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Development of Image Processing Technique for Determining Wood Drying Schedules*1

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ABSTRACT

Image processing technique was adapted for exploring the more convenient ways to investigate the drying characteristics of wood. The acquisition of information about drying characteristics is indispensable for the development or improvement of dry-kiln schedules. A small internal fan type wood dry kiln was combined with image-processing and data-acquisition systems to monitor continuously the formation of checks and moisture reduction during drying. All the images and data were analyzed to improve or estimate the dry-kiln schedules and predict the drying time which would be required to dry green wood to 10% moisture content in internal fan type kiln. Samples of 20 mm- and 50 mm-thick *Metasequoia glyptostrobodies*, *Paulownia coreana* Uyeki, *Pinus densiflora* Sieb. Et Zucc., *Platanus occidentalis* L., *Quercus acutissima* and *Robinia pseudo-acacia* were used to verify the potentiality of this technique.

Keywords : wood drying schedule, image processing technique, formation of checks, moisture reduction

1. INTRODUCTION

Dry-kiln schedules for the large number of tree species in the world have been developed and recommended based on experience and research by numerous people throughout the world. These schedules are recommended as a safe reference to be adjusted upward in severity with experience. There are also many species for which dry-kiln schedules have not recommended yet. Therefore it is needed to find the efficient way to develop or improve the schedules.

Acquisition of precise information about drying characteristics of wood during drying is indispensable for the development or improvement of dry-kiln schedules. Since several researchers detected the acoustic emission (AE) signals during drying to monitor the internal stresses that caused checking, there has been lots of study to apply AE monitoring technique to monitor and control drying process (Cunderlik et al, 1996 and Noguchi et al, 1987). However, it was not possible to observe the behavior of defects occurred during drying with stability mainly to the noise.

Relationships between each drying characteristics such as moisture content, shrinkage, checks,

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and deformation can be considered as basic information. For example recognition of the exact moisture content (MC) at which drying defects such as checks occur during drying with given drying conditions may be essential for finding ways to reduce the occurrence of the drying defects.

Monitoring the images of wood surfaces that change continuously during drying may be a good way to investigate the drying characteristics effectively. But in general image-processing technique has been adapted to decide lumber grade or detect defects for optimization of sawing process (Szymani and McDonald, 1981).

In this study image processing and data acquisition system were combined with a small size wood dry kiln to investigate the drying characteristics throughout the drying of the samples of *Metasequoia glyptostrobodies, Paulownia coreana* Uyeki, *Pinus densiflora* Sieb. Et Zucc., *Platanus occidentalis* L., *Quercus acutissima* and *Robinia pseudo-acacia*. Software was developed to monitor and analyze all the data gathered during drying and the potentiality of this system for developing or improving the dry-kiln schedules was evaluated.

2. MATERIALS and METHODS

2.1. Monitoring System

Fig. 1 shows the monitoring system for drying characteristics(Lee, 2002). Drying temperature, relative air humidity(RH) and air velocity were controlled by computer system. Moisture content during drying was determined by load cell and the data for moisture content, drying temperature, RH, and air velocity were recorded by computer at 10minute-interval.

Image processing system consists of a CCD camera(Kukjae Elec. Co.) with a resolution of 270,000 pixels and a frame grabber board(MI Co.) with a resolution of 640 pixels by 480 pixels. Two small light bulbs were installed in the dryer as a lighting system.

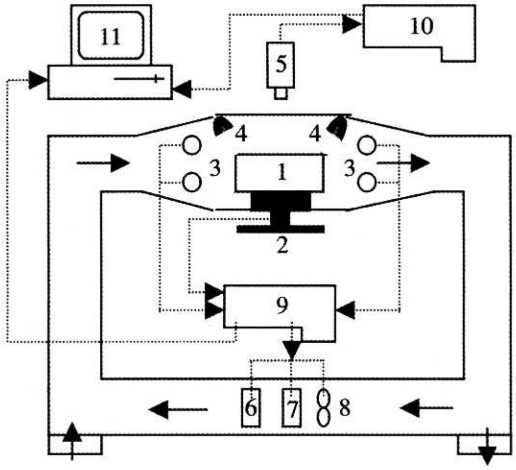

Fig. 1. Schematic of monitoring system for drying characteristics. 1. Wood specimen; 2. Load cell; 3. Temperature and relative, 2. humidity sensors; 4. Lights; 5. CCD camera; 6. Steam, 3. generator; 7. Electrical heater; 8. Fan; 9. Data acquisition, 4.and control board; 10. Frame grabber board; 11. Personal computer.

2.2. Samples and Drying Conditions

Flat-sawn 20 mm- and 50 mm-thick samples (100 mm-wide and 200 mm-long) of green *Metasequoia glyptostrobodies, Paulownia coreana, Pinus densiflora, Platanus occidentalis, Quercus acutissima* and *Robinia pseudo-acacia* grown in Korea were selected.

Drying temperature was maintained uniformly at 100°C from green to constant weight. Air velocity was measured by hot-wire anemometer (Dwyer Inc.) and fixed at 1.5 m/sec. and RH was not controlled.

Images of an end and a surface of each sample board before and after drying were saved by color scanner(Max. 700DPI) to measure the degree of deformation and total areal shrinkage from green to the end of drying.

2.3. Image Analysis Technique

Sample was put on the load cell tray that was covered with black sheet. The gray level of black sheet was about 45, which was low enough to discriminate the sample from the background.

Images of an end and a surface of sample board were saved at 10 minute-interval to investigate an areal shrinkage on the end and the surface of sample board during drying. Areas or sizes of sample boards were calculated by counting the pixels involved in the images of sample boards. The decrease of number of pixels which is representing the area means areal shrinkage. The resolutions of CCD camera and color scanner were 0.42 and 0.34 mm/pixel, respectively.

Formation of surface- and end-check could also be observed by these images after a complete drying process. It was attempted to count the number of checks by image processing technique. However small and vague checks could not be recognized clearly. Therefore some of the saved images were monitored with the naked eyes to determine maximum initial check formation level.

At the end of drying sample board was cut into 5 pieces and the sections of each piece were scanned to evaluate internal-check and cross-sectional deformation at the end of drying. Since internal-checks were relatively dark and clear, it was possible to discriminate internal-checks from sound wood as shown in Fig. 2. Fig. 3 shows the binary images of 50 mm-thick *Platanus occidentalis* sample ends during drying.

2.4. Estimation of Drying Schedule

Conventional kiln drying schedule for each species and thickness were estimated by the oven-drying method suggested by Terazawa

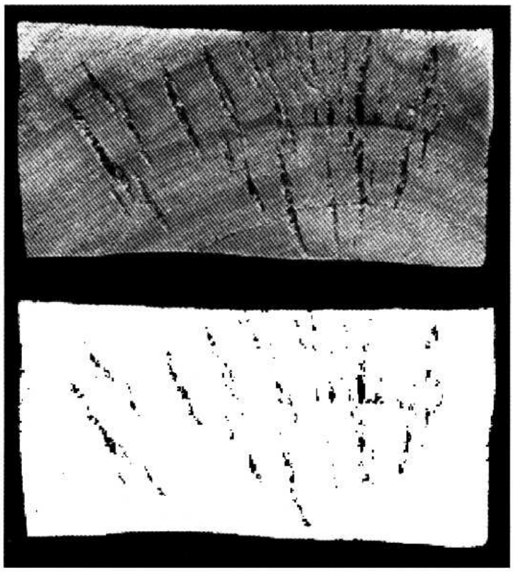

Fig. 2. Original and binary image of cross section of 50 mm-thick *Platanus occidentalis* after oven drying.

(1994). End- and surface-check, internal-check, cross-sectional deformation and drying time to 1% moisture content were investigated to estimate kiln drying schedule and drying time to 10% moisture content.

3. RESULTS and DISCUSSION

3.1. Drying Characteristics

Drying times required from green to constant weights of six species were shown in Table 1 and drying curves of 20 mm- and 50 mm-thick of *Pinus densiflora* at 100°C were represented in Fig. 4. Areal shrinkage curves of end and surface of *Pinus densiflora* in Fig. 5 show that shrinkage occurs as drying starts while the average moisture content were much higher than fiber saturation point below which it is believed that shrinkage begins. Other five species showed same phenomena. Lee and Kim(2001) monitored the drying characteristics of disks of

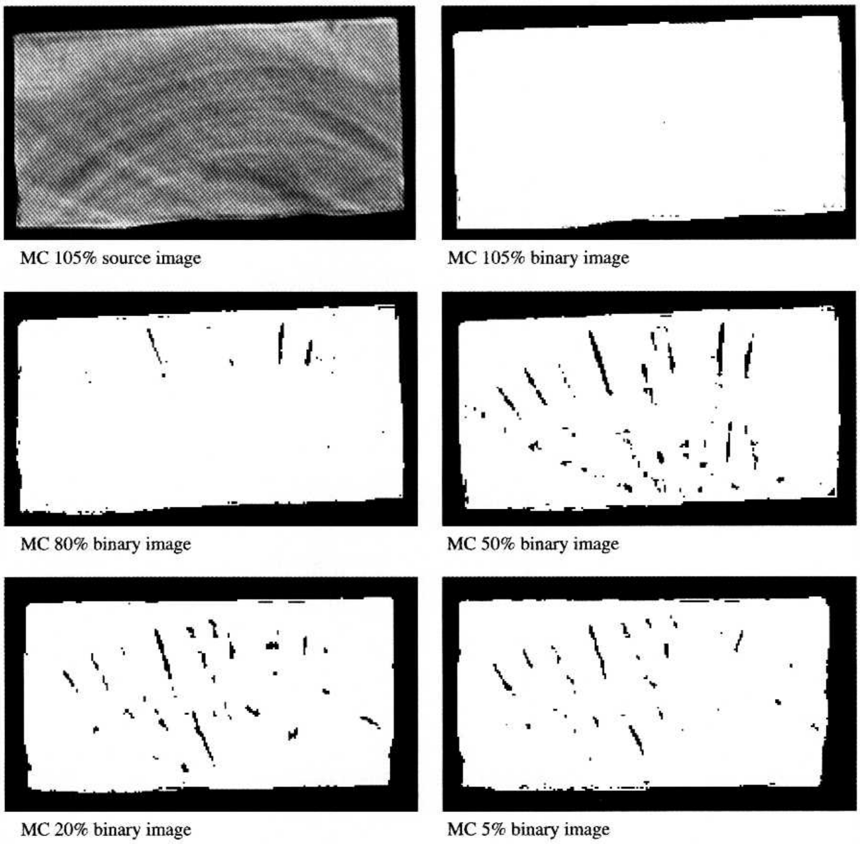

Fig. 3. Binary images of 50 mm-thick *Platanus occidentalis* sample ends during drying.

Table 1. Initial moisture contents of sample boards and drying times required to constant weight at 100°C

Species	Thickness (mm)	Initial MC (%)	Drying time (hr)	Drying Rate (%/hr)
Metasequoia lyptostrobodies	20	38	23.02	1.65
	50	70	41.28	1.69
Paulownia coreana	20	250	28.97	8.63
	50	260	72.75	3.57
Pinus densiflora	20	144	20.22	7.12
	50	127	40.17	3.16
Platanus occidentalis	20	55	27.82	1.98
	50	106	48.63	2.18
Quercus acutissima	20	70	52.18	1.34
	50	71	75.48	0.94
Robinia peudo-acacia	20	50	69.57	0.72
	50	45	91.75	0.49

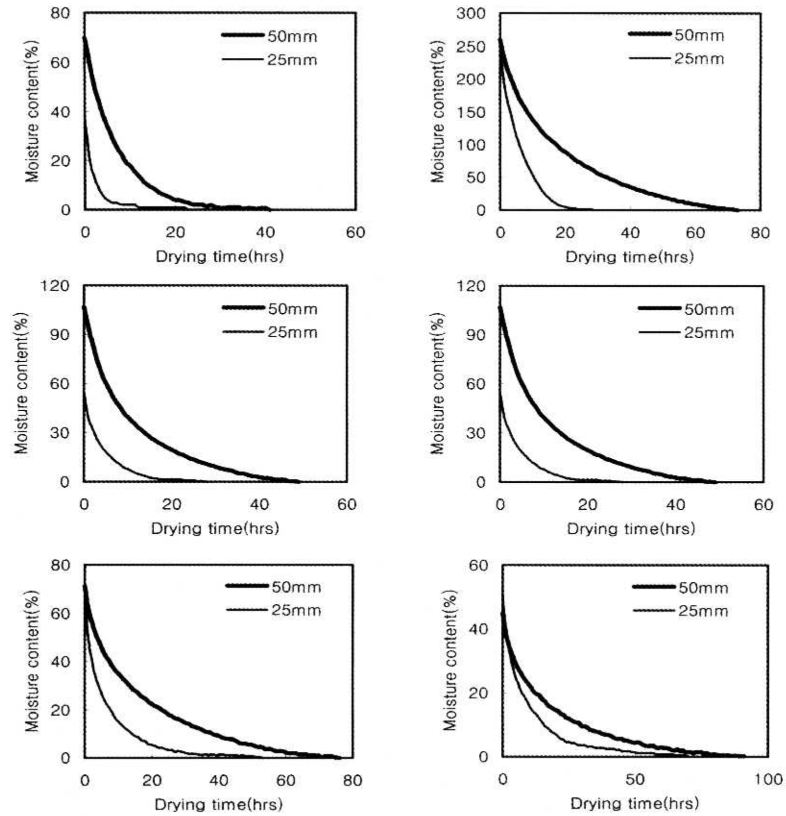

Fig. 4. Drying curves of 20 mm- and 50 mm-thick *Metasequoia glyptostrobodies*, *Paulownia coreana* Uyeki, *Pinus densiflora* Sieb. Et Zucc., *Platanus occidentalis* L., *Quercus acutissima* and *Robinia pseudo-acacia* (from left top to right bottom) during oven-drying at 100°C.

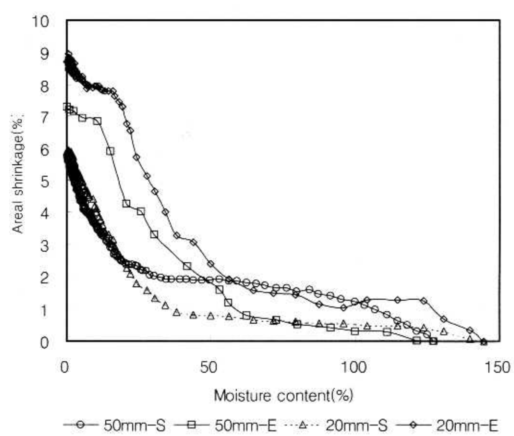

Fig. 5. Areal shrinkage curves of 20 mm- and 50 mm-thick *Pinus densiflora* during oven-drying at 100°C. (S: surface. E: end)

Robinia pseudo-acacia and suggested that image-processing techniques could be a potential way to observe continuously the drying behavior of wood during drying. Surface or end of wood is rapidly dried below fiber saturation point in initial drying stage. Therefore drying stress is expected to develop in initial drying stage and then mild drying conditions are required to prevent formation of initial checking during initial drying stage. These results explain why optimal wood drying schedule must be determined and applied. Drying rates of 50 mm-thick samples of *Metasequoia glyptostrobodies* and *Pinus densiflora* were higher than 20 mm-thick since initial moisture content of 50 mm-thick samples

Table 2. Severity codes of drying defects for six species

Species	Initial checks		Cross-sectional deform.		Internal-checks	
	20 mm	50 mm	20 mm	50 mm	20 mm	50 mm
Metasequoia lyptostrobodies	No.1	No.4	No.4	No.8	No.1	No.4
Paulownia coreana	No.1	No.1	No.3	No.6	No.1	No.1
Pinus densiflora	No.1	No.3	No.3	No.4	No.1	No.3
Platanus occidentalis	No.3	No.6	No.5	No.5	No.4	No.6
Quercus acutissima	No.4	No.6	No.5	No.8	No.5	No.6
Robinia pseudo-acacia	No.3	No.5	No.4	No.4	No.2	No.5

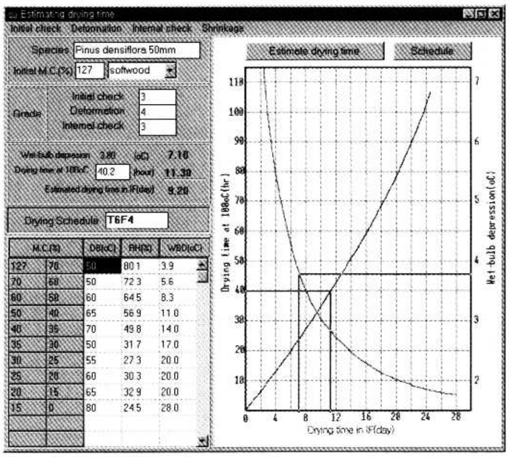

Fig. 6. Main screen for estimation program of drying schedule.

were much higher than that of 20 mm-thick.

Drying defects such as initial end- and surface-checks, internal-checks and cross-sectional deformations were represented for six species with drying defect severity codes suggested by Terazawa (1994) as shown in Table 2. As expected, *Platanus occidentalis*, *Quercus acutissima*, *Robinia pseudo-acacia*, and *Metasequoia glyptostrobodies* showed higher drying defect severity codes.

3.2. Estimated Drying Schedules

Fig. 6 shows the main screen of the drying schedule estimation program developed in this study. Kiln drying schedules and drying times to 10% moisture content for six species were described in Table 3.

These results were compared with the drying

Table 3. Estimated kiln drying schedules and drying time to 10% moisture content of six species

Species	Thickness (mm)	Estimated kiln drying schedule code	Estimated drying time (day)
Metasequoia lyptostrobodies	20	T8A4	6.7
	50	T5C3	12.7
Paulownia coreana	20	T10G4	6.8
	50	T5H3	13.8
Pinus densiflora	20	T10G4	5.6
	50	T6F4	9.2
Platanus occidentalis	20	T5B3	8.4
	50	T3E2	14.6
Quercus acutissima	20	T5C3	12.3
	50	T3C2	17.6
Robinia pseudo-acacia	20	T8B4	12.4
	50	T5B3	16.3

schedules recommended by US Forest Products Laboratory (Simpson, 1991). Although it was not valid to compare the schedules estimated in this study directly with US FPL recommended schedules because the species and initial moisture contents were not matched exactly with Korean domestic ones, the estimated schedules approached relatively well to recommended schedules. For example recommended schedule for 4/4 and 8/4 sycamore(*Platanus occidentalis)* was T6D2 and T3D1, respectively. In this study drying schedule for 20 mm- and 50 mm-thick *Platanus occidentalis* was estimated as T5B3 and T3E2, respectively. The drying time to 10% moisture content for 20 mm-thick *Platanus occidentalis* was estimated as about 8 days. US Forest Products Laboratory (McMillen and Wengert, 1978) estimated drying time to kiln dry 4/4 sycamore from green condition to 6% moisture content as 6 days. Recommended schedule for 4/4 and 8/4 red oak was T4D2 and T3D1 and estimated schedule for 20 mm- and 50 mm-thick *Quercus acutissima* was T5C3 and T3C2, respectively. Therefore estimation of drying schedules using the image-processing techniques was proved to have a potentiality in developing optimal wood drying schedules.

4. CONCLUSION

It requires a great deal of labor and time to monitor the drying characteristics and estimate drying schedules of wood by oven-drying method. Monitoring system with image processing technique shows a good potentiality in minimizing the labor and time. Experiments will be performed to apply and verify these estimated schedules. Improvement of these drying schedules should also be executed to save time, energy, and costs for industrial applications.

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