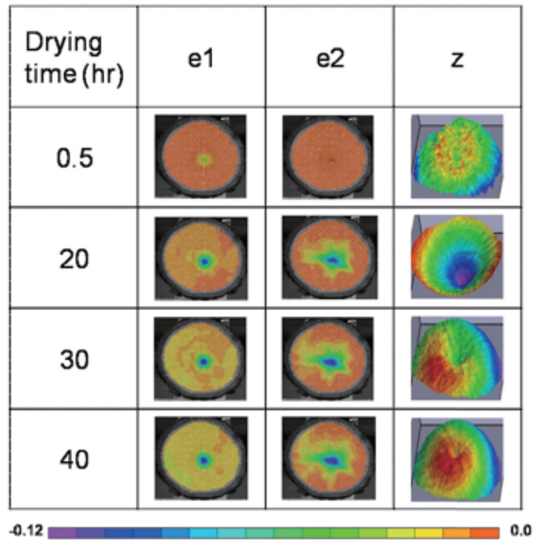


**Fig. 3.** The principal strain components e1 and e2, and horizontal displacements, z, between the lenses and the sample at various drying times. e1 and e2 imply the strains in radial and tangential directions, respectively. The color bar at bottom is a deformation scale. A negative value represents the proportion of wood contraction.

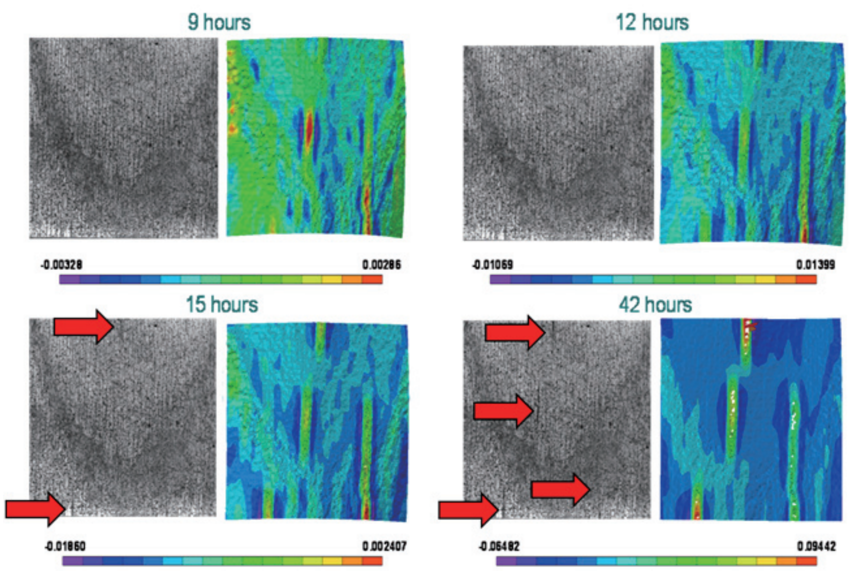


**Fig. 4.** The digital images and strain maps of an Oregon oak sample at various drying time. The color bar at bottom is a deformation scale. Negative and positive values represent the proportions of wood contraction and expansion, respectively.

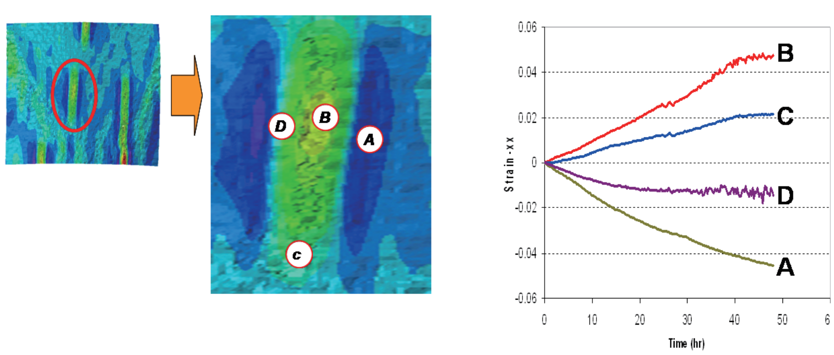


**Fig. 5.** The strains measured at four points around a checking developing during drying.

received tension and compression stress, respectively.

A closer look at a checking in Fig. 5 illustrates its development during drying. The discrepancy of strains between the expansion and shrinking points increased with the drying time. Hence, we could acquired the accurate drying stress originated position and the degree of stress during drying.

From these results, we concluded that the use of a DIC system in wood drying can more accurately visualize strain changes and aid in the preparation of a more effective drying schedule for refractory wood species.

## CONCLUSIONS

Using optical measurement techniques with a DIC (digital image correlation) system, we investigated the displacement changes in Willow tree disks and Oregon Oak planks, producing detailed displacement maps for the two species and the changes that occurred during drying. The stress concentration in the Oregon Oak plank was successfully visualized and the results are summarized as follows:

1. The radial direction contractions for all surfaces were comparatively even over time, while that in the tangential direction was random.
2. The DIC system could detect the drying check due to drying stress more sensitively than could the digital image.
3. Contraction and expansion during wood drying happened simultaneously in narrow areas.

From these results, we conclude that the use of a DIC system in wood drying can better visualize strain changes during wood drying and aid in the development of a more effective drying schedule.

However, the results obtained in this study deal with only surface deformation, and a more systematic study related to thickness variation should follow.

## ACKOWLEDGEMENT

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